SUSTAINABLE REFURBISHMENT METHOD FOR INDUSTRIALIZED PUBLIC RESIDENTIAL BUILDINGS IN THE MEDITERRANEAN CLIMATE

Dissertation

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by

Sara Ticci
09/10/1983
Pisa, Italy

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Professorial advisors	Prof. Frida Bazzocchi
	Prof. Harald Kloft
	Prof. Vincenzo DI Naso
	Prof. Andrea Rocchetti

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*) Either the German or the Italian form of the title may be used.

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ENGLISH ABSTRACT

The European Directive 2010/31/UE, so called Directive "20/20/20", requires intervening on existing buildings, hugely polluting and with a low energy efficiency. Indeed, the building sector accounts for about the 40% of total energy consumption in the Union and, in Italy, the 27% of energy consumption is due to the residential sector, since the 70% of existing residential buildings has a low record of energy efficiency. Retrofitting of existing residential buildings offers therefore a significant opportunity for reducing global energy consumption.
The suburbs of most Italian cities particularly feel this need of restoration. The immense quantity of public housing built from the '60s to the '80s, in response to a pressing need to create housing quickly and with limited financial resources, is now in urgent need of redevelopment both from the energy performance point of view and for increasing the poor internal comfort conditions.
The research defines a sustainable refurbishment method for public residential buildings made with industrialized techniques in the Mediterranean climate, starting from the results obtained by the application of renovation strategies to some sample buildings built with these construction methods during the '60s-'80s, located in the Florence area. Two building complexes are analysed: COMPLEX A located in Prato consisting of 2 buildings and COMPLEX B located in Firenze involving 4 buildings.

The thesis is structured in 5 main chapters:

- Chapter-1 analyses the field of interest, the aim and the methodology of the work. It explains the current situation of social housing in Italy, with a particular attention given to the Florence area, going then to introduce the buildings chosen as sample cases;
- Chapter-2 includes a literature research on the common methodology and strategies used in the sustainable refurbishment in Europe and in Italy;
- Chapter-3 investigates the buildings chosen for the study. This analysis consists of two sections. The first one is the study of the Environmental and Technological System where the main characteristics of the buildings from the architectural point of view are investigated aiming at finding recurring features and constraints. The second part consists of the Energy Analysis of the constructions, both to understand their energy performance in Winter and the thermal comfort conditions in Summer;
- Chapter-4 shows the application of some strategies on one of the buildings chosen for the research, taken as sample case for the definition of the method. These strategies start from the recovery of the building's envelope up to the application of ventilation techniques, aiming from one hand at solving energy consumption issues in Winter and on the other hand, at improving indoor comfort conditions in Summer; the strategies are chosen in order to intervene as less as possible on the buildings, paying particular attention to the type of residential buildings (social housing); at the end of the chapter the recovery method is summarized;
- Chapter-5 presents the results obtained from the application of the recovery method on all the other buildings.

The results in terms of thermal comfort conditions and energy performance are comparable among all the buildings studied in the research. The recovery method might be spread to other buildings with similar characteristics, from the environmental/technological point of view, to the sample cases and located in comparable climate zones.

GERMAN ABSTRACT

Die Europäische Richtlinie 2010/31/UE, die sogenannte 20/20/20, fordert, schon existierende Gebäude mit umweltbelastenden Auswirkungen und niedriger Energieeffizienz zu sanieren. Tatsächlich ist der Bausektor für ca. 40% des gesamten Energieverbrauchs der EU verantwortlich, während in Italien der Wohnungsbau 27% des nationalen Energieverbrauchs ausmacht, da hier 70% der bestehenden Wohnhäuser ein niedriges Niveau an Energieeffizienz aufweisen. Die Sanierung schon existierender Wohngebäude bietet daher eine bedeutende Gelegenheit, den globalen Energieverbrauch zu reduzieren. Die Forschungsarbeit definiert eine umweltverträgliche Sanierungsmethode für öffentliche Wohngebäude, die mit industriellen Bautechniken in der mediterranen Klimazone errichtet wurden. Ausgangspunkt sind die Ergebnisse, die durch die Anwendung von Renovierungsstrategien an einigen Fallbeispielen (Gebäude, die mit diesen Methoden in den 60er – 80er Jahren im Raum Florenz errichtet wurden) erzielt wurden.

Die These ist in fünf Hauptkapitel gegliedert:

Kapitel 1 analysiert den Interessensbereich, die Zielvorgabe und die Arbeitsmethode und behandelt die aktuelle Situation im sozialen Wohnungsbau und im Folgenden die Gebäude, die als Fallbeispiele ausgesucht wurden.

Kapitel 2 befasst sich mit der Literaturrecherche über die allgemein verbreiteten Methoden und Strategien in der umweltverträglichen Sanierung in Europa und Italien.

Kapitel 3 untersucht die verschiedenen Gebäude, die für die Studie ausgewählt wurden. Im ersten Teil geht es um das ökologische und das technologische System; der zweite Teil behandelt die Energieanalyse der jeweiligen Gebäude.

Kapitel 4 zeigt die Anwendung einiger Strategien an einem für die Recherche ausgewählten Gebäude, das als Fallbeispiel für die Definition der Arbeitsmethode gelten soll. Diese Strategien beginnen mit der Sanierung der Gebäudehülle und führen zur Anwendung von Belüftungstechniken, die geringeren Energieverbrauch im Winter und höheren Wohnungskomfort im Sommer zur Folge haben.

Kapitel 5 präsentiert die Ergebnisse, die durch die Anwendung der Sanierungsmethode auf alle anderen Gebäude erzielt wurden.

Die Ergebnisse bezüglich der thermischen Komfortbedingungen und der Energieeffizienz sind bei allen in dieser Forschungsarbeit untersuchten Gebäuden vergleichbar. Diese Sanierungsmethode kann auch auf andere Gebäude, die ähnliche Eigenschaften wie die Fallbeispiele aufweisen und sich in vergleichbaren Klimazonen befinden, übertragen werden.

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1. FIELD OF INTEREST, AIM AND METHODOLOGY

INTRODUCTION

The European Union is increasingly paying attention to the energy issues related to energy and energy saving and this is demonstrated by the considerable number of EU Directive and National Standards on these matters.

The reduction in the Energy demand in the building sector is one of the primary goals of the EU Directive 2010/31/EU, so called Directive "20/20/20", and this is due to the fact that this sector is responsible for about 40% of the final Energy consumption in EU (1).

The objectives of the Directive "20/20/20", to be achieved by 2020, in order to keep the global temperature rise below 2°C are:

- reduction of greenhouse gas emissions by 20%;
- reduction of primary energy consumption by 20%;
- introduction of 20% of energy from renewable sources.

Accordingly, the renovation of existing buildings is considered by the EU an action able to direct the cities towards a low carbon-based society.

The development of restoration projects aimed at optimizing the energy efficiency of buildings, which have often been built without any regard to climatic and environmental factors, is one of the main objectives set already out in the Action Plan of "Agenda 21"[1].

Eco-sustainable restoration of existing buildings is, in view of its limited impact, one of the most ecologically significant courses of action because, compared to "ex novo" construction, it involves less actual building and therefore less consumption of soil and energy.

In Italy, the 27% of energy consumption is due to the residential sector, since the 70% of existing residential buildings has a low record of energy efficiency. A high rate of saving can be therefore achieved merely through the redevelopment of the building envelope and installations.

The problems inherent in building restoration are particularly felt in the suburbs of most Italian cities. The immense quantity of public housing built from the '60s to the '80s, in response to a pressing need to create housing quickly and with limited financial resources, is now in urgent need of redevelopment. Moreover, the living conditions of these buildings, at times realized using poor materials and wrong techniques, require adjustment in order to obtain higher internal comfort conditions. In the redeveloping project, the designer is not allowed to intervene in some aspects, such as the choice of the site or exposure, because the urban context is already pre-established and the constructions are existing. In addition, constraints and limitations imposed by local regulations further reduce the possibility of transformation. Also from the energy point of view, the possible active and passive strategies, in order to achieve a better energy saving, are reduced compared to "ex novo" construction, as well as the technical solutions.

This research aims to define a method for the sustainable renovation of public residential buildings located in the Florence area that present similar characteristics among each other. A great

[1] The "Agenda 21" is a type of manual for the Sustainable Development of the planet from the present time to the 21st century. It is a programme that was outlined by the UN Conference on the Environment and Development that took place in Rio de Janeiro in 1992.

amount of social housing in this area was built with industrialized/prefabricated techniques, the choice was therefore that of studying some buildings realised with these technologies in order to establish a recovery method which could be spread to constructions with similar characteristics to the sample cases and located in comparable climates. Indeed, Florence is located in the Mediterranean Climate[2] with mild Winter, but warm Summer, so that the recovery criteria have to pay attention both on energy savings in Winter and on overheating in Summer. Moreover, a critical issue of the Social Housing is the necessity to economically intervene, with a low environmental impact and durable strategies.

1.1 FIELD OF INTEREST

The research embraces both the theme of social housing and the use or industrialized techniques in the residential buildings in Tuscany. It is therefore useful to briefly analyse the two scenarios we are dealing with in this work.

1.1.1 SOCIAL HOUSING IN ITALY

The history of social housing in Italy has a great tradition that was born simultaneously with

the unification of the State; the Autonomous Institute for residential public buildings (I.A.C.P.) grow in 1903 and they will be active until 2002, the year of their transformation into territorial companies (ATER).

Until the '30s social residential public buildings were built according to their contemporary construction types, both for the typology and for their geographic location, in order to allow them to integrate with the rest of the city. New neighbourhoods were realized with courtyards and through the adoption of minimum requirements, thereby ensuring a good quality of users' life.
(for example Testaccio in Rome, Ripamonti in Milan).

The reconstruction after the Second World War was entrusted to "INA-Casa"[3] that tested new urban shapes, by realizing independent suburbs with no relationships with the surrounding urban area. Between 1946 and 1953 self-sufficient "satellite-cities" were realized outside the city.

Only in the '60s, new design solutions aiming at integrating the social housing neighbourhoods into the city (2). In the late '70s there was an increasing demand for quality by the users; the public authorities began to make surveys in order to understand the users' needs. The result of these surveys was the realization of self-sufficient neighbourhoods with the integration of residences and services. This experience was a failure almost everywhere, because of the inadequate management. In this manner great suburban complexes, in which disadvantaged user groups were concentrated, were born. For these users funding systematically run out before the services into the neighbourhood were realized, leading therefore incomplete works to the inhabitants.

Nowadays all these suburbs are in need of redevelopment, both from a technological point of view and a social point of view. New domestic needs are increasingly arising due to changes in the life style, leading to a necessity in the reorganization of users' space and architectural flexibility.

[2] The Mediterranean climate is one of the 2 subtropical climates with dry Summer, characterized by a mean temperature of the warmest month of above 22°C (Csa Climate type according to Köppen classification (10)). It is proper of the Mar Mediterraneo coastal area. The main characteristics are: mild Winters, very high solar radiation in Summer, rains concentration especially in Winter since Summer is warm and almost dry. (11)

[3] "INA-Casa" is the State action plan to build public residential buildings throughout the Italian territory that was born after the Second World War. This plan, besides the building activity relaunch, aimed at solving unemployment issues, by realizing residential units for low-income families.

1.1.1.1 SOCIAL HOUSING IN FLORENCE[4]

The I.A.C.P. in Florence was born in 1909. The first constructions began in 1911 with the construction of three buildings[5], located within the city of Florence in via Rubieri, via Erbosa and via Annibal Caro[6]. In 1925 Eng. Ugo Giovannozzi, designer for the Institute, was commissioned to realize the project of a 650-units building in via Pisana, but the construction works started only in 1926, reflecting a delay in the construction activities due to financial constraints. After this period of economic crisis, in 1931 the first great complex consisting of 14 buildings for 272 flats was inaugurated. It was located along 3 streets (via Manni, D'orso and Gelli), at the time located in the countryside. This location reflects the tendency to concentrate the "medium class" in the city neighbourhoods, while the "working class" far from the city centre[7]. The early '30s were particularly productive with the construction of 6 buildings for 46 flats (via Pisana), 5 buildings for 44 flats (via Mannelli), 17 buildings for 172 (via del Romito), and the neighbourhood "Victoria" close to Piazza Viesseaux. In these, there is a different conception of the building type and social stratification: in the first 3 cases, addressed to poorer classes, the buildings are characterized by seriality; in the last case the neighbourhood, addressed to richer people, was characterized by the search for a prototype of a "bourgeois house".

Figure 1.1: "Victoria" neighbourhood (3).

Between 1936 and 1938 the building activity stopped, looking only at the identification of new areas suitable for urbanization, including those of Via Carlo del Prete, Via Perfetti Ricasoli and the one near the Victoria bridge. In these areas residents evicted from areas of Santa Croce and San Frediano (subject to rehabilitation), would have housed.

After the Second World War, the main interventions in the Florence area were funded by the "INA-casa" plan. The first major INA-casa district in Florence was the "Isolotto" district (4). The most important feature of this project was the realization of the "garden-district" and the creation of

[4] The reconstruction of the Social Housing history in Florence was made based on the work carried out by E. Bettio and R. Romanelli (3).

[5] They were "block buildings", a variation of the typical "linear buildings". The linear aggregations of the units change direction (the linear buildings have only one direction) in order to create a courtyard in the middle.

[6] The first IACP interventions were realized just inside the city of Florence.

[7] This way of intervention was in perfect harmony with the Fascist regime's attitude.

different unit solutions. The design project of this district began in the years 1950/'51 and the construction works in 1952.

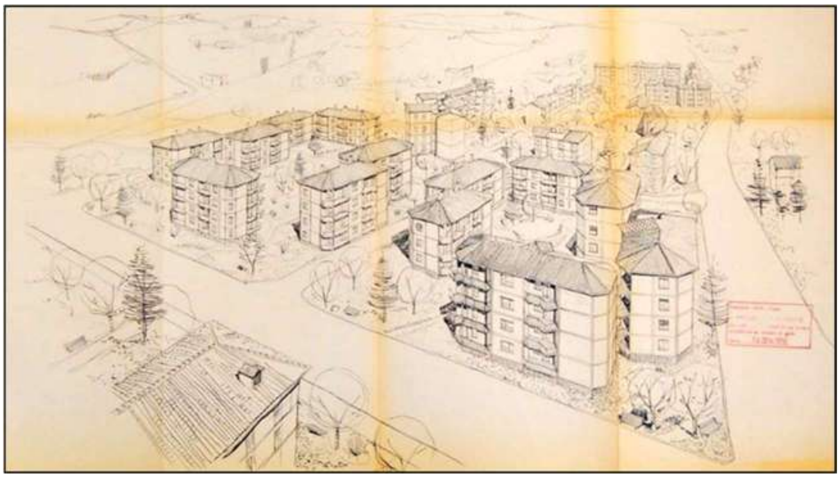


Figure 1.2: Perspective drawing of the “Isolotto” district (3).

Another INA-casa complex was the S.Giusto neighbourhood in Prato, realized in 1965, conceived as a self-sufficient. It consists of the aggregation of 10 blocks, each of them composed by 4 tower buildings at the corners, linked by linear buildings called “arms” and a courtyard in the middle. The I.A.C.P along with the GESCAL[8], as the Contracting Authority, participated as works supervisor to the realization of the lots which ended between 1963 and 1977.

The first initiative fully sponsored by GESCAL was the “Torri a Cintoia” PEEP[9] in an area identified in the Master Plan of 1962, together with the “Mantignano”, “Le Piagge” and “Villa Magna” areas. In the years '72/'73, the first part of Via Canova was built with 5 tower buildings and 2 linear ones for a total of 190 apartments, and finally between '75 and '77, 2 constructions for 108 residences were realized, but the complete fulfilment of the plan lasted until the '90s.

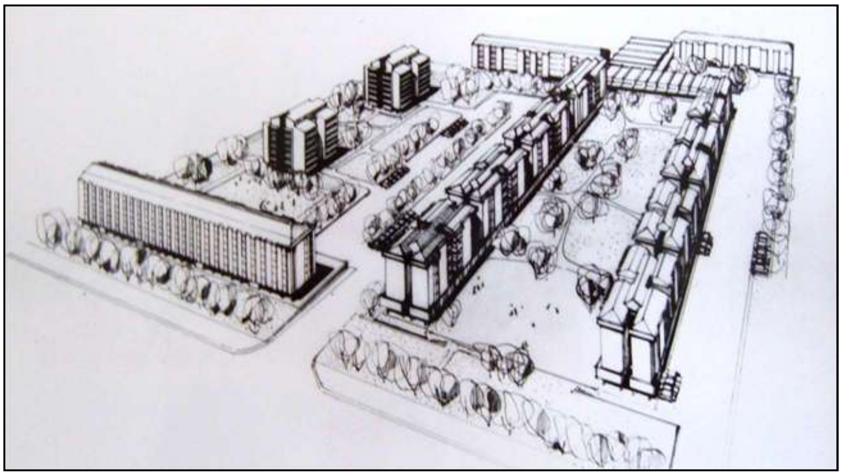


Figure 1.3: Perspective drawing of the “Torri a Cintoia” district (3).

[8] The GESCAL (management for the workers houses) was a founding addressed to the houses assignment to the workers. It was born in 1963, replacing the INA-casa management.

[9] PEEP (Residential public buildings plan) is an urban instrument within the City Urban Planning, used from the municipal administration to plan and to manage all the interventions related to social housing. One of the building complex analysed in the thesis is part of this PEEP.

During the ‘70s and ‘80s the main promoter in building activity was the ten-year plan of Law 457/1978 which promoted either new public residential buildings interventions on given areas demanded at this purpose, or the rehabilitation of the existing building stock. It was during these years that the practice of tender, which required the companies themselves to design besides the construction, in order to reduce costs and to increase the quality of the works. With the aim at limiting the number of tenders to be announced, more interventions to be realized in different locations, were gathered in the same procedure according to the manner of “designing and constructing by means a type-project”, which led to a seriality in the construction, by searching repeatable models in the local area. For this cause the use of prefabricated/industrialized systems increasingly grew during the ‘80s. In 1986 the I.A.C.P. institutes were reformed and changed their name in ATER.

In 2002 the ATER in Florence was divided into 2 private companies: Casa S.p.A and L.O.D.E. This latter gathers 33 municipalities in the Florence area, defining the policy guide lines for the management of the social housing estate, while it makes use of Casa S.p.A for what concerns the operational part of the management: construction of new public residential buildings and rehabilitation of the building stock.

1.1.2 THE PHENOMENON OF INDUSTRIALIZED CONSTRUCTION

The phenomenon of industrialized construction in Italy began in the ‘60s and involved major changes in the organizational structure of the construction process, in terms of stages of planning, design and construction of residential projects, and the different technical and economic structure adopted by both private and cooperative construction companies (5).

In Tuscany, unlike other Italian regions such as Emilia Romagna, industrialized construction was essentially a missed opportunity, inasmuch as the operations were largely on a small scale; the necessary conditions had not been established either for the application of industrial design and construction projects on a large scale, or, especially, for the ready availability of technologies based on the uniformity and repeatability criteria.

However, in the Florence area, there is a number of interesting examples, albeit small in dimensions, of the application of new methods for the industrialization of the construction process, from design to site management and also, although secondarily, the use of precast construction systems (6). In fact, a general survey of this area, from the late ‘70s to the late ‘80s, demonstrates a large number of operations classifiable in this field, taking into account both clients/contractors (IACP and Housing Cooperatives) and constructors (Building firms and Cooperatives).

For what concerns the Contractor Cooperatives that initiated project types involving standardized work, the case of “Progetto Casa Prato ‘80” (Prato House Project ‘80) (7) is of great interest; it has been possible to analyse not only the organization and the program management development, but also the types of building work, also in relation to their location in the territory. This initiative was one of the most consistent programs contracted by housing cooperatives in Tuscany and was part of the "guideline programs" of the A.R.C.A.T Plan that the Consorzio Coopertoscana (Coopertoscana Consortium) and the Consorzio Comprensoriale Pratese agreed to undertake. The strengths of the program were threefold and marked it as a guideline-project: the integration of the cooperatives’ decision-making in higher-level organisms, a complex structure of technical services that monitored the entire proceedings and a particular attention to contract strategy.

On the other hand, regarding the initiatives of the I.A.C.P in the Florence area between 1978 and 1987, the various construction works have been taken into account by careful analyses of the building research group of the Civil and Environmental Engineering Department of Florence[10]; these were located in the territory which at the time constituted the province of Florence, and adopted industrialized construction techniques and/or prefabricated components. A total of 48 public housing projects have been identified, involving 1888 housing units, of which 60% were built in Florence (548 housing units), Prato (290 housing units) and Sesto Fiorentino (294 housing units) (8).

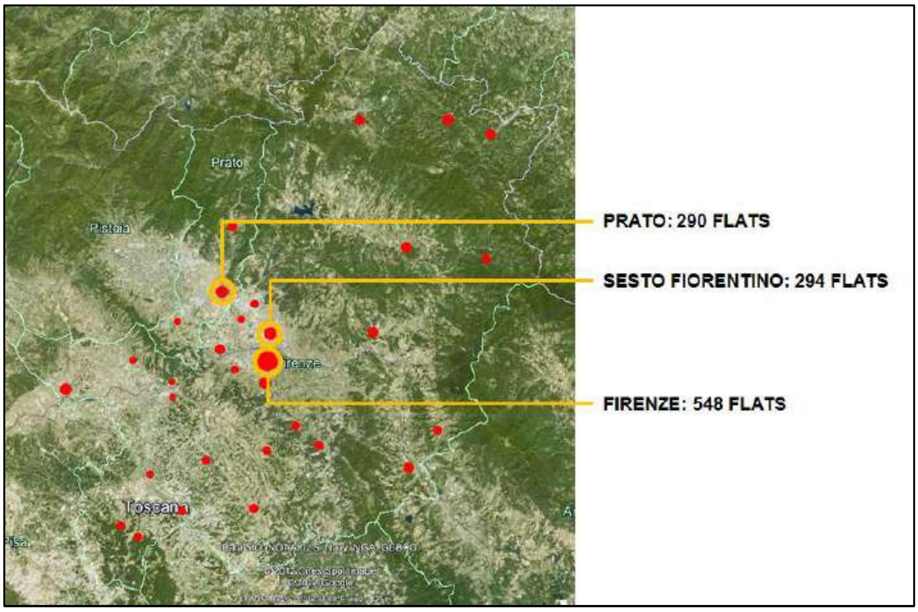
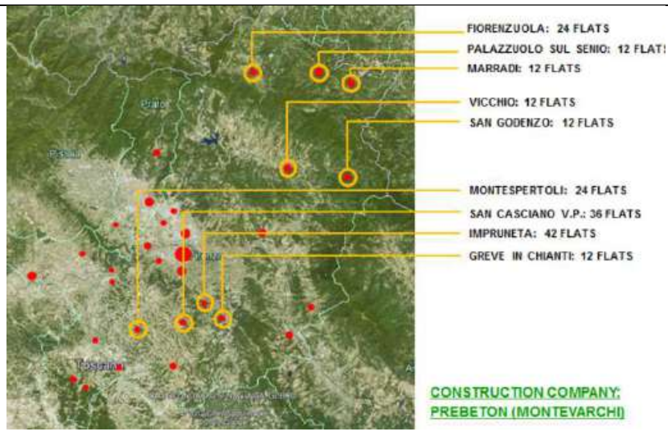
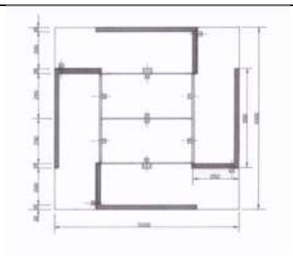
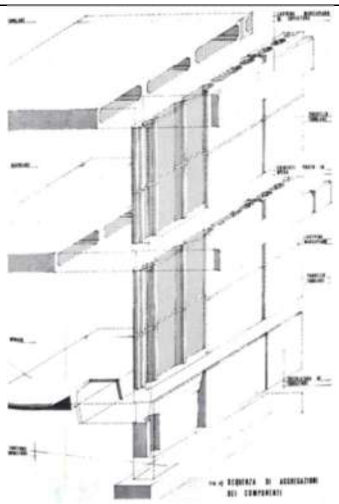
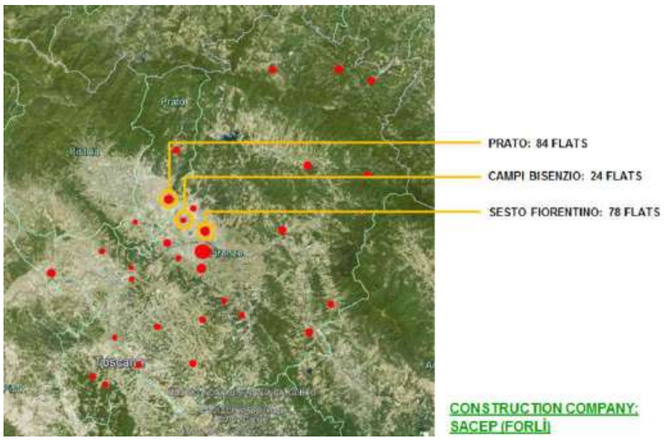
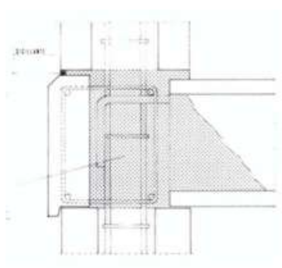


Figure 1.4: I.A.C.P interventions in the Florence Area.

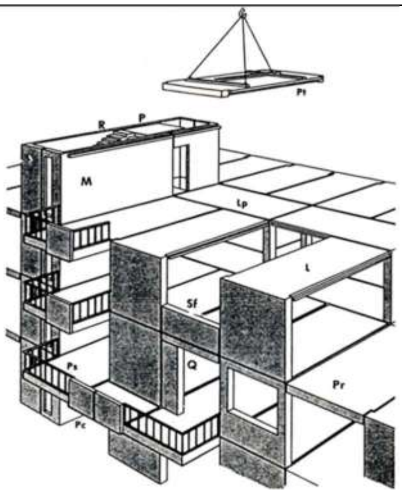
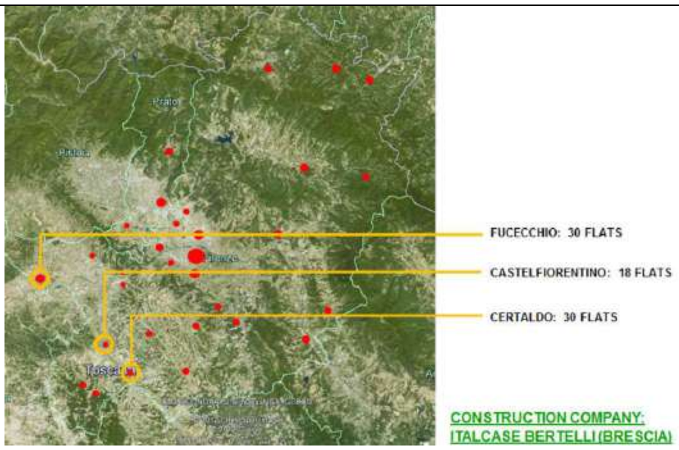
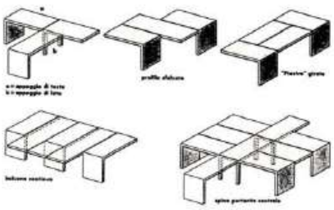
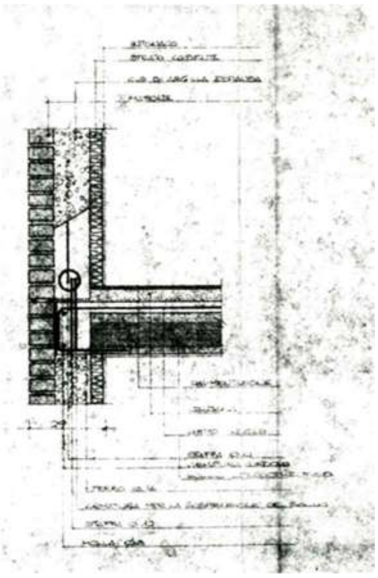
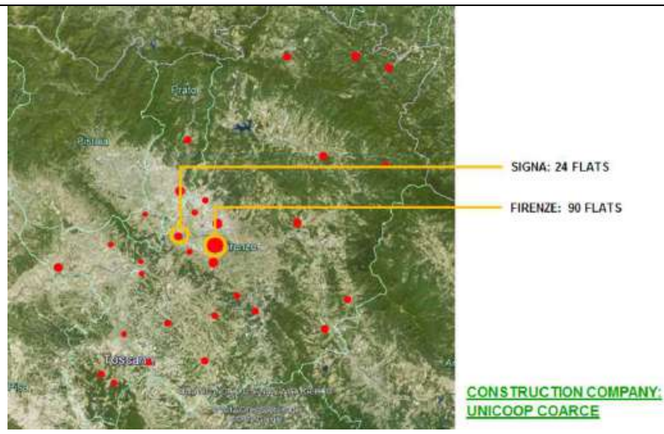
Analysis clearly shows the fragmentation of the construction projects (generally medium-small entities) in the territory, in view of the fact that more than half of the building complexes resulted in less than 36 housing units. For each of these projects it has been possible to identify the technical and structural characteristics adopted. What has also been highlighted is the recurrence of a number of particular companies being awarded contracts, the most significant of which, especially in relation to the consistency of the construction projects, are Italcase Bertelli (Bedizzole (BS)), Immobiliare Scipione Capece (Naples), PREBETON (Montevarchi (AR)), SACEP (Bertinoro (FO)), and Igeco Pontello (Vezzano Ligure (SP)). This recurrence is also due to the particular form of the contracts, which often involved restricted procedure. In the documents, it has also been possible to obtain a list of the building companies invited to submit tenders, which demonstrates that they correspond, in fact, to those recurring in the execution of the construction projects. It should be noted that the building companies were almost always concessionaires or owners of the construction system license that was used for all their construction projects. The documentation underlying the tender takes different forms: in a number of cases there are very prescriptive indications, specifying the materials and technologies to be adopted; in other cases, there are only indications of the equipment and services required, which left open the possibility to provide different construction systems in the bidding stage. It has, therefore, been possible to identify the principle prefabricated building systems used by operators in the Florence area: TRIEDRO, SBS, ELLE, PICA, IGECO-Pontello,

[10] It was possible to analyse these interventions, by studying in detail the documentation of all these projects collected in the Casa S.p.A archive in Florence.

K, etc (9). The majority of the buildings were great panel structures (both in the case of prefabricated panels and in the case of reinforced concrete walls and slabs in prefabricated formworks) and only a small part of them was realized with a frame structure.

<table>
<tr><th colspan="2">TRIEDRO SYSTEM</th></tr>
<tr><td rowspan="2">
</td><td>INTERVENTIONS IN THE FLORENCE AREA</td></tr>
<tr><td>
</td></tr>
<tr><td></td><td>- THREE-DIMENSIONAL CONSTRUCTION TYPE
- THREE-DIMENSIONAL ELEMENT: 2.50x7.75x2.95m
- FLOOR SLABS: 2.50x5.50/7.75m
- COVERING SLABS: 2.50x5.50/7.75m
- STRUCTURAL GRID: MODULE 2.50x2.50m</td></tr>
<tr><th colspan="2">S.B.S SYSTEM</th></tr>
<tr><td rowspan="2"></td><td>INTERVENTIONS IN THE FLORENCE AREA</td></tr>
<tr><td>
</td></tr>
<tr><td></td><td>- PREFABRICATED VERTICAL PANELS
- PREFABRICATED SLABS
- MODULE: 75/60cm
- VERTICAL PANELS: H[11]=3.06m – t=25cm
- SLAB
MODULE 75cm: max L=7.50m-max D=2.25m
MODULE 75cm: max L=7.50m-max D=2.25m</td></tr>
</table>

[11] H= height; t= thickness; L= length; D= width.

ELLE SYSTEM	
	INTERVENTIONS IN THE FLORENCE AREA 
	- THREE-DIMENSIONAL CONSTRUCTION TYPE - THREE-DIMENSIONAL ELEMENT: L SHAPE max L=6m(module 60cm) - H=2.80-3.60m - THREE-DIMENSIONAL BEARING ELEMENTS: STAIRWEELS-BATHROOMS
PICA SYSTEM	
	INTERVENTIONS IN THE FLORENCE AREA 
	- PREFABRICATED BEARING PANELS - PREFABRICATED PANEL-2 LAYERS: -STRUCTURAL EXPANDED CLAY CONCRETE -REINFORCED BRICK - HOLLOW-CORE CONCRETE SLAB

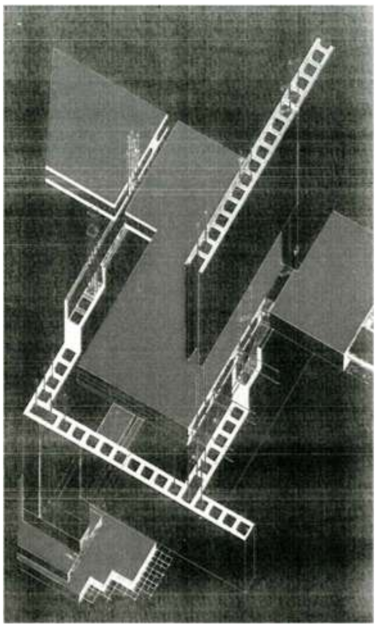
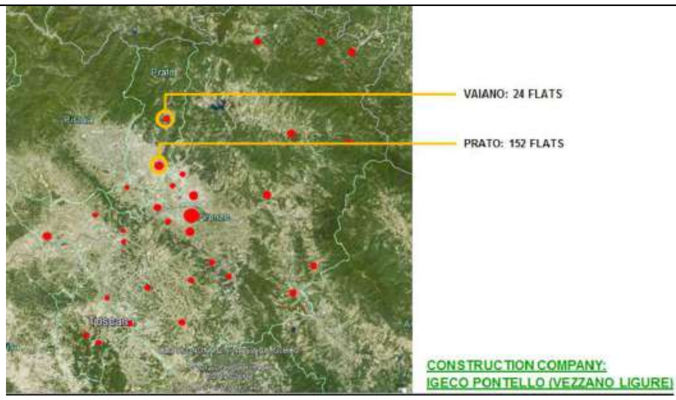
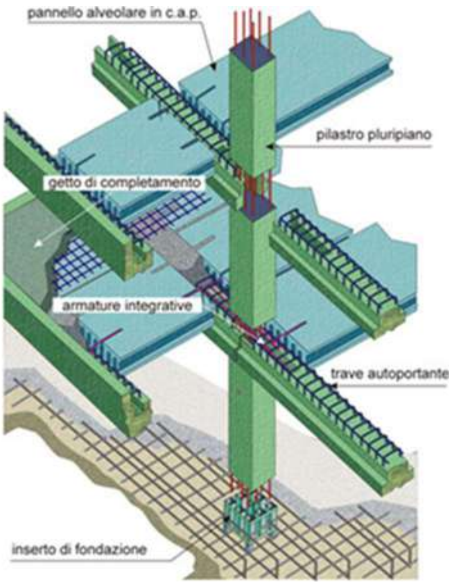
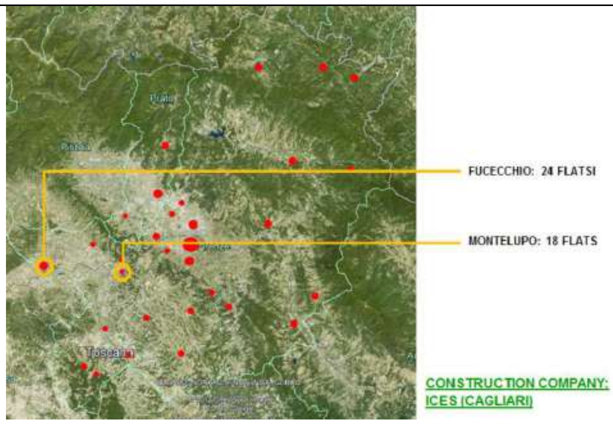
<table>
<tr><th colspan="2">IGECO PONTELLO SYSTEM</th></tr>
<tr><td rowspan="3"></td><td>INTERVENTIONS IN THE FLORENCE AREA</td></tr>
<tr><td>
</td></tr>
<tr><td>- PREFABRICATED MULTI-TUBOLAR PANEL IN LIGHTENED REINFORCED CONCRETE:
H=2.55-3.55m - max L=6m - t=20-24cm
- PREFABRICATED SLABS with DOUBLE PLATES linked by RIBBINGS</td></tr>
<tr><th colspan="2">K SYSTEM</th></tr>
<tr><td rowspan="3">
</td><td>INTERVENTIONS IN THE FLORENCE AREA</td></tr>
<tr><td>
</td></tr>
<tr><td>- LINEAR STRUCTURAL SYSTEM: FRAME SYSTEM
- PARTIALLY PREFABRICATED BEAMS
- PREFABRICATED PILLARS</td></tr>
</table>

Table 1.1: Principle prefabricated building systems used in the Florence area. All the images come from the Casa S.p.A archive.

Moreover, many construction projects adopted systems based on the use of prefabricated formworks of large size in order to streamline and speed up the operational stages on site. For this cause, they can be defined more properly as Industrialized Systems. Among these we can mention: TUNNEL SYSTEM or reinforced concrete walls in PREFABRICATED FORMWORKS.

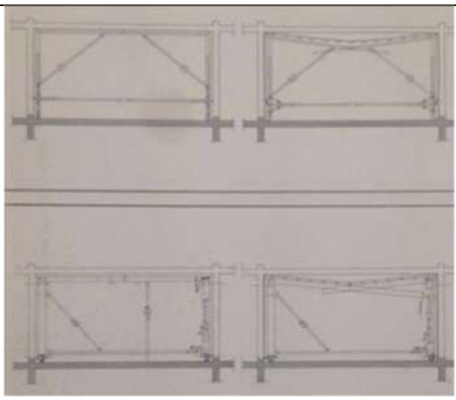
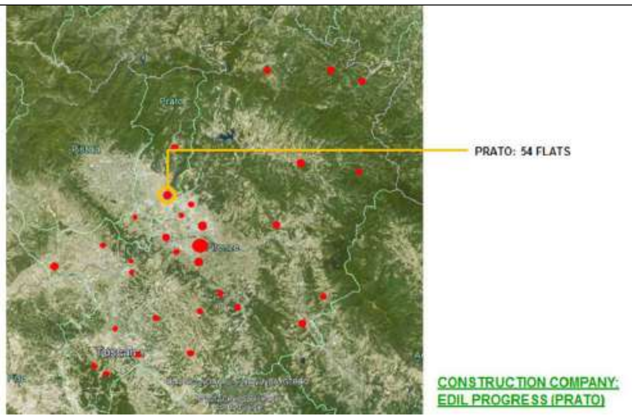
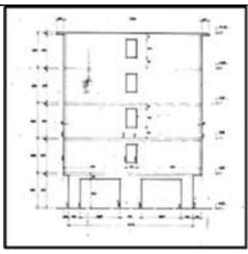
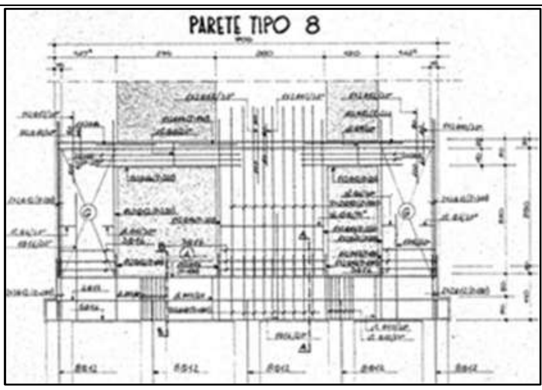
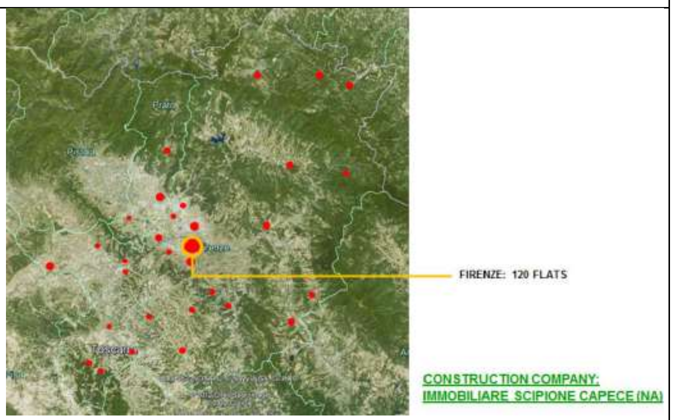
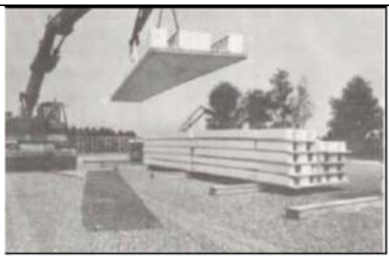
TUNNEL SYSTEM	
	INTERVENTIONS IN THE FLORENCE AREA
	
	- METAL CARPENTRY: LARGE FORMWORKS IN THE FORM OF INVERTED "U" - REINFORCED CONCRET WALLS cast on site - REINFORCED CONCRET SLABS cast on site
PREFABRICATED FORMWORKS	
	INTERVENTIONS IN THE FLORENCE AREA
	
	- METAL CARPENTRY: LARGE FORMWORKS IN THE FORM OF INVERTED "U" - REINFORCED CONCRET WALLS cast on site - "PREDALLE" SLABS

Table 1.2: Some of the industrialized systems used in the Florence area. All the images come from the Casa S.p.A archive.

The analysis of the systems adopted in the various construction projects has also highlighted the intrinsic relationship between the technical characteristics of the various prefabricated/industrialized systems with typological characteristics intrinsic to the construction and housing scale.

1.2 AIM

The research aims to define and validate strategies, consequently defining a method for the sustainable renovation of a class of residential buildings considered to be representative of our environmental context and local building culture and emblematic in the application of prefabricated/industrialized building techniques.

For this purpose, as sample case, we took into account some public residential buildings realized with prefabricated/industrialized systems. They are located in Tuscany, in the Florence area and they were built during the '70s and '80s. The buildings chosen for the research, are placed in Firenze, and in Prato. They are 2 complexes: the complex located in Florence consists of 4 buildings (120 flats in total) dislocated in different parts of the same neighbourhood, the second one presents 2 buildings (54 flats in total) located in the same construction site. Both are realized with industrialized systems.

These cases study were chosen among others, because they demonstrate a series of recurring elements in the geographical area concerned:

- they present great panel structures (even if cast on site, instead of using prefabricated panels/slabs);

- they are located in Firenze and in Prato, within an expanding, but well configured urban patterns;

- this area, unlike others in Italy, lacked the conditions for an extensive application of prefabricated products, working instead mainly in the direction of industrialization of the building process, though this was a new technical approach that could not completely disengage from the tradition building practices;

- although the complex in Firenze represents the highest level of consistency (120 housing units in 4 buildings), it is representative of the dissemination process of the construction projects in the area. Conversely the complex in Prato is characterized by the location of the buildings in the same site; it is therefore interesting to study the 2 different configurations.

Moreover, the great documentation[12] about these building complexes allowed to reconstruct the building process and to understand in detail the constructions in their entirety.

The analysis of the buildings current state, in relation to the environmental and technological system, paying particular attention to the energy performance, leads to the definition of common characteristics to the buildings class. Taking into account these features, it was possible to evaluate and to apply some strategies for the sustainable renovation of the buildings in exam.

These recovery criteria will establish an example that could be spread to buildings with similar characteristics and located in comparable climate zones.

Furthermore, despite this work deals with residential public buildings, it will be possible to extend the research results to the contemporary constructions built on private initiative, that present the same characteristics of the sample cases.

[12] As we already mentioned the documentation about these buildings is collected at the Casa S.p.A Archive. As regards Prato, the documents related to the building process are in the folders: from 105 to 109. The folders containing the design boards are: F105(1-2), F106(1-2), F108(1-5), F109. As regards Firenze the building process documents are in the folders: from 162A to 173. The design boards are in the folders: F163, F165(1-2), F168(1-2-3), F170, F172, F173.

1.3 METHODOLOGY

The methodology of the work is structured as follows:

- Choice of the buildings considered the most representative of the prefabricated/industrialized systems used in the Florence area.
  The choice of the buildings taken as sample cases is derived from a careful analysis of the documentation and design boards about Social Housing realized with industrialized/prefabricated techniques in the Florence area, collected in Casa S.p.A archive;
- Analysis of the environmental and technological system of the buildings in exam with the aim of identifying common and typical characteristics.
  This phase is crucial in order to understand the criticisms and the possible constraints for the different possibilities of interventions. The definition of the constructions common features is useful to create a general scenario on which to intervene, because the strategies to be adopted will have to well fit to all the buildings with similar characteristics;
- Analysis of the buildings behaviour in terms of energy consumption, both in semi-stationary and dynamic conditions.
  After a previous analysis of the construction characteristics, it is worth to analyse both the energy performance of the buildings and the internal comfort conditions inside the apartments. The attention was paid both on the Winter season and the Summer one, because Florence is located in a Mediterranean Climate zone; this means that warm periods can occur, leading to possible discomfort to the users;
- Choice of the strategies and definition of the refurbishment method for the case studies.
  The results came to light during the previous phase led to the choice of the most suitable strategies, according to the class of residential building, the building type and the climate conditions. It was worth to apply the method on one of the 5 buildings in order to get the best result and then applicable on the other constructions. The results should be comparable and similar, according to the previous hypotheses;
- Application of the refurbishment method to the other buildings taken as sample cases.
  This phase is a validation of the strategies adopted for the building taken as sample case in the previous step;
- Synthesis of the results and definition of the refurbishment method for the sustainable renovation of industrialized public residential buildings in Mediterranean climates.
  This phase is a summary of the steps to do when the aim is to recover buildings with similar characteristics located in comparable climates.

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2. STATE OF THE ART REVIEW

This chapter is divided into 3 sections:

1. General presentation of the common methodology for the sustainable refurbishment of existing building. This phase is useful to understand the key points of a sustainable renovation, to be applied in this work as well;
2. Sustainable renovation strategies in public residential buildings. Examples of refurbishment interventions in the social housing estate are analysed, in some of the major countries in Europe and in Italy. This analysis is useful to understand the typical strategies for the recovery of this type of residential buildings. Moreover, in this section an excursus of the main current European Research activities is provided;
3. Implications on the thesis derived from the analysis of the literature. This section explains how and why this work can be located within the European activities and which contributes should give to the Sustainable Renovation of Social Housing field.

2.1 COMMON METHODOLOGY FOR SUSTAINABLE RENOVATION OF EXISTING BUILDINGS

The building retrofit is a new challenge for reducing global energy consumption and greenhouse gas emissions. The problem is to find the most cost-effective strategies, by improving the energy performance of the building without worsening the comfort conditions of the occupants.

Ma et al. (1) summarizes the building retrofit process into 5 main phases:

1. Pre-retrofit survey.

In this phase, the objectives of the work are defined.

2. Energy audits and definition of the Energy Performance.

This is a diagnostic phase in which the strengths and weaknesses of the building are analysed in order to find the best strategies to apply. The audit level has to be chosen by considering the amount of details necessary to know the current state of the building, available budget for the refurbishment. The surveys on site, made with a series of instruments are useful to find parameters to set on the building models realized through simulation software, capable to define the energy performance of the buildings.

Different approaches for evaluating the energy use in a building have been carried out. These approaches can be summarised into 3 categories (2) depending on:

- Design data (from energy audits);
- Analysis of building utility bills;
- Measurements conducted in situ.

Among these approaches we can mention the House Energy Labelling Procedure (HELP) developed by Richalet et al. (3). This is a measurement based approach and it consists of deriving the thermal behaviour of a building from a continuous recording of indoor temperatures related to outdoor climate conditions (temperatures, winds, solar radiation) and internal loads. Parameters are then found from these measurements and used to compute a normalized heating annual consumption (NHAC) for a standard climate and standard operational levels, such as set-point temperatures.

The majority of the procedures for establishing the energy performance of a building are based on the use of all the three categories listed above.

The model based benchmarking is an example of this procedure of combining more approaches. It is worth to underline the model developed by Federspiel et al. (4), in which a benchmark that represents a minimum energy necessary to achieve basic functional requirements of the building, such as thermal comfort controls, acceptable lighting etc., is provided. The benchmark is calculated based on models with ideal system performance.

An advantage of this approach is that these models are independent of design. After the definition of the benchmark for a single building, an efficiency factor is calculated by dividing the model-base benchmark by the actual consumption of the building. This factor can be compared to the factors calculated for other buildings.

The Building Energy and Research Information Centre at the National University of Singapore (BCA-NUS) has developed an energy-rating tool (e-Energy) that is based on statistics of data collected from various buildings in terms of their energy performance or occupancy levels. It consists of 5 scores for different energy audit results (2).

In Canada, Zmeureanu et al. (5) developed an energy rating system for existing houses, consisting of the combination of information derived from utility bills with data collected on site and computer simulations. This system was tested on 45 houses in Montreal.

The method’s aim is that of making the owner aware about the actual energy performance of its house and the possibility to improve it. The method is based on 7 steps. The 1° step is the analysis of utility bills through the use of a software in order to find the Normalized Annual Energy Consumption (NAC) and Cost (NACo). The results are then compared with similar data from other reference buildings. In the 2° step, an index of energy performance in terms of NACo is assigned to the building, in order to have a general idea about the potential savings. For example, if the house presents an index equal to that of a reference new house, the possibilities to improve the energy performance are low; the procedure can therefore stop at this step, otherwise it can further continue. The 3° step consists of collected data on site, through the use of instruments, such as infrared camera in order to identify the thermal bridges, or other instruments to evaluate the thermal transmittance of the envelope.

Measurements on site of other data, such as the size of the windows or walls and the type and capacity of the heating system are taken into account in the 4° step. The 5° step is the creation of a model through the use of a simulation software, by using the data collected in the previous phases and by calibrating the parameters with the utility bills. After the estimation of the house energy performance, in the 6° phase the most suitable strategies are evaluated; through the use of the simulation software the energy savings are calculated along with the evaluation of the costs. The 7° and last step is the realization of a summary report and its submission to the owner of the house.

Poel et al. (6) describes the EPA-ED method for assessing the energy performance of existing dwellings. The EPA method starts with an interview to the client, in order to discuss about strategies and interventions and an audit on site with the aim at collecting all the useful data for establishing the energy performance of the building current state and the evaluation of the cost-effectiveness of some measures. The result is an energy performance certificate. In order to produce this certificate, the EPA consultant is provided with a series of tools, such as guidelines for the inspections, in order to collect the necessary data to be introduced into the software tool, which is the other instrument needed for the evaluations.

The choice of a performance assessment method and diagnostic tool depends on the objective of the recovery intervention, the client and the costs related to the use of instruments for the measurements, or the use of specific software.

3. Choice of the retrofit options and strategies.

The choice of the renovation strategies derives from the results of energy analyses based on data collected on site (previous phase). This phase consists of the quantification of the achieved improvement by the application of the strategies considered the most suitable. To do that there are several energy simulation software, such as EnergyPlus, DOE-2, TRNSYS, etc., able to estimate the energy savings due to the building retrofits.

Crawley et al. (7) provides a list of 20 simulation software and their characteristics in order to understand what tool is more useful than another one in solving particular issues or in validating specific measures, by comparing their results in the application of particular retrofit strategies.

Asadi et al. (8) developed a mathematical model to help in the evaluation of the best strategies in a retrofit intervention. An existing house is taken as sample case and a combination of strategies are taken as variables: windows, external walls insulation materials, installation of solar collectors. The objective is to achieve the minimum retrofit cost and maximum energy savings. The model allows for the simultaneous consideration of all available combinations of alternative retrofit actions.

Yalcintas (9) uses the Artificial Neural Networks (ANN) for developing a model that evaluates energy savings from retrofit interventions, by using data collected from 2 retrofit project before and after the refurbishment. The model integrates local climate variables, occupancy data and building-operation schedules.

A great number of different models and tools exists in literature. They are essential in the evaluation of the performance of retrofit measures. Because of their uncertainties, the choice of the software or the model is fundamental in order to guarantee the affordability of a chosen strategy and its result in terms of energy savings.

4. Site implementation.

The chosen strategies are then applied on site. In this phase tests and verifications are implemented in order to verify if the systems are operating in an optimal manner.

5. Validation and verification of energy savings.

After the application of the strategies, measurements are necessary to evaluate the real actual savings of the “renovated” building. The method used for this purpose is called Measurement and Verification (M&V). This is the process of using measurement to determine savings. Savings cannot be directly measured, but their “values” can be found by comparing measured use before and after implementation of a project (10).

M&V has been used to verify energy savings in several projects. It is worth to mention the work conducted by Lee (11). The work analyses the actual energy savings associated with lighting retrofits using short and long-term monitoring.

2.2 SUSTAINABLE RENOVATION STRATEGIES IN PUBLIC RESIDENTIAL BUILDINGS

The complexity of problems regarding recovery of residential areas in our suburbs is common to the main European cities that have to deal with the need for regenerating the vast building heritage of the '50s/'70s. People started talking about energy saving during the '70s of last century, following the first serious oil supply crisis. In addition to the past problems, which were mostly related to concerns associated with the exhaustion of fossil fuel sources, further problems emerged over carbon dioxide emissions, whose gases would be responsible for the "greenhouse effect" and the resulting global climate change. With the Kyoto Protocol (1997), various States, among which Italy, have pledged to reduce these emissions, consequently pursuing a new policy of sustainable development, mainly cantered on energy conservation and exploitation of renewable energies.

The building industry is one of the areas where an enormous amount of energy can be saved intervening right from the planning phase, whether addressed to new construction, recovery or redevelopment. Sustainability, from a recovery point of view, has now become essential, since the great majority of constructions, in Italy and in the rest of Europe, date back to the '50s/'70s and therefore need a complete overhaul. Deficits that were frequently found in these housing developments are technical/constructive (degradation of the façades, roofs, doors and windows, etc.), thermal (low thermal resistance of building envelope), plant engineering (plants not compliant with legal standards), and related to space (underdevelopment of places, lack of green and public areas, etc.).

The restoration of residential districts such as the ones in France and Germany, has shown that a simple recovery and slight reconstruction, with the purpose of improving energy performance and lifting of facades, however, must come with a social redevelopment, which aims to improve accessibility and urban connections, and create collective areas, services, and public green spaces. Both in the French and the German case, district renovation was preceded by a long programming work that involved all stakeholders in the process, beginning with users who were given the opportunity to suggest the most suitable solutions according to their needs.

2.2.1 EXAMPLES IN EUROPE

FRANCE

France was the first country to start redevelopment policies on a large scale. Immediately after the war, as a result of growing housing needs determined by an increasing population and emigration flows towards large urban centres, social housing activities were focused on the allocation of housing units to the lower classes and needy people. Therefore, high-density building complexes were constructed using precast elements which allowed to minimize costs and speed up the construction process. Nevertheless, the qualitative aspect, social issues, and inclusion problems were ignored in such complexes, thus creating deep divisions with the city and the emergence of slums. After trying interventions aimed only at upgrading technical and functional aspects of the buildings, carrying out the most urgent building installations and facades lifting operations, France also launched a comprehensive national energy saving policy, by converging urban regeneration policies and environmental requirements, plus introducing incentives and facilities aimed at promoting the reduction of CO_2 emissions and improving energy efficiency.

In the late ‘70s the OPAH[1] program was created (Opération Programmée d’Amélioration de l’Habitat), with the intention of coordinating objectives and state funding with local structures (including private ones), and facilitating access to the funds of ANAH[2] (Agens National pour l’Amélioration de l’Habitat). Promoters of the interventions were mainly HLM public housing authorities (Abitations à Loyer Moderé) and different regional and departmental OPAC (Office Public d’Aménagement et Construction), which constantly planned interventions with diagnostic and feasibility studies, and continuously consulted dwellers (mandatory consultation of users).

In addition to grants for building redevelopment earmarked for PALULOS[3] social housing operators (Prime à l’Amélioration des Logements à Usage Locatif et Occupation Sociale), government family support programs were also undertaken (state subsidies), programs concerted with the Ministry of Education (to stimulate education, provide local education facilities, decentralize educational activities, etc.), and the Ministry of Social Affairs (offices and placement agencies, especially for youth employment). In a particular procedure called DSQ (12) (Développement Social des Quartiers), redevelopment is presented as "a project focused on the integrated principle between different levels of social, economic and urban intervention, oriented towards the local and the involvement of dwellers". Similarly, the HVS operation (13) (Habitat et Vie Social) represents an administrative and financial state procedure for the recovery of Grand Ensembles, characterized by forms of physical and social degradation, which aims to eliminate distance between cities and suburbs, certain that such deterioration was due to the obsolescence of neighbourhoods, but above all, to their marginalization from the rest of the city.

SAMPLE CASE: THE MAZOREL DISTRICT

Malighetti (14) analyzes a series of recovery interventions realized in social housing districts. For the similarity in the aspect and in the structural system the “Mazorel” district is shown as sample case in France.

The “Mazorel”, located in Crest, a small city in the Southern France, was built in 1969-1972. It consists of 2 linear buildings with 88 flats, oriented along the East-West axes: the main rooms face South, while the service ones are oriented towards North. They are large panel prefabricated concrete buildings: the façades are characterized by a strong modularity with equal sized openings.

- MAIN ISSUES BEFORE THE RECOVERY INTERVENTION:

Technological/energy aspects

- degradation of the joints between the panels;
- degradation of the windows;
- low temperatures inside the flats in Winter;
- thermal bridges.

Functional/distributional/environmental aspects

- single functionality (residential function);
- common and external areas were not defined and anyway of low quality;
- monotony on the façade.

- RECOVERY INTERVENTION

This district was recovered in 1994. The buildings orientation, with the main façade

[1] See: www.communaute-de-communes-portes-ile-de-france.fr/.
[2] See: www.anah.fr/lanah.html.
[3] See: www.icfhabitat.fr/palulos.

North/South oriented, led to the exploitation of passive solar strategies (see par. 2.2.4). The main intervention was the construction of solar greenhouses on the South façade next to the living rooms. This intervention besides the energy saving due to the use of heat produced by the greenhouse for heating the space, has increased the space areas of almost 8m^2 (before the intervention the day-area was under-dimensioned). In Winter the air enters into the greenhouse through vents, where it is pre-heated by the solar radiation passing through the transparent surfaces of the envelope[4].

In Summer the greenhouse can be completely open, in such a way it allows to let the cool air go inside the house. Another passive solar strategy used in this intervention is the "Trombe wall", located at the extremity of the buildings still on the South façade. This wall, starting from the outdoor layer, consists of a transparent surface made with glass plates, an air cavity and the existing wall painted black with the function of thermal storage. The glasses are supported by a transoms and mullions structure which presents "brise soleil" for avoiding the overheating in Summer. These walls are in correspondence of the bedrooms: in Winter this system contributes to heat the spaces, by introducing into the room the warm air heated in the cavity, by means openings realized in the existing wall. In Summer these vents are closed in order to avoid the overheating.

On the other façade, the main interventions were: addition of an insulation layer and the substitution of the windows with more efficient ones.

In this intervention active solar strategies were used as well (see par. 2.2.4). Indeed, 39m^2 of water solar collectors for domestic hot water heating were installed. Obviously, the amount for this intervention was not negligible, but the 40% of the costs for the solar strategies was covered by the European Commission.

Figure 2.1: The "Mazorel" district. On the left: Building view before the intervention. On the right: Building view after the intervention (14).

[4] A solar greenhouse consists of transparent surfaces made with single glasses capable to let the solar radiation pass through them.

GERMANY

The redevelopment process in Germany mainly intends to revitalize large districts built by the DDR in the former East Berlin, in order to cope with the enormous housing problem. These neighbourhoods were built using heavy precast technology, in the form of apartment blocks designed to contain as many people as possible in small spaces. The strategies adopted in Germany for the recovery of the housing estates were differentiated in two levels (14):

1. Reaching a higher quality level in the buildings, while achieving better energy efficiency.
2. Intervening in the social fabric creating settlements that encourage social cohesion and develop local identity, encouraging contractors and transport companies to set in motion sustainable and public mobility mechanisms.

In order to support recovery projects, the federal government developed a soft loan mechanism granted by the KfW, German State Bank, which can be accessible to private citizens, professionals and companies. In 1995, Solidarpakt I was launched (first solidarity package), an economical support that financed infrastructures, businesses and social, in terms of unemployment benefits, pensions, etc., so as to reduce economical differences between western and eastern citizens. In 2005, Solidarpakt II was then launched, once again designed for recovery programs.

The first pilot project funded in former East Germany is the one for the Berlin-Hellersdorfs district[5], through the support provided by the so-called "Slab Program", promoted by the Federal Government and the city of Berlin, which considered recovering these neighborhoods necessary, giving them new development possibilities, in line with a sustainable perspective. Furthermore, another main concept of this project is that technical and functional recovery has to be accompanied by an urban and social redefinition, with a strong involvement of residents, from the decision-making process up to the selection of materials, shapes and colours. The principles of the recovery interventions were:

- Free areas upgrading;
- Inspection of pathways for pedestrians and cyclists;
- Inclusion of functions, other than residential ones, such as shops, services, cultural activities areas, etc;
- Improvement of green spaces;
- Definition of new neighbourhood areas;
- Redevelopment of waste deposits.

Recovery interventions on buildings were mainly aimed at improving energy efficiency through modern technical installations of roofs, with the improvement of heat insulation of the façades and the recovery of existing loggias by substituting parapets in precast slabs with metallic coloured ones, which helped to stop the serial and repetitive character of the buildings.

Based on the same criteria, the restoration project of Platten districts of Leinefelde, in Thuringia, was carried out. In 1995, the LWG Leinefelde, owner of the buildings in the South part of the city, which in the '50s were supposed to house 13 thousand new dwellers and were progressively abandoned due to the shutting down of an important cotton mill in the '80s, entrusted the redevelopment of a group of buildings to the architect Stefan Forster. The project, which was eventually inserted as an EXPO 2000 pilot project, presents an improvement of functional and spatial

[5] The renovation involved 560 buildings for a total of 33000 flats.

quality of the building and housing unit, with requalification strategies on a neighbourhood scale, and the use of solar energy technologies with passive and active systems.

SAMPLE CASE: THE LEINEFELDE DISTRICT

A brief description of the recovery intervention of one of the districts in Leinefelde is shown trough the re-elaboration of the data collected in the Malighetti's work (14). The choice of describing this intervention is still due to the similarity to the building analysed in this thesis.

This intervention realized in the '70s, is located in Lessinsgstrasse 10-32 (Leinefelde) and consists of 3 linear buildings with 5 floors and 8 flats/floor for a total of 120 flats whose 42 were unoccupied before the recovery intervention. The structure is made with panel in reinforced concrete.

- MAIN ISSUES BEFORE THE RECOVERY INTERVENTION:

Technological/energy aspects

- degradation of the joints between the panels;
- low thermal resistance of the envelope.

Functional/distributional/environmental aspects

- stiff internal distribution of the flats;
- monotony on the façade.

- RECOVERY INTERVENTION

The neighbourhood was recovered in 1998. The loggias were covered realizing the so-called "Winter-gardens". New balconies were realized. 2 single flats were joined in order to realize a duplex flat, for a total of 4 duplex-apartments. A new key element in the design was the perimeter masonry wall which combined several functions: it gave a base to the building, it created private gardens at ground floor level, in such a way it established a kind of barrier, a buffer zone between the building and the street. The envelope was recovered through the addition of an insulation layer on all facades, as well as through the substitution of the windows.

Figure 2.2: Renovated building in Leinefelde. On the left the perimeter masonry wall. On the right the new balconies[6].

[6] (www.sfa.de/regeneration-east/01.01.1999).

DENMARK

In Denmark, the suburbs redevelopment issues do not reach gravity levels as well as in the other Countries, especially for what concerns the social aspects. This is mainly due to the reduced size of the districts. The redevelopment actions are addressed to the reconnection between the building in the district, through the re-designing of the green areas or common spaces. In 1994 the SBS (Urban Renewal Company) started a program for the refurbishment of a buildings block, "Hedebygade" in the district Outer Vesterbo (Copenhagen). The redevelopment followed different steps based on different projects for each block of the district, for a total of 12 sub-projects (15). Each project had different objectives: passive cooling, using natural ventilation systems, the microclimate improvement through the use of green plants inside the units, exploitation of the solar energy by means PV panels and solar greenhouses, etc...

SAMPLE CASE: THE YELLOW HOUSE

The recovery intervention we will explain as sample in Denmark, represents an interesting example of application of solar strategies. The intervention considers only a building and not a district, unlike the other explained projects and the construction system is different, as well as the dimensions, but the intervention strategy makes this project an example of "sustainable retrofitting" of social housing.

The building in question is the "Yellow house" located in Aalborg. It consists of 4 floors with 2 flats/floor. The structure is made with load bearing masonry. It was built in 1900.The main façade are North and South oriented.

- MAIN ISSUES BEFORE THE RECOVERY INTERVENTION:

Technological/energy aspects

- degradation of the joints between the panels;
- low thermal resistance of the envelope;
- high energy demand for heating.

Functional/distributional/environmental aspects

- stiff internal distribution of the flats;
- monotony on the façade.

- RECOVERY INTERVENTION

The project was based on traditional strategies and active and passive solar strategies. It was chosen as sample case in the Danish research program IEA SHC task 20 Solar Energy in Building Renovation, a research conducted within the program SHC (Solar Heating & Cooling Programme)[7]. The main goal of the renovation was to reduce the energy demand for heating, ventilation and domestic hot water. The innovation of this project was the introduction of a South facing, highly insulated and heated glazed balcony (see fig.2.3). A PV panel is integrated in the parapet: this system pre-heats the air which, going up in the cavity between the PV panels, enters the room through inlets

[7] The Solar Heating and Cooling Program was established in 1977, one of the first programs of the International Energy Agency (IEA). The Program's work is unique in that it is accomplished through the international collaborative effort of experts from Member countries and the European Union. It had the aim to address the attention towards solar energy technologies and designs that include active solar heating and cooling, photovoltaics, passive solar and daylighting, being important components of a sustainable energy future http://archive.iea-shc.org/.

realized under the window. The air circulation is guaranteed by the depression created by the extractors located in the kitchen and in the bathroom (16).

Figure 2.3: The “Yellow house” renovation project. On the left the South façade of the building. On the right the vertical cross section of the advanced glazed balcony (17).

2.2.2 EXAMPLES IN ITALY

Public housing in Italy established itself in the post-war period. With the 1949 bill (Fanfani Law), the INA-CASA sector plan was initiated, thanks to which Parliament passed "measures to increase employment, facilitating the construction of houses for workers"; the ‘60s were characterized by a great housing need and the beginning of a second phase: Law 167/1962 introduces Economic and Social Housing Plans (Piani di Edilizia Economica Popolare - PEEP) and aims to provide tools to public corporation in order to program interventions in the housing market and to have an effect on the structure of the urban territory, countering land speculation and addressing housing development with area plans (to be implemented on expropriated areas) for economic and social housing. In a brief time, the new homes "were associated to arising negative effects and seen as a sign of cultural and ideological failure" (18).

In 1971, Law 865 was promulgated, which effectively turned the Institutes of Public Housing from economic public bodies to non-economic public bodies, therefore with a prevalence of social welfare activity. Law 865 not only worked for the transformation of the aforesaid Institutes, but also set objectives that ranged over the whole economic and social economy. In fact, the subject matter now was the integration of housing policy, land development and standard regulation. In the late '70s and early '80s, the enactment of some laws (especially Law 457 of 1978, known as the Ten-Year Plan for Residential Construction), changed the funding system and allowed an increase in construction and recovery activity. In the ‘90s, the construction of public residential neighbourhoods which took place between the ‘50s/’70s, however, later gave way to the redevelopment of these large complexes, often exposed to degradation processes which have compromised their image. Hence, the new urban policies are oriented towards a new objective that allows to redevelop an urban fabric which grew disorderly, pursuing the logic of recovery and reuse of existing buildings and preservation of urban culture.

Since the early ‘90s, with the Complex Programs regulations, the innovative wave has brought along the need to define an instrument capable of solving problems of integration, land use, lack of services, illegal and unauthorized building. Within the Complex Programs, there are two that have a priority reference to public housing redevelopment: the Urban Recovery Programs (PRU-Programmi di Recupero Urbano), introduced with Law 493 of 1993, and the District Contracts (CdQ-Contratti di Quartiere) in the two editions of 1997 and 2001. Complex programs are therefore created to give an answer to a structural situation of our country, the need for recovery and redevelopment that involves all cities and urban centres, from small to large ones. The house plan (Piano Casa) was introduced with Decree Law 112/2008, which includes the use of closed real estate funds as a possible means to enhance and increase housing supply in the area. These real estate funds can be established with the participation of public and private parties, and may be articulated in an integrated system of local relevance funds. Italy is indeed still very far from the innovative experiences of urban recovery proven in other countries of northern Europe, but the substantial amount of housing stock characterized by its age (older than 50 years), has led to a growing need for conservation, restructuring and consolidation interventions. As a matter of fact, the new regulations enacted in Italy after the transposition of European Directive 2002/91/EC, are helping to speed up this process, thanks to the introduction of a mandatory energy certification, both for new buildings construction and for existing buildings.

SAMPLE CASE: CdQ I S. EUSEBIO

S. Eusebio is a district located in Cinisello Balsamo (Milano). It consists of 2 main areas: the first one built in the ’60s, with linear buildings and terraced houses (“le villette”) and the other one with a C shaped linear building (“il Palazzone”) and 5 tower buildings, built in the ‘70s.

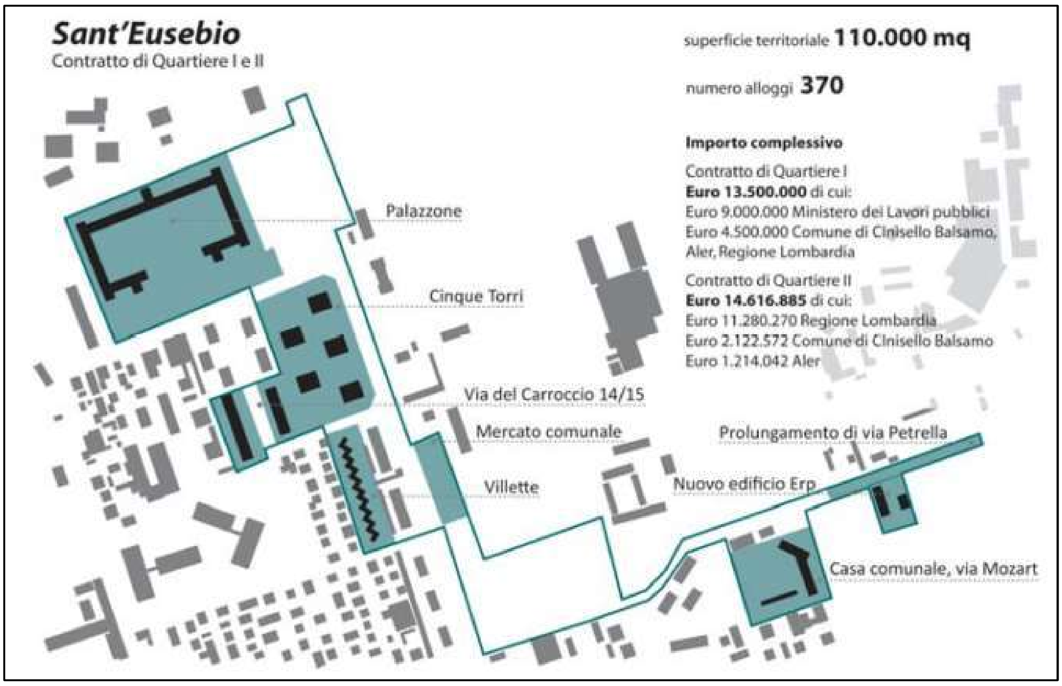

Figure 2.4: S. Eusebio district (18).

The CdQ I takes into account the renovation of "il Palazzone" building. This construction has 8 floors and 1 "pillar floor" for a total of 288 flats. The flats are medium-large sized (80-100m^2), too big sized flats in relation to the "new" families (singles, family with only one parent etc.) which require for smaller spaces.

- MAIN ISSUES BEFORE THE RECOVERY INTERVENTION:

Technological/energy aspects

- degradation of the windows;
- low thermal resistance of the envelope;
- high energy demand for heating.

Functional/distributional/environmental aspects

- too big flats;
- stiff internal distribution of the flats;
- monotony on the façade;
- building mono-functionality.

- RECOVERY INTERVENTION

The recovery intervention started in 1998 and it involved the reorganization of 50 flats in order to realize apartments with smaller dimensions compared to the existing ones: 36-70m^2 for simplex flats and 90m^2 for duplex flats. A support centre for the older people was created at the "pillar floor". The renovation was organized in 2 phases: the first one involved the renovation of the structure and the implants, the second one the refurbishment of the flats. Technological towers were realized in order to introduce the lift shafts and to contain the pipelines for the new radiant panel heating system. With the aim at rationalizing the recovery intervention a flexible strategy was studied: 30 not housed flats were used as "parking flats" for people living the flats subject to renovation. Besides new duplex flats are inserted at the last floor, obtained through the conversion of single flats locate at the last 2 floors. These apartments present fully glazed fronts which surround the solar greenhouses with a double height. These bright areas are used for office-spaces or telework-spaces, demonstrating the contemporary trends towards new ways of life. Besides the reutilization of the area located at the "pillar floor", new constructions were built inside the courtyard in order to host some shops, with the aim at differentiating the functions in the district.

Figure 2.5: Renovation of S.Eusebio district: on the left "il Palazzone" before the recovery intervention. On the right a rendering of the technological towers designed for the renovation project (14).

Summarizing the recovery intervention strategy, it was mainly oriented towards 3 directions:

- improvement of the public residential buildings management: technological towers, renovation of the implants, re-distribution and re-organization of the flats;

- new public areas: green spaces, education/leisure activities spaces, health and social services areas;
- new areas for shop and commercial activities.

2.2.3 CURRENT SUSTAINABLE RENOVATION PROGRAMS

After the previous analysis of some significant renovation projects in Europe, it is worth to analyse the current research programs in the Social Housing renovation field. As we will explain in the next paragraph (par. 2.2.4), the main trend in European research activities is to establish tools and guidelines to recover social housing districts, by intervening at the Neighbourhood Scale, taking into account social aspects of the integration of users living in these areas within the city community.

Among these projects, SURERO (19) (Sustainable Refurbishment Europe) is a project developed between 2002 and 2004 aimed at providing housing companies with practical management tools for integrating sustainable development and tenant participation in their refurbishment plan and management without increasing the normal costs for the tenants. It has evaluated the current processing and know-how in urban renewal of post-war housing stock. Its focus is the sustainability approach to achieve a balance between financial, social and environmental priorities within the above named three fields of housing rehabilitation and maintenance. Its main objective is the dissemination of sustainable good practice strategies on the basis of co-operation between practitioners and research; the European countries taking part this project were: Sweden, Denmark, Finland, the Netherlands, Great Britain, France, Germany, Czech Republic and Italy.

HQE^{2}R[8] (Sustainable Renovation of Building for Sustainable Neighbourhood) is a project partly funded by the European Union within the program "Environment and Sustainable Development", which aims to provide a model to guide recovery projects towards improving solutions of urban life. The project aims to demonstrate the feasibility of recovery of entire neighbourhoods, through a combined assessment of environmental, social and economic aspects and sustainability by incorporating, in this evaluation, all the elements that make up the “built”: buildings, infrastructures, open spaces, green areas. The integrated approach is designed to be disseminated and applied throughout Europe; the methodology is being tested in 14 different cities of seven EU Member States (Denmark, France, Germany, Italy, Netherlands, Spain and the UK). The approach proposed by HQE^{2}R for sustainable neighbourhood regeneration is organized into four main phases (20):

1. Preliminary identification of the problems and initial strategic decisions
2. Analysis: data collection (Inventory) and participatory diagnosis of sustainable development;
3. Study of the action plan: generation and evaluation of alternative scenarios;
4. Implementation, monitoring and evaluation of the plan for the sustainable recovery of the neighbourhood.

HQE^{2}R offers specific tools, in particular:

- Choice of 6 principles of sustainable development on an urban scale;
- Definition of 5 general (TARGET) and 21 specific objectives for the Sustainable Development (SD) and the identification of 51 key issues at the building and neighbourhood scale;

[8] Developed between 2001 and 2004.

- A method for participate diagnosis of sustainability at the neighbourhood level and a specific analytical matrix;
- Sustainability indicators which are identified in: indicators of state, for the diagnosis of neighbourhoods and buildings; a system of indicators (ISDIS) related to the SD objectives and to the key issues for assessing the sustainability of the neighbourhood; monitoring indicators for different projects for the neighbourhood or the city;
- Recommendations to promote and enhance participation in the recovery projects;
- Three support models to decision (pilot version) for choosing the best restoration project. 2 models at the neighbourhood scale: a) ENVI model for the environmental assessment of the scenarios; b) INDI model, based on the SD indicators, helping to find alternative scenarios evaluation. A building scale model, ASCOT model, for the global costs evaluation;
- Recommendations to integrate sustainable development in the urban planning;
- Recommendations to integrate sustainable development in the construction process and for the study of not built elements;
- Guidelines for the sustainable projects management.

HQE^2R adopted six principles, considered essential for the sustainable development of cities:

a. Economic efficiency;
b. Social equity;
c. Environmental protection;
d. Long-term vision;
e. Global Vision;
f. Governance.

Considering these principles, 5 main objectives of SD (TARGET) were defined and 21 SD specific objectives that form the theoretical basis of HQE^2R:

A. Protecting and enhancing the heritage and preserving resources;
B. Improving the local environmental quality;
C. Encouraging diversity;
D. Improving the integration;
E. Promoting social cohesion.

The final result of HQE^2R consists in the possibility of comparing, in an immediate way, the state of fact evaluation, with that of different scenarios of possible development. The output end results are summarized in radar charts. The same is done with development scenarios that have the primary aim to improve the critical issues identified by the current state analysis.

RESTATE[9] is a research project involving 10 European countries (Italy takes part to this project), interesting in both the physical and social decline of large housing estates[10] after the Second World War and with the aim at developing new trends for the improvement of these districts. The main objectives of the study are:

- Identifying the social and economic changes occurred in the estates after the war, aiming at understanding the main factors causing the decline of these areas;

[9] RESTATE. Restructuring Large Scale Housing Estates in European Cities: Good Practices and New Visions for Sustainable Neighbourhoods and Cities. RESTATE website: http://www.restate.geog.uu.nl. Developed between 2003 and 2005.

[10] A large-scale housing estate is a group of buildings that is recognised as a distinct and discrete geographical area (30).

- Developing a checklist of aspects that have demonstrated to be important in successful results in the recovery policies;
- Producing guidelines in which best-practices to achieve sustainable development of these areas are defined;
- Understanding how the European policies could contribute to effective responses to problems related to these areas.

The project includes some case studies which can be considered the central part of the program. Indeed, they define information about the estate such as history, social, economic, physical issues and developments, identifying the policies promoted in these areas with their effects and the results.

SOLANOVA[11] is the program dealing with the renovation of large existing buildings made with panel structures in the Eastern-Europe built in '70s and 80's. The project proposed strategies by combining 3 main issues:

- how to design according to human needs;
- how to achieve high levels of energy performance;
- how to integrate and optimize solar power.

In 2005, one seven-storey prefabricated panel building in the Hungarian town of Dunaùjvàros was transformed into the first 3-l-panel-building[12] of the country after the application of passive-house concepts.

Figure 2.6: On the left SOLANOVA building before renovation. On the right SOLANOVA building after renovation (21).

The renovation consisted of the optimization of the heating system by adopting solar panels on the South façade in order to cover the energy demand for service water. An insulation layer was added on the building façade in order to reduce the thermal transmittance. the renovation was completed in 2005. The aim of this project was to enlarge the results to other kind of large residential buildings.

With the new EU required standards, aiming at reaching the so-called Nearly Zero Energy Building (NZEB), the approach at urban/neighbourhood scale is increasingly addressing towards a

[11] SOLANOVA-Solar-supported, integrated eco-efficient renovation of large residential buildings and heat –supply-systems

[12] Three-liter-panel-building refers to a technical terminology used in the German-speaking countries. It is used to indicate the equivalence $1l/m^2y$ of gasoline$\leq 10kWh/m^2y$. It means that 3-l-panel-building refers to $30kWh/m^2y$ (22).

much-detailed analysis of the problems and solutions at the building scale. At the same time the concept of neighbourhood renovation changes with the new concept of smart grid and the boundaries are not limited only to the borders of the neighbourhood, but they enlarge towards the entire city. Accordingly the researches aim at finding results able to be spread at the European level (22).

It is worth to mention the CONCERTO project (23). The aim of this program is to give solutions at European level in order to achieve the energy self-sufficiency within Europe, taking into account the effects of climate changes. The program is organized following several actions:

- the development of Renewable Energy Resources;
- the integration of Renewable Energy Resources in sustainable buildings;
- the production of heat and energy and district heating (through biomasses).

CONCERTO embraces cities and communities and provides for social-economic analysis in accordance with the changes in energy costs and the social impact of the adopted measures and strategies. The project, through the analysis of the results obtained among different case studies among the community, has shown that existing buildings can cut their CO^2 emission by up 50%, through the implementation of renewable sources, smart grids etc. It teaches how a renovation project can be successful, that it has to be accepted by the people whom it affects. Inhabitants must understand why potential short-term inconveniences are necessary for their long-term comfort. The project suggests conducting initial consultation with the residents when planning a renovation intervention.

Figure 2.7: Renovated district in Delft. Example of heating district (23).

EPI-SoHO (Energy Performance Integration in Social Housing a strategic approach for portfolio management) is another interesting project. It was realized between 2006 and 2008. The aim of this program was to integrate the energy aspects in the management of the existing buildings and to define long-term strategies for its recovery intervention. It acts through pilot project. In Italy the pilot project was realized in Venice with 2 main objectives (24):

1. Starting to define the energy performance of the ATER's buildings portfolio;
2. Starting to include energy in the management strategies of the social housing stock.

The key issue is to develop a flexible technique that can easily be adapted to local conditions and future developments. It is therefore crucial to clearly determine which aspects are global and this means at an international level and which aspects should be adaptable to local conditions and, furthermore, which future developments are to be expected. The main issue of the building stock is the diversity in the buildings construction systems; this constraint has to be taken into account.

Several projects are addressed to technological aspects of the buildings as construction, by focusing on the possible implementation of the envelope, on an upgrading of systems and on improving the building behaviour in Summer.

In this respect, we can mention the SuRE-Fit program (Sustainable Roof Extension Retrofit for High-Rise Social Housing in Europe). This project aims to summarize the most advanced aspects and results of the technologies related to the roof extension for multi-storey buildings. The work conducted in Bratislava, discusses the possibilities of application of additional housing units on the top of high-rise social housing in Slovakia (25). The work shows that the accessibility to these new ecological technologies is affected by the amount of initial budget. Furthermore, the most widespread problem is that properties are occupied during the building renovation intervention, and the works can create difficulties to the inhabitants.

The AVASH project (26) (Advanced Ventilation Approaches for Social Housing) focuses on all aspects related to the ventilation seen as a fundamental aspect to be taken into account in a recovery intervention. It aims to find the most suitable ventilation and insulation strategy for existing social housing.

Another program worthy to be mentioned is COOLREGION (27) (Energy Efficient Cooling in Regions of North and Central Europe). It deals with issues related energy savings for cooling aiming at analysing energy cooling systems. This is realized through the creation of pilot projects which present the adoption of specific strategies for cooling, according to the region (EU members) they belong to.

This section aimed at proving a list of the main actual research projects carried out in Europe in the field of refurbishment of Social Housing, in order to get a global scenario of the current trends and to analyse the possible research sub-systems still to be studied, to be taken into account in the thesis work.

2.2.4 COMMON RETROFITTING STRATEGIES

From the analyses of the European policies for the refurbishment of Social Housing it is recognizable the possibility to divide the interventions into 3 levels (the choice of one strategy with respects to the other one depends on the renovation aims):

1. <u>Neighbourhood Scale</u>: it is directed at improving the built environment quality, by intervening on the building, on the public areas with the aim to create new interconnections in the inhabitants' life and the environment. To do this the main strategies used in the European projects are:

   - improvement of the accessibility to the suburb areas through a rationalization of the practicability, by differentiating the vehicle passages from the pedestrian ones or by introducing a correct number of parking slots;

   - partial demolition or reconstruction of the buildings in order to improve the exploitation of the public areas;

- interruption of the mono-functionality of building complexes, by introducing new functions, such as shops, structure for the support to weaker people (older people, kids);
- reorganization of the spaces between the buildings, by differentiating the common green area from the private ones.

2. Building Scale: It is directed at improving the building quality, which is often at a high level of degradation. In general, the strategies are:
   - partial demolition and reconstruction of the buildings, with the aim at realizing new urban interconnections;
   - addition of new volumes on the top of the building in order to insert new flats with different sizes compared to the existing ones;
   - addition of new volumes on the façade o at the building bottom in order to create new different sized flats;
   - modification of the ground floor of the buildings with the introduction of new functions;
   - technological towers to improve the implants equipment;
3. Flat Scale: it is addressed to the improvement of the quality inside the flats, obtained through:
   - increasing of the flat's area through the closure of the loggias and the internal redistribution of the flats;
   - addition of volumes on the façade in order to improve the flats' areas of the under-sized flats;
   - addition of external loggias and balconies.

Retrofitting experiences across Europe have shown that if a general approach is a fundamental tool for planning a renovation process at the Neighbourhood Scale, the characteristics of each building located in the district environment are essential factors in the realization of an effective renovation intervention. Accordingly, retrofitting interventions at Building Scale is the central key of any renovation procedure. Indeed, on one hand, the building renovation leads to the improvement of energy efficiency, on the other hand can reorganize the external areas and, in such a way, improving the environmental aspects, by intervening at an Urban Scale. Having said that, we can affirm that the retrofitting strategies embrace always more than one level of intervention, being all the levels strictly connected one with each other.

In this respect we can mention the work carried out by Boeri et al. (28) related to the definition of suitable strategies to the renovation of the "Pilastro" neighbourhood located in Bologna (Italy). The strategies are organized in 3 steps:

1. Intervention on the envelope, in order to improve the energy performance;
2. Intervention on the units. The work analyses 2 possibilities: the 1° one is low-cost, through the redevelopment of the units in terms of indoor layout, without changes in the building, but only through the installation of integrated systems, such as controlled mechanical ventilation and integration of renewable energy sources; the 2° one is more invasive through the introduction of the subtraction of new volumes, in order to reduce the flatness of the façade;
3. realization of satellites volumes in order to create a functional mix.

This case of recovery intervention project well reflects the interconnection between all the 3 above mentioned intervention scales.

All the renovation strategies are strictly connected to the different technological solutions. From the examples found in literature and through the study of the most actual research trends in this field, although many techniques do exist, it is possible to summarize these strategies into 3 main groups (22):

1. Replacement/integration of limited number of elements, such as windows, parts of the façade or the floor slab. This is common in minor renovations;
2. Building envelope implementation. It consists of the creation of a new envelope for the building: cladding, double glazed façade, or the addition of a new insulation layer. This strategy aims to improve the energy efficiency of the whole building. The number of layers depends on the objectives of the intervention. Several options exist in this field, depending on the issues found in the energy performance.
   Indeed, the strategies for the building envelope can be differentiated into "Winter strategies" and "Summer strategies". The first ones can be done by applying layers of insulating material on the slabs, roof and external walls, by substituting the windows with more efficient ones and by eliminating air infiltrations, through the application of effective sealants; the "Summer strategies" for the envelope are more difficult to be realized in a retrofitting intervention and the most common strategy is to block the solar radiation through the windows, by applying selective glasses or by the addition of blinds on the windows. However other strategies can be the use of ventilated roofs or walls.
3. Volumetric additions. They can be realized on the top of the building or at the basement or on the façade. They have the function to increase the floor area and since they can act as loggias and greenhouses, they can also improve the energy performance of the building.

Obviously, the choice between the 3 strategies depends on the depth of renovation we will to realize. The energy performance required by Directive 2010/31/EU (29) often needs a deeper intervention, so that the 2° and 3° strategies are the most common when we deal with great recovery interventions in order to compliant the standards. Besides these strategies, the systems and installations have to be upgraded in order to compliant the new standards for the energy efficiency. The renovation of the envelope is not enough if it is not combined with an upgrading of the implants. With the strategy of volumetric additions, it is possible to exploit solar gains when they act as greenhouses[13] or they can allow the exploitation of natural ventilation[14] especially in Mediterranean climate conditions. Because of the variable outdoor climate conditions, the air flows are often not capable to guarantee the right comfort levels, so that in renovation projects the use of hybrid systems (natural ventilation helped by mechanical fans) is often the most suitable solutions (see chapter 4).

All these strategies are strictly connected to the solar energy exploitation. As we highlighted by analysing the examples of some renovation interventions of Social Housing in Europe[15], the attention is focused on the exploitation of Solar Strategies. This is due to the fact that the main issues

[13] They behave as buffer zones, by capturing the solar radiation and in such a way they pre-heat the space, reducing then the energy demand for heating.

[14] The air flow is activated by realising vents on the roof of the volumetric addition or on the façade in order to create a cross-ventilation effect.

[15] A particular attention on the exploitation of solar energy is also evident in the recent research projects analyzed in the previous section.

of public residential buildings are due to high levels of energy consumption in Winter[16] and because of in a preconfigured scenario, like in an existing building, these strategies are simpler to be applied[17].

The Solar Strategies can be active or passive and both were used in the sample cases analysed in this chapter.

The PASSIVE SOLAR STRATEGIES consist of all the technologies able to control the thermal exchanges between outdoor and indoor spaces, by exploiting the solar radiations as energy source and the building envelope components as capitation elements. They can be divided in DIRECT and INDIRECT GAIN STRATEGIES. The firs ones are the simplest, because they exploit the solar radiation passing through the windows' glasses. In the indirect strategies, the thermal "tank" is contained in the envelope and the solar radiation does not reach directly the internal spaces, but it is captured from a collector and, at a distance from this latter of about 10cm, there is the tank. The radiation is then transferred to the space for radiation or convection ("Trombe" wall). The other passive solar strategy often used in the renovation of social housing is the "Radiator System", that is an ISOLATED GAIN STRATEGY. The main characteristic of this strategy is that the collector and the thermal tank are isolated with respect to the internal spaces which receive the heat only when they need heating through a distributional system of radiators.

The solar greenhouses are volumes added to the construction. They are made with glasses which let the radiation pass inside the space. They can be divided into direct gain greenhouses (when the separation between the added volume and the building is realized with transparent elements: the radiation passes through these elements and the tank is the slab or the ceiling inside the home) and indirect greenhouses (when the separation element a wall acting as a tank; in this way, the glass surface acts as a solar collector).

The ACTIVE SOLAR STRATEGIES use elements for the solar radiation capture, but for their functioning need mechanical systems for the accumulation and for the distribution of thermal energy. The main systems are the Thermal Solar Panels, especially used for heating domestic water. In this case the thermal-convection fluid is the water. The Solar Panels with the air as fluid are used as under-windows ventilating systems in order to heat the inlet air (Yellow House in Denmark). The PV panels (photovoltaic systems) are the other active solar system. In a recovery intervention, as well as the thermal solar panels, the main problem of the use of PV panels is that the optimal orientation is not always possible. By the way they can be integrated on the façade and they can be used as under-windows ventilating systems as in the previous case.

2.3 IMPLICATIONS

Several researches have been carried out during the last years on the refurbishment of social housing, both for what concerns the social aspects, the economic support and technological improvements. The work undertaken in this research can be placed in the field of technological improvements, by intervening at the building scale level. Indeed, as we showed in the previous sections, a fundamental aspect to be taken into account is the renovation of the building as a whole, in order to achieve an effective result. This means that a careful analysis of the possible strategies

[16]Indeed, for example the exploitation of greenhouses or Trombe walls can reduce the energy demand for heating.

[17] For example, the introduction of PV panels on the roof or integrated on metal structure frames linked to the existing facade.

addressed to the improvement of the energy performance of the building is necessary both for complaining the new energy standards and for adding further strategies in the next steps (for example at the urban scale level), by considering an already efficient starting point.

Moreover, the choice to move the attention towards the intervention at the building scale level is due to the fact that the buildings taken as sample cases are detached buildings, located in the same district, but far from each other, and therefore a renovation at the urban scale is difficult.

By the way the buildings studied in the present work, as the majority of the public residential buildings, present a “pillar floor” and the site where they are located is organized in green areas and common areas, but being small interventions (120 flats-Canova and 54 flats-Iolo), the districts do not need deep interventions at the urban scale as much as they need a renovation at the building scale. Furthermore, from the analyses of the current researches, all the data collected from the various surveys or “pilot” projects lack a systematic way to make comparative assessments, but there is a trend of realizing as many ways of interventions as the different boundary conditions, such as climate, building type etc. This thesis is placed in this scenario, by trying to give another piece of the puzzle with the definition of a method of recovering social housing realized with prefabricated buildings. SOLANOVA has already studied prefabricated buildings, but for a different climate. For this cause, defining a methodological procedure for recovering this building type in the Mediterranean climate, could be useful to create an example for other buildings, like the sample cases, located in a comparable climate to the Tuscany one.

Moreover, the work wants to meet the needs of the users: from one side by intervening as less as possible on the building as structure (in such a way avoiding bothering the users’ life and to exponentially increase the cost for the intervention), on the other side by improving the internal comfort conditions inside the flats, improving then their way of life.

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3. ANALYSIS OF THE INDUSTRIALIZED PUBLIC RESIDENTIAL BUILDINGS AS CASE STUDIES

This chapter analyses the buildings chosen for the study. This analysis consists of two sections:

1. Study of the Environmental and Technological System where the main characteristics of the buildings from the architectural point of view are investigated aiming at finding recurring features;
2. Energy analysis of the buildings in order to evaluate the common issues in the Energy Performance, paying particular attention to the thermal comfort conditions.

The critical analysis of the buildings, according to the results obtained from the above-mentioned steps, will lead to the definition of the most suitable strategies applicable to the buildings.

3.1 ANALYSIS OF THE ENVIRONMENTAL AND TECHNOLOGICAL SYSTEM

The objective of this section is to study the buildings in detail in order to understand their typological characteristics. To do that, we referred to the building type factors classification (1).Through the use of these factors we are able to describe the building, starting from a more general characterization of the construction site, up to description of the construction techniques and materials.

These building type factors can be summarized into 5 classes according to distinctive characteristics:

1. **Land use and Environmental Characteristics.** This factor takes into account the relation between the construction and the building site, by analyzing:
   - shape and dimensions of the building site;
   - the ratio of building volume to the building site area (land area indexes, heights etc.);
   - the relation between the public/private use of building parts (ground floor use, necessary public passages at the ground floor etc.);
2. **Formal and Aesthetic characteristics.** This factor includes the building aspect, that is the symbols characterizing the elevations, for example the façade organization (modularity, color and materials use, projections etc.);
3. **Morphological and Dimensional Characteristics.** Shape and dimensions of the building are analysed through this factor;
4. **Distributional and Functional characteristics.** This factor analyses how the functions are distributed into the building (at the building scale: flats' organization, relation between stairwell and flat. At the flat scale: internal distribution of the flats, functional bands);
5. **Technical and Technological characteristics.** This is the last factor to be analysed, were all the construction elements are studied. It means a detailed analysis of the different subsystems belonging to the technological system: structural system, external envelope, internal partitions, implants and finishing.

Through the definition of all these type factors it is possible to know the building as a whole, by highlighting the main characteristics of the building type. As we already mentioned, the buildings chosen for the work are emblematic for the application of prefabricated/industrialized techniques that, as we will see in the next sections, from one hand have guaranteed the velocity and the simplicity during the construction, but on the other hand these techniques have created either constraints in the internal distributional of the flats (partitions walls in reinforced concrete) or in the plant maintenance operations (for example pipes integrated in the casting).

Because of the modularity related to the structure and the requirement to have to satisfy (social housing), all the buildings present simple shapes and the majority of them are linear or tower buildings. The next paragraphs analyse 2 building complexes:

BUILDING COMPLEX	CONSISTENCY	BUILDING TYPE	INDUSTRIALIZED SYSTEM
A: IOLO (PRATO)	BUILDING A	LINEAR	TUNNEL SYSTEM
	BUILDING B	LINEAR	
B: CANOVA (FIRENZE)	Qd1	LINEAR	Reinforced concrete walls in PREFABRICATED FORMWORKS
	Qa19	LINEAR	
	Qb16/Qb40	TOWER	

3.1.1 COMPLEX A: Prato-Iolo

The intervention area which will be analysed is located in Iolo, at the city of Prato, and consists of two linear buildings (BUILDING A: 32 flats and BUILDING B: 22 flats) situated on a secondary street perpendicular to the main roads connecting the suburb to the city centre[1].

Figure 3.1: G-maps extract and indication of the intervention.

Figure 3.2: Building A (photo on the left). Building B (photo on the right).

[1] For the Building Process see APPENDIX A

The analysis will be performed according to the building type factors classification. The first factor, analysing the site of intervention, will be in common between the two buildings, as well as the last one, because both buildings have the same technological system.

1. Land use and Environmental Characteristics

The lot on which the buildings in question are located has dimensions 76x72m.

The ratio of building area to the building site area is about 23%. The buildings are oriented mainly along the East-West axis, perpendicular to the main roads, as well as other neighbouring properties. Buildings are linear with the classical rectangular shape, placed symmetrically relative to the central appurtenance zone axis. They differ mainly by size: building A has an extension of approximately 65m, while building B has a length of 53m, but both present the same depth of about 11m.

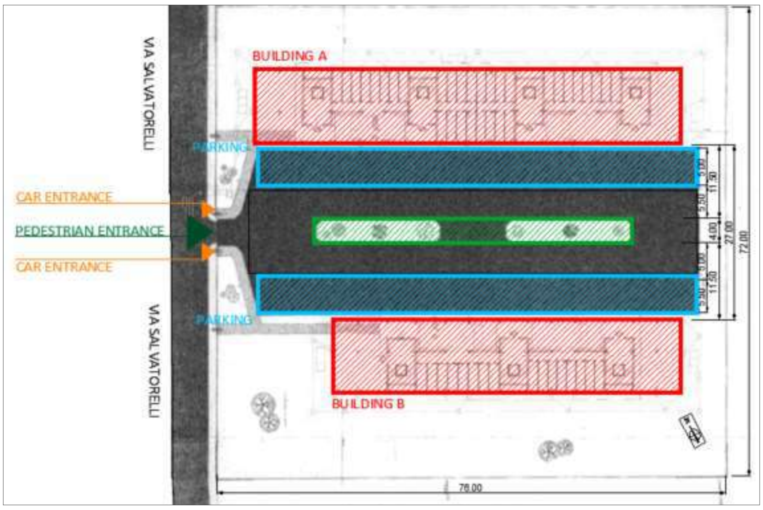


Figure 3.3: COMPLEX A-General Plan on which the building site organization is highlighted (buildings A and B, the parking area, the green area, the driveway and the walkway).

The car access to the lot is from the main street, Via Salvatorelli, as well as pedestrian one, characterized by a path paved with cement-grit, which connects the street with the buildings. The entrances to the buildings occur from the central courtyard with depth of about 27m, in which are placed two strips of parking places along both buildings and a private road marked by two green spaces that separates both traffics (vehicles and pedestrians). The areas behind the buildings are reserved to private green areas. Only the main housing access occurs through the stairwells situated on the main front of both buildings; the stairwell on the other floors are located on the secondary front. The ground floor, or "pillar floor"[2], is characterized by the presence of porches and cellars.

The porches create a direct link between the area and the appurtenant central green area located at the back, and are created thanks to the opening of large passages on the transverse walls in reinforced concrete which constitute the main structure of the buildings.

The next paragraphs will analyse the two buildings in detail, still following the BUILDING TYPE FACTORS classification.

[2]The documentation about the buildings, found in the Casa S.p.A archive refers to ground floor, by defining it as “pillar floor”. In reality it is simply an open space.

2. Formal and Aesthetic characteristics

BUILDING A

The facades are regular and simply plastered. The elevations present a modularity depending on the structural system. The openings are placed in the same position depending on the modules and all with a width of 1.10m. The South façade has “loggia”, 1.20m deep, which are 0.60m overhang regarding the facade, due to the back shift (still 0.60m) of the building just in correspondence of stairwells.

Figure 3.4: South Elevation-Building A: The yellow part highlights the cellars, while the colours red and blue the two different type of flats.

Besides the presence of these overhangs that somehow characterise this elevation, another element to be highlighted is the differentiation by the use of different colours of the plaster with the intent to remark, from one side, the locations of different use destinations, and on the other side to give some movement to the facade, which would appear highly flat due to its strong modularity (fig.3.5 on the left). The partitions of the “pillar floor” are in fair-face reinforced concrete, while the walls of the cellars (fig.3.5 on the right), and access to stairwells always in concrete, present vertical grooves obtained with special formworks during the casting process.

Figure 3.5: (On the left) Portion of the South Elevation. We can see the white bands that highlight the rows of windows and backward white facades with balconies overhanging. (On the right) Vertical grooves on the cellars external walls.

The North elevation has the same characteristics of modularity of the previous one and the same differentiation in the use of different paintwork on the front.

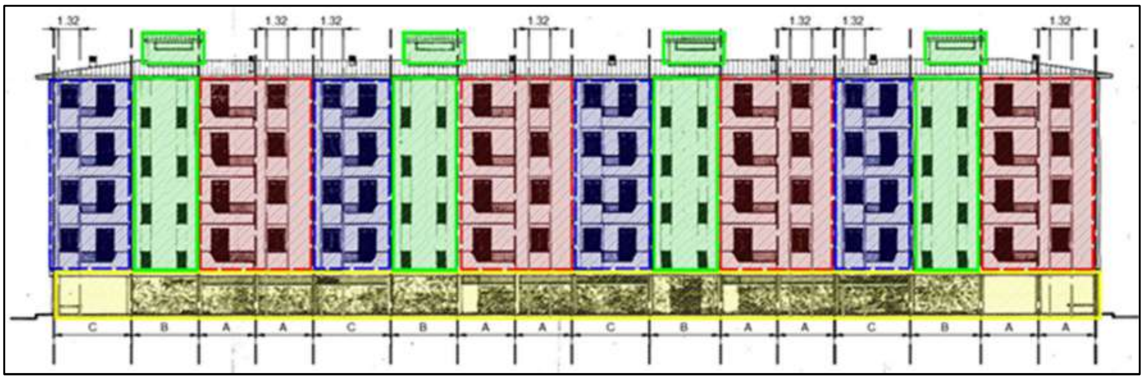


Figure 3.6: North Elevation Building-A: The yellow part highlights the cellars, the colors red and blue the two different types of flats and in green the stairwells.

The wall of stairwells, in this case, faces directly the external side of the building, rearward of about 1.35m respect to the facade, while the South elevation back shifting is noted in correspondence of the residential units, even though the access to stairwells is anyway backward, but less evident due to the presence of the porch. On this side, the characterization of the facades is given by the presence of terraces projecting the elevations (1.20m).

Figure 3.7: Overhanging balconies on North Facade (Left photo). Recessed staircase (Right photo).

BUILDING B

In this case the building elevation, although linear and presenting only the overhanging balconies as significant elements of the facade, has as a main feature the retreat of the walls of the "cellars"[3], from the main façade. Indeed, these cellars are located at the fourth floor and they become an emerging volume with respect to the roof floor.

The modular organization is also found on the façades, where the openings are placed in the same position, all in line with the plans and different coloured strips of plaster are repeated also in this building.

[3] The document regarding the project of this building, refer to these spaces as "cellars". In reality they are attic spaces, for the place where they are located.

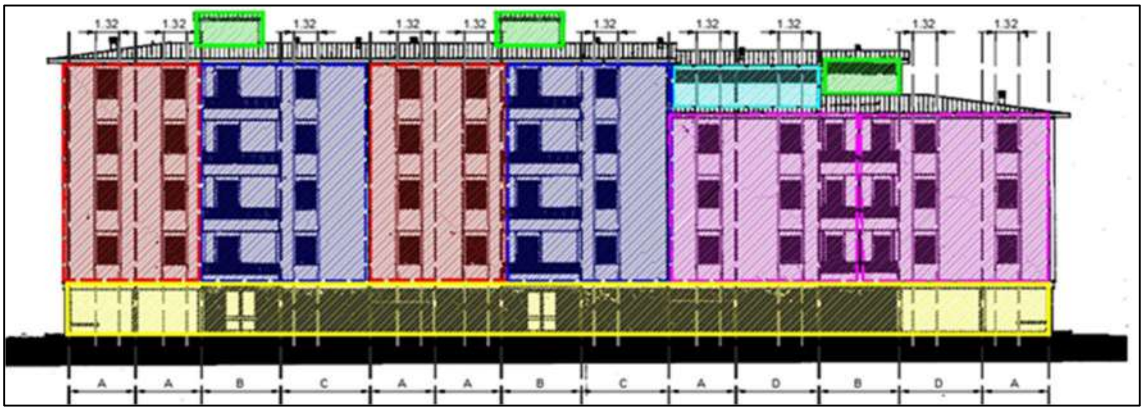


Figure 3.8: South Elevation-Building B

Figure 3.9: North Elevation-Building B

3. Morphological and Dimensional Characteristics.

BUILDING A

From both buildings, BUILDING A is the largest one (65x11m). It contains 32 apartments disposed over 4 floors with 8 units per floor.

The areas with the arcades are located at the ends of the building and at the main front, in correspondence of 2 blocks of 8 cellars each one and to which we may access through passages created on the lateral septa of the stairs case.

On the west side, the porch has dimensions of approximately 7x11m and occupy the 2 smaller modules of the structure with which the building is made (modules width 3.60m).

On the east side, the porch is obtained in the greater module of the structure and have dimensions of about 3.80x11m. The other two porches have a development of about 11m and a depth of 4m. These areas present a cement-grit square tiles paving, so as to differentiate them from the sidewalk placed around the perimeter of the building and on the entrance areas that are made with square and horizontal concrete tiles. The other two blocks of cellars are located in the central area of the building.

The stairwells are about 4x5m. On the ground floor, the stairwell expands to include the entrance area (4x7m). The stairs have 3 ramps and lift in the centre. In front of the entrances to the vertical connections are located some porch areas with the aim to create a waiting space before entering the building.

Figure 3.10: Ground floor plan ("Pillar floor") of Building A: porches are highlighted in blue, the stairwells in green and in red the cellars. The more highlighted dashed red line represents the seismic joint.

BUILDING B

Building B, even if similar to type A, is smaller (53x11m), has 22 apartments displaced over 4 floors. These have the same modular plan of the first building up to the seismic joint. After such element, the structure is distinguished by the need to built apartments of different size than those analysed until now.

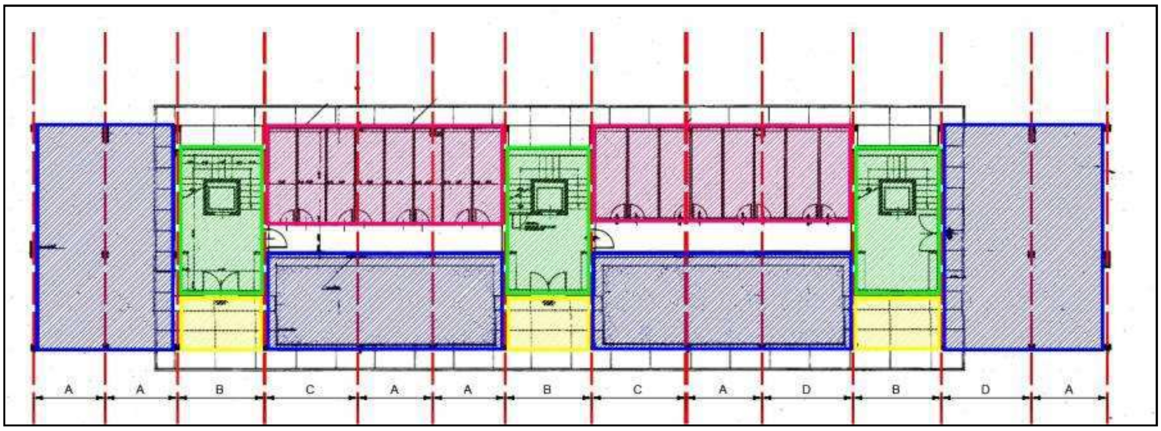


Figure 3.11: Ground floor plan ("Pillar floor") of Building B: porches are highlighted in blue, the stairwells in green and In red the cellars. The more highlighted dashed red line represents the seismic joint.

The porches are always placed at the ends of the building and on the front side. There are three stairwells with the same dimensions of building A. Each vertical link leads to 8 cellars. From the total number of cellars, 16 of these are placed on the ground plan, while the other 8 are placed at the fourth floor, which can be reached through the stairs placed further west.

The stairwells are always recessed with respect to the facade on both front and back sides and entrances by a small porch. The west stairs have a side entrance, so in this case, the entrance porch appears larger (about 8x11m, axis distance between the walls of 4.50m e 3.50m).

The East portico area always occupies the two smaller modules of the structure (7x11m), while the porches on the north elevation have dimensions of approximately 11x4m.

4. Distributional and Functional characteristics

<u>BUILDING A</u>

The building is linear and therefore it follows a modularity in the organization of the plan. Indeed, the plan consists of the aggregation of 4 modular blocks; each block contains a central stairwell and 1 flat on each side of the stairs (fig.3.12).

The type of structure used allows an easy distribution of units. Each stairwell is used by two units of different sizes:

- TYPE A (4 users, about 70m^2);
- TYPE B (3 users, about 60m^2).

Both present the secondary band, consisting of distributional area and services, in the middle. In the bigger accommodation, this secondary band position is placed in the middle regarding the building depth, while in the smaller one it is shifted with respect to the axis. This displacement is possible, because the supporting septa of the structure are only in the transverse direction and longitudinally there are no obstacles.

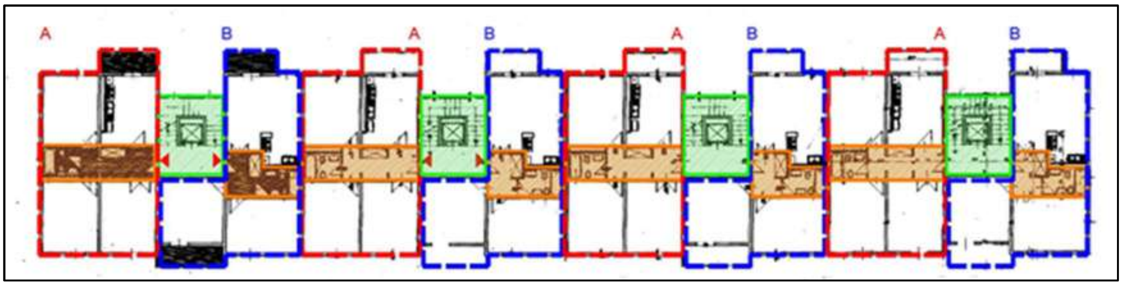


Figure 3.12: Typical Floor Plan-Building A: Service areas are highlighted in orange, in red and blue flat TYPE A and flat TYPE B respectively and in green the stairwells.

Residential Unit TYPE A has the central band used as entrance and services. It is 2m deep, large enough for the manoeuvres of a disabled person in a wheelchair. It has 2 double bedrooms, 1 small kitchen and a living room which leads to a terrace which is 1.20m deep. The arrangement of the unit, as mentioned previously, is well defined by the position of the transversal septa. The openings in the supporting partition walls are made in the same position in the various units and with similar dimensions, in such a way to not affect the structural behaviour of the entire building. In fact, the entrances to the apartments are big 1.10x2.10m and are always placed symmetrically with respect to the stairwell; while in the central septum, the opening with dimensions 1.10x2.43m, connecting the living area with the sleeping area, is repeated in all the TYPE A accommodations.

On the west side, the closing septum has only one hole measuring 0.85x1.50m for the inclusion of the bathroom window.

The shafts for the implants are located inside of plasterboard walls in the proximity of the bathroom and the kitchen through the realisation of slots on the slab already predisposed during the casting phase and which are repeated for all floors.

The Residential Unit TYPE B, of smaller size, has a living room with a terrace and recessed kitchen on the North, and a single bedroom and a double bedroom with a terrace on the south. In this case, as mentioned before, the range of services is decentralised with respect to the midline of the building. The bathroom, located in this area has the same size of the one in unit type A. In this case, the technical shaft is shared between the bathroom and the kitchen, while in the apartment TYPE A, since these two rooms are distant from each other, there are two separate shafts.

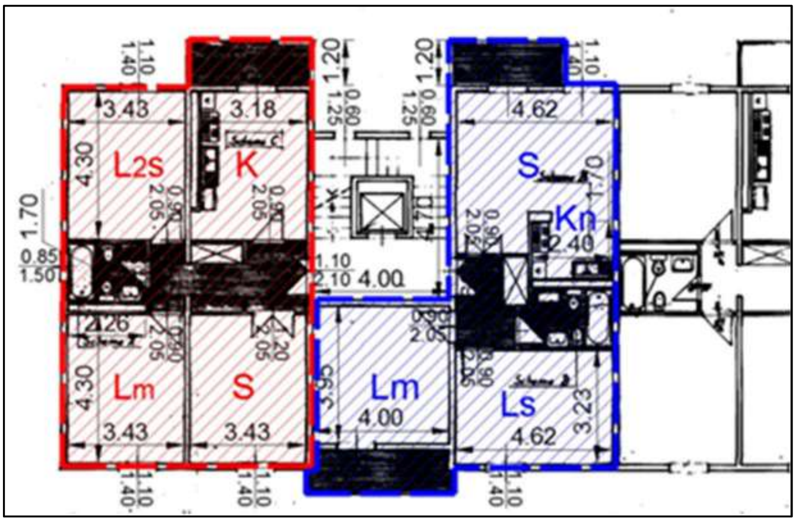


Figure 3.13: Residential Units TYPE A in Red and TYPE B in blue. Internal Arrangement. Lm=Double bedroom; L2s= Bedroom with 2 single beds; Ls= Single bedroom; K= Kitchen; Kn= Niche kitchen; S= Living room.

BUILDING B

Building B is linear as the previous one and therefore it follows a modularity in the organization of the plan. The typical plan presents 3 modular blocks with a central stairwell and 1 flat on each side of the stairs (fig.3.14). On the first 3 floors, there are 2 apartments TYPE A, 2 apartments TYPE B and 2 apartments TYPE C (5 users, about 85m^2).

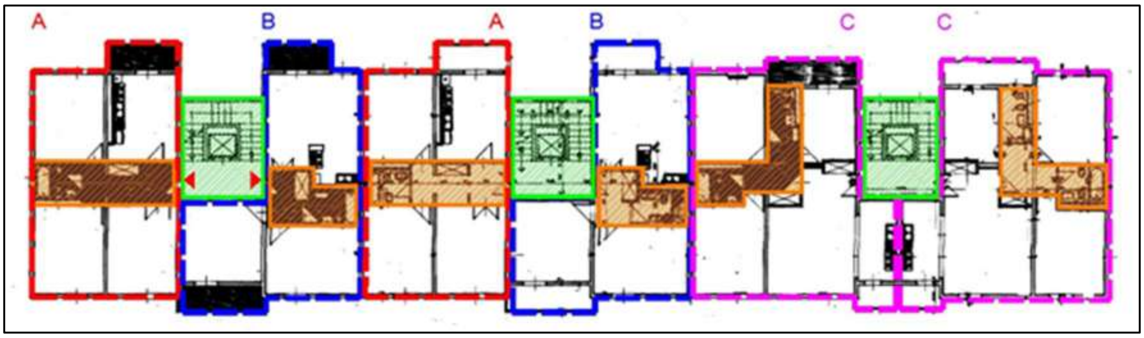


Figure 3.14: Typical Floor Plan-Building B: Service areas are highlighted in orange, in red and blue flat TYPE A and flat TYPE B respectively and in green the stairwells.

In the accommodation TYPE C, even if entrance to the flat is still located in the central part, the real secondary band is placed in the night zone, presenting a L shape. This means that a part of this band is located also along the transversal direction.

The internal distribution depends on the structural system: the internal partition walls in the transversal direction mark the division between the rooms, instead the flat internal distribution along the longitudinal direction, has no structural impediments. The entrance to the apartment is always from a side opening created on the wall of the staircase. The unit consists of 1 double bedroom, 1 twin bedroom, 1 single bedroom and a living area with a kitchenette located in front of the stairs. There are 2 terraces: the first one placed on the South front, with a length equal to the structural module (about 4.40x1.20m) and the second one, a small loggia (2x1.20m) which can be accessed from the kitchen. The two accommodations TYPE C, are symmetric regarding the stairwell that serves them. This way both kitchens are placed long the same partition wall, giving the possibility to create one unique shaft for the implants.

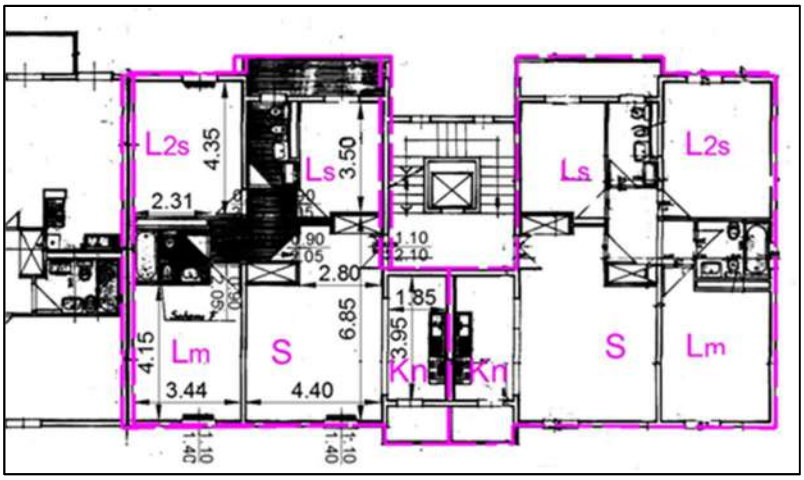


Figure 3.15: Residential Units TYPE C. They are symmetric regarding the stairwell.

The fourth floor is different from the other ones: it presents 2 apartments TYPE A and 2 TYPE B, but the last modular block located on the East side of the building, consists of only a block of cellars. These cellars are set back from the main building and its total footprint is about 8x8m.

Figure 3.16: Fourth Floor Plan-Building B. The cellars are highlighted in pink in the figure.

5. Technical and Technological characteristics.

The last type factor analyses the technical and technological aspects. As mentioned before, both have the same characteristics as regards the structure, the envelope and the implants.

THE STRUCTURE

The structure adopted for the buildings in question is made with the **Tunnel Forming Method** which consists of vertical partitions walls and casting concrete slabs with industrialized system of formworks. The static calculations were carried out "[...] in accordance with the technical normative mentioned in DM Public Works 06.28.1980 issued by the Ministry of Public Works (in accordance with Law 05/11/1971 n.1086) and relative instructions set out with the Circular of the Central Technical Services 30/06/1980. The test methods and loads and overloads values are also in line with the requirements of the DM Public Works 10.03.1978 and the instructions set out in the Circular of the Central Technical Services 11/09/1978. [...]"[4].

[4] From the Calculation Report found in the folder 106 pg. 3.

The **Tunnel Forming Method** (2) is characterised by the use of a particular type of metal fixtures and consists of large formworks with a "reversed U" shape (entire tunnel), or even a "reversed L" (middle-tunnel) that will then be coupled to form the U.

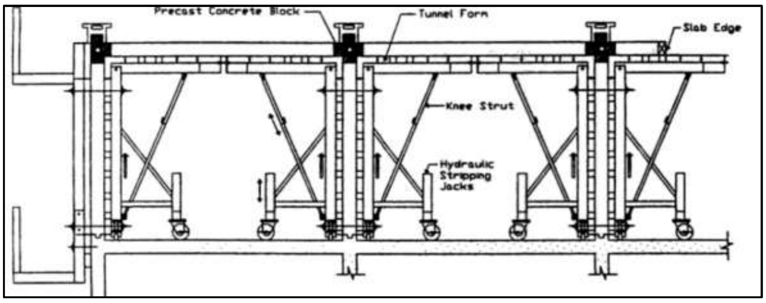


Figure 3.17: Tunnel System (3).

The components of the tunnel are two vertical flat elements and one horizontal metal element. All these elements are reinforced on the internal side with folded plates which have the function of containing the concrete casting. The basic modules generally have a depth of 125cm and are juxtaposed to one another to form the depth of the tunnel with the necessary measure required to cover the entire body of the building. The height of each element is equal to the useful gross height of the room to be obtained and the span depends on the structural calculation and on the size of the project rooms.

The tunnel elements are then placed on the floor side by side and with a distance of about 14-16cm from one another to realise the thickness of the structural septa.

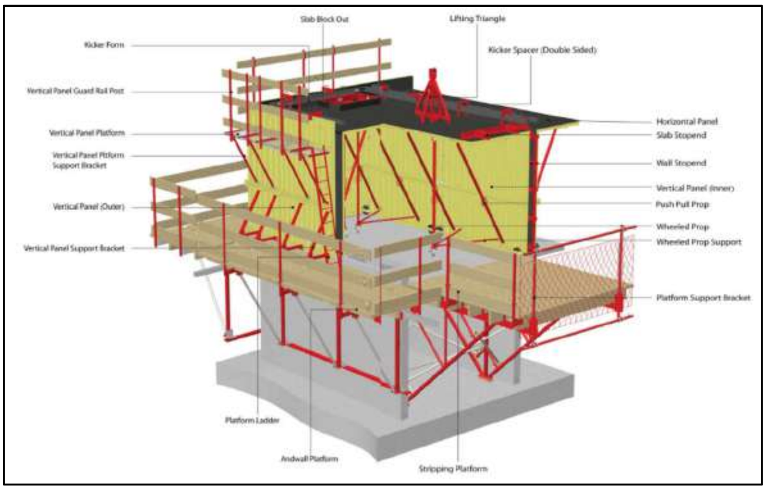


Figure 3.18: Tunnel formwork system section[5].

This set of tunnel elements, which constitutes the core of the whole building, is completed by a set of accessories needed for the casting phases or to interface the structure with the completions. These elements are: the "banches", special metal formworks for the walls which gave them the external finishing; special structural fixtures for the stairwells and lifts; horizontal jet restrictors for the slab plans and vertical ones placed in the spaces between the various pipes; the vertical and horizontal mobile formworks for obtaining openings in walls and floors.

[5] http://apadanabana.com/

Besides, there are a whole series of accessories to accelerate the concrete compaction, such as wall-mounted vibrators for compaction of vertical jets or burners for the production of heat within the tunnels. Even for a correct site organisation these formworks are provided with mobile parapets or walkways and integrated worktops and hooks for the anchorage of the tunnel to the crane. Normally, the work site is arranged in such a way to an apartment per day (80-120m^2), what in commonly called a “tunnel-cycle”. Prior to the casting stage it is necessary to place the electric and water pipes inside the concrete structural walls.

When all the necessary elements were placed and once the casting was made, then the daily cycle could be considered complete. The next day the dismantling could be done by pushing the tunnel manually outside or with the help of winches able to extract them in a horizontal manner.

USED MATERIALS		
ELEVATIONS	Concrete	R’bk=250
	Steel	FeB44K
	Welded Mesh	Controlled=2.600 Kg/cmq
FOUNDATIONS	Concrete	R’bk=250
	Steel	FeB44K

Table 3.1: Used materials for the structure.

Foundations: The foundations are made of T reversed beams connected by reinforced concrete curbs.

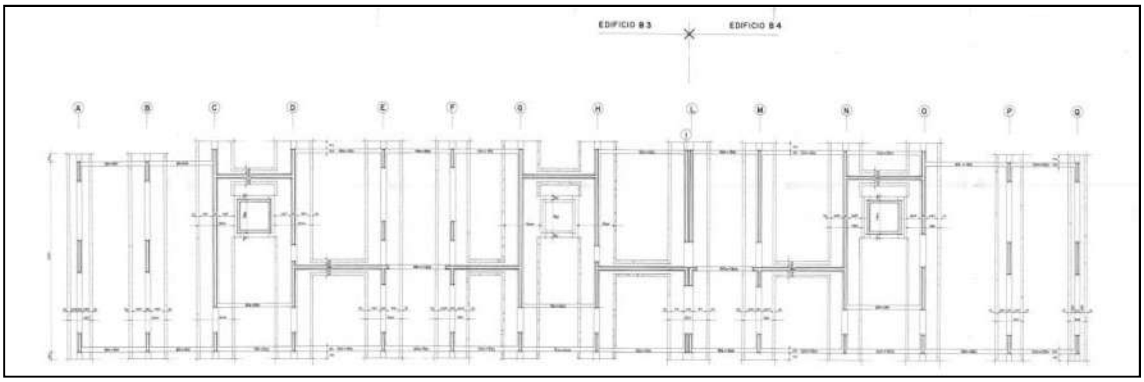


Figure 3.19: Foundation Plan Building B-(F106.2T33_STRUCTURAL).

In order to establish the most reliable placing level, it is taken in consideration the geological survey of Geol. N. Tommasini made for an adjoining land of the same Institute and effectuated comparison tests. On 27/10/1980, during open excavations (building A), it was found that the soil stratigraphy showed the following:

- 0.00÷-0.60 vegetal land;
- -0.60÷-1.70 clay with silt and sand.

On 22/01/1981, after excavations for building B, the same characteristics of 27/10/1980 were found. On the bottom of the excavation (-1.70m) penetration and soil tests were performed. From these tests, the compressive strength values resulted to be between 3 and 4.25 Kg/cm^2.

Based on the geotechnical investigations results, the direct foundations were sized and verified in order to transmit into the underlying soil, a maximum load of 1.4kg/cm^2. During the execution of the foundations it was made a layer of lean concrete with thickness 20cm, larger than the measure provided, because of excavation necessities. For this reason, the pressure applied by the structures on the ground turned out to be minor, for the better loads distribution[6].

Structural walls: the bending and axial stresses were evaluated by considering the frame behaviour of the entire building where the vertical elements are constituted by structural walls and the horizontal elements by the slabs. There are 22 types of septa with thickness of 15cm, considering that some types are present in both buildings. (A = 1, B = 2, C = 3, D = 4, E = 5 = 14, F = 6 = 15, G = 7, H, I, L, M, N, O, P, Q, 8, 9 = 10, 11, 12, 13 = 17, 16, 18). The building A presents the frames organised according to a variable wheelbase distance following the sequence AABC, where A= 3.63m, B= 4.15m (stairwell) and C= 4.83m. The sequence is repeated in the same way for the whole building development.

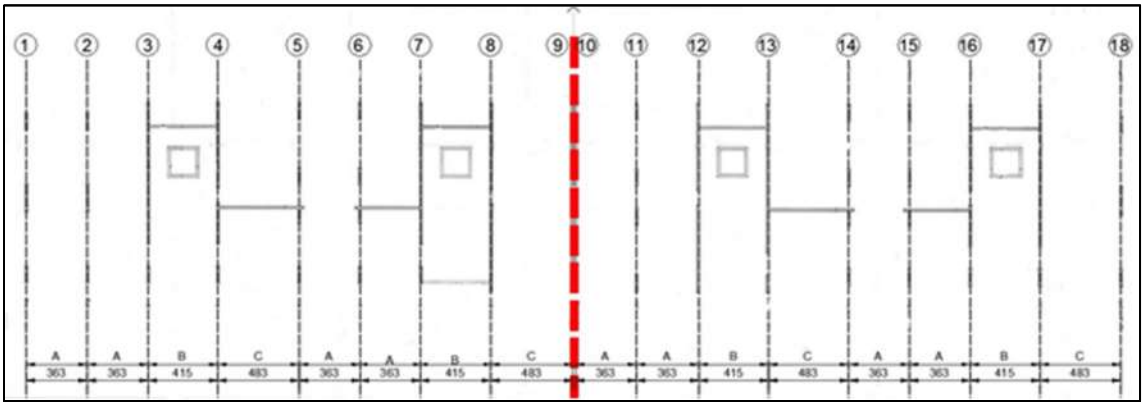


Figure 3.20: Concrete Frames Building A. Distinct "pillar floor" septa with frame numbers.

The openings have a maximum width of 1.10m and height changing from 2.10m to 2.43m, depending on the presence of frames or if they are only a passage. They are made in the middle area, which corresponds to the entrance area and corridors of the various units.

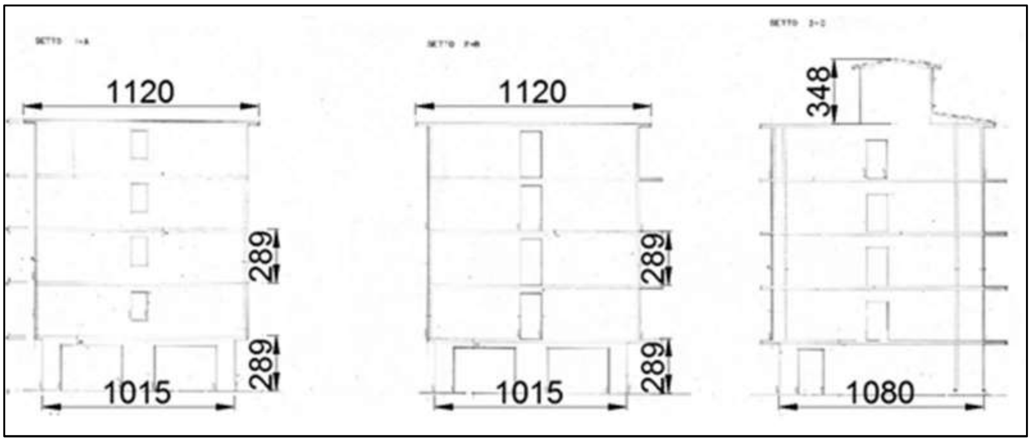


Figure 3.21: Structural Fixtures of some transverse structural walls. (F106.2T33_STRUCTURAL).

Even the portion to the left of the seismic joint in building B has the same sequence of wheel base distances AABC, while the portion to the right of the seismic joint has the sequence ADBDA, where wheel base D measures 4.60m.

[6] From the Land and Foundation Works Report written by the Works Supervisor. Folder 106 pg. 64.

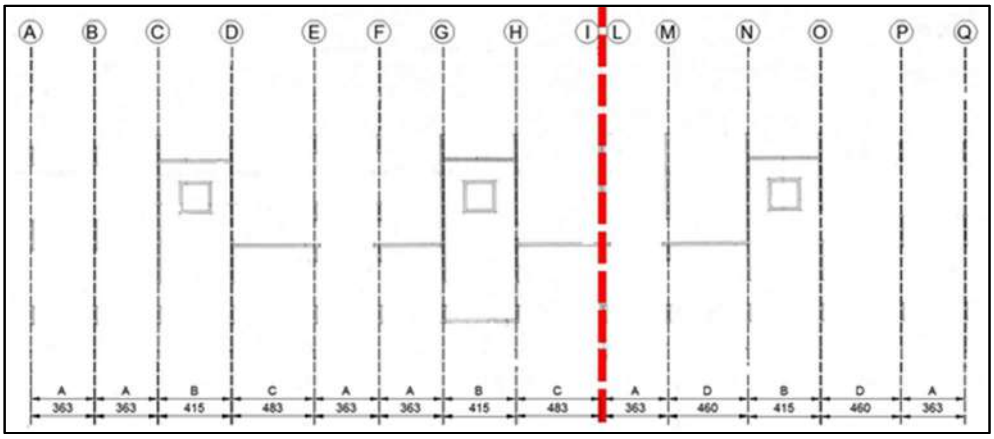


Figure 3.22: Concrete Frames Building B. Distinct “pillar floor” septa with frame numbers.

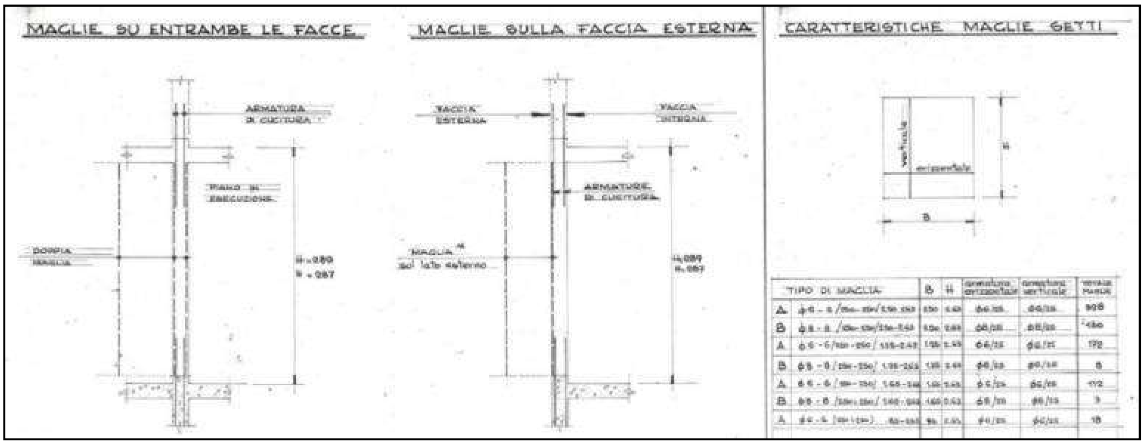


Figure 3.23: Partitions Mesh characteristics. (F106.2T33_STRUCTURAL).

Verification of the Partitions stability was conducted in accordance with French standards ('Document Tecnique Unifié n.23T October 1975').

Regarding partitions on facade, these are casted in a later moment with respect to the transverse partitions and the floor slabs, which represent the real tunnel formed system. For this reason, a special formwork and reinforcement is provided.

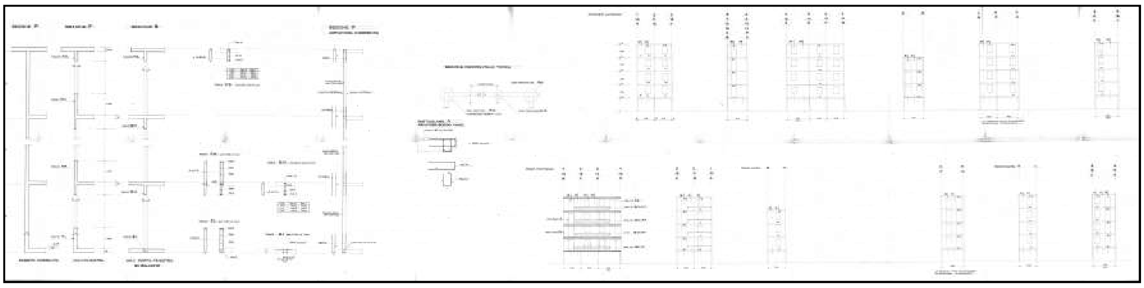


Figure 3.24: Facade Walls. (F106.2T33_STRUCTURAL).

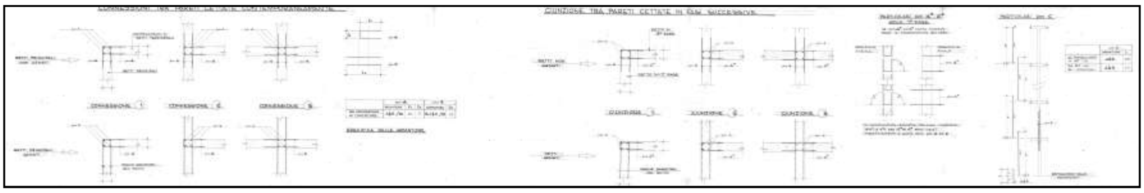


Figure 3.25: Intersections between walls. (F106.2T33_STRUCTURAL).

Floor structures: according to the value of the negative bending moments derived from the frame calculation, the span loads have been obtained in order to evaluate the typical slab sections. The stability tests were performed in reference to the method of “allowable loads”. The floor slabs are 16cm thick, while the attic one is 14cm.

The cover consists of running header overlaid bricks and hollow blocks above with concrete slab 12cm thick.

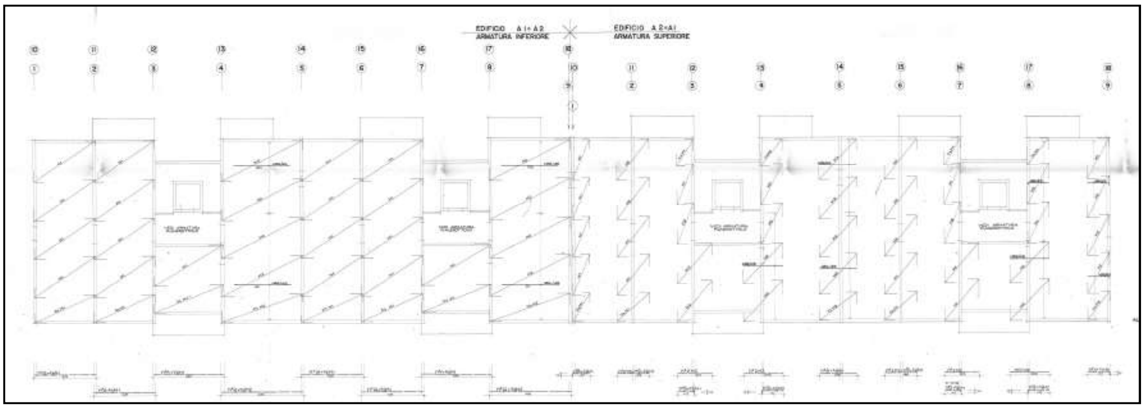


Figure 3.26: Slabs Reinforcement. (F106.2T33_STRUCTURAL).

Stairs: They are composed by 3 precast ramps (ABC). The longitudinal ramps with dimensions 1.10x3.10m, are hooked to the walls where particular openings are realised with a width of approx. 1m and height 35cm. The transversal ramp leans to the landings of the other two ramps.

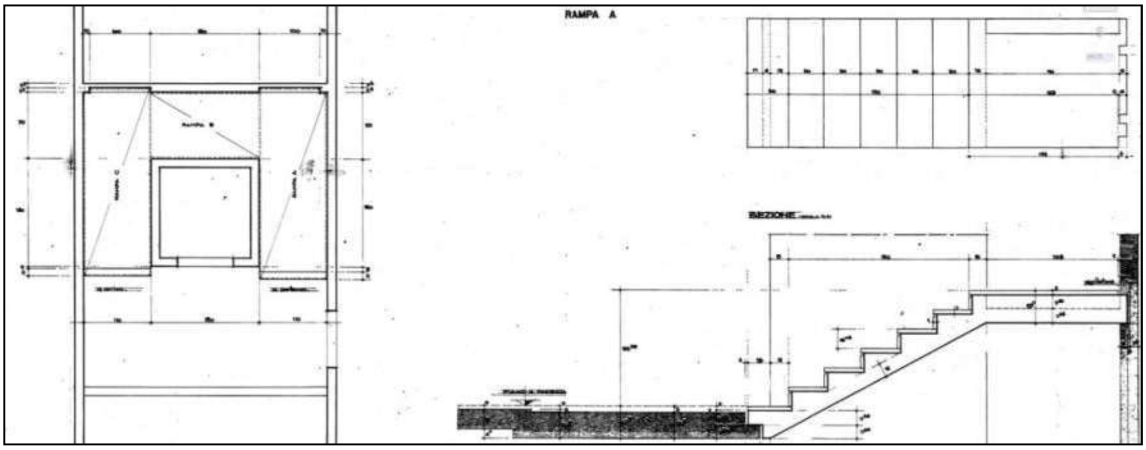


Figure 3.27: Stairs Fixtures. (F106.2T33_STRUCTURAL).

The exit landing floor of 21cm thickness presents a shape to allow the accommodation of the stair flights and is connected to the floor structure by mechanical fasteners.

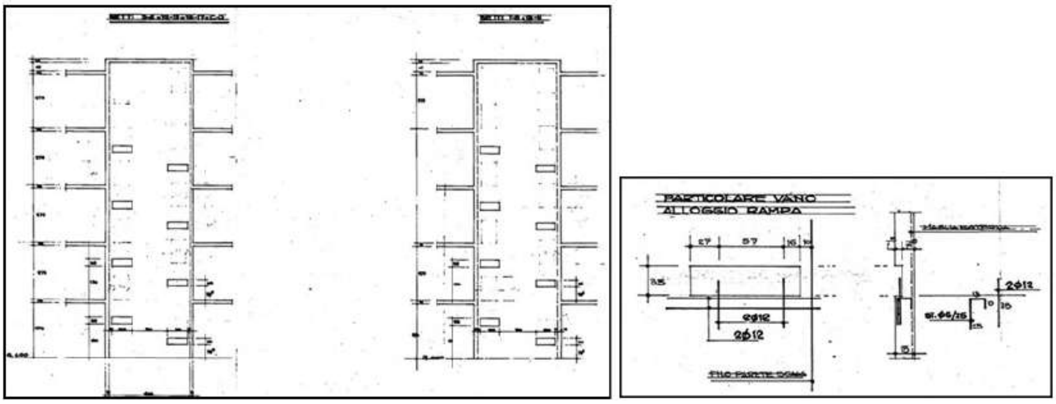


Figure 3.28: Facade Partition Fixtures (left). Detail of the ramp accommodation room (Right). (F106.2T33_STRUCTURAL).

THE ENVELOPE

Walls

The external walls are made up of reinforced concrete with 15cm of thickness and an internal counter-wall thick 5cm of type PLACOMUR (polystyrene insulation glued to the supporting wall and plasterboard panel coating). The interior partitions in plasterboard are 10cm thick and all interior plaster are made up of gypsum. The insulation is also included within the staircase and attic walls.

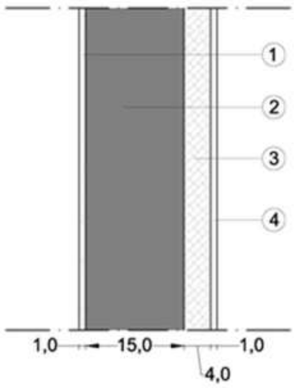
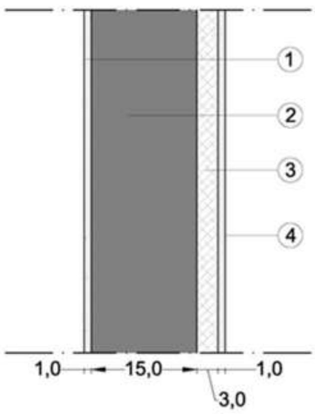
EXTERNAL WALLS		
	STRATIGRAPHY	Width (m)
	1-External Plaster	0.01
	2-Reinforced Concrete wall	0.15
	3-Polystyrene	0.04
	4-Gypsum Internal Cladding	0.01
STAIRS AND ATTIC WALLS		
	STRATIGRAPHY	Width (m)
	1-Internal Cladding (toward the stairs or outdoor if attic wall)	0.01
	2-Reinforced Concrete wall	0.15
	3-Polystyrene	0.03
	4-Gypsum Internal Cladding (toward the flats or toward the attic floor if attic wall)	0.01

Table 3.2: External and Internal walls stratigraphy.

Slabs

Still considering the insulation system, in addition to the aforementioned insulation of external walls and stairs, the “pillar floor” and the attic are also insulated.

The lower surface of the reinforced concrete slab (15cm thick) between the first and ground floor consists of ERACLIT panels (mineralized wood wool insulation panel) with thickness 5cm and scratched plaster finishing, glued to the intrados of the slab.

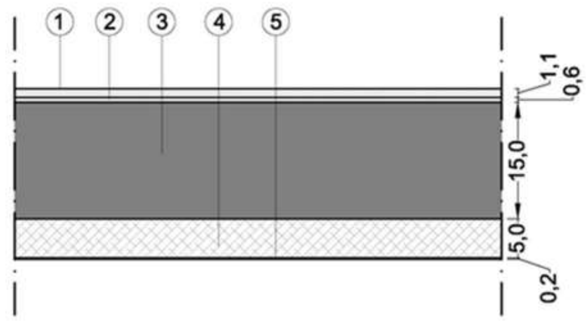
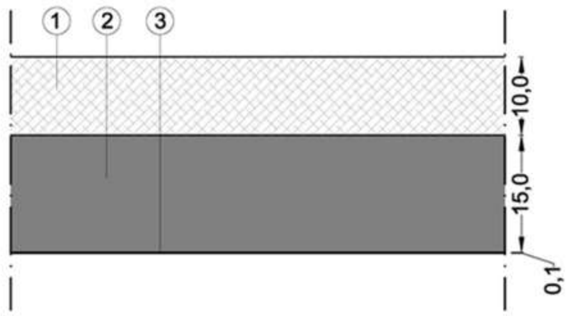
<table>
<tr><td colspan="3">“PILLAR FLOOR” SLAB</td></tr>
<tr><td rowspan="6">
</td><td>STRATIGRAPHY</td><td>Width (m)</td></tr>
<tr><td>1-Ceramic</td><td>0.01</td></tr>
<tr><td>2-Adhesive</td><td>0.006</td></tr>
<tr><td>3-Reinforced Concrete wall</td><td>0.15</td></tr>
<tr><td>4-Eraclit Panel</td><td>0.05</td></tr>
<tr><td>5-Smoothing with plaster</td><td>0.002</td></tr>
<tr><td colspan="3">ATTIC FLOOR SLAB</td></tr>
<tr><td rowspan="4">
</td><td>STRATIGRAPHY</td><td>Width (m)</td></tr>
<tr><td>1-Leca concrete</td><td>0.10</td></tr>
<tr><td>2-Reinforced Concrete slab</td><td>0.15</td></tr>
<tr><td>3-Smoothing with plaster</td><td>0.001</td></tr>
</table>

Table 3.3: Stratigraphy of the floors enclosing the heated volume.

The other floors do not have any insulation system and are made of reinforced concrete slab thick 15cm with smoothing plaster finishing and tile covering on the several rooms, single firing tiled flooring for bathrooms, red gres tiles for terraces, cellars and corridors.

On the entrance halls and stairs landing to the different floors, slabs of Trani marble 20x40. The covering of the steps is made of light Trani stone slabs.

The slab on grade is made by a 5cm thick concrete slab with a welded mesh 8cm thick laying on a fine gravel of thickness 7.5cm.

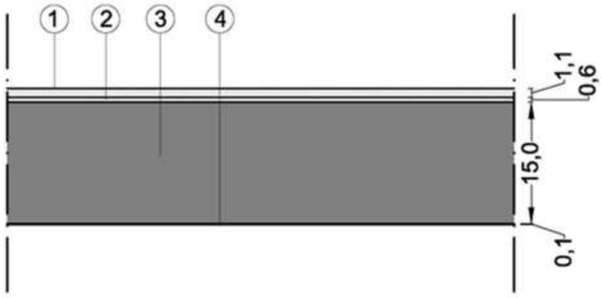
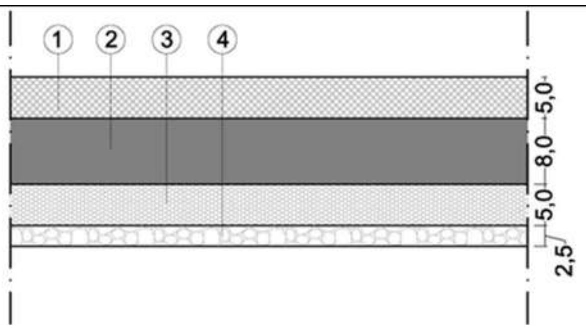
<table>
<tr><th colspan="3">TYPICAL FLOOR SLAB</th></tr>
<tr><td rowspan="5">
</td><td>STRATIGRAPHY</td><td>Width (m)</td></tr>
<tr><td>1-Ceramic</td><td>0.01</td></tr>
<tr><td>2-Adhesive</td><td>0.006</td></tr>
<tr><td>3-Reinforced Concrete slab</td><td>0.15</td></tr>
<tr><td>4-Smoothing with plaster</td><td>0.001</td></tr>
<tr><th colspan="3">SLAB ON GRADE</th></tr>
<tr><td rowspan="5">
</td><td>STRATIGRAPHY</td><td>Width (m)</td></tr>
<tr><td>1-Concrete paving</td><td>0.05</td></tr>
<tr><td>2-Concrete slab with welded steel mesh</td><td>0.08</td></tr>
<tr><td>3-Fine gravel</td><td>0.05</td></tr>
<tr><td>4-Gravel</td><td>0.025</td></tr>
</table>

Table 3.4: Typical floor plan and slab on grade stratigraphy.

Roof

The roof consists of concrete slab covered with slate tiles. The slab is placed on hollow clay planks supported by small walls, placed on the attic floor, following the slope direction.

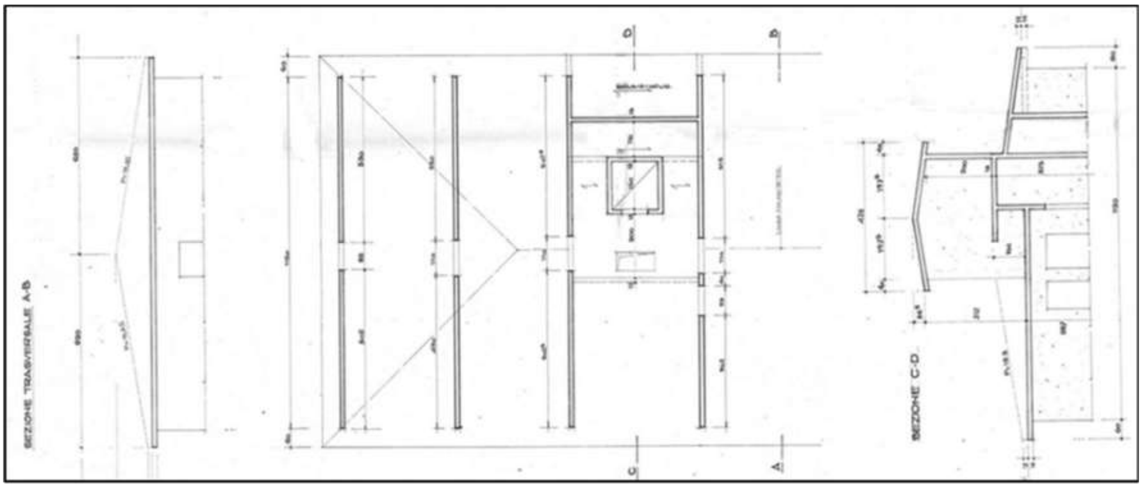


Figure 3.29: Structural Works on level 11.56m where the attic and roof slabs overhanging are highlighted regarding the building (F106.2T33).

As it is shown in fig. 3.29 the attic floor juts out from the main footprint of the buildings, creating eaves projections of about 0.60m. In correspondence of the niches on facade, where the staircases are placed, this extension appears to be bigger. On the backside, the depth is 1.35+0.60m (1.35m is the dimension of the staircase back shifting), but in this case the projection is obtained by the extension of the roof slab of the stairs, which appears inclined for this reason. On the main front, where the building is 0.60m backward, in correspondence of the terraces, the eaves projection will measure 0.60+0.60m.

Windows and Doors

The interior doors are made of plastic laminate with glass panels. The entrance doors to the apartments are also in plastic laminate, encased with oak plywood. The windows and door-windows of the apartments are made of Swedish pine wood and have plastic blinds and window sills and thresholds in Trani marble and travertine overhanging approx. 2cm from the facade.

In the cellars, all doors or windows fixtures are made of iron. They are placed on the top of the compartment and cover all the span, going to engage directly on the lateral structural walls. The staircases windows are made of iron frames of sizes 0.60x1.25m.

Figure 3.30: Windows in the cellars(Left). Windows in the staircases (right).

Technical implants

The heating system is autonomous with a predisposition for a methane boiler for each single apartment and a simple distribution system of radiators. The pipes for water distribution to the several heating terminals are positioned inside the slab casting.

The boilers are placed in the kitchen. In apartments TYPE A the kitchen is set against a false gypsum plasterboard wall with thickness 8cm separating the services duct area of about 17cm deep, from the load-bearing wall. Chimneys and pipes pass through slots made on the slabs. On what concerns the passage of the boiler exhaust pipe, the slot has dimensions 20x43cm, while for the intake of the kitchen and for the sink drain they have dimensions 20x40cm. The shafts are placed in the same position for all levels, down to the pillar floor and up to the roof covering.

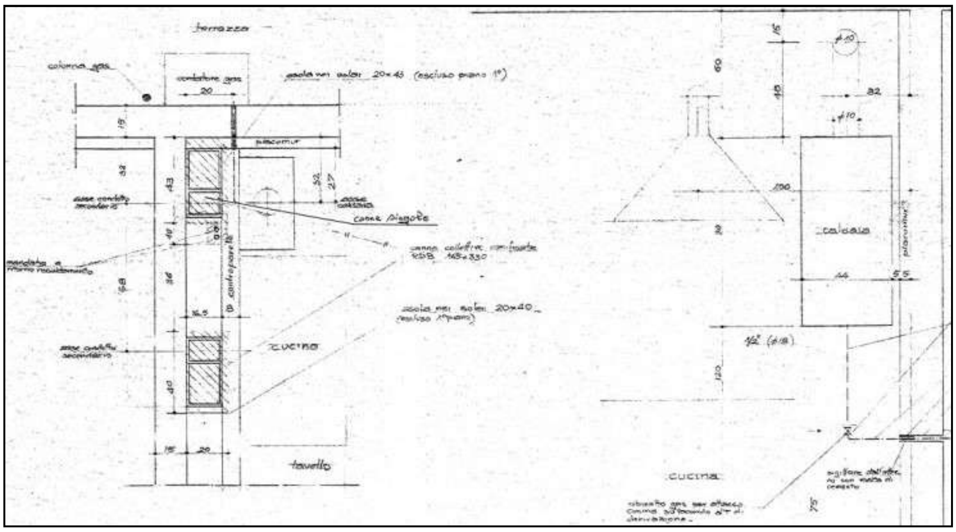


Figure 3.31: Kitchen in Apartment Type A (F108.4T9).

In Apartments Type B, the recessed kitchen is placed in the living room and mirrored respecting the bathroom in order of creating a single common services duct for the passage of several pipelines. Slots of dimensions 20x40cm are also produced on the slabs and the service duct is covered by two plasterboard walls thick 8cm. The fires suction hood, located away from the main services duct, made necessary the construction of an additional small air shaft for the passage of the pipe to the roof. The slot on the floors is also of size 20x40cm. The apartments TYPE C in building B have kitchens placed mirrored regarding the common services duct that has a depth of 25cm. The slots on the slab for the passage of pipes have a larger size compared to the previous examples (33x47cm).

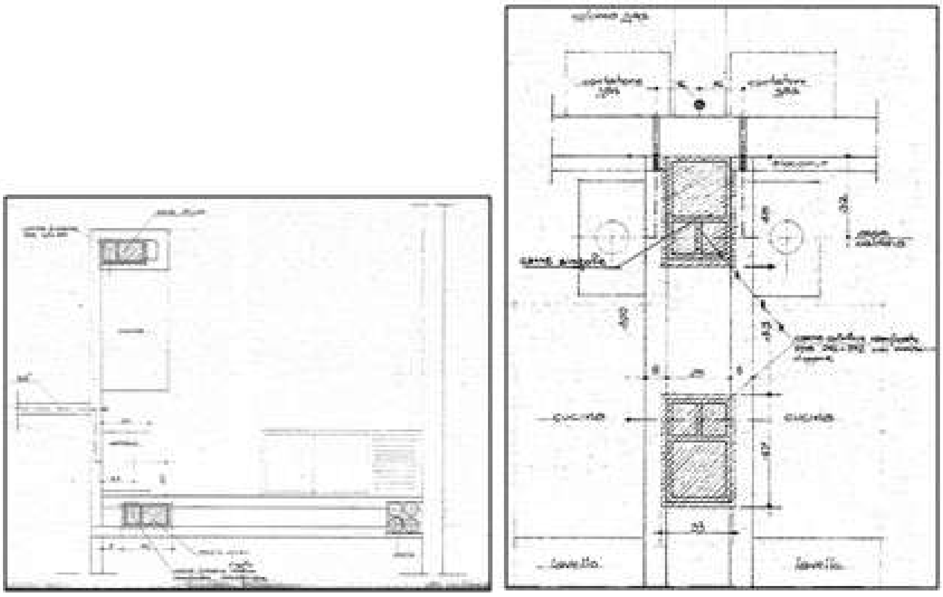


Figure 3.32: Kitchen in Apartment Type B(Left). Kitchen in Apartment Type C(Right) (F108.4T9).

The toilets in both buildings follow similar layout distributions.

In building A we may find two kinds of toilets layout: LAYOUT A and LAYOUT B. The plan dimensions are equal (2.30x1.70m), except for the bath adjacent to the recessed kitchen which is slightly larger due to the insertion of a washing machine, but they are different concerning the position of the shaft. As it is shown in the schemes below, the ducts are realised by double gypsum plasterboard walls thick 10cm, spaced about 20cm. The pipes pass through slots of size 20x50cm created on the floor.

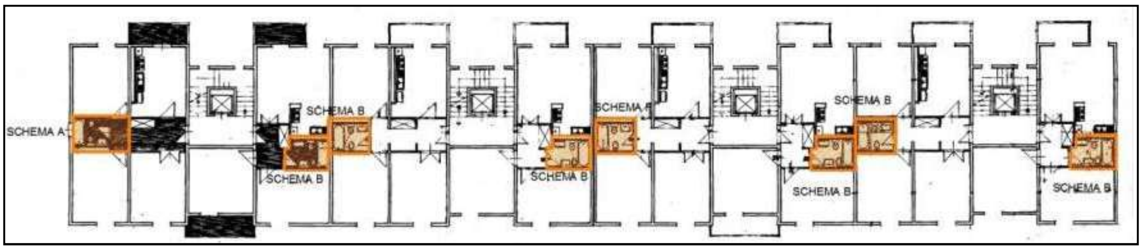


Figure 3.33: Toilets Layout Building A. In orange the bathroom types.

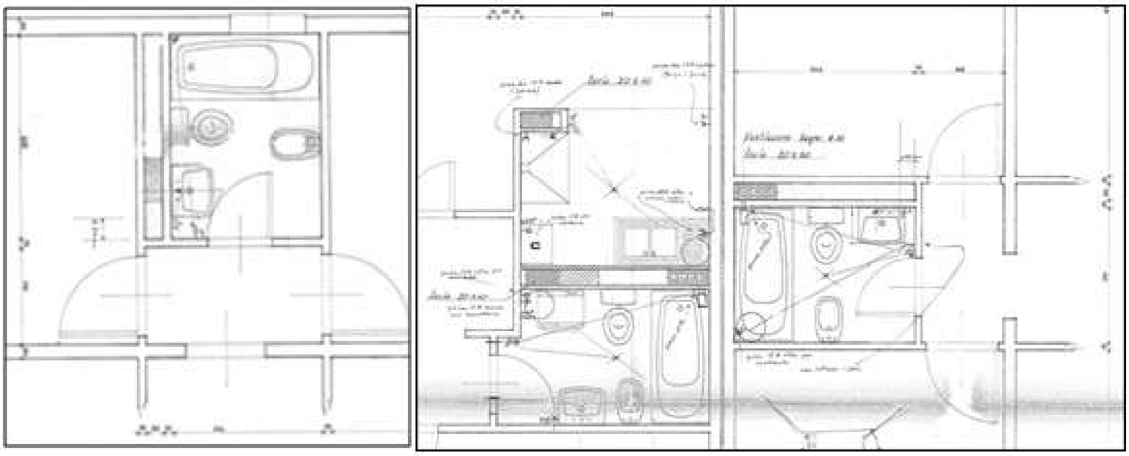


Figure 3.34: Toilets-LAYOUT A (Left). LAYOUT B (Right) (F108.3T9).

Building B, being the same as the previous one until seismic joint, presents the same layout A and B for the bathrooms, while to the right of the joint the two apartments Type C have different toilets layout: LAYOUT E and F.

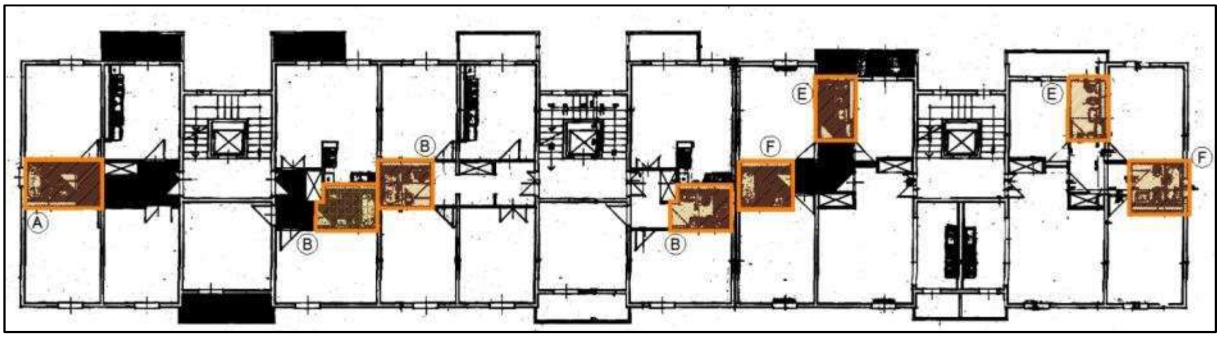


Figure 3.35: Toilets Layout Building B. In orange the bathroom types.

LAYOUT E has dimensions 1.25x2.60m, narrower than the previous due to the lack of a bathtub. In this case, as seen from the section in fig.3.36, the plasterboard wall, that hides the service ducts, goes up to the ceiling in correspondence of the toilet, while behind the other toilet fixtures stops 95cm from the floor, creating a sort of supporting furniture about 25cm deep.

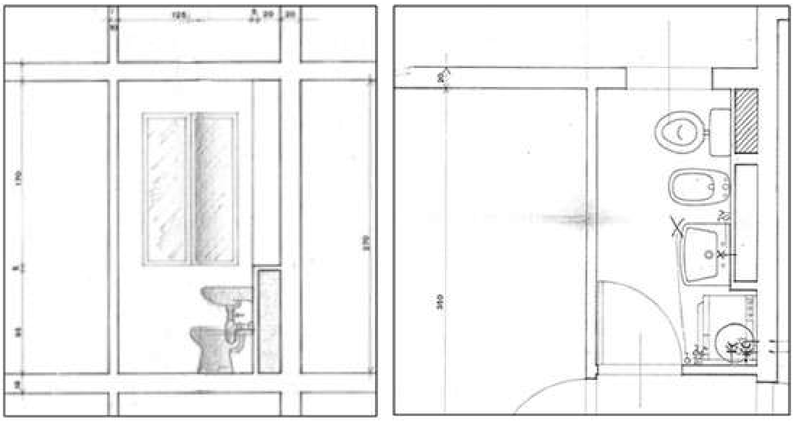


Figure 3.36: Toilet-LAYOUT E. Section of the toilet (left). Plan of the toilet (right) (F108.4T9).

The layout F has the same dimensions as the previous toilets (A and B), it means about 1.70x2.30m. Regarding the internal disposition, it is identical to LAYOUT B, except for the service duct which is placed on the opposite wall.

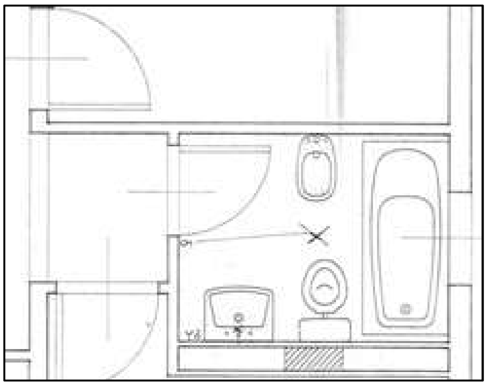


Figure 3.37: Toilet-LAYOUT F (F108.4T9).

The toilet pipes reach the ground floor (pillar floor), coming out from the slab and they are reconnected to the general services, outside protected by a metal casing (see figure below).

Figure 3.38: Drain Pipes coming from the toilets duct service in apartment TYPE A, Building A (Left). Drain Pipes coming from the kitchen duct service in apartment TYPE A, Building B (Right).

The figure below shows the typical electrical implant of the flats TYPE A and TYPE B. As we already mentioned, the pipes are located within the slabs and walls during the casting phase. In the plan, the continuous lines represent the pipes located in the casting of the “pavement” slab, while the dashed lines are the pipes located on the ceiling slab (dashed lines with bigger segments) and within the walls (dashed lines with smaller segments).

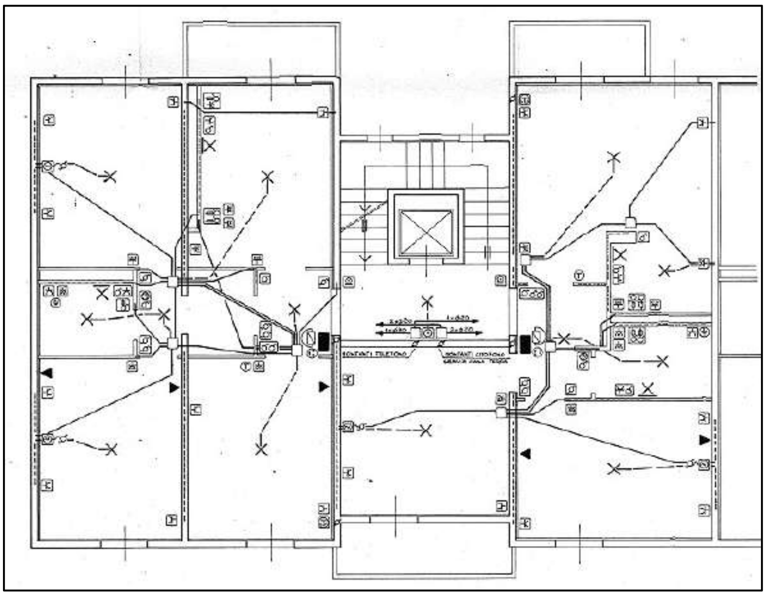


Figure 3.39: Electrical implant in flat TYPE A and TYPE B (F108.5T1).

3.1.2 COMPLEX B: Firenze-Via Canova

The project is located in Florence, in the suburb Torri a Cintoia, which lies to the east of the city centre; it is made up of buildings on 4 lots (named Qd1, Qa19, Qb16 and Qb40), spaced far apart in the vicinity of Via Canova, the main road of the neighbourhood (4). The tender notice for this project, approved in 1979, was part of the programmed construction of public housing and it involved the construction of a total of 120 housing units. As it is explained in the Building Process (APPENDIX B), Qb16, Qa19 and Qd1 were built according to the contract time, while Qb40 (it is identical to Qb16) was finished in a second moment. In the table below the lots of intervention are summarized:

BUILDING COMPLEX	CONSISTENCY	BUILDING TYPE	Number of flats	INDUSTRIALIZED SYSTEM
B: CANOVA (FIRENZE)	Qd1	LINEAR	48	Reinforced concrete walls in PREFABRICATED FORMWORKS
	Qa19	LINEAR	24	
	Qb16/Qb40	TOWER	24 each	

Table 3.5: Consistency of the intervention

Figure 3.40: G-maps extract and indication of the lots of intervention.

The analysis will be performed according to the building type factors classification. The technological characteristics will be analysed at the end of the study because all buildings present the same construction systems.

Qd1

Figure 3.41: Qd1- (On the left) North elevation, along Via Canova. (On the right) South Elevation.

1. Land use and Environmental Characteristics.

This site includes the largest construction compared to the other buildings. It is a multi-storey building with 7 floors above ground, approximately 77m long and with a depth of 9m, roughly oriented along the East-West axis. The lot on which the building is located measures about 96x40m.

The ratio of building area to the building site area is about 25%.

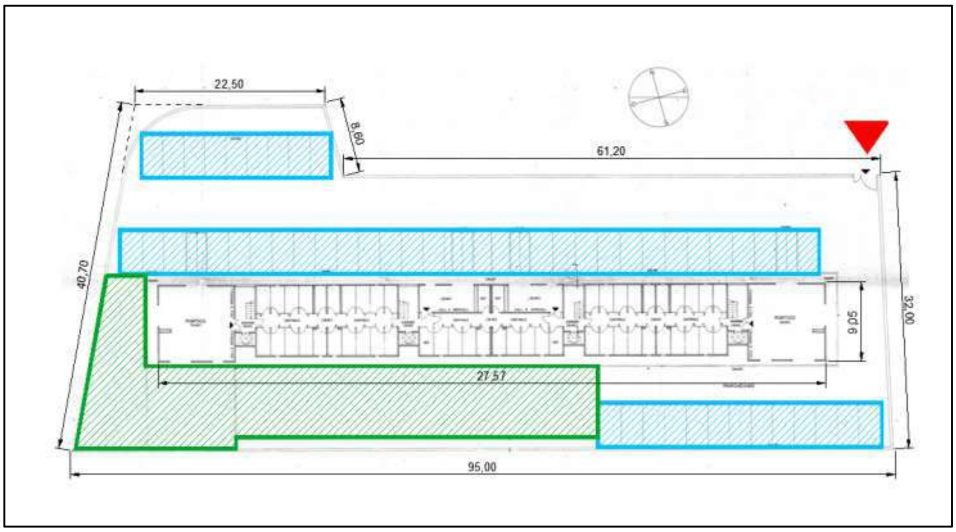


Figure 3.42: General Plan on which the building site organization is highlighted (the green area, the parking area and the entrance).

The car access to the lot is from the main street, Via Antonio Canova, as well as pedestrian one, characterized by a path paved with cement-grit, which connects the street with the buildings.

The building is located in the middle of the lot, dividing the site into 2 parts: the section along the main street is reserved for parking, while the areas behind the building is mainly reserved to private green areas along with another strip of parking.

The housing access occurs through the four stairwells. The entrances to the two stairwells located in the middle of the building occur by going through two porches realised on the main front (North façade). The other two entrances are located at both sides of the building; also in this case the entries to the stairwells are achieved by going through two porch areas located at the two opposite edges of the building.

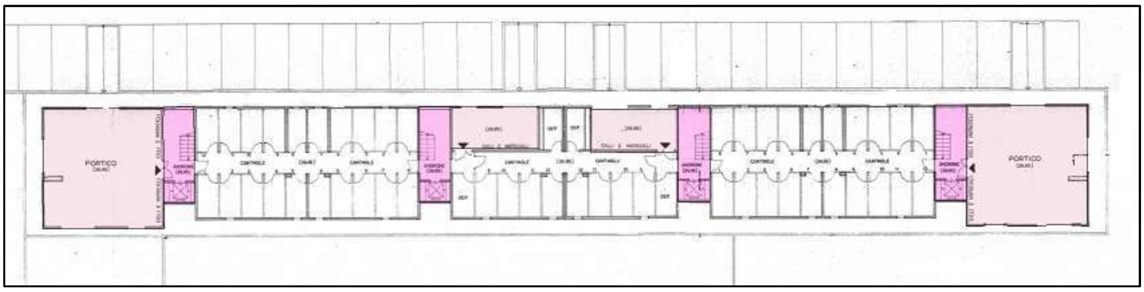


Figure 3.43: Ground floor plan with the identification of the porches and stairwells.

Accordingly, the ground floor, or "pillar floor", is characterized by the presence of porches and cellars. The porches create a direct connection between the parking area and the appurtenant central green area located at the back, and these porches are created with the opening of large passages on the transverse walls in reinforced concrete which constitute the main structure of the buildings. There are three cellar areas enclosed between the two lateral porches: the central one contains 8 cellars and the other two areas 20 cellars each.

2. Formal and Aesthetic characteristics

The façades are regular and simply plastered. The elevations present a modularity depending on the structural system that is organized in 8 different structural boxes: the biggest boxes at the extremities and the smallest ones at the central part of the building (see the next point 5).

In the North façade, the openings are placed in the same position depending on the modules and all present a width of 2.50m, as well as the width of the stairwells. The various floors are highlighted by the presence of stringcourses. The structural boxes are not highlighted in this façade because the elevation is pretty flat, while in the South elevation they are recognizable, due to projections or regressions of the external walls and construction elements.

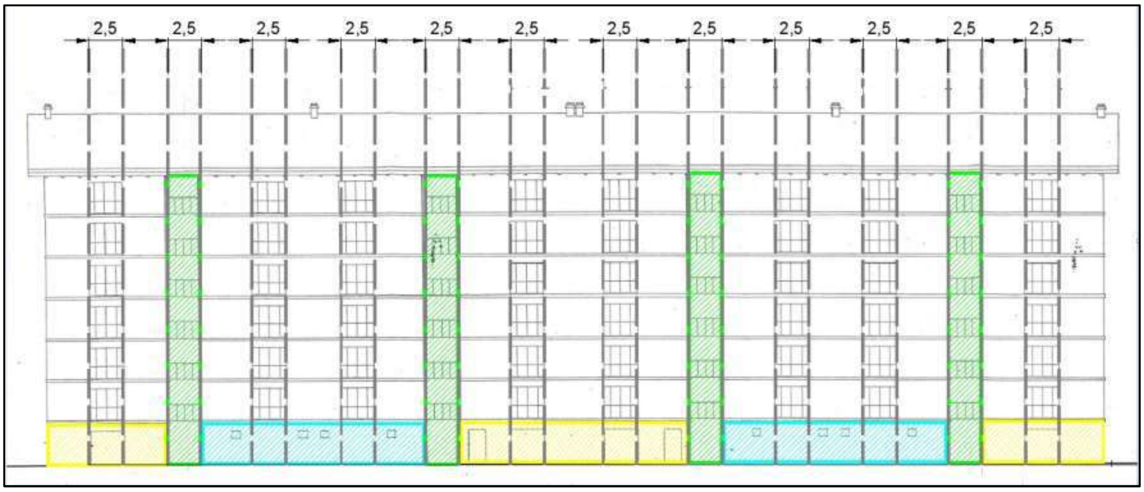


Figure 3.44: North Elevation: The porches are highlighted in yellow, the stairwells in green and the cellars in light blue.

Indeed, the South façade has terraces, 1.20cm deep. The stairwells are recessed of 1.20m related to the central part of the building (enclosed between the two central stairwells) which contains the smaller apartments, while the lateral parts, linked by the other two more external stairwells, overhang of about 60cm. The windows are located symmetrically both with respect to the stairwells (green strings in fig.3.45) and to the chimneys (pink string in fig. 3.45). Indeed, this elevation is also marked by the walls located in front of these just mentioned methane boiler chimneys placed in the terraces, with the aim at hiding them on the façade. These walls create strings running the length of the building, starting from the first floor. Moreover, the presence of the attic floor, used as drying room, with the round windows[7], interrupts the modularity, by creating a complete different floor scheme.

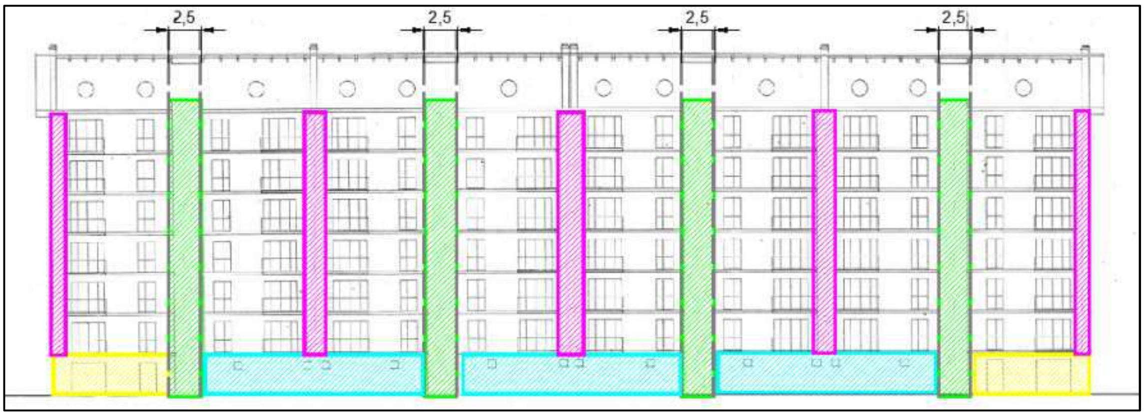


Figure 3.45: South Elevation: The porches are highlighted in yellow, the stairwells in green and the cellars in light blue. The walls surrounding the chimneys are highlighted in pink.

3. Morphological and Dimensional Characteristics.

Building Qd1 contains 48 apartments disposed over 6 floors with 8 units on each one. The typical plan is organized in 8 boxes (2 different size) with one flat for each box. The bigger flats are located at the ends of the building in the boxes with dimensions 8.75x8.75m, while the central flats in the box with dimension 8.125x8.125m. The areas with the arcades are located at the ends of the building with dimensions of approximately 9x9m, and at the main front, in correspondence of 1 block of 10 cellars. These areas present a gres paving so as to differentiate them from the sidewalk placed around the perimeter of the building and on the entrance areas that are made with square and horizontal concrete tiles. Besides the already mentioned block of 10 cellars (dimensions about 16.7x8.4m) the other two blocks of cellars (dimensions about 16.7x8.4m each) are placed in the central part of the building. The stairwells are about 2.5x7.2m. They have 2 ramps and the lift is located in front of the ramps. As we already mentioned these stairwells link the flats to the attic floor that presents some spaces fitted out as drying rooms. These areas, being under the roof, present a variable height (due to the roof slope of 30%), until to arrive at a maximum of 2.70m.

The inter-floor height is 3.00m, except for the ground floor which is 3.20m.

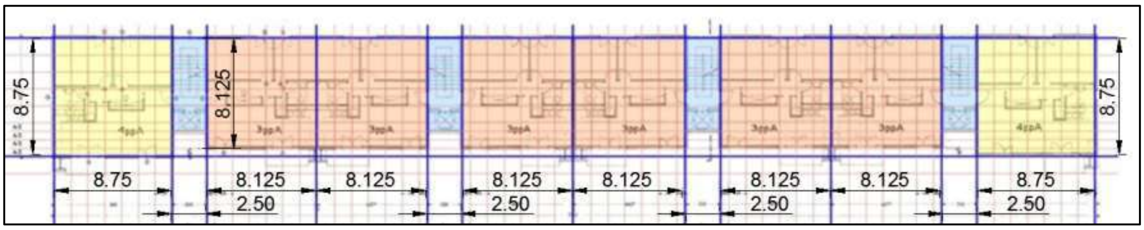


Figure 3.46: Typical floor Plan. Dimensions of the 2 different sized boxes.

[7] These windows are used both for lighting and for ventilating the space.

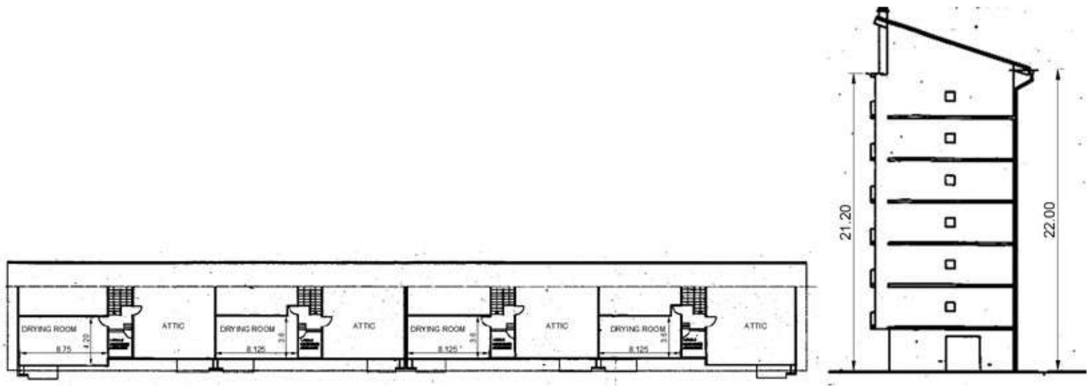


Figure 3.47: Attic Floor plan and east/west elevation with the indication of the heights.

4. Distributional and Functional characteristics

As in the previous cases, the building is linear and therefore it follows a modularity in the organization of the plan. Indeed, the plan consists of the aggregation of 4 modular blocks; each block contains a central stairwell and 1 flat on each side of the stairs (fig.3.48).

The 8 "structural boxes" that make up the building are clearly recognizable in the plan. The 2 boxes at the extremities are identical and have a larger size (8.75x8.75m), while the 6 central ones are characterized by a smaller size (8.125x8.125m). These dimensions of the boxes depend on a basic module of 1.25m (size of the precast elements constituting the formwork), so that each box has length and width as multiple of this measure.

A seismic joint is also present on the line of symmetry of the building.

The type of structure used allows an easy distribution of the units. As regards the first and fourth module, each stairwell is used by two units of different sizes, while in the second and third module the stairwells are used by two equal flats. The 2 different units are:

- TYPE A (4 users, about 75m^2);
- TYPE B (3 users, about 65m^2).

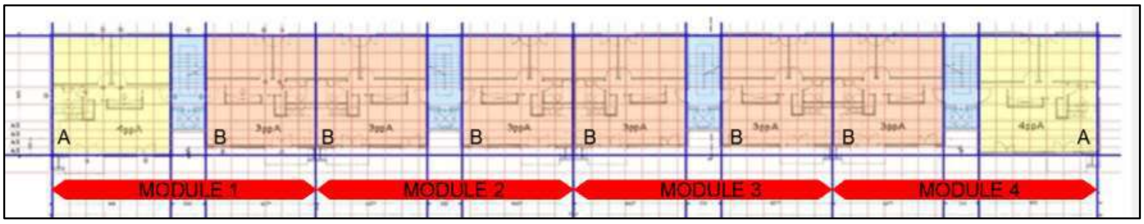


Figure 3.48: Typical Floor Plan. Indication of the modules.

The 4-person apartment consists of 2 double rooms, a living room, a kitchenette, a bathroom and a terrace, while in the 3-person apartment a double room is replaced with a single room.

Both present the secondary band in the middle of the flat, precisely dividing it into living and sleeping area.

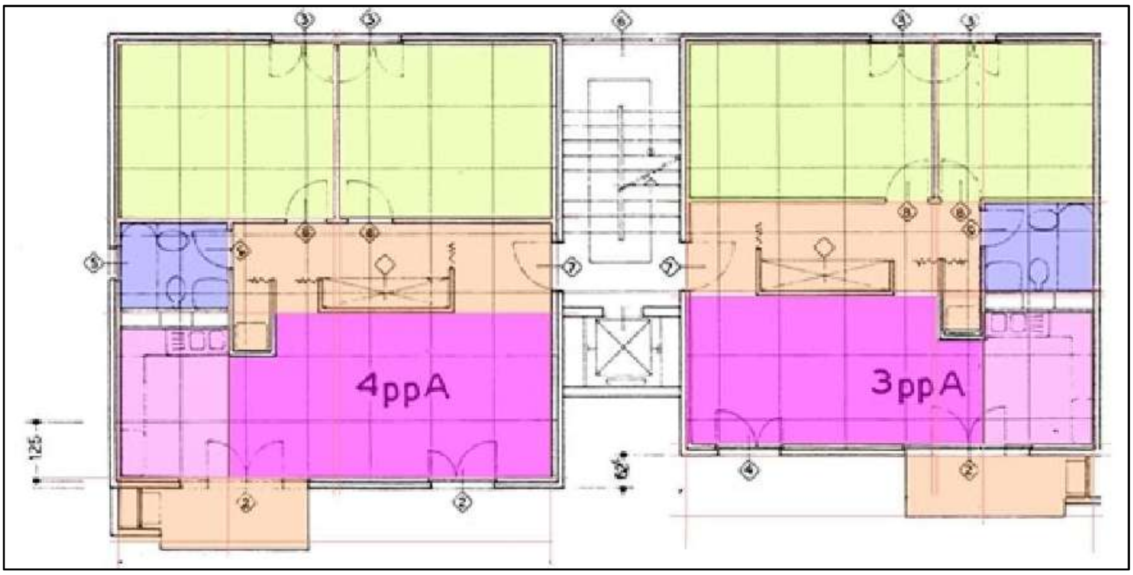


Figure 3.49: Typical Floor Plan. Indication of the modules.

Each individual unit was to be contained in a structural module. The internal distribution of the rooms was therefore not subject to any restrictions imposed by the structure. As we already mentioned, the windows on the main elevations follow a modularity: their length occupy 1 or 2 basic modules of the structure (module=1.25m).

The entrances to the apartments have dimensions 0.90x2.00m and are always placed symmetrically with respect to the stairwells. On the west and east side, the external structural walls have only one hole measuring 0.60x0.75m for the inclusion of the bathroom window.

Each unit is further linked to the attic floor through the same stairwell linking it to the ground floor.

Qa19

Figure 3.50: Qa19-(On the left) South elevation. (On the right) North Elevation.

1. Land use and Environmental Characteristics.

This site includes another linear building construction. It is a multi-storey building with 5 floors above ground, approximately 36m long and a depth of 10m, roughly oriented along the East-West axis. The lot on which the building is located measures about 66x40m. The ratio of building area to the building site area is about 15%.

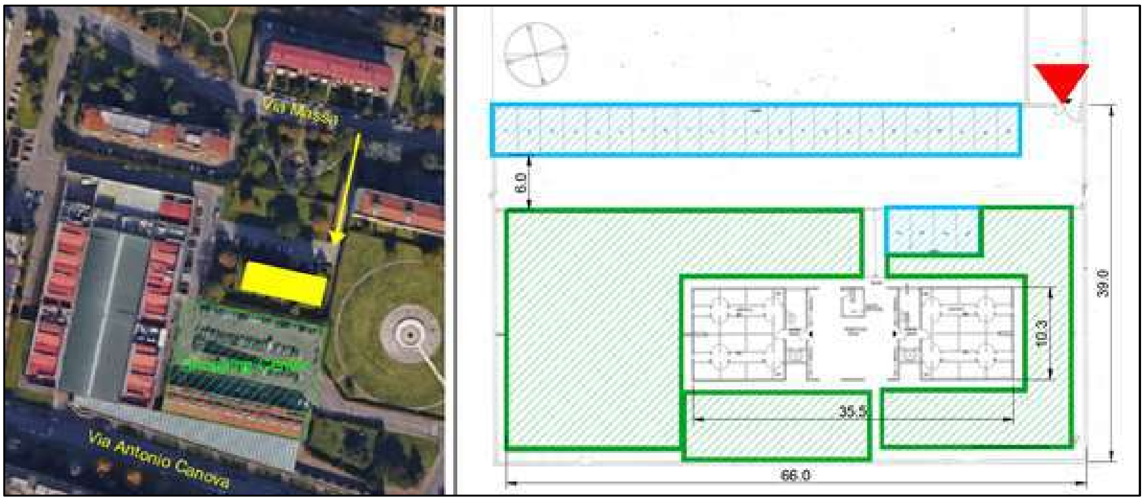


Figure 3.51: (On the left) G-maps extract with the individuation of the car access to the lot. (On the right) General Plan on which the building site organization is highlighted (the green area, the parking area and the entrance).

The car access to the lot is from the street Via Massa, a parallel street to the main one Via Antonio Canova. The Site is bordered on the South by a shopping centre, while on the North by a public green area. The building is surrounded by a large green area, that creates a sort of barrier against the shopping centre. The parking area is located on the North, along the lot border.

The access to the building is from the courtyard and in particular through a sidewalk realised in the green area on the North side. The housing access occurs through the two stairwells of the building. The entrances to the two stairwells occur by going through the central porch. The structure of the building is well recognizable. It consists of 3 structural boxes: the central one contains the porches and the 2 lateral ones the cellars.

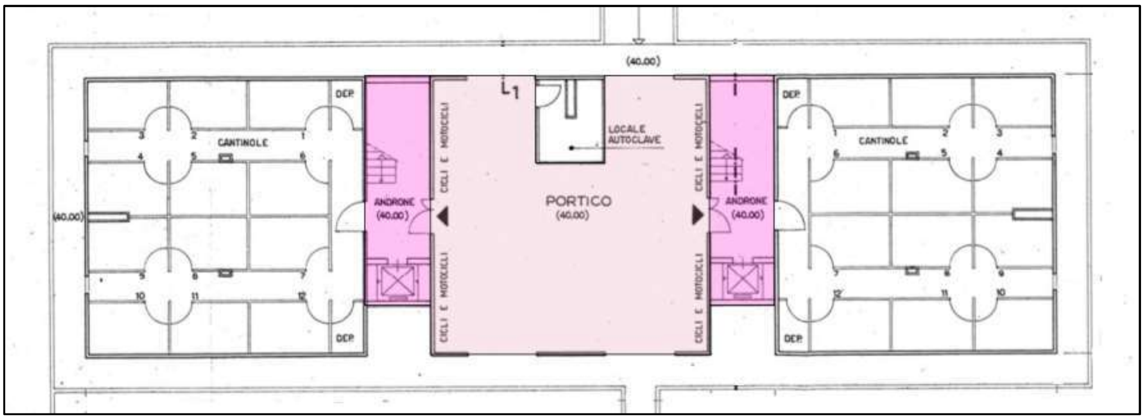


Figure 3.52: Ground floor plant with the identification of the porches and stairwells.

Accordingly, the ground floor, or "pillar floor", is characterized by the presence of porches and cellars. The porches create a direct connection between the parking area/green area and the appurtenant central green area located at the back, and are created with the opening of large passages on the transverse walls in reinforced concrete which constitute the main structure of the buildings. The 2 lateral boxes of the building contain 12 cellars per box.

2. Formal and Aesthetic characteristics

Also in this case the facades are regular and simply plastered. The elevations present a modularity depending on the structural system that is organized in 3 identical structural boxes.

In the North façade, the differentiation of the modules is recognizable; indeed, the central box is delimited by the 2 stairwells, while the other two modules are located at the end of the building. The presences of the chimneys (pink strings) on the North façade indicates that kitchens in these 2 lateral modules are located in this side of the building, while in the central part they are absent.

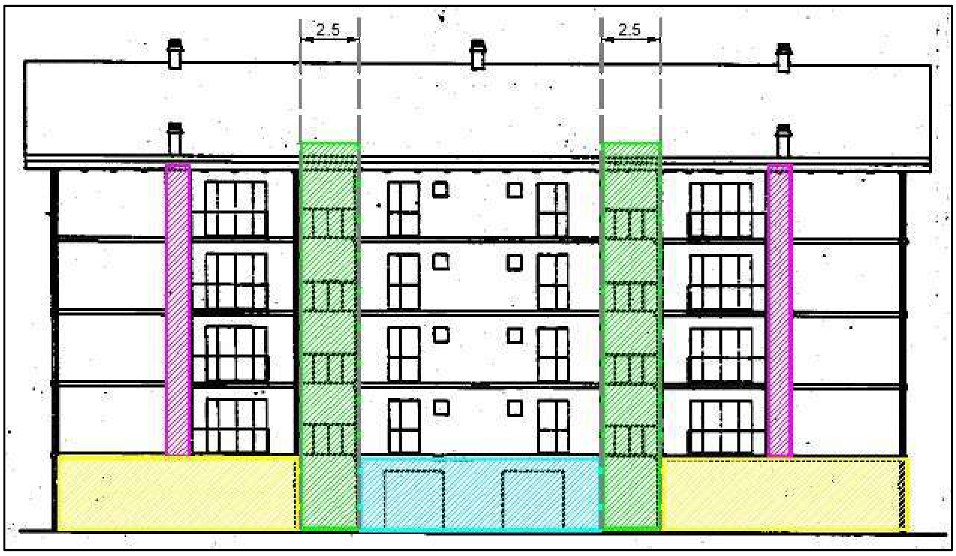


Figure 3.53: North Elevation: The porches are highlighted in yellow, the stairwells in green and the cellars in light blue.

In the South façade, the lateral parts are equal to those in the North façade; the presence of the chimneys also in this elevation means that these boxes contain 2 identical flats mirrored to the longitudinal axis of the box. Instead the central part of the building hosts 2 flats mirrored with respect to the transversal axis of the box and the central wall hides the 2 boilers chimneys of these 2 aforementioned apartments. Moreover, the presence of the attic floor, used as drying room, with the round windows, interrupts the modularity, by creating a complete different floor scheme.

Figure 3.54: South Elevation: The porches are highlighted in yellow, the stairwells in green and the cellars in light blue.

3. Morphological and Dimensional Characteristics.

Building Qa19 contains 24 apartments disposed over 4 floors with 6 units on each one. The typical plan is organized in 3 identical boxes with 2 flats for each box with dimensions 10x10m.

It features the ground floor used as cellars, porches and entrance areas. The areas with the arcades are located in the centre of the building. On the west and east side, there are 2 blocks of cellars which dimensions 10x10m and occupy the 2 bigger modules of the structure which the building is made with.

The stairwells are about 2.5x7.2m. They have 2 ramps/floor and the lift is located in front of the ramps. As we already mentioned these stairwells link the flats to the attic floor that presents some spaces fitted out as drying rooms. The inter-floor height is 3.00m, except for the ground floor which is 3.20m.

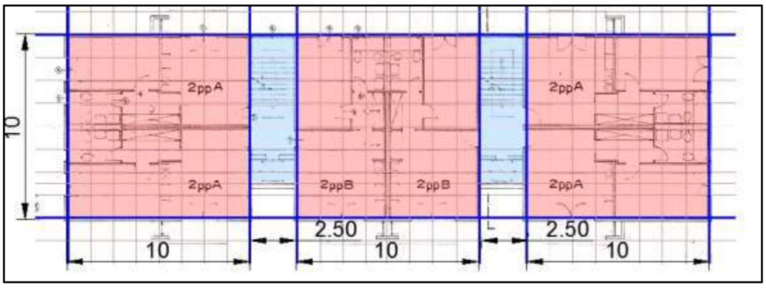


Figure 3.55: Typical floor Plan. Dimensions of the 3 identical boxes.

4. Distributional and Functional characteristics

As in the previous case, the building is linear and therefore it presents a modularity in the organization of the plan. The typical plan is organized in 3 modular boxes; each block contains the stairwell, still in the middle of the block, and in this case, 3 flats are linked to the stairs (in all the other cases we had 2 flats) (see fig.3.56). The 3 "structural boxes" that make up the building are clearly recognizable in the plan. Each box contains 2-person apartments. In the central box, the flats are organized along the transversal direction; they are therefore mirrored with respect to the transversal axis. The other 2 boxes, located at the extremities host 2 flats equal in the dimensions to the central ones, but in this case, they are mirrored with respect to the longitudinal axis.

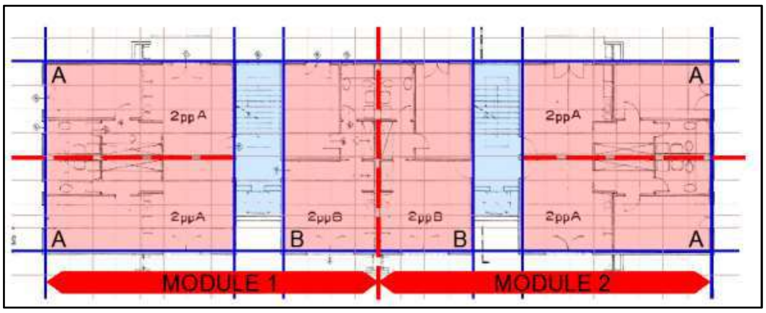


Figure 3.56: Typical Floor Plan. Indication of the modules.

The 2-person apartment consists of 1 double room, a living room, a kitchenette, a bathroom and a terrace. The apartments in the central box have the secondary band located along the transversal axis, while the flats in the other boxes have this area along the longitudinal axis. These areas are not directly linked to the entrance, but they are actually the service area for the night zone.

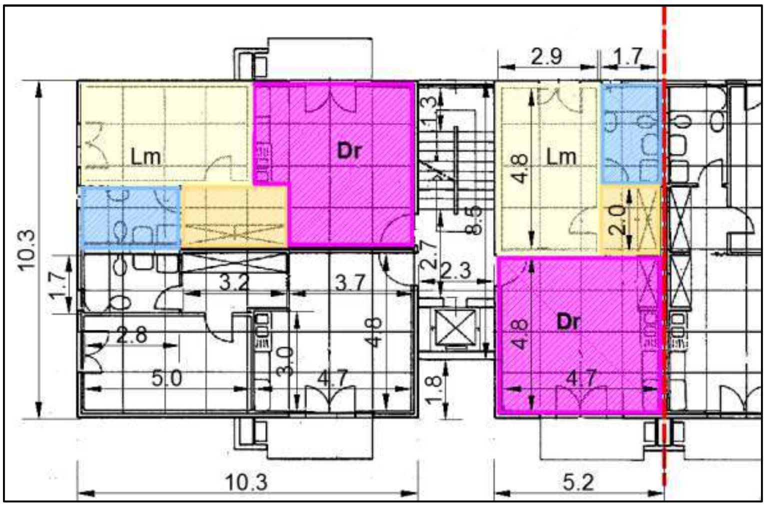


Figure 3.57: Residential Unit Arrangement.

The entrances to the apartments have dimensions 0.9x2.0m and are always placed symmetrically with respect to the stairwell. On the west and east side, the external structural walls have only 2 holes measuring 0.60x0.75 for the inclusion of the bathroom window. Also in this building, the windows on the main elevations follow a modularity: their length occupy 1 or 2 basic modules of the structure (module=1.25m). Each unit is further linked to the attic floor through the same stairwell linking it to the ground floor.

Qb16/Qb40

Figure 3.58: Qb16-The buildings located in Qb16 and Qb40 are identical in the aspect. These photos show Qb16 building. (On the left) West elevation. (On the right) South Elevation.

1. **Land use and Environmental Characteristics.**

Qb16 and Qb40 are located in different areas, they present therefore different site organization, but the buildings have equal characteristics. They are tower buildings of 7 floors above ground, with a plan dimension of about 21x20m. Being towers, there is not a predominant orientation, but all the façades are oriented according almost perfectly to the 4 different cardinal points. The lot Qb16 measures about 42x57m, while Qb40 about 50x52m. The ratio of building area to the building site area is about 18% for both the sites.

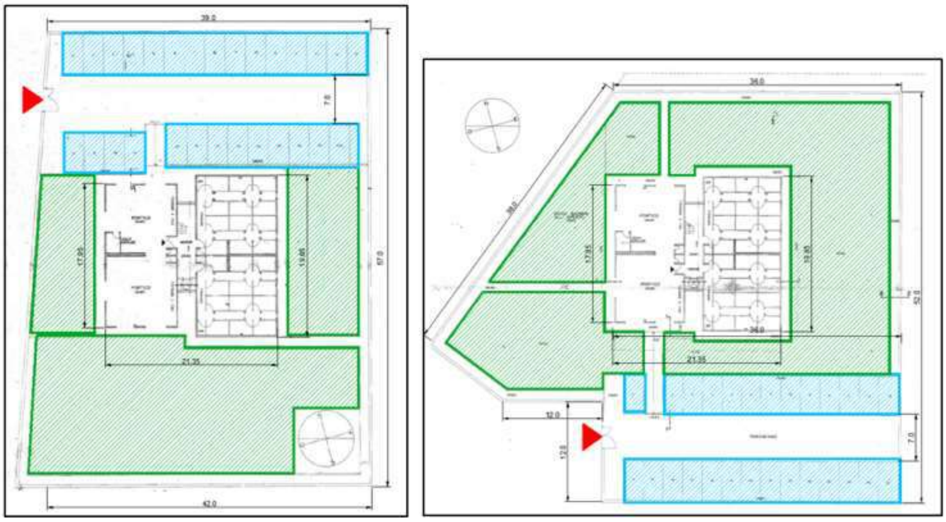


Figure 3.59: General Plan on which the buildings' sites organization is highlighted (the green area, the parking area and the entrance). On the left Qb16 site, on the right Qb40.

Figure 3.60: G-maps extract with the individuation of the car access to the lot. On the left Qb16, on the right Qb40.

The car access to the Qb16 lot is from the street Via Santa Maria a Cintoia, a perpendicular street to the main one Via Antonio Canova. Qb40 is located at the end of the main street, and the access to the site is from a secondary street perpendicular to the main one.

The access to the building is from the North side for what concerns Qb16, while in Qb40 site the entrance is from the South side. Both sites present a parking area with 2 strings of parking spots and the street in the middle at the North extremity of the lot as regards Qb16, while at the opposite for Qb40. The buildings are completely surrounded by green areas and the accesses to the housing occur through a sidewalk realised in this area, in the North part of the lot for Qb16 and in the South one for Qb40. The housing access occurs through the single stairwell of the building. The entrances to the stairwell occur by going through a porch area. Also in this case the structure of the building is well recognizable. It consists of 4 structural boxes organized around the stairwell: 2 smaller boxes used as porches and motorcycles parking and the other 2 larger boxes contain 24 cellars.

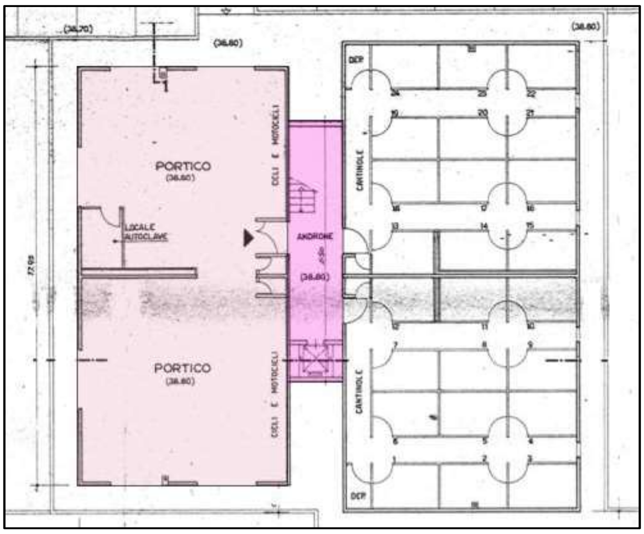


Figure 3.61: Ground floor plant with the identification of the porches and stairwells.

The ground floor, or "pillar floor", is therefore characterized by the presence of porches and cellars. The porches create a direct connection between the parking area and the appurtenant central green area located at the back, and are created with the opening of large passages on the transverse walls in concrete which constitute the main structure of the buildings.

2. Formal and Aesthetic characteristics

Also in this case the facades are simply plastered and present a modularity depending on the structural system that is organized in 4 structural boxes. The North and South elevations are identical for what concerns the aspect, and what it is interesting to note is that the stairwell, in the middle of the building, creates the separation between the 2 sizes of boxes. On one side, there are the two larger structures, on the other side the two smaller ones. This division is highlighted in the North and in the South façade, because the larger boxes overhang with respect of the other ones of 95cm, creating a movement to the façade. The difference between the two elevations is that in the North part the stairwell is recessed compared to the edge of the smaller boxes of 2.30m, while at the opposite site, is even hider, being recessed of 4.30m (still compared to the edge of the smaller boxes). As in the other buildings, the chimneys are located in the terraces realised in these facades.

Figure 3.62: (on the left) North Elevation (on the right) East Elevation: The porches are highlighted in yellow, the stairwells in green and the cellars in light blue.

In the other two elevations, East and West side, the division into structural boxes is not highlighted. The modularity is still evident, obtained by the windows dimension and their position.

3. Morphological and Dimensional Characteristics.

Buildings Qb16/Qb40 contains 24 apartments disposed over 6 floors with 4 units on each one. The typical plan is organized in 4 structural boxes with 1 flat for each structural box. As we already mentioned the structural boxes present different dimensions: the smaller ones measure 8.75x8.75m, while the bigger ones 10x10m. It features the ground floor used as cellars, porches and entrance areas. The areas with the arcades are located in the smaller 2 boxes of the building. This area presents a gres paving so as to differentiate it from the sidewalk placed around the perimeter of the building and on the entrance areas that are made with square and horizontal concrete tiles.

The 2 blocks of cellars are located in the larger sized boxes (10x10m). The inter-floor height is 3.00m, except for the ground floor which is 3.20m. The stairwells are bigger than in the other buildings because they have to be used by four flats per floor (about 2.5x11.25m). They have 2 ramps and the lift is located in front of the ramps. As we already mentioned these stairwells link the flats to the attic floor that presents some spaces fitted out as drying rooms.

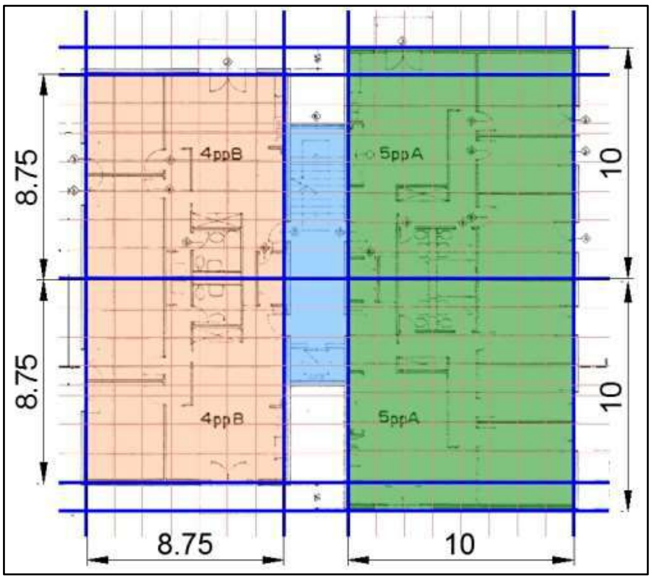


Figure 3.63: Typical floor Plan. Dimensions of the 3 identical boxes.

4. Distributional and Functional characteristics

These buildings are towers; they present therefore the stairwell in the middle of the plan. Each box of the structure contains 1 apartment.

The larger boxes host 5-person apartment (94.5m^2), while the smaller ones 4-person flats (75m^2). The 4-person apartment consists of 2 double rooms, a dining room with a kitchen, a bathroom and a terrace. The 5-person apartment presents a bathroom and a single room more than the other flat. Both flats present similar internal distribution: an area close to the living room is accessed from the main entrance of the flat. In order to reach the night zone there is a distributional area located in the middle of the box in parallel direction with respect to the stairwell. The service areas are located in the blind zones of the flats and they are adjacent to the service areas of the other flats mirrored with respect to the horizontal axis (red dashed line in fig.3.64).

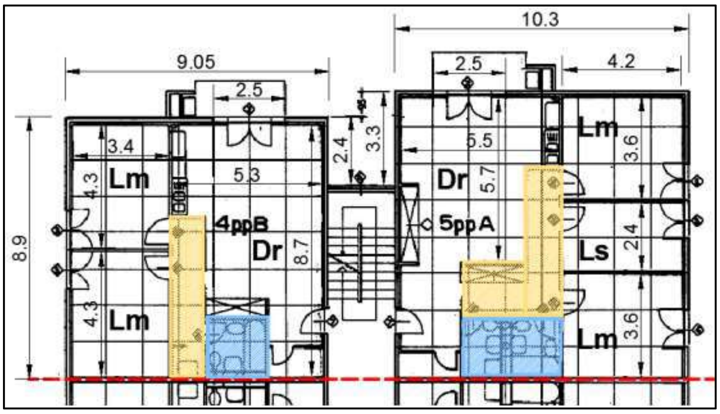


Figure 3.64: Residential Units Arrangement. In yellow the service area and bathrooms in blue. Lm= double bedroom, Dr= Dining Room, Ls= Single bedroom.

The entrances to the apartments have dimensions 0.9x2.0m and are always placed symmetrically with respect to the stairwell. Also in this building, the windows on the main elevations follow a modularity: their length occupies 1 or 2 basic modules of the structure (module=1.25m).

The shafts for the implants are realised inside of plasterboard walls in the proximity of the bathroom and the kitchen through the realisation of slots on the slab already predisposed during the casting phase and which are repeated for all floors. Each unit is further linked to the attic floor through the same stairwell linking it to the ground floor.

5. Technical and Technological characteristics

The analysis of the technological aspects is in common between the three buildings, because they were realised with the same industrialized system and by using identical materials as regards the envelope and the same technical implants.

THE STRUCTURE

The Immobiliare Scipione Capece, that won the contract for the construction of Canova building complex (see APPENDIX B), decided, for a variety of reasons related in particular to the flexibility of the internal distribution of the housing modules, to opt for a constructive system composed of reinforced concrete walls cast on site in precast formwork and floors, consisting of lattice plate integrated with additional transverse reinforcement laid in place.

The buildings were then conceived as an aggregation of square structural boxes, made of 15cm thick perimeter load-bearing walls and floors whose span corresponded to the depth of the building. As a result of the structural grid, which is organized on a 1.25m modularity (size of the precast elements constituting the formwork), 3 different "structural boxes" were constituted with the following net sizes of the partitions: 8.125x8.125m (for the 60m^2 housing units), 8.75x8.75m (for the 70m^2 units) and 10x10m (for the 85m^2 and 45m^2 units).

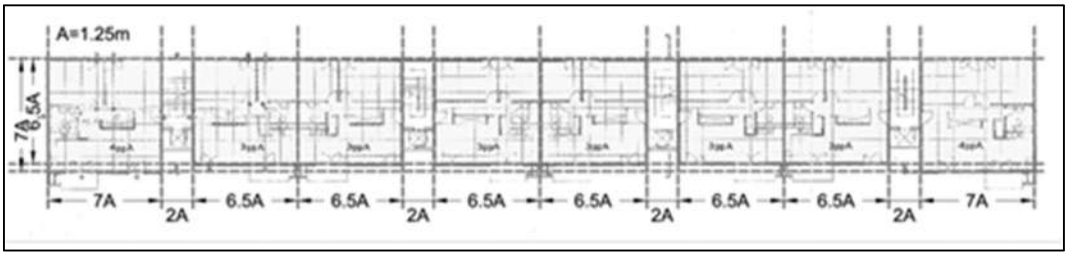


Figure 3.65: Lot Qd1: type plan with the identification of "structural boxes".

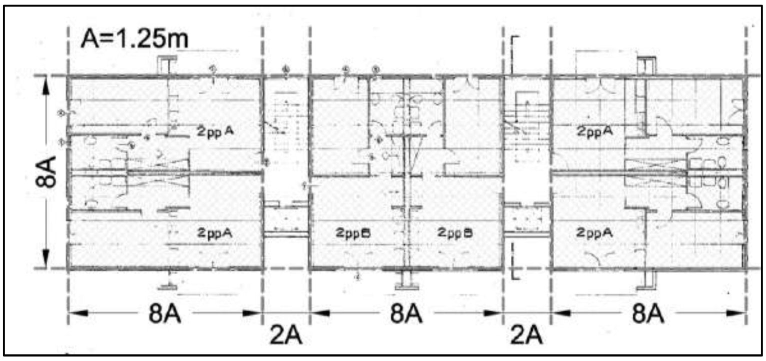


Figure 3.66: Lot Qa19: type plan with identification of "structural boxes".

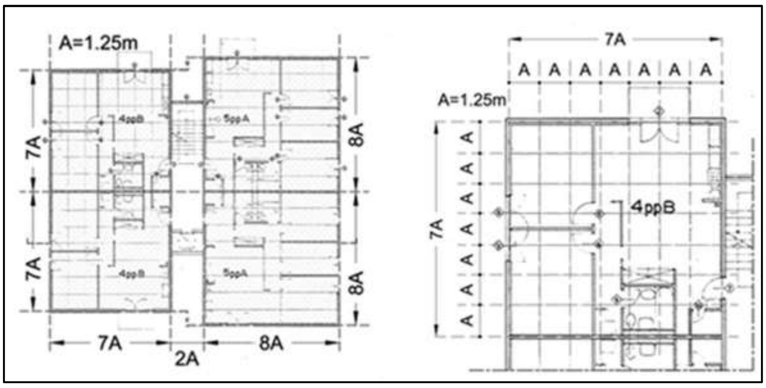


Figure 3.67: (On the left) Lots Qb16 and Qb40: type plan with identification of "structural boxes". (On the right) explanation of modularity for a housing unit.

For the structural calculation[8], the designers made reference to the "Rules for calculation and construction of large panel structures", issued by the Ministry of Public Works, register. no.6090 11/08/1969. In point 1.1.1 (validity range) of these regulations, it is stated that: "These rules apply to structures formed by connecting large horizontal panels (floors) and vertical ones (walls) and linear structural elements (beams and pillars). It is considered a "large vertical panel", a vertical panel that is a floor high and whose width exceeds 1m. [...] The material used for resistance is reinforced and non-reinforced concrete." The criterion used for the partition design was different compared to the one used for pillars, which referred to Law no.1086 of 05/11/1971. The main problem for the designers, in the calculation of walls, was to define the average tension of compression above which it would have been necessary to dispose skeletons and their quantity.

USED MATERIALS		
ELEVATIONS	Concrete	R'bk=250
	Steel	FeB44K
	Welded Mesh	Controlled=2.600 Kg/cmq
FOUNDATIONS	Concrete	R'bk=250
	Steel	FeB44K

Table 3.6: Used materials for the structure.

<u>Foundations</u>

The foundations were simplified compared to a more traditional structure; in fact, they were made with beams located at the base of the walls, resting on 60cm diameter bearing piles

The first solution was to realise precast piles, but from the "Report Variation on Foundations"[9], we learn that the foundations with this solution, were proven to be difficult to execute, after Geognostic investigations, reason why a drafting of a variation turned out to be necessary. From the investigations carried out, a foundation on circular piles with 60cm diameter was indicated; its purpose was to support a load of up to a maximum of 70t.

The loads of the vertical walls were transmitted onto these piles, through a 70x60cm under beam, which was an integral part of the walls. This beam had the dual task of covering the head of the pillars and distributing stress transmitted by them to the wall above. The beneficial effect of having an under beam consisted in the distribution of the stress, which means that without it, stress

[8] From the Calculation Report found in the folder 163E.

[9] folder 165.1.

could have reached rather high levels and therefore determined the presence of substantial shear reinforcements.

In the fig.3.68 the foundation beam of the building Qa19, above mentioned, is represented, with the 3 identical structural boxes. The 4 walls composing the box lay on this beam.

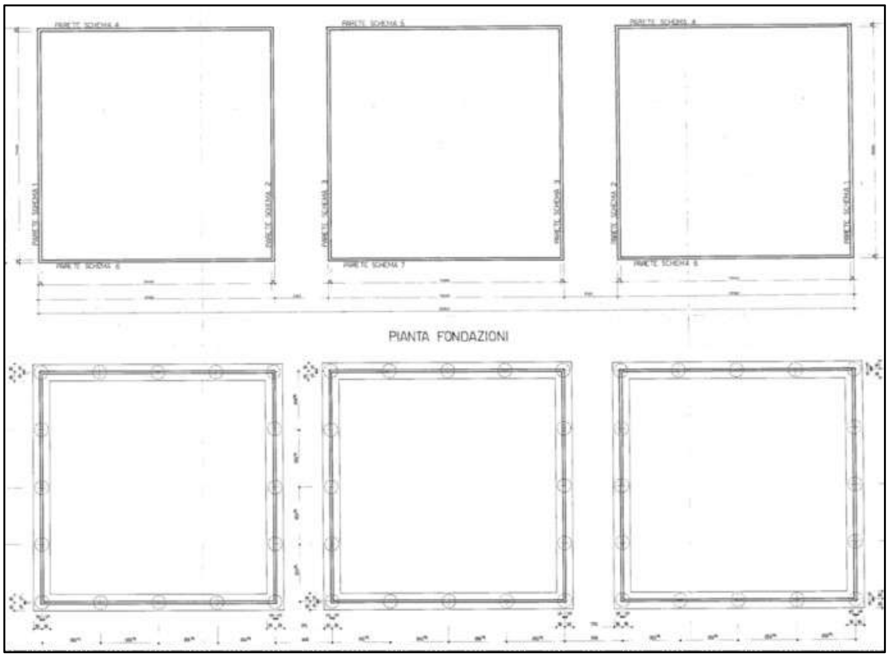


Figure 3.68: Foundation Plan Qa19-(F165.1 T9).

Walls

The walls, cast on site in precast formworks, present different schemes related to the box dimension, to the openings and consequently to the concrete reinforcements. Such openings, for the implementation of doors and windows, were obtained simply by introducing suitably shaped iron masks into the formwork, nevertheless, ensuring a more precise arrangement of the frames.

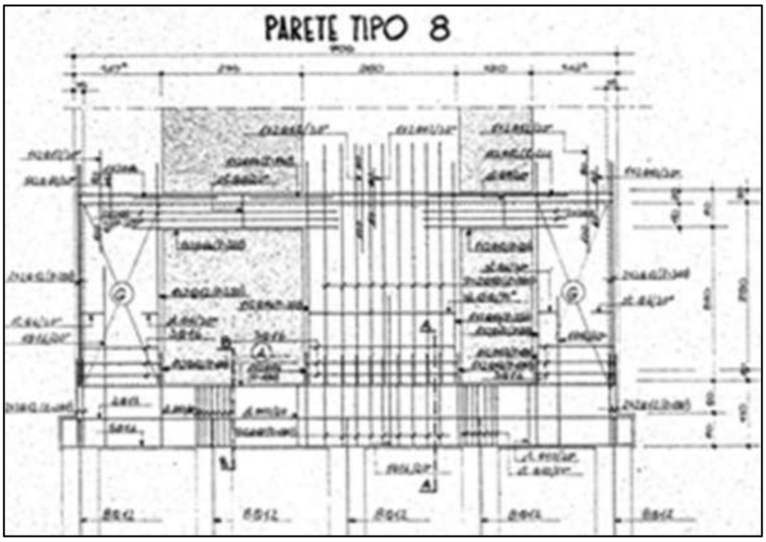


Figure 3.69: Executive detail of a wall panel at the foundation-(S9_STRUCTURAL)

In the figure below a scheme of Qd1 walls organization is represented. Only the left part of the plan is shown because the right part is equal and mirrored with respect to the first one. As we mentioned in the lot Qd1 description, each building floor consists of 8 structural boxes. At the extremities the largest ones, and the smallest in the central part. The 2 different sized boxes present therefore different scheme of walls, due to the different dimensions. In the fig.3.70 the detail of the first level wall panels (walls 8-9) are shown together with the correspondence between them with the South elevation and the boxes plan, for what concerns the openings position. Obviously, the wall panel 9 is repeated in the 3 central boxes. The same situation occurs for the other elevations: the organization of the wall panels will be identical in the central boxes, as well as the lateral ones will present equal wall panels.

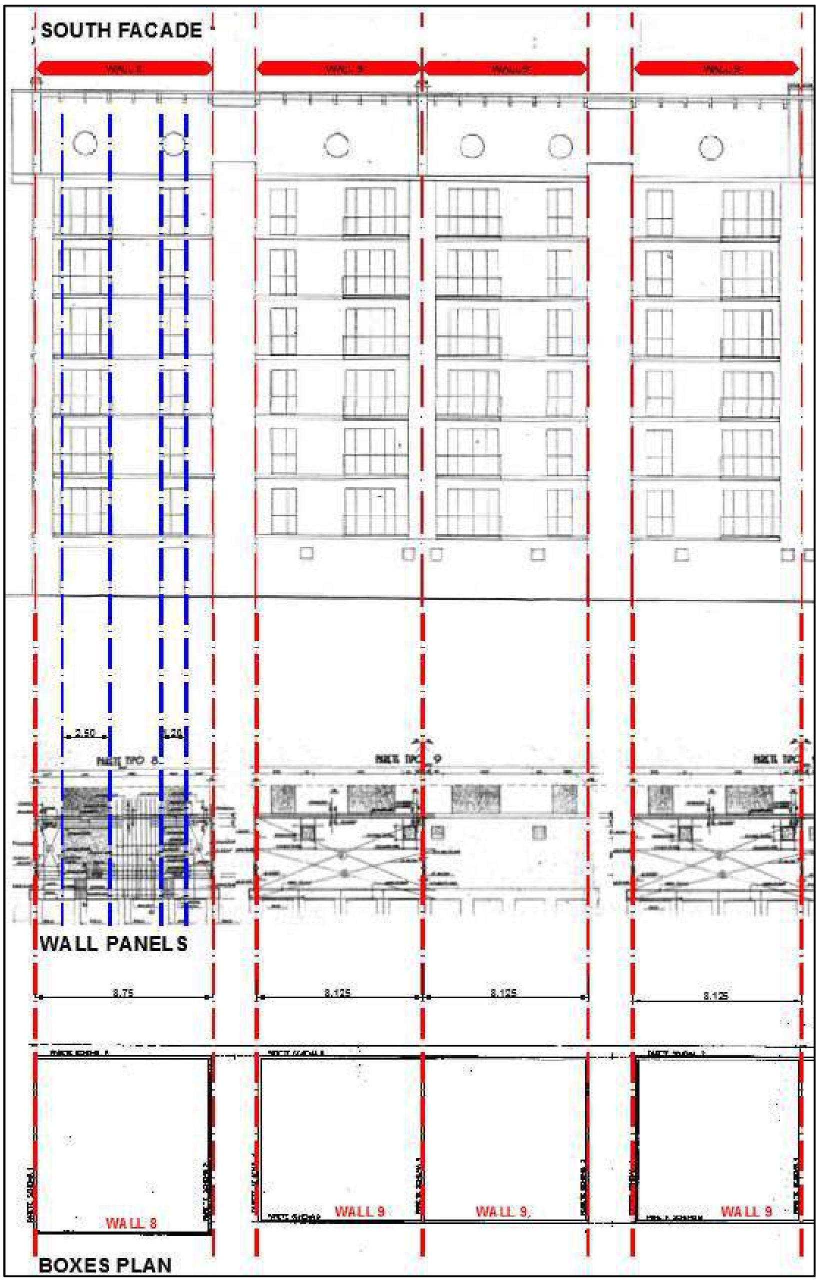


Figure 3.70: Lot Qd1-Organization of the wall panels.

Slabs

The slabs are "Predalles" type slabs ("Celerpan" is the commercial name of the Predalles slab used in this construction and produced by RDB Company). Conversely, the original solution provided for floors with reinforced concrete slab cast in situ, bound to SCAC type precast beams, overhanging with respect to the head of the vertical partitions.

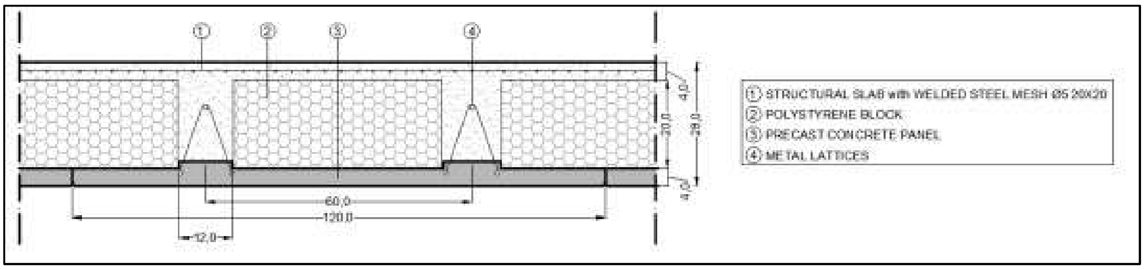


Figure 3.71: Celerpan slab section.

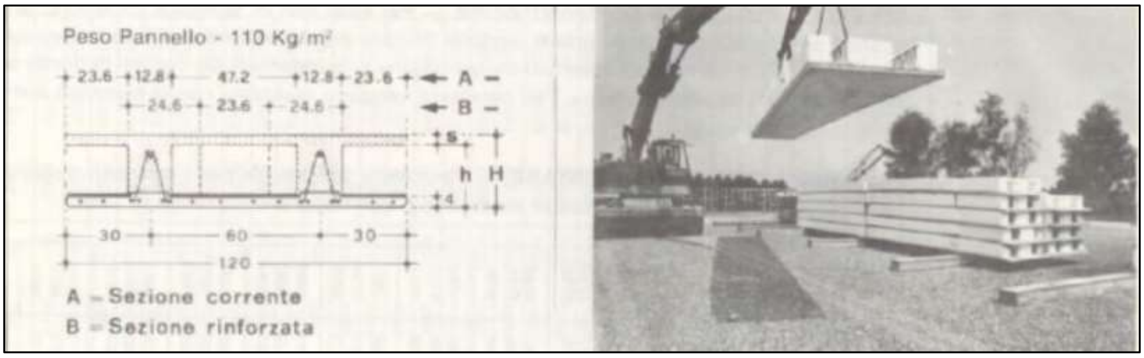


Figure 3.72: Celerpan lattice plates (RDB-Folder 165 2).

This type of slab consists of precast concrete panels in which metal lattices are inserted with wheelbase of 60cm, with the function of structural stiffening. Polystyrene blocks are inserted between these lattices, with the function of lightening.

These latter elements can be glued to the panels in situ, or the system can arrive already completed. In this project the Celerpan production company (RDB) provided only the precast concrete panels, but it gave instructions for the polystyrene gluing to the construction company.

The concrete is then cast in situ to complete the slab. The final section of the floor slab measures 24+4cm.

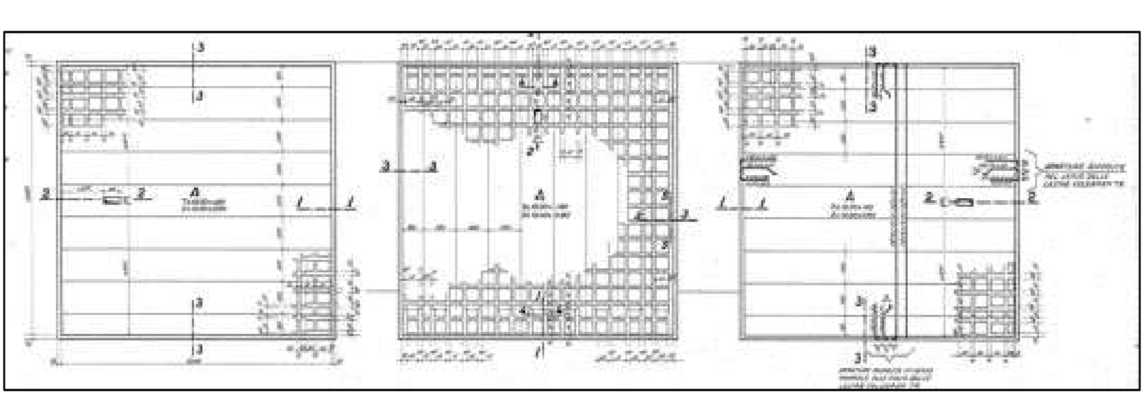


Figure 3.73: Lot Qa19-Solution for slab floors implementation with the use of Celerpan type of lattice plates. (D/7509_F165.2 T9).

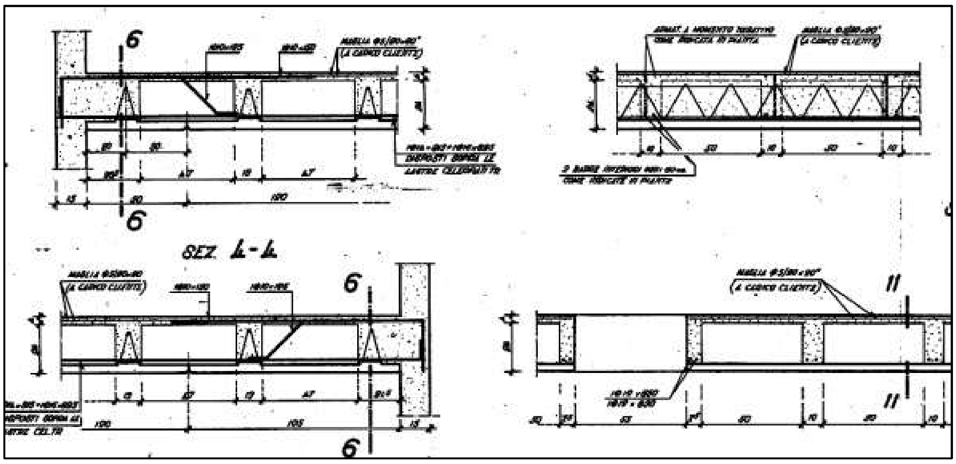


Figure 3.74: Typical sections of Celerpan slab. (D/7509_F165.2 T9)

The roofing in Qb16/Qb40 and Qd1 is made with simple structure lattice plate floors as well, but with a different thickness (31+4cm).

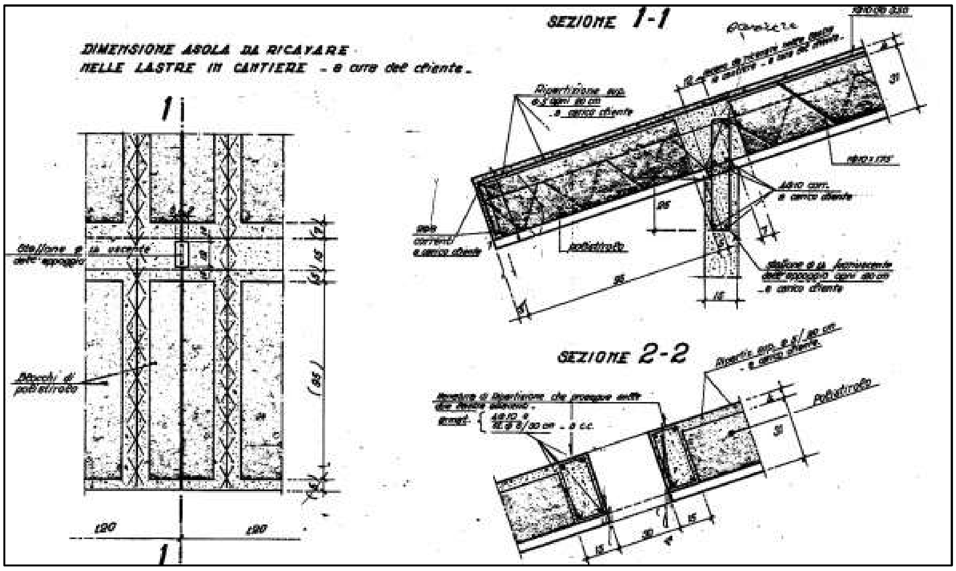


Figure 3.75: Typical sections of Celerpan covering slab. (D/7608_F165.2 T9)

As regards Qa19, the covering slab was realised with Celersap system (still realised by RDB company). It consists of pre-stressed concrete beams and hollow brick blocks with the function of structural lightening.

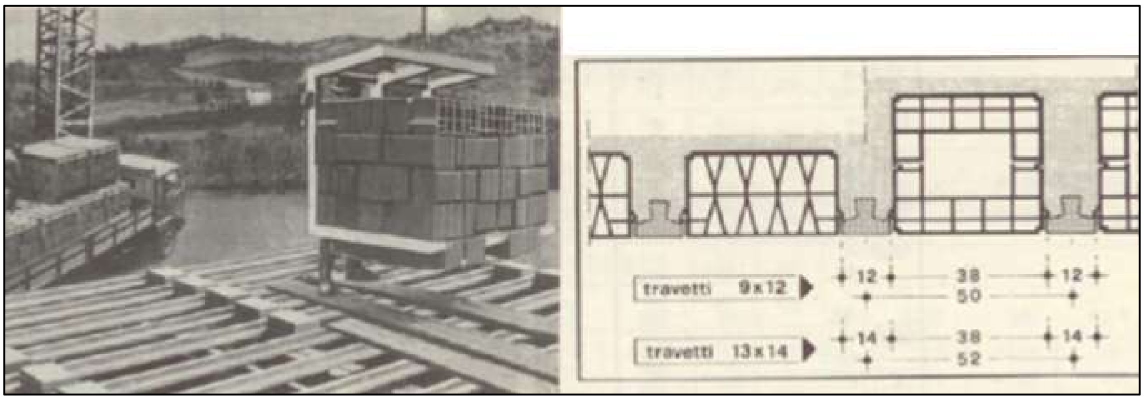


Figure 3.76: Celersap slab (RDB-Folder 165 2).

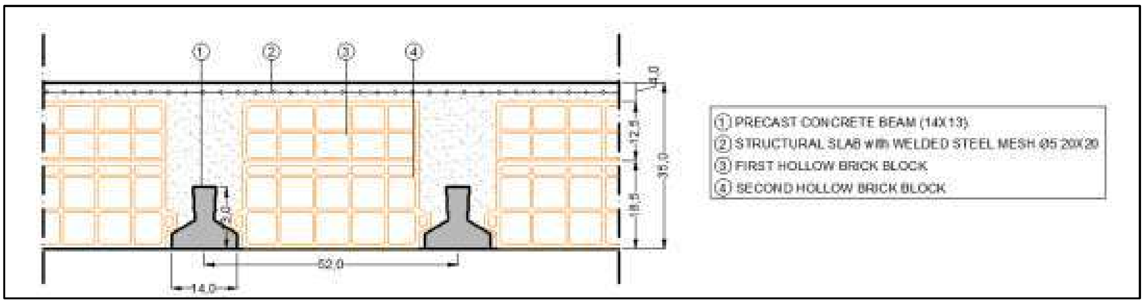


Figure 3.77: Celersap slab section.

<u>Stairs</u>

The stairwells are identical for all interventions: They are made with precast ramps and landings, placed from above. The supports for the precast element of the stairs are realised through “sella gerber” supports. In the walls supporting the stairs reinforced concrete shelves are provided with a particular shape able to perfectly link to the extremity of the precast element of the stair.

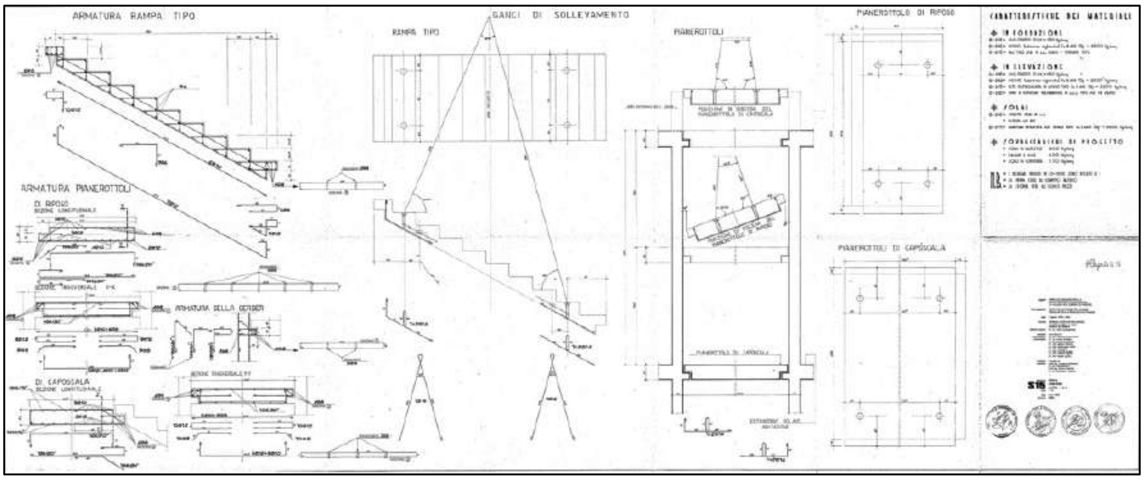


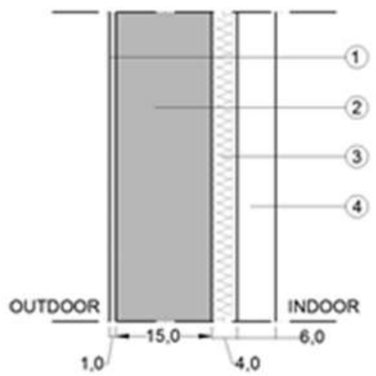
Figure 3.78: Precast reinforced concrete stairs: technological solution and erection diagram (S15_STRUCTURAL)

THE ENVELOPE

Walls

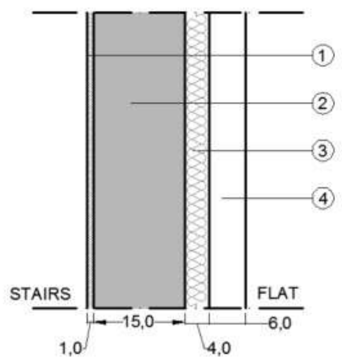
The proposed structural solution wanted to simultaneously meet several requirements: speed of implementation, structural rigidity and distribution flexibility. The construction times were optimized using precast formwork, consequently returning the outer faces which in the end had to be completed with a plastic quartz coating. It is specified that the insulation of the vertical outer walls was to be done from the inside by adopting a 4cm thick fiberglass insulation and an internal finishing layer of plasterboard. All the internal partitions are in gypsum with thickness 8cm.

EXTERNAL WALLS



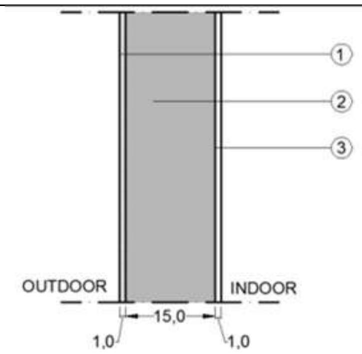
STRATIGRAPHY	Width (m)
1-External Plaster	0.01
2-Reinforced Concrete wall	0.15
3-Glass wool	0.04
4-Gypsum Panel	0.06

INTERNAL STAIRS WALLS



STRATIGRAPHY	Width (m)
1-Internal Plaster	0.01
2-Reinforced Concrete wall	0.15
3-Glass wool	0.04
4-Gypsum Panel	0.06

ATTIC WALLS/ EXTERNAL STAIRS WALLS



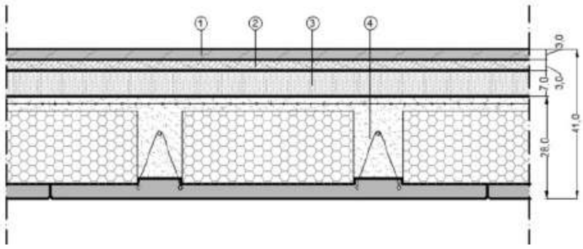
STRATIGRAPHY	Width (m)
1-External Plaster	0.01
2-Reinforced Concrete wall	0.15
3-Internal Plaster	0.01

Table 3.7: External and Internal walls stratigraphy.

Slabs

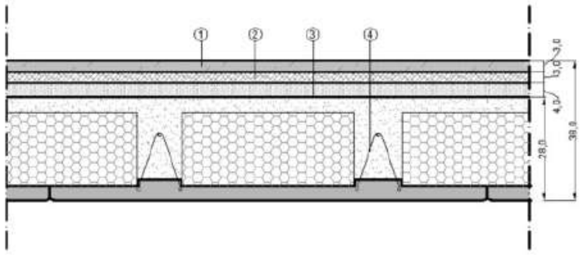
A cellular concrete insulation, 4 to 7cm thick, was planned for the attic floor and floor slab above porches and basements (cellars).

“PILLAR FLOOR” SLAB



STRATIGRAPHY	Width (m)
1-Marble	0.03
2-Mortar	0.03
3- Cellular concrete	0.07
4-Celerpan Slab	0.28

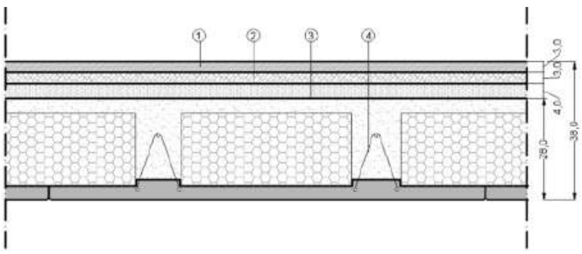
ATTIC FLOOR SLAB



STRATIGRAPHY	Width (m)
1-Marble	0.03
2-Mortar	0.03
3-Cellular concrete	0.04
4-Celerpan Slab	0.28

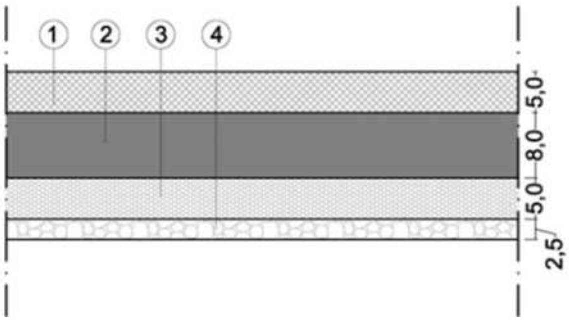
Table 3.8: Stratigraphy of the floors enclosing the heated volume.

TYPICAL FLOOR SLAB



STRATIGRAPHY	Width (m)
1- Marble	0.03
2-Mortar	0.03
3-Cellular concrete	0.04
4-Celerpan Slab	0.28

SLAB ON GRADE



STRATIGRAPHY	Width (m)
1-Concrete paving	0.05
2-Concrete slab	0.08
3-Fine gravel	0.05
4-Gravel	0.025

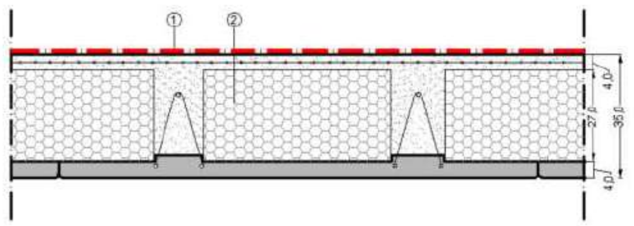
COVERING FLOOR		
	STRATIGRAPHY	Width (m)
	1- Bituminous membrane	0.004+0.004
	2-Celerpan Slab	0.28

Table 3.9: Typical floor plan, slab on grade and covering floor stratigraphy.

A 4cm layer of thermal and acoustic insulation, achieved with cellular concrete casting, was added on all inter-floor gaps, in order to reduce footfall noise and at the same time to ensure a lower consumption to individual users in case of non-simultaneous operation of the heating systems.

Windows and Doors

The main entrance doors to the building (more precisely into the stairwells) are in aluminium. The entrance doors to the apartments are in wood and the interior doors are made of hollow-core wood. The windows and door-windows of the apartments are in painted steel and have plastic rolling shutters. The windows sills and thresholds are in marble travertine overhanging approx. 4cm from the facade. Window shutters with double-glazing were inserted in order to reduce thermal leakage.

In the cellars, all doors or windows are made of iron. The staircases windows are in painted steel placed to cover all the span of the stairwell (2.30x1.20m), going to engage directly on the lateral partition walls of the flats.

Figure 3.79: Window Fixtures (lot Qd1).

Technical implants

On the whole, all technological solutions were used with the intent of reducing construction and management costs. For these reasons, simple building technologies and plant engineering were used, as well as fast implementation. The designers opted for an independent heating system with gas-fired boilers installed outside on the terraces.

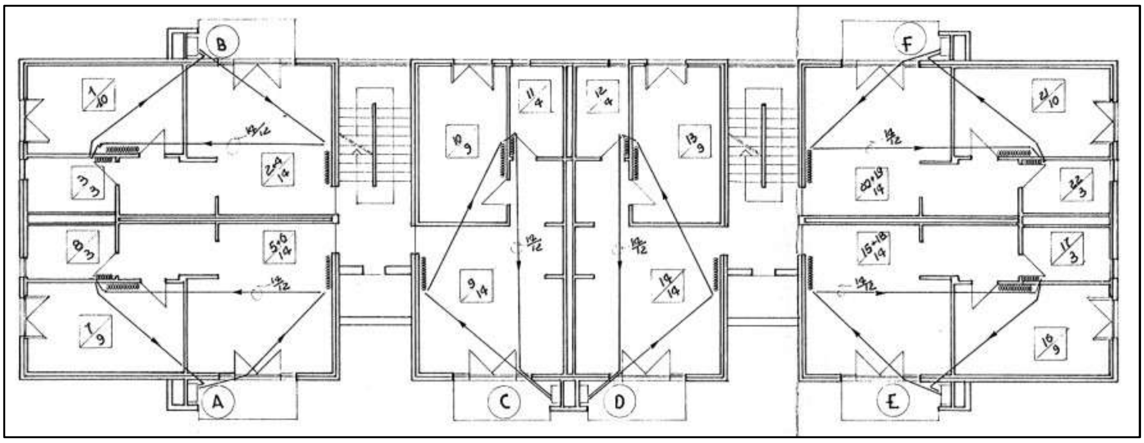


Figure 3.80: Lot Qa19-Scheme of the heating system with the distribution of radiators (F 168.3).

With the purpose of reducing implementation times and performance control, even the bathrooms were made with pre-assembled elements, consisting of a fitted wall placed between bathrooms or between bathroom and kitchen. These fitted walls were built with a metal precast substructure and equipped with pipes, electrical boxes, etc… Mechanical joints were realised above and below, in order to connect these walls to the structure, while the sealing between walls and floors was basically filled with silicone. These walls also served as atrium walls within which all system pipes were passed from the top floor to the basements, through holes made in factory on Celerpan floor slabs. Even placing the plants in correspondence to the vertical perimeter walls was extremely simple thanks to the presence of an internal plasterboard counter-wall.

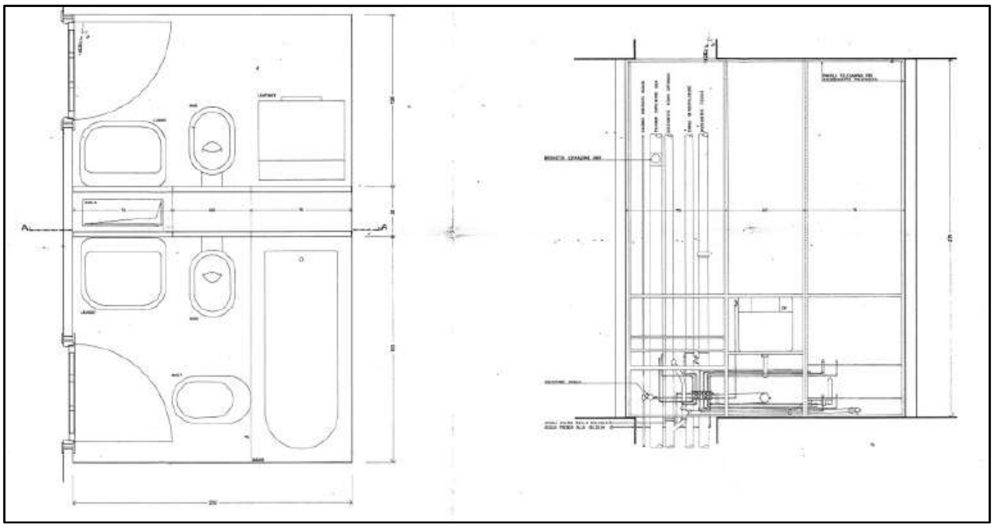


Figure 3.81: Pre-assembled bathrooms (F 163.1).

In building Qd1 this fitted wall is between the bathroom and the kitchen and in the central flats the bathroom-kitchen block is even mirrored.

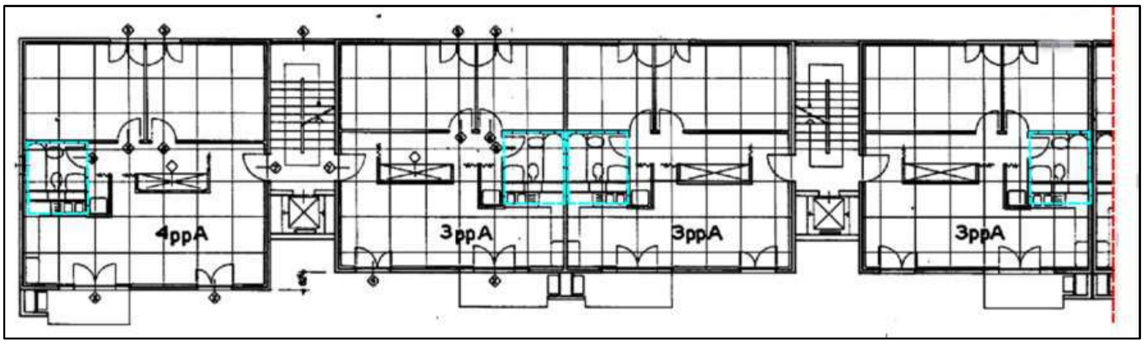
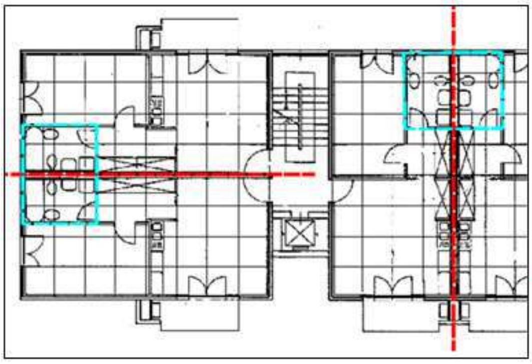


Figure 3.82: Toilets Layout Qd1.

In the building Qa19, the fitted wall and consequently the useful space for the pipes is in common between 2 different flats. Indeed, the bathroom blocks are mirrored with respect to the longitudinal axis as regards the lateral flats and to the transversal axis in the central flats.

In buildings Qb16/Qb40 the fitted wall is used related to the different flats. The smallest flats have the bathroom block mirrored with respect to the structural wall of the box, so that having the fitted space in common is impossible; each bathroom has their own fitted wall. In the largest apartments, the 2 bathroom-blocks are still mirrored with respect to the structural wall, but in this case, the fitted wall is between 2 bathrooms which belong to the same flat.



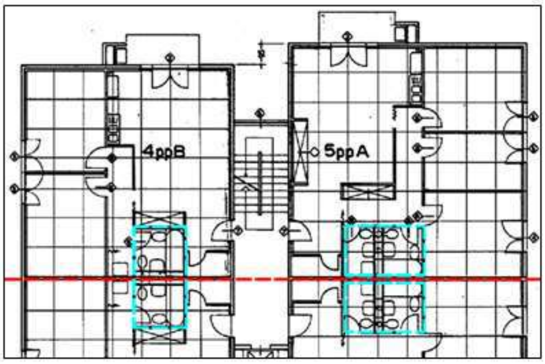


Figure 3.83: (On the left) Toilets Layout Qa19. (On the right) Toilets Layout Qb16/Qb40.

3.1.3 RECURRING FEATURES

The previous analysis led to understand the common characteristics of the buildings in exam. We can summarize the results following the BUILDING TYPE FACTORS (T.F) which may help to better identify and link the features of the buildings.

T.F	DESRIPTION	COMPLEX A		COMPLEX B		
		A	B	LOT Qd1	LOT Qa19	LOT Qb16
1	LOCATION	SUBURBS		SUBURBS	SUBURBS	SUBURBS
	ORIENTATION	ALONG E-W AXIS	ALONG E-W AXIS	ALONG E-W AXIS	ALONG E-W AXIS	NO MAIN AXIS
	SITE AREA	FRONT: PARKING BACK: GREEN AREA		FRONT: PARKING BACK: GREEN AREA	FRONT: PARKING BACK: GREEN AREA	FRONT: PARKING BACK: GREEN AREA
	$\frac{m^2 building}{m^2 site}$	23%		25%	15%	18%
	GROUND FLOOR	CELLARS-PORCHES	CELLARS-PORCHES	CELLARS-PORCHES	CELLARS-PORCHES	CELLARS-PORCHES
2	FAÇADE FINITURE	SIMPLY PLASTERED	SIMPLY PLASTERED	SIMPLY PLASTERED	SIMPLY PLASTERED	SIMPLY PLASTERED
	FAÇADE ASPECT	MODULAR	MODULAR	MODULAR	MODULAR	MODULAR
	PROJECTIONS ON THE FACADE	TERRACES	TERRACES	TERRACES	TERRACES	TERRACES
	RECESSIONS ON THE FACADE	STAIRS	STAIRS	STAIRS	STAIRS	STAIRS
3	BUILDING TYPE	LINEAR	LINEAR	LINEAR	LINEAR	TOWER
	DIMENSIONS	65x11m	52x11m	77x9m	36x10m	21x20m
	FLOORS	4	4	6	4	6
	FLATS/FLOOR	8	1-2-3°[10]: 6 4°[11]: 4	8	6	4
	HEIGHT UNDER EAVES	14.50m	14.50m (max)	21.37m (min)	15.70m (min)	21.37m (min)
	INTERFLOOR HEIGHT	2.70m	2.70m	2.70m	2.70m	2.70m
	GROUND FLOOR HEIGHT	2.90m	2.90m	2.90m	2.90m	2.90m
	N°-STAIRS	4	3	4	2	1

[10] 1°, 2° and 3° FLOOR.

[11] 4° FLOOR.

T.F		DESCRIPTION	COMPLEX A		COMPLEX B		
			A	B	LOT Qd1	LOT Qa19	LOT Qb16
4		MODULAR BLOCK[12]	4 2 FLATS/M[13]	1-2-3°: 3 2 FLATS/M 4°:2 2 FLATS/M	4 2 FLATS/M	2 3 FLATS/M	0[14]
		FLAT TYPE	A 70m^2 / B 60m^2	A 70m^2 / B 60m^2 / C 85m^2	A 75m^2 / B 65m^2	A[15] 45m^2	A 94m^2 / B 75m^2
		FLAT ARRANGMENT	Strictly dependent on the structure	Strictly dependent on the structure	No obstacles in the internal distributions	No obstacles in the internal distribution	No obstacles in the internal distribution
		SERVICE AREA	ALONG THE LONGITUDINAL AXIS IN THE MIDDLE OF THE FLATS		L-A[16] in the middle of the flats	In the middle of the S-B[17]	In the middle of the S-B[18]
		FUNCTION of ATTIC FLOOR	BUFFER ZONE	BUFFER ZONE	DRYING ROOM	DRYING ROOM	DRYING ROOM
5	STRUCTURE	SYSTEM	TUNNEL		Reinforced concrete walls in PREFABRICATED FORMWORKS		
		FOUNDATION	T REVERSED BEAMS		PILES		
		WALLS	REINFORCED CONCRETE WALLS		REINFORCED CONCRETE WALLS		
		SLABS	REINFORCED CONCRETE SLABS		CELERPAN SLAB		
		STAIRS	PRECAST STAIRS		PRECAST STAIRS		
	EXTERNAL ENVELOPE	EX.WALLS[19]	POLYSTIRENE on the internal surface		GLASS WOOL on the internal surface		
		“PILLAR” FLOOR[20]	ERACLIT panels on the slab intrados		CELLULAR CONCRETE on the slab extrados under the MARBLE PAVING		
		WINDOWS	PINE WOOD/double glazing		PAINTED STEEL/ double glazing		
		ROOF	SLATE TILES over the concrete slab		BITUMINOUS MEMBRANE over the slab		
	INTERNAL PARTITIONS	ATTIC FLOOR	CELLULAR CONCRETE on the slab extrados		CELLULAR CONCRETE on the slab extrados under the paving		
		TYPICAL FLOOR	NO INSULATION-GRES PAVING		CELLULAR CONCRETE on the slab extrados under the MARBLE PAVING		
		DOORS	PLASTIC LAMINATE		WOOD		

[12] The MODULAR BLOCK represents the typological organization of a linear building which is repeated for all the length of the building.

[13] M= MODULAR BLOCK.

[14] A tower building has a different organization of the plan. It consists usually of a central core (the stairwell) with the flats surrounding it.

[15] The building in Lot Qa19 presents identical flats, but the central apartments are organized in the transverse direction instead of in the longitudinal one.

[16] L-A= Longitudinal axis.

[17] S-B= Structural box. The service area is located either along the transversal axis or the longitudinal one, depending on the orientation of the flat.

[18] In this case the service areas are located in the perpendicular direction with respect to the entrance of the flat.

[19] Only the position of the insulation layer is defined in this table as main characteristic to be listed.

[20] Only the position of the insulation layer is defined in this table as main characteristic to be listed.

T.F	DESCRIPTION		COMPLEX A		COMPLEX B		
			A	B	LOT Qd1	LOT Qa19	LOT Qb16
5	IMPLANTS	THERMAL	AUTONOMOUS HEATING SYSTEM		AUTONOMOUS HEATING SYSTEM		
		BATHROOM	Double plasterboard walls with a space in the middle for the pipelines		FITTED WALLS with pre-assembled pipelines		
		KITCHEN	The kitchen is set against a false wall separating the services duct area		FITTED WALLS with pre-assembled pipelines		

Table 3.10: Summary of the main building features.

Looking at the table, the main common characteristics are:

TYPE FACTOR 1:
- Similar site area organization;
- Orientation: mainly along East-West axis;
- Cellars and porches at the basement.

TYPE FACTOR 2:
- Modularity;
- Plaster finishing.

TYPE FACTOR 3:
- Dimensions: 36÷77-9÷11m-almost the same; the tower building is the exception
- Plaster finishing.

TYPE FACTOR 4:
- Flat dimensions: mainly 65÷75m^2. The biggest flats are located in the tower building and the smallest ones in Qa19;
- Presence of an attic floor;
- Flat arrangement: despite the different structural systems imposes in one case the internal distribution and in the other case does not create any constraints, the flats are always organized according to the classical flat distribution: secondary band with services and distributional area between the day-zone and the night-zone.

TYPE FACTOR 5:
- STRUCTURE: different structural systems, but the results is a great panel structure with slabs and walls in reinforced concrete;
- EXTERNAL ENVELOPE: The insulation of the walls is on the internal surface. This creates several thermal bridges. Double glasses windows and the attic and “pillar” floor are insulated;
- IMPLANTS: The technical implants are identical: autonomous heating system and radiators as emission system.

From the previous analyses we can affirm that the 2 building complexes and, therefore the 5 buildings, are similar especially for what concerns the technical and technological aspects. The conservation state is good as regards the façade, the implants and the internal finishing; the most relevant issue is the mold inside the apartments due to the too cold internal surfaces of the external walls in particular points where a discontinuity in the insulation layer occurs (fig.3.84).

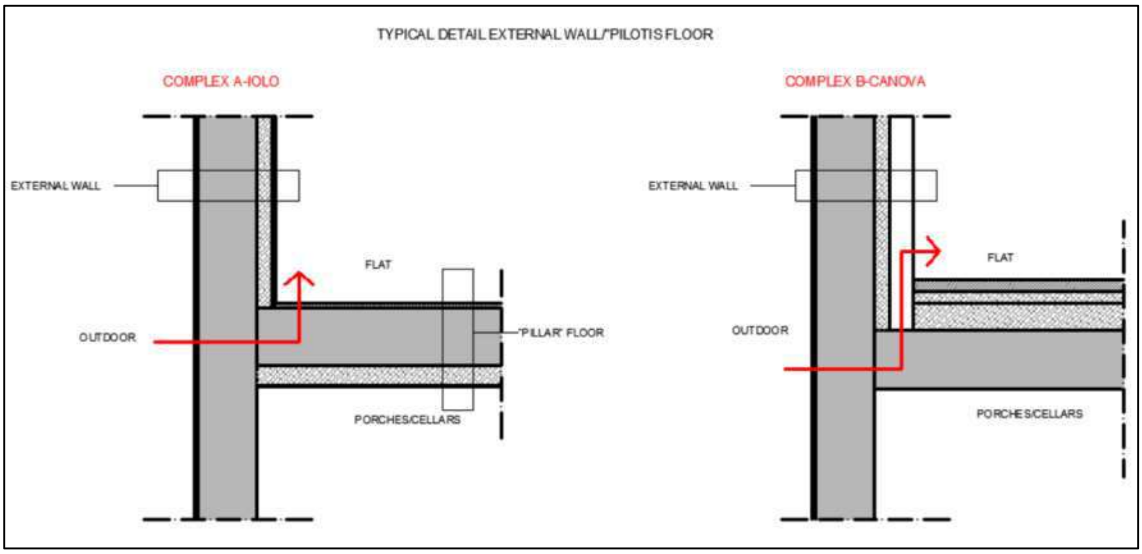


Figure 3.84: Typical thermal bridges in the 2 building complexes.

It is worth to underline that the renovation strategies to be applied on the case study buildings will have to impact as less as possible both from the costs point of view and for not causing discomfort to the tenants. Furthermore, the great panel structure does not allow to make great interventions on the façade, such as other great openings (if the problems was high indoor temperatures) or particular projections; in COMPLEX A buildings, the structural walls even mark the division between the rooms, so that an internal re-distribution of the flats is therefore difficult.

All these constraints narrow the possibilities of intervention on the environmental and technological system.

Moreover, the choice of the strategy is strictly depending on the next section results, where the buildings behaviour in terms of energy consumption is performed together with the evaluation of indoor comfort conditions.

3.2 ENERGY ANALYSIS (BASE CASE)

This chapter analyses the behaviour in terms of energy consumption of the buildings, in order to understand their weaknesses and to find possible recovery strategies compatible with the building type. This study is carried out both in semi-stationary and dynamic conditions.

The semi-stationary model is performed on a seasonal basis (with a monthly computational step). The final goal is to define the Global Energy Performance index (***EP_{gl}***), according to the National Legislative Standards D.lgs. 192/2005 (5) in order to establish the Energy Class of the building[21].

The analysis in dynamic conditions (performed on an annual basis with an hourly computational step), is necessary to know a more well-founded thermal-dynamic behaviour of the building, which is closely dependent on the variability of environmental conditions (6). The simulation software used for this purpose is TRNSYS-Trnbuild[22].

Before going in detail into the analysis of the current state (which we will call BASE CASE) of the buildings it is worth to describe the 2 different calculation conditions, in order to understand the methodology and the hypothesis. Moreover, a careful analysis of the comfort conditions inside the flats will be performed with the aim at finding the best solutions to improve both the energy performance and the health[23] of the users; a 3rd section in this introduction with the definition of thermal comfort conditions is therefore necessary.

1. Semi-stationary conditions

For the evaluation of the Energy Performance of the building we will refer to the Decree 192/2005, above mentioned, and to the Guide Lines D.M.26/06/(7) for the regulation checks along with the UNI/TS11300-1 (8) for the calculation methodology.

The first step of this analysis consists of the analysis of the climate zone[24]. To do this we will refer to the climate data provided by the National technical rule UNI 10349 (9).

The Standards (5) for the evaluation of the energy performance introduces the "Reference Building" as a comparative parameter in order to create a set classes scale with which to compare the energy class of the building. This "Reference Building" for the building subject to verification is: "[...]identical building in terms of geometry (shape, area, volume), orientation, location, with fixed thermal characteristics and energy parameters [...]"(5)[25].

The energy classes scale is defined by considering the Non Renewable Global Energy Performance index of the "Reference Building" (***$EP_{gl,nren,rif}$*(2019,2021)**[26]). This index marks the

[21] The Energy Performance classification scale consist of 10 classes: A4, A3, A2, A1, B, C, D, E, F, G (from the more efficient to the less one). These classes have been introduced by the new Guide Lines D.M.26/06/2015 Appendix 1 (7).

[22] The software was developed at the University of Wisconsin and distributed in Europe with IISiBat interface, developed by CSTB (Sophia Antipolis-France).

[23] When we deal with comfort we have inevitably to refer to I.A.Q (indoor air quality) within the flats and too high levels of humidity or high temperatures values. All these factors can lead to health issues to the inhabitants.

[24] In accordance with DPR 26/08/1993 n.412 (19), as it will be analysed in the buildings section, the climate zone where the buildings in exam are located is D, 1400<HDD (Heat Degree Days)≤2100. Indeed, Prato presents 1668 HDD and Firenze 1821 HDD.

[25] Article 2: Definitions, paragraph l-novies.

[26] The use of the benchmark 2019/2021 is important taking into account the objective of the Directive 2010/31/UE is to reach the "nearly zero energy buildings" by this date.

separation between class A1 and B, while the other ranges are identified by multiplication factors of this parameter (see fig. 3.85).

The Global Energy Performance index (***EP_{gl,nren}***[27]) is calculated as follows:

$EP_{gl,nren} = EP_H + EP_w + EP_V + EP_c + (EP_L + EP_T)$[28] (kWh/m²y), where (3.1)

EP_H= Primary Energy Index for the heating period. It takes into account the heating system efficiency. It is calculated as $EP_H = EP_{H,nd} / \eta_H$ (kWh/m^2y)

η_H= mean seasonal efficiency of the heating system

$EP_{H,nd}$= Useful Energy Index for the heating period. It is calculated net of systems as $EP_{H,nd} = Q_{H,nd} / S$ (kWh/m^2y)

S= useful area (m^2)

$Q_{H,nd}$= Ideal Energy demand for heating (kWh). The calculation is contained in (8)

EP_W= Primary Energy Index for service hot water. It takes into account the system efficiency. It is calculated as $EP_w = EP_{w,nd}/\eta_w$ (kWh/m^2y)

η_W= mean seasonal efficiency of the system

$EP_{W,nd}$= Useful Energy Index for the production of the domestic hot water. It is calculated net of systems as

$EP_{W,nd} = Q_{W,nd} / S$ (kWh/m^2y)

$Q_{w,nd}$= Ideal Energy demand for the production of the domestic hot water. The calculation is contained in UNI/TS 11300-2 (10) (kWh)

EP_V= Primary Energy Index for ventilation. It takes into account the ventilation system efficiency. It is calculated following (10) (kWh/m^2y)

EP_C= Primary Energy Index for cooling. It takes into account the cooling system efficiency. It is calculated as $EP_c = EP_{c,nd}/\eta_c$ (kWh/m^2y)

η_c= mean seasonal cooling system efficiency

$EP_{c,nd}$= Useful Energy Index for cooling. It is calculated net of systems as $EP_{C,nd} = Q_{C,nd} / S$. (kWh/m^2y)

$Q_{C,nd}$= Ideal Energy demand for cooling. The calculation is contained in (8) (kWh)

	Classe A4	≤ 0,40 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,40 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe A3	≤ 0,60 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,60 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe A2	≤ 0,80 $EP_{gl,nren,rif,standard\ (2019/21)}$
0,80 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe A1	≤ 1,00 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,00 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe B	≤ 1,20 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,20 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe C	≤ 1,50 $EP_{gl,nren,rif,standard\ (2019/21)}$
1,50 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe D	≤ 2,00 $EP_{gl,nren,rif,standard\ (2019/21)}$
2,00 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe E	≤ 2,60 $EP_{gl,nren,rif,standard\ (2019/21)}$
2,60 $EP_{gl,nren,rif,standard\ (2019/21)}$ <	Classe F	≤ 3,50 $EP_{gl,nren,rif,standard\ (2019/21)}$
	Classe G	> 3,50 $EP_{gl,nren,rif,standard\ (2019/21)}$

Figure 3.85: Classification scale on the basis of $EP_{gl,nren.}$ (7)-Appendix 1.

[27] For the building subject to the analysis.

[28] EP_L= Primary Energy Index for artificial lighting. It is not taken into account in Residential buildings, as well as EP_T= Primary Energy Index for transport for people and cargo (lifts, sidewalks etc.)

Accordingly, the study of the energy performance of a building is made through an energy balance related to the use of the heating, cooling and ventilation systems and for the service hot water. The BASE CASE of the building in exam does not include the ventilation and cooling systems, the primary energy demand related to these systems, therefore, will not be calculated for the evaluation of the Energy Class, even if the behaviour of the envelope in Summer will be examined.

According to (8) the methodology for the calculation of the monthly energy performance, after the previous definition of the climate conditions, it is necessary:

- to define the thermal zones of the building which will be all those included inside the air-conditioned volume, along with the definition of the outside ones and the internal conditions (strictly dependent on the intended use of the building).
- to evaluate for each month of the year $Q_{H,nd}$, $Q_{w,nd}$, $Q_{C,nd}$.
- to calculate the heating (and the cooling) season. The heating season depends on the climate zone and the duration is considered in accordance with the standards

Climate Zone	Start	End
A	1st December	15th March
B	1st December	31st March
C	15th November	31st March
D	1th November	15th April
E	15th October	15th April
F	5th October	22th April

Table 3.11: Heating season length related to the climate zone (8).

- **Ideal Energy Demand for Heating ($Q_{H,nd}$) and Cooling ($Q_{H,nd}$)**

According to (8) the Energy Demand for Heating and Cooling is computed as follows:

$$Q_{H,nd} = Q_{H,t} - \eta_{H,gn} * Q_{g,n} = (Q_{H,tr} + Q_{H,ve}) - \eta_{H,gn} * (Q_{int} + Q_{sol,w}) \quad (3.2)$$

$$Q_{C,nd} = Q_{gn} - \eta_{C,ls} * Q_{C,ht} = (Q_{int} + Q_{sol,w}) - \eta_{C,ls} * (Q_{C,tr} + Q_{C,ve}), \quad (3.3)$$

where

$Q_{H,ht}$= total thermal energy exchange during the heating season (kWh)

$Q_{C,ht}$= total thermal energy exchange during the cooling season (kWh)

$Q_{H,tr}$= total thermal energy exchange for transmission during the heating season (kWh)

$Q_{C,tr}$= total thermal energy exchange for transmission during the cooling season (kWh)

$Q_{H,ve}$= total thermal energy exchange for ventilation during the heating season (kWh)

$Q_{C,ve}$= total thermal energy exchange for ventilation during the cooling season (kWh)

Q_{gn}= total thermal gains (kWh)

$Q_{sol,w}$= solar gains (kWh)

Q_{int}= internal gains (kWh)

$\eta_{H,gn}$= thermal gains utilization factor

$\eta_{C,ls}$= thermal losses utilization factor

η_{c}= mean seasonal cooling system efficiency

For each thermal zone, the and for each month the thermal energy exchanges are:

Heating Season

$Q_{H,tr} = H_{tr,adj} * (\theta_{int,set,H} - \theta_e) * t + \{\Sigma F_{r,k} \emptyset_{r,mn,k}\} * t$ (3.4)

$Q_{H,ve} = H_{ve,adj} * (\theta_{int,set,H} - \theta_e) * t$ (3.5)

Cooling Season

$Q_{C,tr} = H_{tr,adj} * (\theta_{int,set,C} - \theta_e) * t + \{\Sigma F_{r,k} \emptyset_{r,mn,k}\} * t$ (3.6)

$Q_{C,ve} = H_{ve,adj} * (\theta_{int,set,C} - \theta_e) * t$, (3.7)

where

$H_{tr,adj}$ = global thermal exchange coefficient for transmission (W/K)

$H_{ve,adj}$ = global thermal exchange coefficient for ventilation (W/K)

$\theta_{int,set,H}$= set-point temperature (°C) for the heating system. It is set on 20°C

$\theta_{int,set,C}$= set-point temperature (°C) for the cooling system. It is set on 26°C

θ_e= mean outdoor temperature

$F_{r,k}$= shape factor between the building element and the sky

$\emptyset_{r,mn,k}$= extra heat flow due to the infrared radiation toward the sky (W)

t= duration of the month (s)

From the equation (3.4):

$H_{tr,adj} = H_D + H_g + H_U + H_A$, where (3.8)

H_D= thermal exchange coefficient for transmission through the envelope. It is calculated as the sum of the envelope surfaces areas multiplied by their U-values (transmittance values of the external walls, floors and windows towards outdoors) (W/K)

H_G= thermal exchange coefficient for transmission towards the ground (W/K)

H_U= thermal exchange coefficient for transmission through no-heating or no cooling areas (W/K)

H_A= thermal exchange coefficient for transmission through no-heating/cooling areas (W/K)

From the equation (3.5):

$H_{ve,adj} = \rho_a * c_a * \{\Sigma b_{ve,k} * q_{ve,k,mn}\}$, where (3.9)

$\rho_a * c_a$= volume thermal capacity= 1200 J/(m^{3}K)

$b_{ve,k}$= correction factor for the temperature in the case of natural ventilation. $b_{ve,k} \neq 1$, when the inlet air is pre-heated or pre-cooled. The buildings analysed in this work are naturally vented, so that $b_{ve,k}=1$

$q_{ve,k,mn}$= air flow rate (m^3/s) and it is calculated as:

$q_{ve,k,mn} = q_{ve,0,k} * f_{ve,t,k}$, where (3.10)

$q_{ve,0,k}$= minimum air flow rate and it is calculated as:

$q_{ve,0,k} = n * V/3600$ (3.11)

$f_{ve,t,k}$= corrective factor (0.6 for residential buildings)

V= volume of the thermal zone (m^3)

***n* (ACH)**= number of air exchange rates (h^{-1}). (0.5h^{-1} for residential buildings).

The value $0.5h^{-1}$ is expressed also in the European Standards UNI EN 15251 (11) which is referred to energy performance of buildings addressing indoor air quality (IAQ). These standards classify the building according to different quality categories and for each category a recommended ventilation rate is provided:

Category	Explanation	ACH (h^{-1})
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons.	0.7
II	Normal level of expectation and should be used for new buildings and renovations.	0.6
III	**An acceptable, moderate level of expectation and may be used for existing buildings.**	**0.5**
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year.	-

Table 3.12: Quality categories of a building with the ventilation rates for the residencies (11).

As it is shown in the table, ACH=0.5/h is a value that should be used in existing buildings in order to have an acceptable level of indoor air quality.

The value of 0.5 expressed in the National Standards, is an estimation of the number of air exchange rates and it is considered always steady during all the year in the evaluation of the energy performance of a building (see equation 3.11). This value is considered the most appropriate in order to dilute the contaminants and to avoid the mold growth (12).

The internal gains $\boldsymbol{Q_{int}}$ depend on the heat produced in the conditioned space from the internal sources (users' metabolism, lighting, electrical installations). For this value we will refer to the ISO 7730 (13) which divides the activities in 11 classes and for the activity class described as "seated and rest" the value is 100 Watts (1° class).

The solar gains $\boldsymbol{Q_{sol,w}}$ are calculated in relation to the available insulation ratio and it depends on the orientation of the structure elements.

- **Ideal Energy Demand for the production of domestic hot water** ($\boldsymbol{Q_{W,nd}}$)

It is calculated according to (10) and from the table below, the daily energy demand for the production of the domestic hot water $\boldsymbol{q_{acs}}$ is used to calculate the total energy demand:

$$\boldsymbol{Q_{W,nd}} = q_{acs} * S * days \text{ (W/y)} \quad (3.12)$$

Fabbisogni	Calcolo in base al valore di S_u per unità immobiliare [m²]			Valore medio riferito a S_u = 80 m²
	≤50	51- 200	>200	
a	1,8	$4{,}514 \times S_u^{-0{,}2356}$	1,3	1,6
Fabbisogno equivalente di energia termica utile [Wh/G m²]	52,3	$131{,}22 \times S_u^{-0{,}2356}$	37,7	46,7
Fabbisogno equivalente di energia termica utile [kWh/m² anno]	19,09	$47{,}9 \times S_u^{-0{,}2356}$	13,8	17,05

Figure 3.86: Energy demand for the production of domestic hot water (10).

The National Standards (7) list a series of verifications which have to be satisfied along with the definition of the Energy Class (see fig.3.85):

a. Mean global thermal exchange coefficient (**H'_T**)

$H'_T = H_{tr,adj}/\Sigma A_k$ (W/m^{2}K), where (3.13)
$H_{tr,adj}$= global thermal exchange coefficient (see eq. 3.8) (W/K)
A_k= each element (k) area (m^2)

The table below shows the thresholds for this value according to (S/V)= shape factor[29]

Numero Riga	RAPPORTO DI FORMA (S/V)	Zona climatica				
		A e B	C	D	E	F
1	S/V ≥ 0,7	0,58	0,55	0,53	0,50	0,48
2	0,7 > S/V ≥ 0,4	0,63	0,60	0,58	0,55	0,53
3	0,4 > S/V	0,80	0,80	0,80	0,75	0,70

Figure 3.87: Maximum value of H'$_T$, table 10 (7).

b. Evaluation of the envelope energy performance in Winter through the calculation of ***$EP_{H,nd}$*** (see eq. 3.1). The Standards give the following quality indicators: high, medium and low quality.

Prestazione invernale dell'involucro	Qualità	Indicatore
$EP_{H,nd} \leq 1^* EP_{H,nd,limite\,(2019/21)}$	alta	
$1^* EP_{H,nd,limite\,(2019/21)} < EP_{H,nd} \leq 1{,}7^* EP_{H,nd,limite\,(2019/21)}$	media	
$EP_{H,nd} > 1{,}7^* EP_{H,nd,limite\,(2019/21)}$	bassa	

Figure 3.88: Indicators of the Winter envelope energy performance, table 3 Annex 1 (7).

c. Evaluation of the envelope energy performance in Summer through the evaluation of equivalent Summer area (***$A_{sol,est}$***)[30] and the Periodic Thermal Transmittance (***Y_{IE}***)[31]. The thresholds are shown in the table below:

Prestazione estiva dell'involucro		Qualità	Indicatore
$A_{sol,est}/A_{sup\,utile} \leq 0{,}03$	$Y_{IE} \leq 0{,}14$	alta	
$A_{sol,est}/A_{sup\,utile} \leq 0{,}03$	$Y_{IE} > 0{,}14$	media	
$A_{sol,est}/A_{sup\,utile} > 0{,}03$	$Y_{IE} \leq 0{,}14$		
$A_{sol,est}/A_{sup\,utile} > 0{,}03$	$Y_{IE} > 0{,}14$	bassa	

Figure 3.89: Indicators of the Summer envelope energy performance, table 4 Annex 1 (7).

[29] The shape factor is the ratio of the dispersant surfaces to the heating volume (5).
[30] $A_{sol,est}$= equivalent Summer area of the buildings that is the sum of the equivalent surfaces of each window component section 2.2 (7).
[31] It represents the product between the attenuation factor and the stationary thermal transmittance of the building component. It then describes both the damping degree and the thermal wave phase shift coming from the outside.

2. **Dynamic conditions**

TRNSYS is a dynamic thermal simulation tool which allows to evaluate the energy behaviour of a building, mono and multi-zone, and its technological system. It presents a modular structure and a versatility in the use. The system is in fact defined by the user through a "network" consisting of modules called "TYPE", chosen by type and number, from time to time, in relation to its objectives. Each type (component) is described by a mathematical model, which will then be solved on the basis of data made available, through a connection network, from other "TYPE". TRNSYS performs a zone type calculation on the basis of a concentrated nodes model and has an accuracy internationally recognized. A project in TRNSYS is built graphically by connecting the various components within the Simulation Studio, the main graphical interface of the software, and by setting the global parameters of the simulation. TYPE 56 represents the building model that is a non-geometrical balance model with one air node per zone. This represents the thermal capacity of the zone air volume and capacities which are connected with the air node. Our buildings have then been modelled as a set of thermal zones[32] with different internal conditions:

Thermal zones	Heating system	Internal Gains (W/person)	Lighting Gains (W/m^2)	Set-point Temperature (°C)	ACH (h^{-1})
Stairwells	NO	/	0.5	15	0.2
Flats	YES	100	5	20	0.5
Cellars/Attic	NO	/	0.5	10	0.2

Table 3.13: Input data according to the different thermal zones, equal for all the buildings in exam.

For what concerns the climate input data we have taken into account the TMY3 (Typical Meteorological Year) Data Sets for Florence found in the Energy Plus Database. We are referring to hourly time series because we are evaluating the buildings in dynamic conditions.

3. **Thermal Comfort**

Thermal comfort is defined in different ways, all of them attributable to the physical sensation of physical and mental well-being which a person feels in a certain environment (14). This feeling depends on 2 variables:

1. subjective variables, depending on the physical and emotional characteristics of the human being;
2. objective variables, related to the microclimate of the environment.

For evaluating the first variables, statistical methods are considered, while the second ones can be simulated through physical models and experimentally measured.

The comfort feeling depends on the body's ability to keep the thermal equilibrium. The internal energy production and the heat losses make the body temperature around 37°C.

The evaluation of the thermal comfort within a building is necessary because the human being spends the 85% of the time in closed areas (both for working and at home). An optimal relationship between the achievement of the well-being and the minimization of the energy consumption in a building can be obtained through:

[32] According to the paragraph 3.1 all the analysed buildings present similar characteristics and the functions are the same, so that they present the identical thermal zones types.

- conditioning systems controls depending on the climate conditions inside the building, rather than the outdoor ones;
- controls on the superficial surfaces of the building walls (for example through the insulation in Winter or the thermal inertia[33] in Summer), which lead to minor use of the air-conditioning system and, consequently, to an energy saving.

The human body can be seen as a thermodynamic system. In order to keep the thermal conditions, the body has to make a balance between the heat generated and the heat released by itself. The balance equation is:

$M - E_{dif} - E_{ev} - E_{resp} = E_r + E_c$, where (3.14)

M= heat generated from the body due to the metabolism

E_{dif}= heat released due to the skin sweating

E_{ev}= heat released due to the evaporation

E_{resp}= heat released due to the breathing

E_r= heat released or absorbed for radiation from the clothed body external surface

E_c= heat released or absorbed for convection from the body external surface

One method for the evaluation of the thermal equilibrium conditions and well-being was developed by Fanger (1972) (15) and adapted in ISO Standard 7730 (13). It is based on the determination of the PMV index (Predicted Mean Vote) calculated from an equation of thermal balance for the human body, by using a combination of the 6 main parameters (temperature, humidity, mean radiant temperature, air velocity, activity, clothing). The equation is:

$F(M, L, I_{cl}, \theta_a, v_a, RH, \theta_{mr}, \theta_s, E_{SW})=0$, where (3.15)

M= metabolic rate (met)[34]

L= heat released due to the breathing

I_{cl} = clothing insulation (clo)[35]

θ_a[36]= air temperature (°C)

θ_{mr}[37]= mean radiant temperature (°C)

θ_s = mean skin temperature (°C)

RH[38]= relative humidity (%)

E_{sw}= heat released due to the skin sweating (W/m^2)

v_a[39]= air velocity (m/s)

[33] The thermal inertia is defined as the ability of a material or a structure to vary more or less slowly its temperature in relation to external temperature changes or to a heat source/internal cooling.

[34] 1 met= 58.1W/m^2

[35] 1 clo= 0.155m^{2}K/W

[36] For a person spending the majority of the time sitting, we consider the mean temperature between the pavement and 1.1m of height.

[37] It is the mean temperature of the surfaces surrounding the environment.

[38] The effect of the Relative Humidity on the thermal comfort depends on the conditions: when the indoor temperature is moderate (15-20°C) and the person is doing a sedentary activity (stationary conditions), the Rh has no effects on the comfort sensation; while if the person is moving in another room at the same temperature of the first room but with different values of RH (dynamic conditions) the effect is 2-3 times above the effect in stationary conditions (14).

Fanger assumes that the thermal sensation, for a certain activity, is a function of the heat load of the body defined as the difference between the heat produced by the body and the heat losses toward the environment. He established a physical/psychical scale, expressed through a vote of comfort on a scale from -3 (very cold) to +3 (very hot) (16):

INDEX PMV	SENSATION
+3	HOT
+2	WARM
+1	SLIGHTLY WARM
0	NEUTRAL
-1	SLIGHTLY COOL
-2	COOL
-3	COLD

The Standards ISO 7730 recommends to stay within the range -2÷+2 for the PMV index with these ranges of the main parameters (14):

VARIABLES	VALUES
M	0.8-4met
I_{cl}	0-2clo
θ_a	10-30°C
P_a[40]	0-2700Pa
θ_s	10-40°C
v_a	0-1m/s

The PMV index represents the mean vote of a group of people subject to a combination of different variables; it does not provide for the effect on a single human being.

Fanger proposed another index PPD (Predicted Percentage of Dissatisfied), that is a statistic index calculated as:

PPD= $100-95\exp[-(0.03353 \cdot PMV^4+0.2179 \cdot PMV^2)$ (3.16)

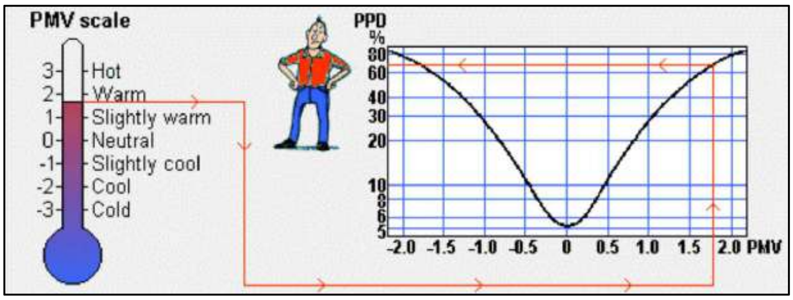


Figure 3.90: Index PPD and PMV variation (16).

[39] In Winter this value has to be low, while in Summer higher levels of air velocity can contribute to convective exchanges.

[40] P_a= Atmospheric Pressure

Thermal zones are defined in 3 thermal zones by 3 different ranges which correspond to 3 different values of PPD:

A		B		C	
PMV	PPD	PMV	PPD	PMV	PPD
-0.2÷+0.2	<6%	-0.5÷+0.5	<10%	-0.7÷+0.7	<15%

Table 3.14: Thermal comfort zones.

For the evaluation of the thermal comfort levels in this work we will refer to this model, taking into account the following values for the main parameters:

M	I_{cl}	v_a
1.2met	0.5clo[41]	0.25m/s

Table 3.15: Main parameters used in the evaluation of the comfort level inside the buildings in exam.

These values derive from the quality categories defined by UNI EN 15251 (see tab.3.13) and in relation to them, the Standards sets a series of values related to the different activities. The activity in a residential building is defined as “Sedentary” in the Standards. For what concerns the air velocity (v_a), we consider the maximum value for thermal comfort in Summer, given by the Standards ASHRAE 55-81 (17).

[41] Maximum value for cooling in Summer season. Tab A.2 p.26 (11).

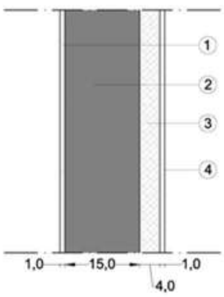
3.2.1 COMPLEX A: Prato-Iolo

First of all, it is necessary to define the Climate Zone of interest:

PRATO-IOLO	
Elevation	61m
HDD	1668
Climate Zone	D
Latitude	43°53'
Longitude	11°5'
Outdoor temperature (project)	0°C
Indoor temperature (project)	20°C
Heating period	150 days/year

Table 3.16: Prato-Climate Data. Values found in (9).

The buildings present 3 different thermal zones: the stairwells, the flats and the cellars/attic. As we already mentioned, the 2 buildings present the same technological characteristics, so that the energy performance of the building elements surrounding the heated volume will be in common:

EXTERNAL WALLS			
	STRATIGRAPHY	Width **s** (m)	Conductivity **l** (W/mK)
	1-External Plaster	0.01	0.75
	2-Reinforced Concrete wall	0.15	1.3
	3-Polystyrene	0.04	0.036
	4-Gypsum Internal Cladding	0.01	0.45
	Total Transmittance *U*[42] (W/m²K)	**0.698**	
STAIRS WALLS			
	STRATIGRAPHY	Width **s** (m)	Conductivity **l** (W/mK)

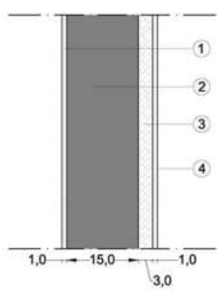
[42] According to the UNI EN ISO 6946 (20) the transmittance (U) of a building element is calculated with this equation: $U = \dfrac{1}{\dfrac{1}{h_{si}} + \sum_i \dfrac{s_i}{\lambda_i} + \sum_k R_k + \dfrac{1}{h_{se}}}$, where

h_{si}= internal advection coefficient (W/m²K)
h_{se}= external advection coefficient (W/m²K)

In this case:
h_{si}= 8W/m²
h_{se}= 23W/m²

Building element typology		Border zone: OUTSIDE	Border zone: NO-HEATED ZONE
WALLS	outdoor / indoor	h_{si}= 8 W/m²K h_{se}= 23 W/m²K	h_{si}= 8 W/m²K h_{se}= 8 W/m²K
SLAB ascending flow	outdoor / indoor	h_{si}= 9.3 W/m²K h_{se}= 23 W/m²K	h_{si}= 9.3 W/m²K h_{se}= 9.3 W/m²K
SLAB descending flow	outdoor / indoor	h_{si}= 5.8 W/m²K h_{se}= 16 W/m²K	h_{si}= 5.8 W/m²K h_{se}= 5.8 W/m²K

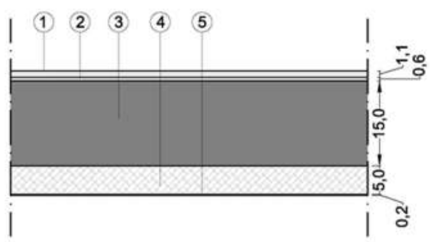
s_i= layer (i) thickness (m)
l_i= thermal conductivity of the layer material (i) (W/m²K)
R_k= 1/C thermal resistance of the non-homogenous element (k) (m²K /W), where C is the conductance of the element (W/m²K).



	1-Internal Cladding (toward the stairs)	0.01	0.45
	2-Reinforced Concrete wall	0.15	1.3
	3-Polystyrene	0.04	0.036
	4-Gypsum Internal Cladding (toward the flats)	0.01	0.45
	Total Transmittance *U*[43] (W/m²K)	**0.798**	

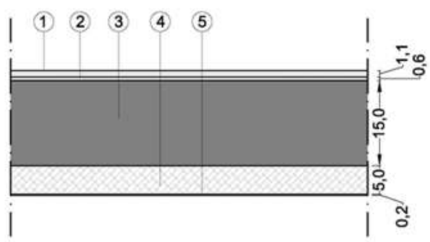
Table 3.17: COMPLEX A. U-values of the walls. Transmittance Values and thermal resistance calculation are taken from the "Thermal Insulation and Thermal Plant Report" (Folder 108).

"PILLAR FLOOR" SLAB



STRATIGRAPHY	Width *s* (m)	Conductivity *l* (W/mK)
1-Ceramic	0.01	1
3-Reinforced Concrete slab	0.15	1.3
4-Eraclit Panel	0.05	0.055
5-Smoothing with plaster	0.002	0.75
Total Transmittance *U*[44] (W/m²K)	**0.799**	

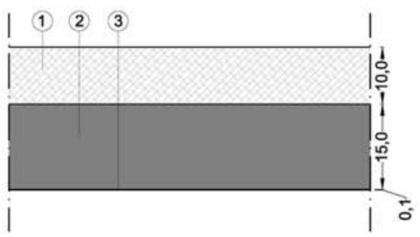
CELLARS FLOOR SLAB



STRATIGRAPHY	Width *s* (m)	Conductivity *l* (W/mK)
1-Ceramic	0.01	1
3-Reinforced Concrete slab	0.15	1.3
4-Eraclit Panel	0.05	0.055
5-Smoothing with plaster	0.002	0.75
Total Transmittance *U*[45] (W/m²K)	**0.724**	

ATTIC FLOOR SLAB

\\



STRATIGRAPHY	Width *s* (m)	Conductivity *l* (W/mK)
1-Leca Concrete	0.10	0.125
2-Reinforced Concrete slab	0.15	1.3
5-Smoothing with plaster	0.001	0.75
Total Transmittance *U*[46] (W/m²K)	**0.895**	

Table 3.18: COMPLEX A. U-values of the slabs. Transmittance Values and thermal resistance calculation are taken from the "Thermal Insulation and Thermal Plant Report" (Folder 108).

The transmittance for the windows is $\boldsymbol{U_w}$**= 2.9 W/m²K**. The presence of the roll blinds is taken into account in the evaluations of the Energy Performance of the buildings under dynamic conditions

[43] In this case, since the stairwells are no-heated zones, h_{si}= 8W/m² - h_{se}= 8W/m².
[44] In this case the slab is toward outside, h_{si}= 5.8W/m² - h_{se}= 16W/m².
[45] In this case, since the cellars are no-heated zones, h_{si}= 5.8W/m² - h_{se}= 5.8W/m².
[46] In this case, since the attic floor are no-heated zones, h_{si}= 9.8W/m² - h_{se}= 9.8W/m².

in Summer, by considering a control on the closure of the blinds when the Solar Irradiance is above 300W/m^2 in Summer months[47]. These values occur during the central hours of the days.

BUILDING A

1. Semi-stationary conditions

In the table below a summary of necessary data to evaluate the Energy Demand for heating and the final Global Energy Performance *($EP_{gl,nren}$)* are listed:

IOLO BUILDING A	
TOTAL DISPERSANT SURFACES ***(S)***	3660m^2
HEATED VOLUME ***(V)***	7319m^3
USEFUL AREA ***(A)***	2152m^2
SHAPE FACTOR ***(S/V)***	0.50m^{-1}
WINDOWS AREA/*S*	0.09

The figure below shows the thermal zones in BUILDING A: 8 flats/floor. Accordingly, we will have 32 thermal zones, considering that the construction consists of 4 floors.

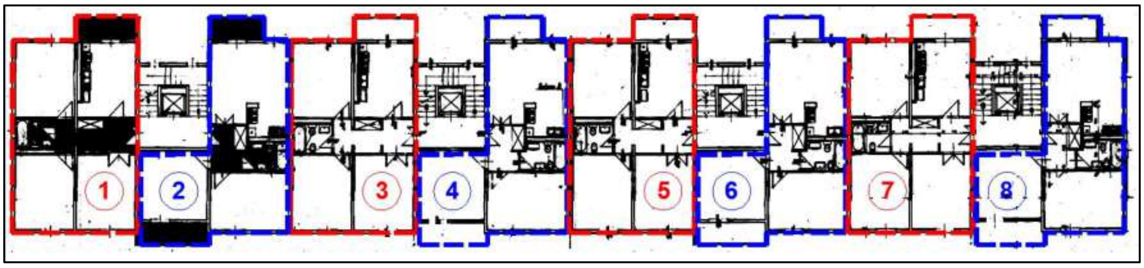


Figure 3.91: Thermal zones in BUILDING A typical plan.

The Global Energy Performance index ($\boldsymbol{EP_{gl,nren}}$)[48] is:

$EP_{gl,nren}$= 111.36 kWh/m^{2}y

$EP_{gl,nren,rif}$(2019,2021)= 46.85 kWh/m^{2}y

According to the fig.3.85 the building Energy Class is **E**, in fact:

2.00* $EP_{gl,nren,rif}$(2019,2021) < $\boldsymbol{EP_{gl,nren}}$ ≤ 2.60* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K (see fig.3.87)

[4747] In accordance to UNI/TS 11300-1, p.40 (8).

[48] We consider an ideal centralized system instead of thermal boilers for each flat in order to have a global behaviour of the whole building. What we are interested in is the thermal behaviour of the envelope. Obviously a more efficient technological system would lower the energy class, but in this work we want to maintain the same heating system. First of all, it is necessary to improve the envelope performance and then we can intervene on the implants.

$H'_T = 0.88$ W/m²K

$H'_T > H'_{Tlim}$ **UNVERIFIED**

b. Envelope Energy Performance in Winter through the calculation of $\boldsymbol{EP_{H,nd}}$

$EP_{H,nd} =$ 55.35 kWh/m²y

$EP_{H,nd,lim}$(2019,2021)= 11.14 kWh/m²y

The result is:

$EP_{H,nd} > 1.7 * EP_{H,nd,lim}$(2019,2021) → **LOW QUALITY OF THE ENVELOPE**

c. Envelope Energy Performance in Summer through the evaluation of ($\boldsymbol{A_{sol,est}}$) and ($\boldsymbol{Y_{IE}}$)

$A_{sol,est}/S= 0.061$

Y_{IE}=0.29W/m²K

The thresholds are:

$(A_{sol,est}/S)_{lim}= 0.03$

$(Y_{IE})_{lim}$= 0.14W/m²K

The result is:

$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ and $Y_{IE} > (Y_{IE})_{lim}$ → **LOW QUALITY OF THE ENVELOPE**

2. Dynamic conditions

Because of instability issues due to the software, it was useful to split the flats 2-4-6-8 in 2 different thermal zones (see fig. below). At the end, we will have 12 thermal zones for each floor, but the evaluations will be done by considering the flat anyway. To do that we will make an average of each parameter of interest (temperature, relative humidity etc.) of these 2 divided zones in order to obtain the mean value for the flat.

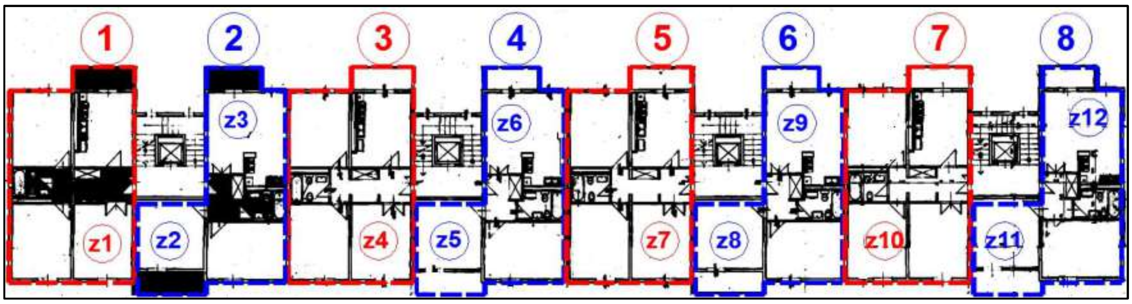


Figure 3.92: Thermal zones used in the Trnsys model for BUILDING A.

From the results of the dynamic simulations we obtained the sensible energy demand for heating, called in the model *Q_heat* which corresponds to $Q_{H,nd}$ in the semi-stationary conditions (see eq.3.1), *Q_heat/S* corresponds to $EP_{H,nd}$.

The fig. 3.85 shows the hourly trend during the year of the sensible power for heating. In Summer the heating system is turned off, and the power is therefore equal to zero. The most relevant power peaks occur in January and in December. These are values averaged across all the flats in order to have an overall behaviour of the building, according to the aim of the thesis that is to find a common methodology to all this type of buildings, so that, at least in this case, it is sufficient to consider the all building, instead of analyzing each flat.

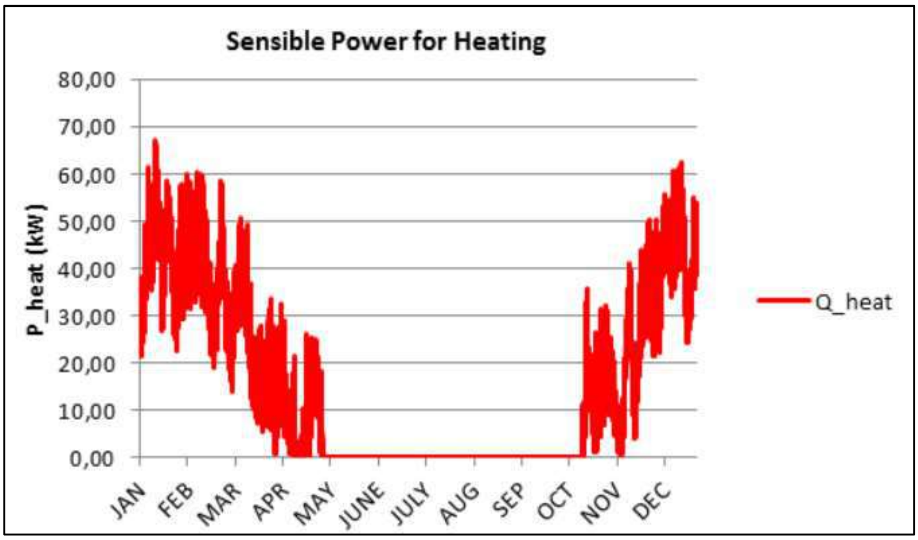


Figure 3.93: BUILDING A. Sensible Power for heating hourly trend.

By the way, if we analyse the behaviour of the floors, from the figure below, we can note that the most "energy-hungry" flats are located at the fourth and first floor, in accordance with the expectations, because of their borders with the outdoors and with no-heated zones (cellars, attic, stairwells).

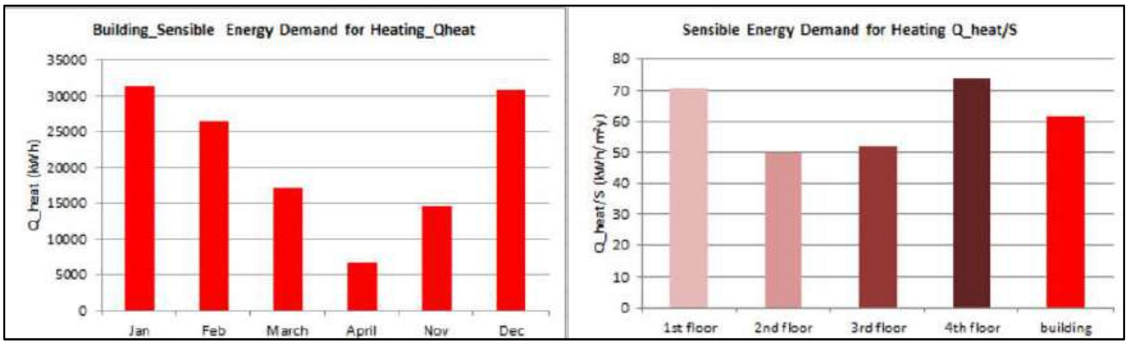


Figure 3.94: BUILDING A. Sensible Energy Demand for Heating. (On the left) the average values of *Q_heat* per month averaged across all the flats. (On the right) The average values of *Q_heat/S* per floor.

- From the analysis in semi-stationary conditions we found:

$EP_{H,nd}$ = 55.35 kWh/m^{2}y

- From the analysis in dynamic conditions we found:

Q_heat/S= 61.40 kWh/m^{2}y

The 2 values differ of about 10%, in line with the results obtained from the University of Perugia for the comparison between the results obtained from different software both in semi-stationary conditions and in dynamic ones (18).

WHOLE BUILDING

The dynamic simulations allow to evaluate the indoor temperatures (T_ind), the Relative Humidity (RH), the Humidity Ratio (Absolute Humidity-HR) hour by hour, in order to know the internal comfort conditions which, along with the knowledge of the energy performance of the building, may help to find the most suitable strategies.

Having said that the first step is to evaluate the mean indoor temperatures of the whole building, with the aim to know the worst indoor conditions and in this case, it is useful to take into account some flats as sample cases.

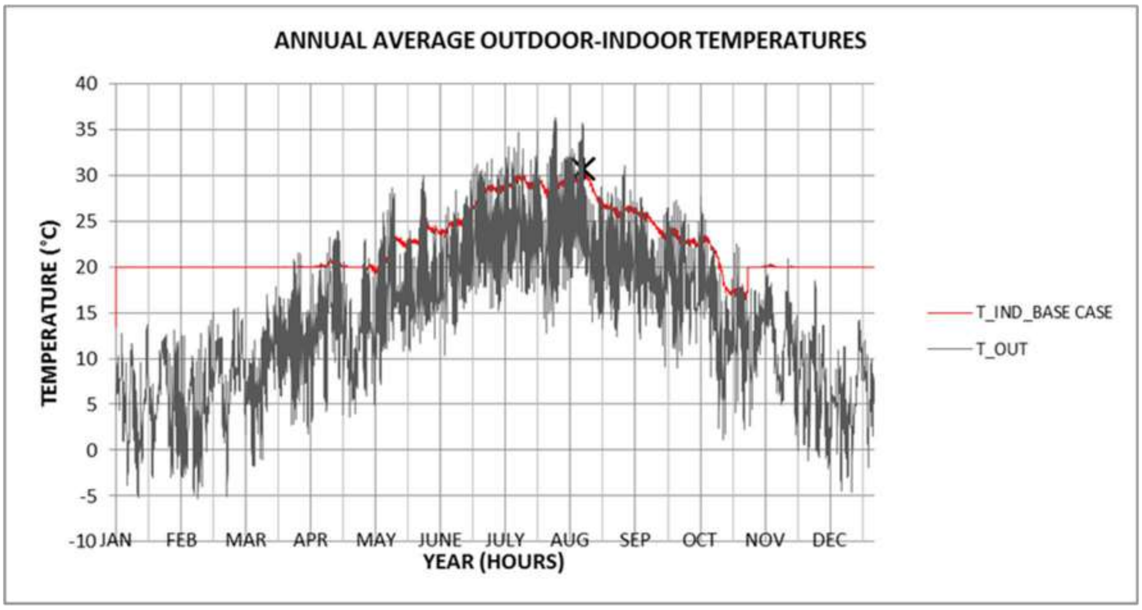


Figure 3.95: BUILDING A. Hourly trend of mean temperatures during all the year and the outdoor temperature hourly trend (T_out). These are values averaged across all the flats.

Obviously, the temperatures in Winter are always steady, around 20°C, that is the set-point temperature for the heating system. We will also include October in the Summer period, because it is out of the heating period, even if this month along with September and May should be considered as "shoulder months", while the others "central months". The hourly trend of temperatures in Summer is shown in the fig. below and the table 3.19 is organized following this difference, especially by evaluating also the minimum values in the "shoulder months".

SUMMER	**CENTRAL MONTHS**	**JUNE**	**JULY**	**AUGUST**
		BASE CASE	**BASE CASE**	**BASE CASE**
	MEAN T (°C)	25.61	28.92	28.29
	MAX T (°C)	31.47	32.36	32.63
	SHOULDER MONTHS	**MAY**	**SEPTEMBER**	**OCTOBER**
		BASE CASE	**BASE CASE**	**BASE CASE**
	MEAN T (°C)	21.98	24.84	20.31
	MAX T (°C)	26.92	28.87	24.59
	MIN T (°C)	18.26	21.26	15.24

Table 3.19: BUILDING A. Characteristic mean temperature values averaged across all the flats.

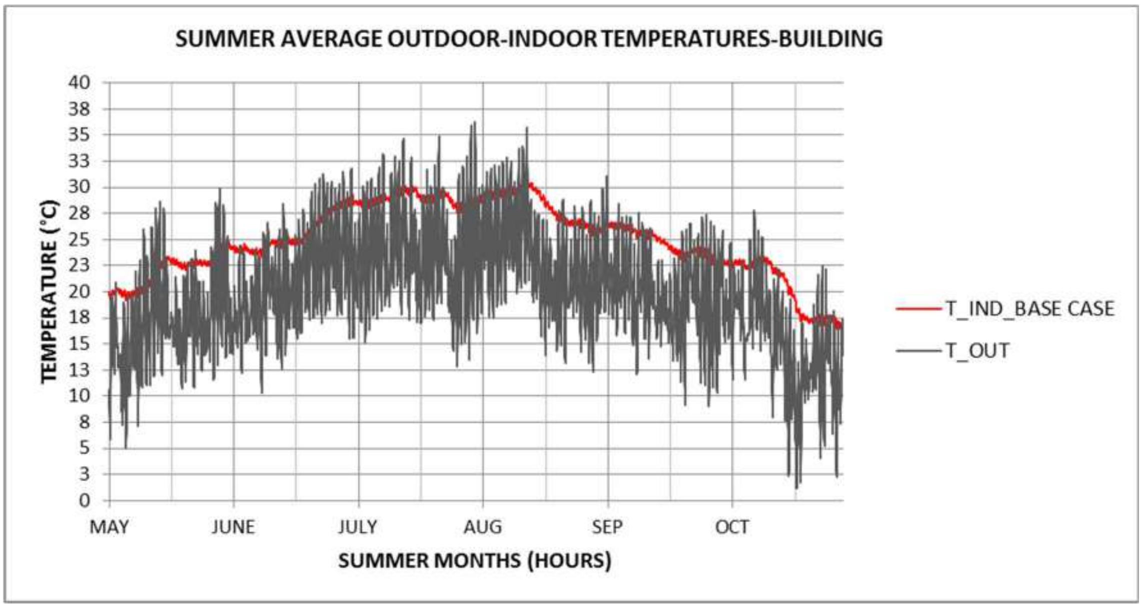


Figure 3.96: BUILDING A. Hourly trend of mean temperatures in Summer (average values of the whole building). Comparison between BASE CASE and outdoor temperatures.

All the floors present an average temperature value above 28°C. The maximum value of temperatures occurs in August and at the 4° floor in the flat 6 (zone 8), while the minimum value is in October still at the fourth floor, but in flat 1. This trend is shown in figure 3.97, where the warmest floor is the 4° (violet line).

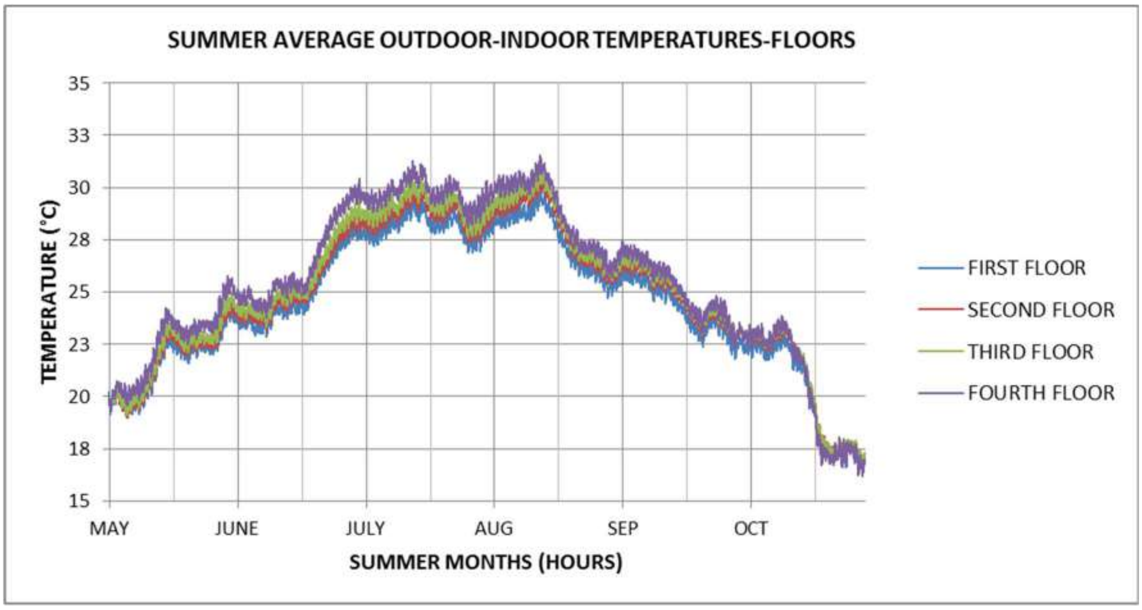


Figure 3.97: BUILDING A. Hourly trend of mean temperatures during Summer months per each floor.

In order to evaluate more in detail the temperatures in Summer another parameter was analysed that is the number of hours during each Summer month exceeding 26°C and 28°C that will be summarized as #hoursT[49]>26-28°C. The first value is the threshold for the comfort range, and the second one was chosen especially looking at the mean temperatures in July and August (above 28°C), with the aim to evaluate how many hours in the month overcome this value and in which period of

[49] It means number of hours with Temperatures above 26-28°C.

that month. From the fig.3.99 we can note that July and August present almost all the month temperatures above the comfort limit value (26°C) and in August more than half month has hours with temperatures above 28°C. As regard RH[50] values, if we look at the fig.3.98 the most humid months are May, June, September and October, but in this case, the 2° floor is the most humid compared to the others (see table 3.20).

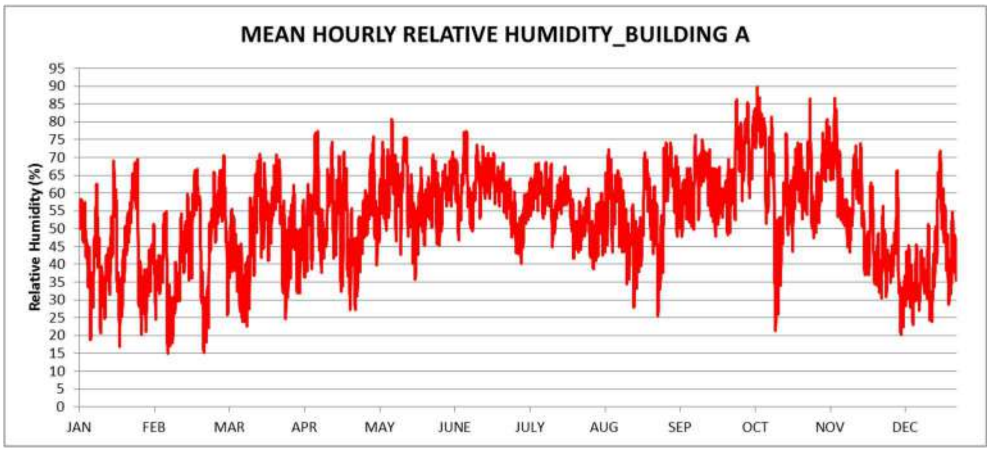


Figure 3.98: BUILDING A. Mean Relative Humidity trend during the year.

	FLOOR_MEAN RH (%)				BUILDING MEAN RH (%)
	1	2	3	4	
may	59.73	61.06	59.76	56.50	59.26
june	63.89	64.56	62.46	59.34	62.56
sep	63.17	63.25	61.81	59.95	62.04
oct	65.98	66.29	65.71	64.61	65.65

Table 3.20: BUILDING A. mean RH value in the most humid months.

Also in this case, taking into account the threshold of the RH comfort range (60%), we evaluated the number of hours exceeding this value. Moreover, we analysed the hours above 70%, another value considered in literature when we deal with humid issues. We will call this parameter as #hoursRH[51]>60-70%. The fig.3.99 on the right shows what we already underlined before: May, June, September and October are the most humid months, and the last one presents almost half month with RH above 70%.

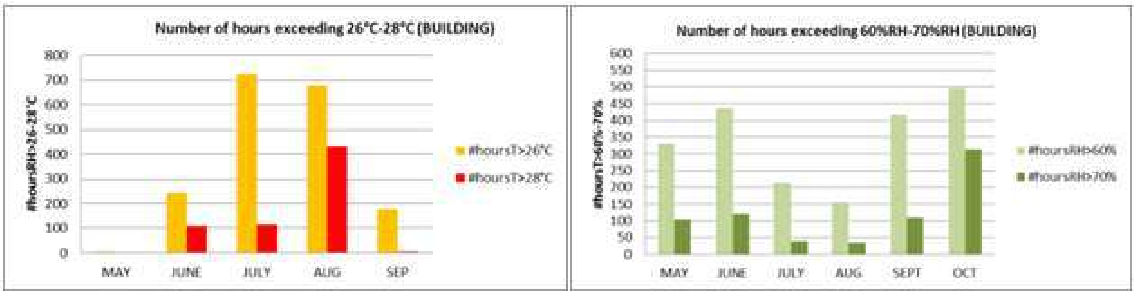


Figure 3.99: BUILDING A. (On the left) #hoursT>26-28°C. On the right #hoursRH>60-70%

[50] RH= Relative Humidity

[51] It means number of hours with Relative Humidity above 60-70%.

From these considerations, we can affirm that it is useful to analyse more in detail the worst flat per each floor from the temperatures point of view because on average all the floors present temperature values above 28°C in July and in August and moreover, in this way we will analyse those floors having higher values of RH (2° and 3°), which we would have left aside, taking into account only the 4° floor with the highest temperatures. Stated this, the flats chosen to be monitored in the different strategies or analyses derive from their position in the floor (ad example at the extremity or in the middle) and from their RH and T values. At 2° and 3° floor the warmest flats will have also high level of RH, for what we have said before. At 1° floor we choose the flat at the extremity and at the 4° floor the flat with the highest temperature values. Summarizing, the flats are:

FLOOR 1	FLOOR 2	FLOOR 3	FLOOR 4
FLAT 8	FLAT 6	FLAT 2	FLAT 6

Table 3.21: BUILDING A. Flats with the worst internal conditions chosen as sample flats to be monitored.

FLATS

FLOOR 1: FLAT 8

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 19.40°C;
- JUNE: The #hours>28°C are about 150 (720 total hours) °C;
- JULY: All the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.57°C).

The fig.3.100 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	26.05	29.23	28.50
MAX T (°C)	30.00	30.78	31.04
	MAY	SEP	OCT
MEAN T (°C)	22.42	25.05	20.50
MAX T (°C)	25.65	27.25	23.73
MIN T (°C)	19.40	22.31	16.57

Table 3.22:BUILDING A. Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 1-FLAT 8).

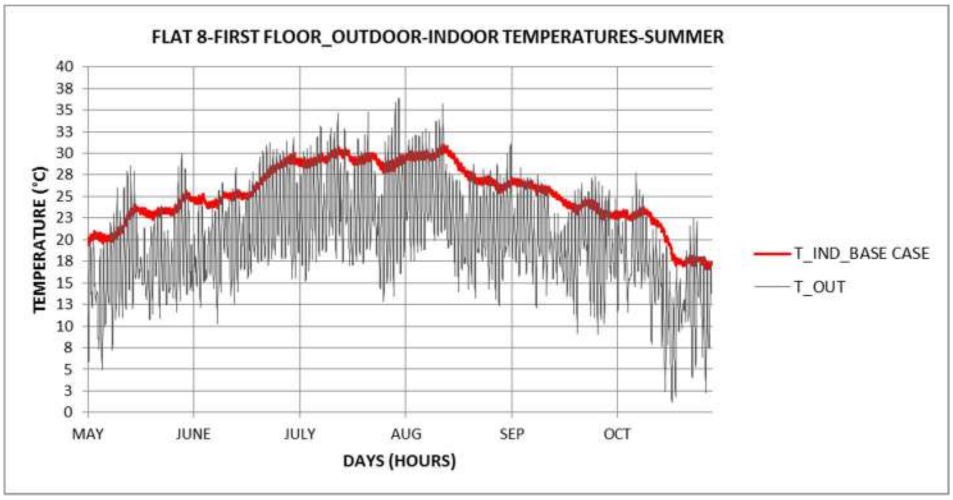


Figure 3.100: BUILDING A. Hourly trend of temperatures in Summer (FLOOR 1-FLAT 8).

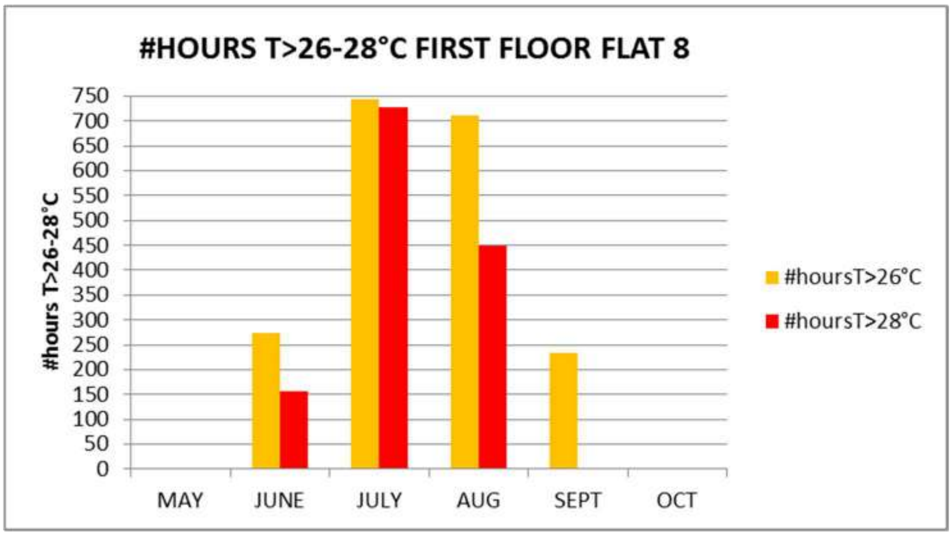


Figure 3.101: BUILDING A. Number of hours exceeding 26-28°C during Summer months (FLOOR 1-FLAT 8).

RELATIVE HUMIDITY (RH):

The Relative Humidity is lower where indoor temperatures are higher.

- MAY: About half month has hours above 60% of RH and 150h exceeding 70%;
- JUNE: More than half month (450h) presents hours above 60% of RH and 200h exceeding 70%;
- JULY: Few hours exceed 70% of RH, but about 300 hours present RH>60%;
- AUGUST: Few hours exceed 70% of RH, but about 300 hours present RH>60%;
- SEPTEMBER: The flat presents the same situation as in June;
- OCTOBER: It's the most humid month. It has 500 hours above 60% of RH, of whom 350h present RH>70%.

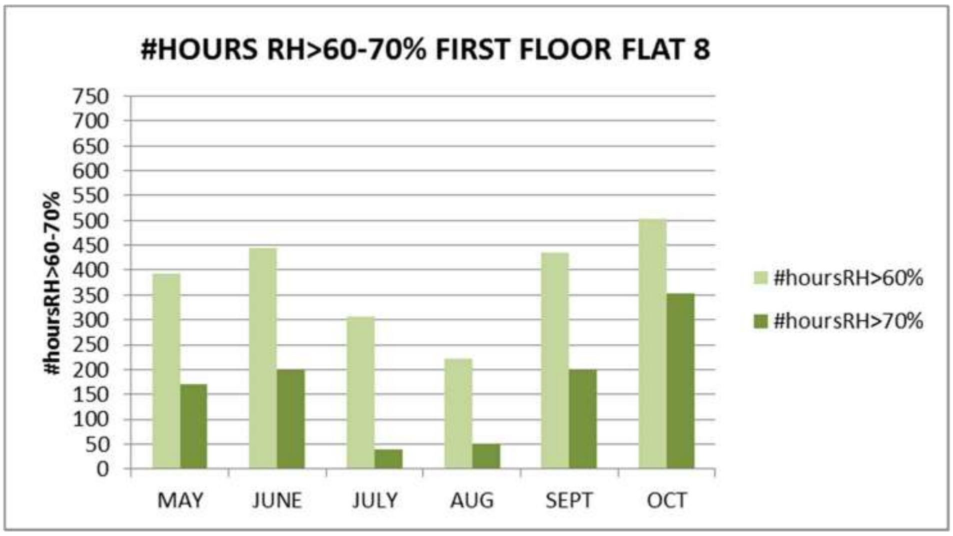


Figure 3.102: BUILDING A. Number of hours exceeding 60-70% of RH during Summer months (FLOOR 1-FLAT 8).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%)[52] we will analyse the number of hours with PPD<6-10-15% (#hours<6-10-15%PPD). The higher is the value (especially in the case of PPD<6%) the better will be the internal comfort conditions. The figure below shows that in July and in August there are no PPD<6-10-15% and this means that the percentage of dissatisfied in these months is high. In September, almost all the month presents PPD<15%; in May and in June about 500 hours has PPD<15%. The fact that that the PPD values decrease in October depends on the value of I_{cl} [53](insulation clothing, see table 3.16).

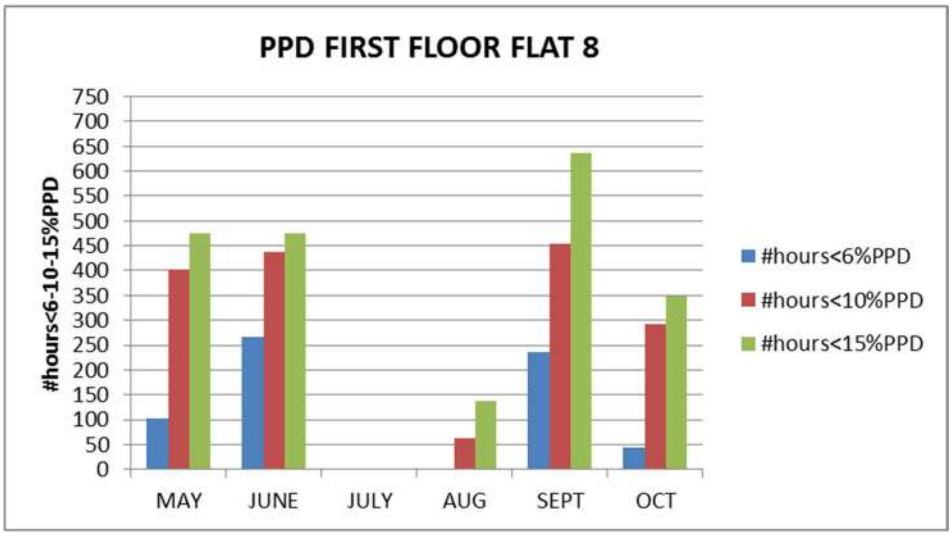


Figure 3.103: BUILDING A. Number of hours with PPD<6-10-15% (FLOOR 1-FLAT 8).

[52] As we already mentioned in the introduction of this section (see tab.3.15) these percentage correspond to a PMV range (The values calculated in the building model should stay inside these ranges. Accordingly (PPD<6% =-0.2<PMV<+0.2; PPD<10% =-0.5<PMV<+0.5; PPD<10% =-0.7<PMV<+0.7).

[53] In October we consider the same value I_{cl}= 0.5clo as in the other Summer months. It would be better to consider a higher value (the indoor temperatures are not as high as in the other Summer months), but in this way we evaluate the thermal comfort in the worst conditions. It is obvious that users can modify their comfort conditions by wearing warmer clothes, but in this work we consider October as a Summer month.

FLOOR 2: FLAT 6

TEMPERATURES:

- MAY: The temperatures are acceptable and the min temperature value is 19.22°C;
- JUNE: The #hours>28°C are about 100 (720 total hours) °C;
- JULY: All the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and 450h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.56°C).

The fig.3.104 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	25.74	29.00	28.37
MAX T (°C)	29.45	30.39	30.83
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.06	24.96	20.49
MAX T (°C)	25.02	26.92	23.68
MIN T (°C)	19.22	22.36	16.56

Table 3.23: BUILDING A. Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 2-FLAT 6).

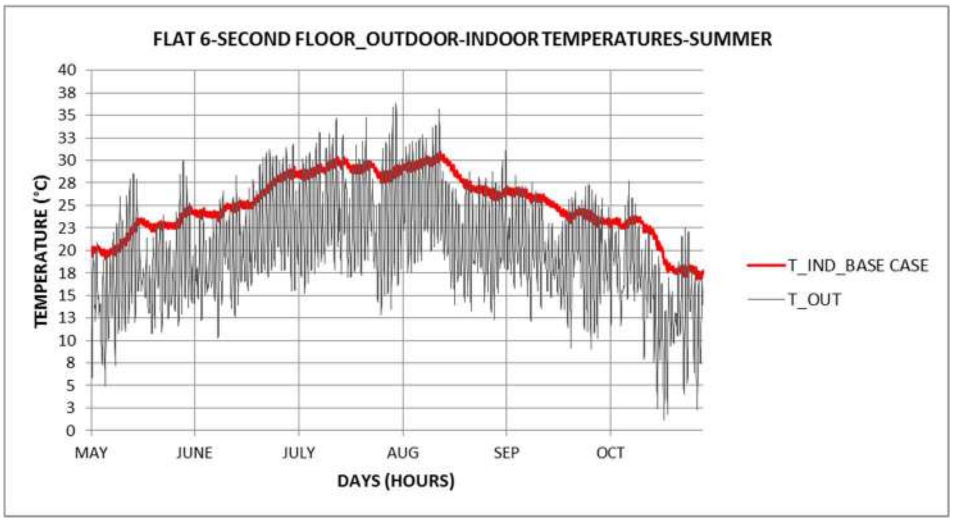


Figure 3.104: BUILDING A. Hourly trend of temperatures in Summer (FLOOR 2-FLAT 6).

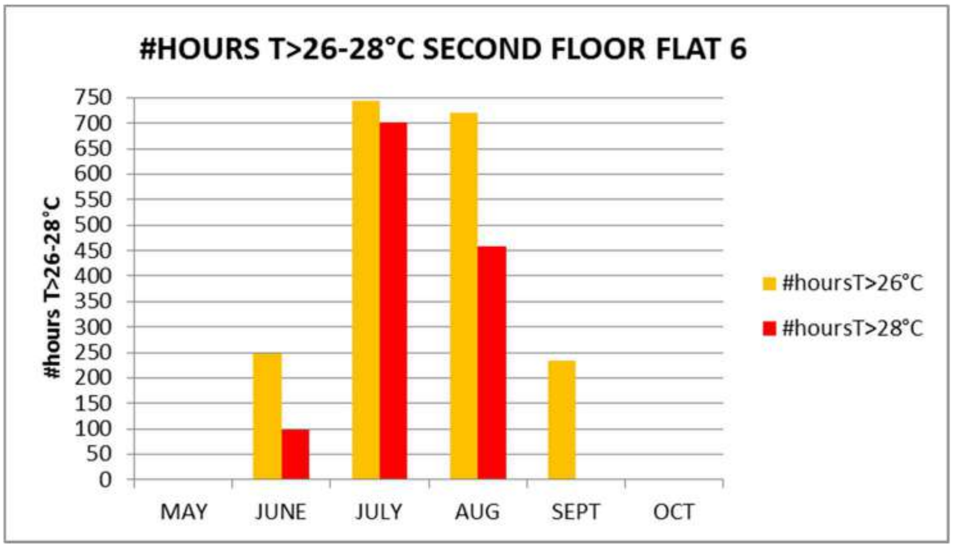


Figure 3.105: BUILDING A. Number of hours exceeding 26-28°C during Summer months (FLOOR 2-FLAT 6).

RELATIVE HUMIDITY (RH):

The Relative Humidity is lower where indoor temperatures are higher.

- MAY: About half month has hours above 60% of RH and 150h exceeding 70%;
- JUNE: More than half month (550h) presents hours above 60% RH and 250h>70%;
- JULY: In this case the flat presents about 550h of RH>60% and the half of these> 70%;
- AUGUST: 350 hours exceed 60% of RH and the half of these exceeds 70%;
- SEPTEMBER: The flat behaves like in May;
- OCTOBER: It is the most humid month also in this case, because 350h present RH>70%.

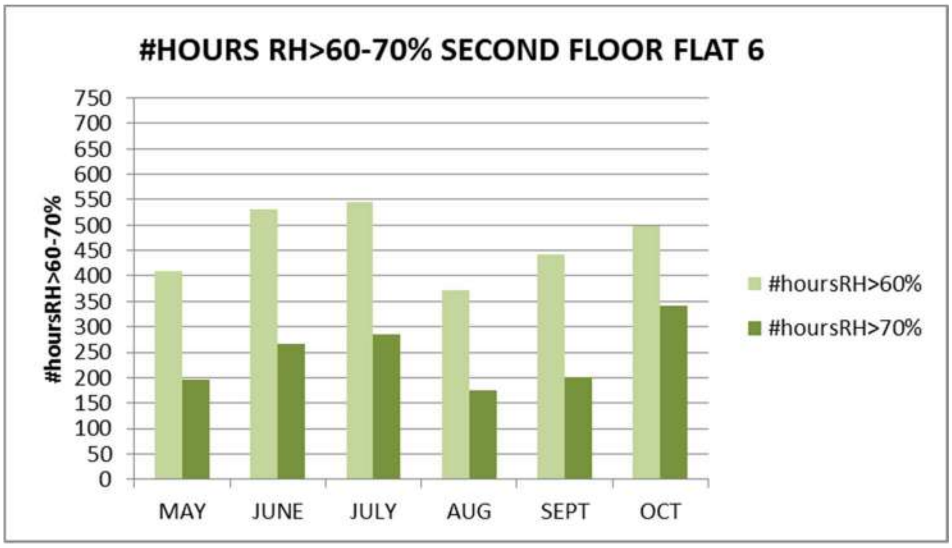


Figure 3.106: BUILDING A. Number of hours exceeding 60-70% of RH during Summer months (FLOOR 2-FLAT 6).

COMFORT INDEX (PPD VALUES):

As in the previous flat, in July and in August there are no PPD<6-10-15% and this means that the percentage of dissatisfied in these months is high. Even if the RH is higher than in the other flat, the PPD values are almost the same; this means that high indoor temperatures have more effects compared to the RH. In September, almost all the month presents PPD<15%; in May and in June about 500 hours has PPD<15%.

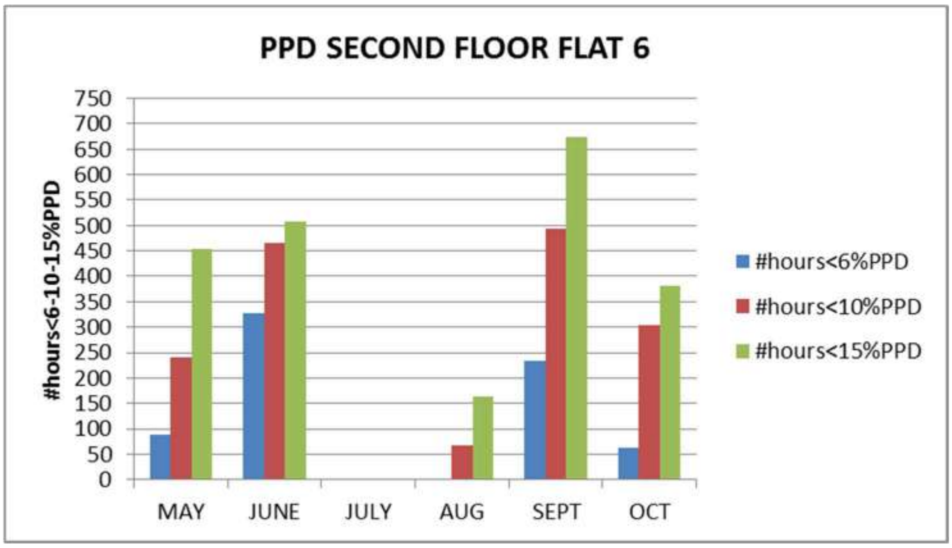


Figure 3.107: BUILDING A. Number of hours with PPD<6-10-15% (FLOOR 2-FLAT 6).

FLOOR 3: FLAT 2

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 19.06°C;
- JUNE: The #hours>28°C are about 150 (720 total hours) °C;
- JULY: All the month presents hours above 26°C (744 total hours) and all of these exceeding 28°C;
- AUGUST: All the month presents hours above 26°C (744 total hours) and 500h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.38°C).

The fig.3.108 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	25.80	29.12	28.45
MAX T (°C)	29.66	30.60	31.03
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.07	24.97	20.41
MAX T (°C)	25.13	27.03	23.75
MIN T (°C)	19.06	22.28	16.38

Table 3.24: BUILDING A. Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 3-FLAT 2).

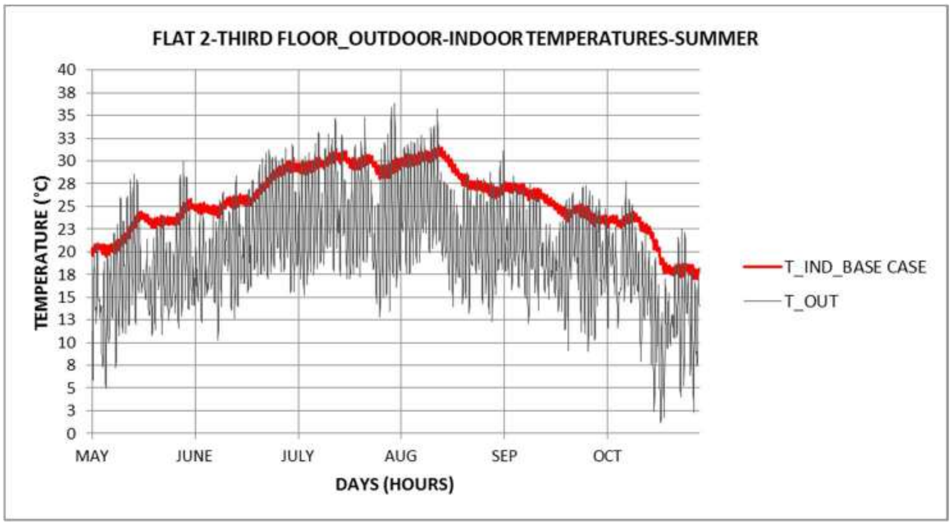


Figure 3.108: BUILDING A. Hourly trend of temperatures in Summer (FLOOR 3-FLAT 2).

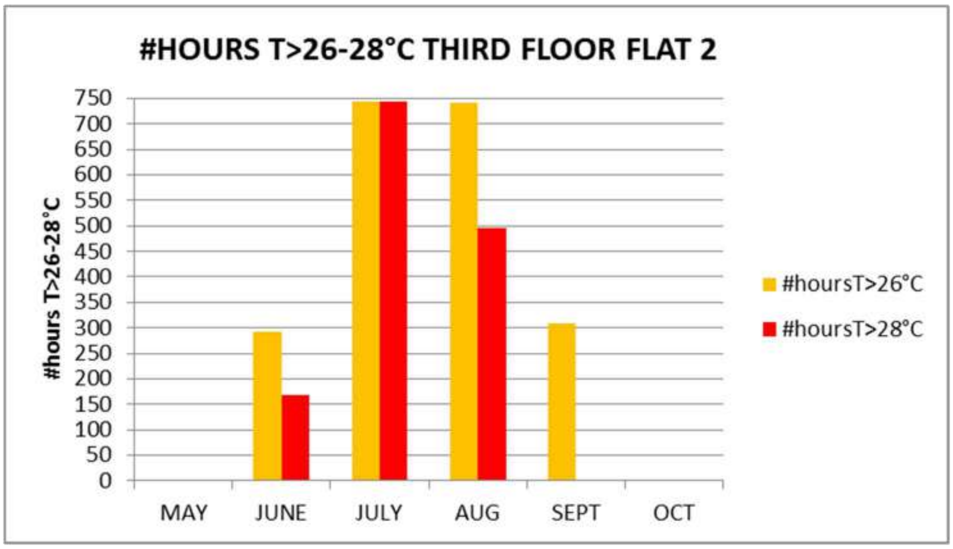


Figure 3.109: BUILDING A. Number of hours exceeding 26-28°C during Summer months (FLOOR 3-FLAT 2).

RELATIVE HUMIDITY (RH):

This flat presents high levels of RH.

- MAY: More than half month has hours above 60% of RH and 150h exceeding 70%;
- JUNE: More than half month (550h) presents hours above 60% of RH and 250h>70%;
- JULY: In this case the flat presents about 500 hours of RH>60%, but a small amount of these (less than 100 hours) exceeds 70%;
- AUGUST: 300 hours exceed 60% of RH and 100h exceed 70%;
- SEPTEMBER: The flat behaves like in May;
- OCTOBER: It is the most humid month; almost all the flat presents RH>70%.

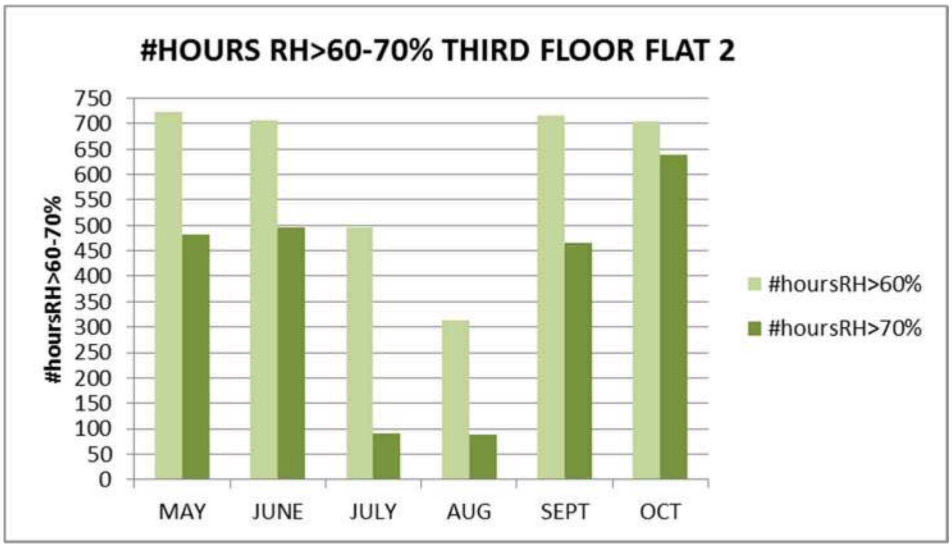


Figure 3.110: BUILDING A. Number of hours exceeding 60-70% of RH during Summer months (FLOOR 3-FLAT 2).

COMFORT INDEX (PPD VALUES):

This flat presents similar characteristics to that at the 2° floor. It is useful to compare the results of this apartment with those of the flat at the 2° floor. In July and in August there are no hours with PPD<6-10-15% and this means that the percentage of dissatisfied in these months is high, as well as at the 2° floor. Even if the RH is higher than in the other flat, the PPD values are almost the same; this means that high indoor temperatures have more effects on the percentage of dissatisfied compared to elevated RH values. In September the internal conditions worsen compared to the flat 3 at the 2° floor (#PPD<6-10-15% value decreases) and, since the mean temperature values are similar to the flat in exam, in this month RH influences the comfort conditions (in this case RH has higher values); in June we have a little decrease of temperatures at the 2° floor, compared to this case, along with a reduction of RH values and this difference lead to a decrease of comfort in this flat. In May the mean temperature values are the same in the 2 flats, but the RH is higher in flat 2 at the 3° floor, with the result of an improvement of indoor comfort conditions. In October the indoor conditions improve along with a decrease of temperatures and an increase of RH (still compared with the 2° floor).

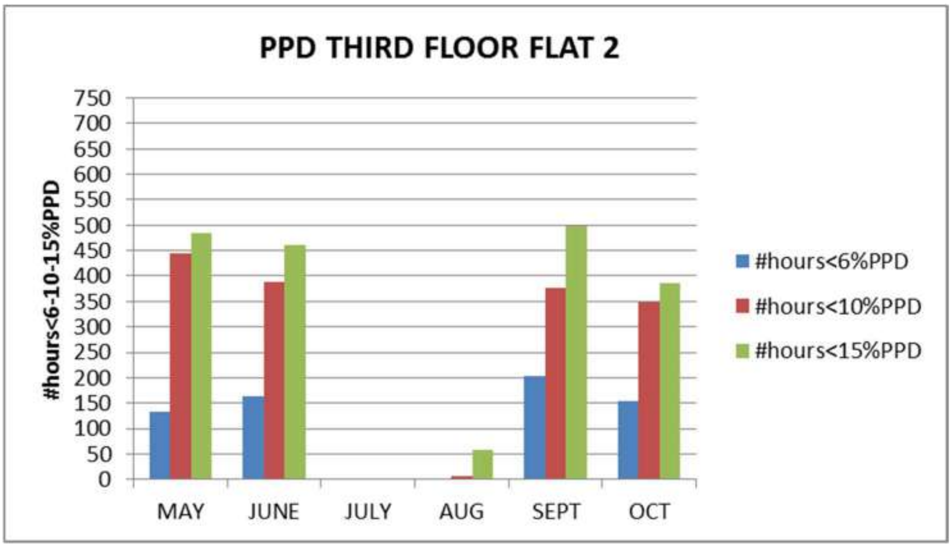


Figure 3.111: BUILDING A. Number of hours with PPD<6-10-15% (FLOOR 3-FLAT 2).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 19.25°C;
- JUNE: The #hours>28°C are about 200 (720 total hours) °C;
- JULY: All the month presents hours above 28°C (744 total hours);
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and 550h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.20°C).

The fig.3.112 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	26.30	29.67	28.83
MAX T (°C)	30.39	31.14	31.40
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.48	25.17	20.34
MAX T (°C)	25.69	27.30	23.88
MIN T (°C)	19.25	22.29	16.20

Table 3.25: BUILDING A. Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 4-FLAT 6).

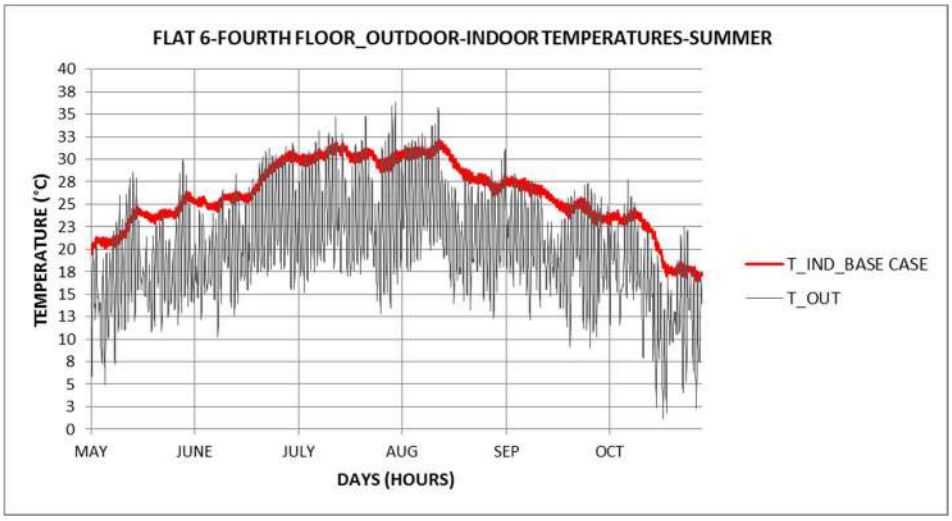


Figure 3.112: BUILDING A. Hourly trend of temperatures in Summer (FLOOR 4-FLAT 6).

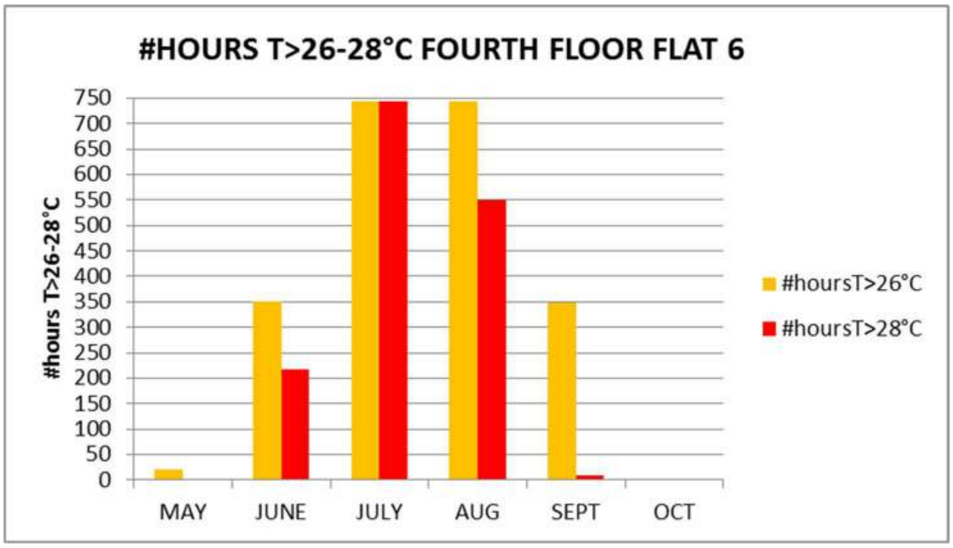


Figure 3.113: BUILDING A. Number of hours exceeding 26-28°C during Summer months (FLOOR 4-FLAT 6).

<u>RELATIVE HUMIDITY (RH):</u>

The Relative Humidity is lower where indoor temperatures are higher.

- MAY: About half month has hours above 60% of RH and 100h exceeding 70%;
- JUNE: About half month (350h) presents hours above 60% of RH and 100h exceeding 70%;
- JULY: In this case the flat presents about 200 hours of RH>60% and it does not present hours above 70%RH;
- AUGUST: 150 hours exceed 60% of RH and few hours above 70%RH;
- SEPTEMBER: The flat behaves like in May;
- OCTOBER: It is the most humid month also in this case, because 300h present RH>70%.

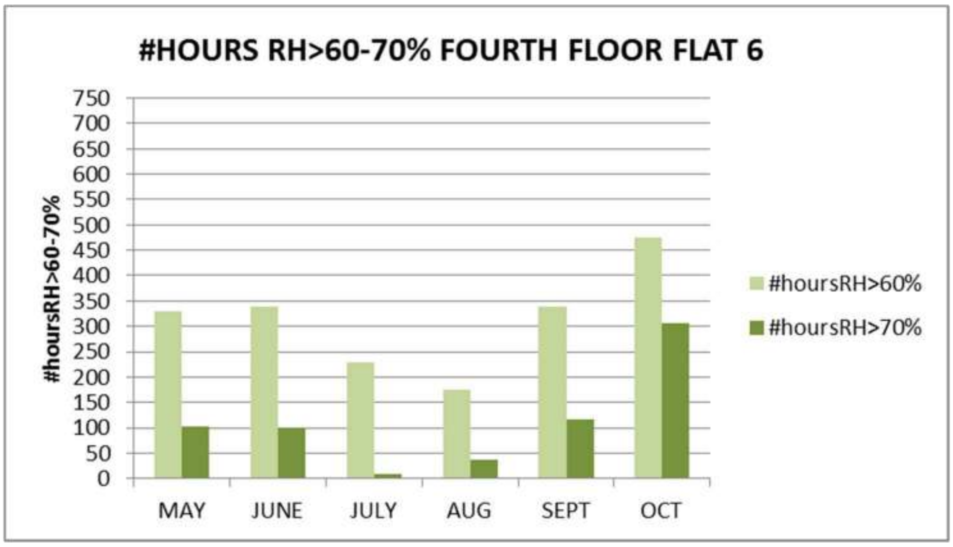


Figure 3.114: BUILDING A. Number of hours exceeding 60-70% of RH during Summer months (FLOOR 4-FLAT 6).

COMFORT INDEX (PPD VALUES):

This flat presents similar characteristics to flat 8 at the 1° floor. In July and in August there are no hours with PPD<6-10-15% and this means that the percentage of dissatisfied in these months is high. In May the mean temperature values are similar, a lower level of RH is registered in this flat 6 with a consequent improvement of comfort levels. In June flat 6 presents higher temperatures and consequently lower levels of indoor comfort. In September the higher mean temperatures, compared to flat 8 at the 1° floor, make the comfort conditions lower even if the RH is lower in comparison with flat 8. In October the 2 flats present the same levels of RH, but in this flat the comfort values are a bit better, due to a small decrease of temperature, but if we look again at the flat 2-floor 3, an even better comfort level is obtained by high level of RH, with the same mean temperature values of the other flats.

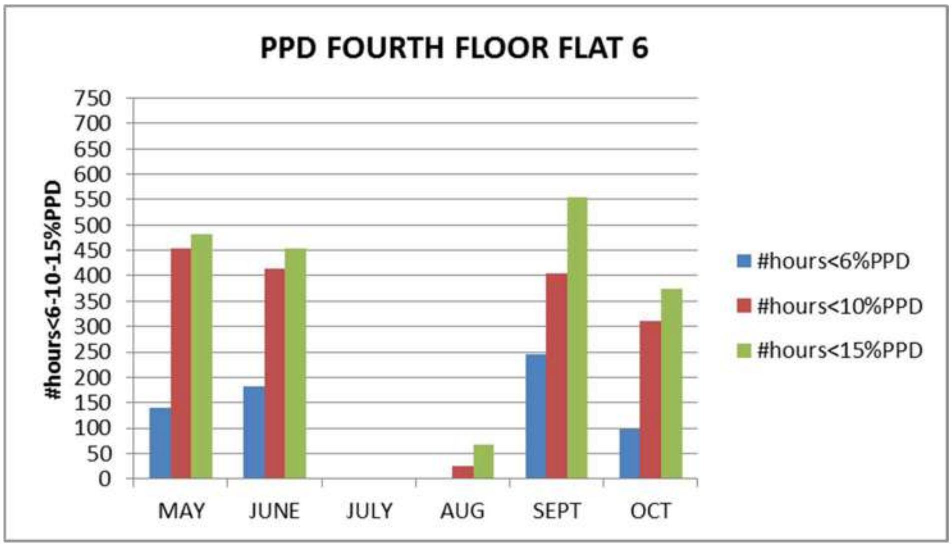


Figure 3.115: BUILDING A. Number of hours with PPD<6-10-15% (FLOOR 4-FLAT 6).

SYNTHESIS

Summarizing the results of the BASE CASE in BUILDING A

WHOLE BUILDING:

Winter Season

- Low quality of the envelope;
- Heat losses;
- Energy class: E;

Summer Season

- Low quality of the envelope;
- Overheating in the flats during the central months: temperatures above 28°C all the month in July and in August;
- High levels of RH in June, September and October.

FLATS:

We can say that the warmest flats are located at the 1° floor (FLAT 8) and at the 4° floor (FLAT 6) except in October when all the flats present almost the same mean temperature values. The most humid flat is located at the 3° floor (FLAT 2).

In July and August all the flats have low levels of internal comfort, due to the high values of temperatures and the RH has no effects on the final result in terms of comfort. Indeed, for example in FLOOR 3-FLAT 2 the RH is higher than in the other flats, but the PPD values do not suffer increase or decrease. High levels of RH are not felt as a comfort improvement in a flat with high temperatures.

Instead in October higher levels of RH lead to a better comfort inside the flats. Indeed, considering the fact that all the flats present almost the same mean temperature, the best flat in terms of comfort is found in FLOO3-FLAT 2, where there are also high levels of RH. We could say that higher levels of RH in flats with lower indoor temperatures (close to Winter temperature set-point 20°C) make the apartments more comfortable.

In June, when the indoor temperatures are high, but the mean temperatures do not overcome 26°C, lower values of RH improve the indoor comfort. We are referring to FLOOR 3-FLAT 2 and FLOOR 2-FLAT 6. In fact, these 2 flats present temperatures under 26°C, but the latter has lower RH values and better indoor conditions. The other 2 flats present temperatures above 26°C and even if they have lower levels of Relative humidity, they have higher temperatures, so that their comfort conditions are worse than in the other ones. Accordingly, also in this case lower temperatures lead to better indoor comfort conditions, and lower levels of RH in flats with temperatures above 26°C are not felt as a comfort improvement.

In September, all the flats present almost the same mean temperature values (25°C). The worst flat in terms of indoor comfort condition is represented by FLOOR 3-FLAT 2, the most humid one. It means that in September the increase of Relative Humidity worsens the Indoor thermal conditions.

May is an intermediate month between October and June. In the flats with lower mean temperatures (22°C, FLOOR 3-FLAT 2 and FLOOR 2-FLAT 6), high levels of RH improve the indoor conditions (FLOOR 3-FLAT 2), while in the warmest flats (23°C, FLOOR 4-FLAT 6 and FLOOR 1-FLAT 8), lower Relative Humidity levels lead to better indoor comfort conditions (FLOOR 4-FLAT 6).

BUILDING B

As regards the resistance of the building elements, the values are equal to those used in BUILDING A.

1. **Semi-stationary conditions**

In the table below a summary of necessary data to evaluate the Energy Demand for heating and the final Global Energy Performance *($EP_{gl,nren}$)* are listed:

IOLO BUILDING A	
TOTAL DISPERSANT SURFACES ***(S)***	$2895m^2$
HEATED VOLUME ***(V)***	$5791m^3$
USEFUL AREA ***(A)***	$1607m^2$
SHAPE FACTOR ***(S/V)***	$0.53m^{-1}$
WINDOWS AREA/*S*	0.09

The figure below shows the thermal zones of BUILDING B: 6 flats/floor for the first 3 floors. At the last floor there are only 4 flats. Accordingly, we will have 22 thermal zones.

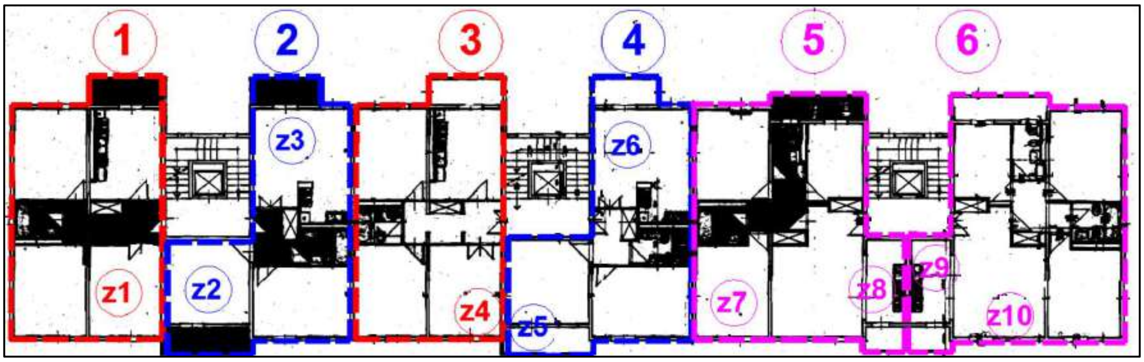


Figure 3.116: Thermal zones in BUILDING B typical plan. The sub-zones (zN) will be considered in the dynamic model.

The Global Energy Performance index (**$EP_{gl,nren}$**) is:

$EP_{gl,nren}$= 120.18kWh/m^{2}y

$EP_{gl,nren,rif}$(2019,2021)= 53.61kWh/m^{2}y

The building Energy Class is **E**, in fact:

2.00* $EP_{gl,nren,rif}$(2019,2021) < **$EP_{gl,nren}$** ≤ 2.60* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K

H'_T= 0.86 W/m^{2}K

H'_T> H'_{Tlim} **UNVERIFIED**

b. Envelope Energy Performance in Winter through the calculation of $\boldsymbol{EP_{H,nd}}$

$EP_{H,nd}$ = 57.52kWh/m^{2}y

$EP_{H,nd,lim}$(2019,2021)= 14.3kWh/m^{2}y

The result is:

$EP_{H,nd} > 1.7*EP_{H,nd,lim}$(2019,2021) → **LOW QUALITY OF THE ENVELOPE**

c. Envelope Energy Performance in Summer through the evaluation of ($\boldsymbol{A_{sol,est}}$) and ($\boldsymbol{Y_{IE}}$)

$A_{sol,est}/S$= 0.063

Y_{IE}=0.29W/m^{2}K

The thresholds are:

$(A_{sol,est}/S)_{lim}$= 0.03

$(Y_{IE})_{lim}$= 0.14W/m^{2}K

The result is:

$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ *and* $Y_{IE} > (Y_{IE})_{lim}$ → **LOW QUALITY OF THE ENVELOPE**

2. Dynamic conditions

From the results of the dynamic simulations we obtained the sensible energy demand for heating, called in the model *Q_heat* which corresponds to $Q_{H,nd}$ in the semi-stationary conditions and *Q_heat/S* corresponds to $EP_{H,nd}$.

If we analyse the behaviour of the floors, from the figure below, we can note that the most "energy-hungry" flats are located at the fourth and first floor.

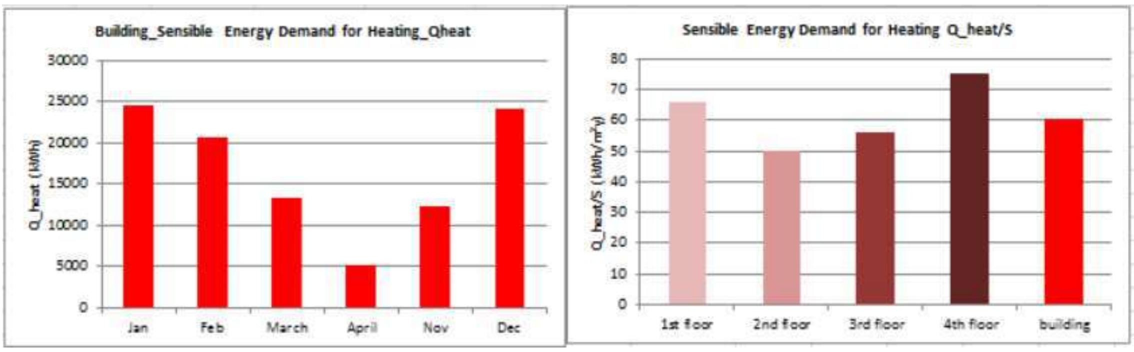


Figure 3.117: BUILDING B. Sensible Energy Demand for Heating. (On the left) the average values of *Q_heat* per month averaged across all the flats. (On the right) The average values of *Q_heat/S* per floor.

- From the analysis in semi-stationary conditions we found:

$EP_{H,nd}$ = 57.52 kWh/m^{2}y

- From the analysis in dynamic conditions we found:

Q_heat/S= 60.22 kWh/m^{2}y

The 2 values differ of about 10%, in line with the results of BUILDING A.

WHOLE BUILDING

As in BUILDING A, we analysed the mean temperatures of the building as a whole, by making an average of all the flats values.

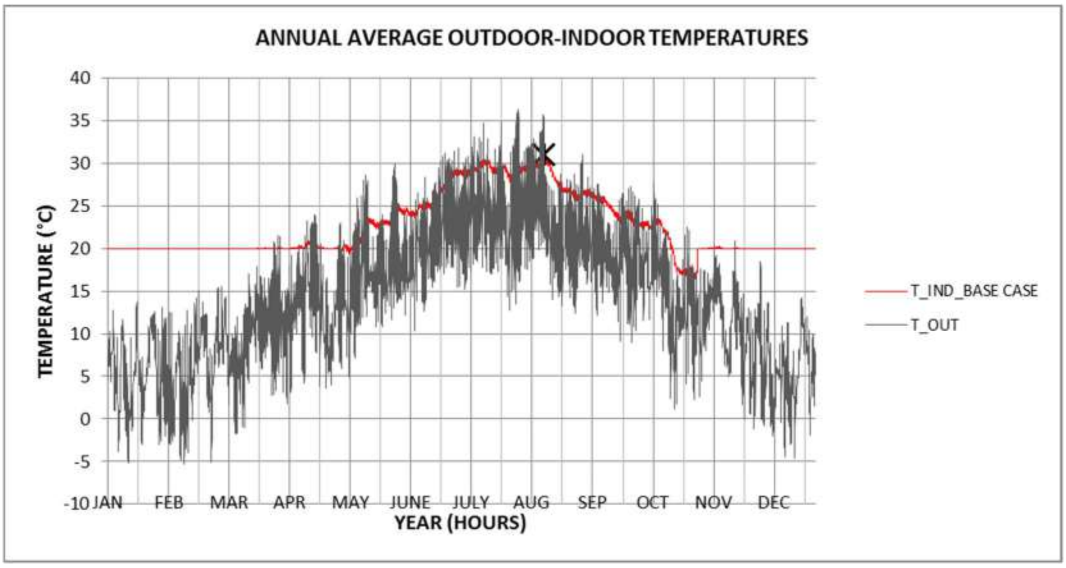


Figure 3.118: BUILDING B. Hourly trend of mean temperatures during all the year and the outdoor temperature hourly trend (T_out). These are values averaged across all the flats.

Obviously, the temperatures in Winter are around 20°C, that is the set-point temperature for the heating system.

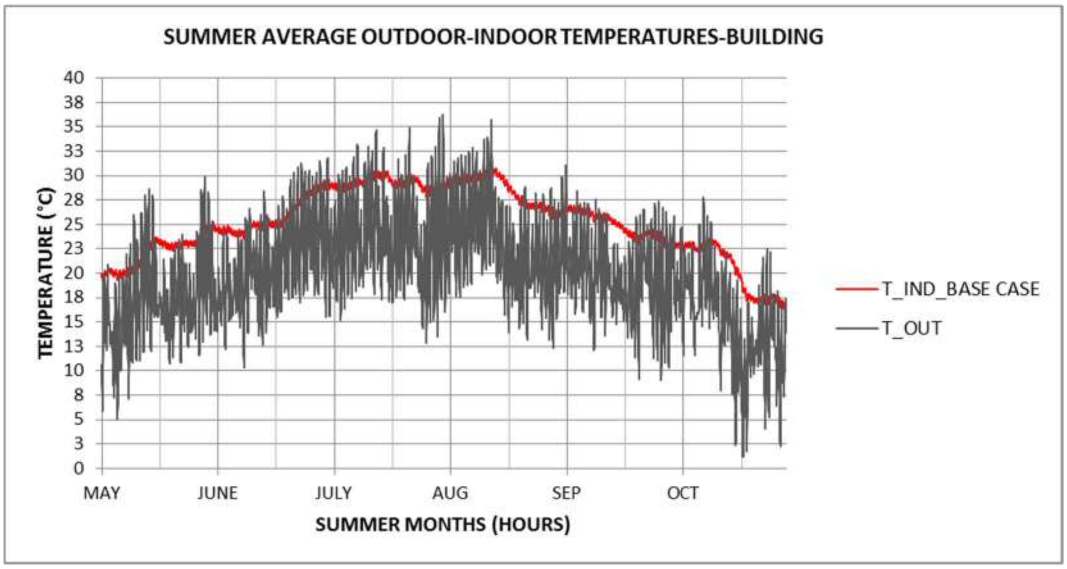


Figure 3.119: BUILDING B. Hourly trend of mean temperatures in Summer (average values of the whole building). Comparison between BASE CASE and outdoor temperatures.

The max value of temperatures occurs in August and at the 4° floor in the flat 6 (zone 10), while the min value is in October still at the fourth floor, but in flat 1. This trend is shown in the figure below, where the warmest floor is the 4° (violet line).

SUMMER	CENTRAL MONTHS	JUNE	JULY	AUGUST
		BASE CASE	BASE CASE	BASE CASE
	MEAN T (°C)	25.88	29.24	28.55
	MAX T (°C)	31.57	32.29	32.59
	SHOULDER MONTHS	MAY	SEPTEMBER	OCTOBER
		BASE CASE	BASE CASE	BASE CASE
	MEAN T (°C)	22.18	25.02	20.32
	MAX T (°C)	27.05	28.49	24.01
	MIN T (°C)	18.58	21.55	15.36

Table 3.26: BUILDING B. Characteristic mean temperature values averaged across all the flats.

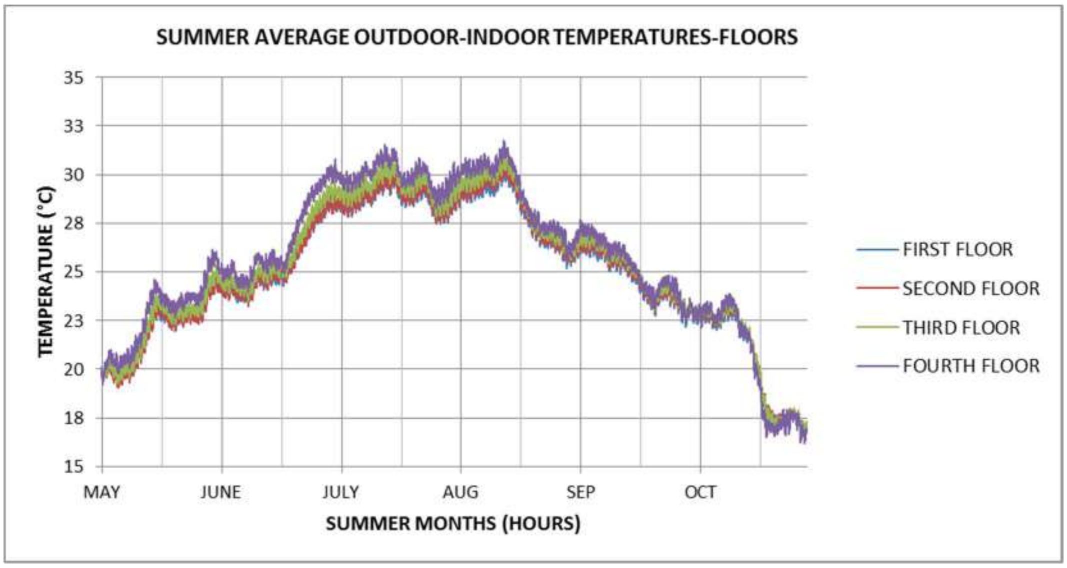


Figure 3.120: BUILDING B. Hourly trend of mean temperatures during Summer months per each floor.

From the fig.3.121 we can note that July and August present almost all the month temperatures above the comfort limit value (26°C) and in August more than half month has hours with temperature above 28°C.

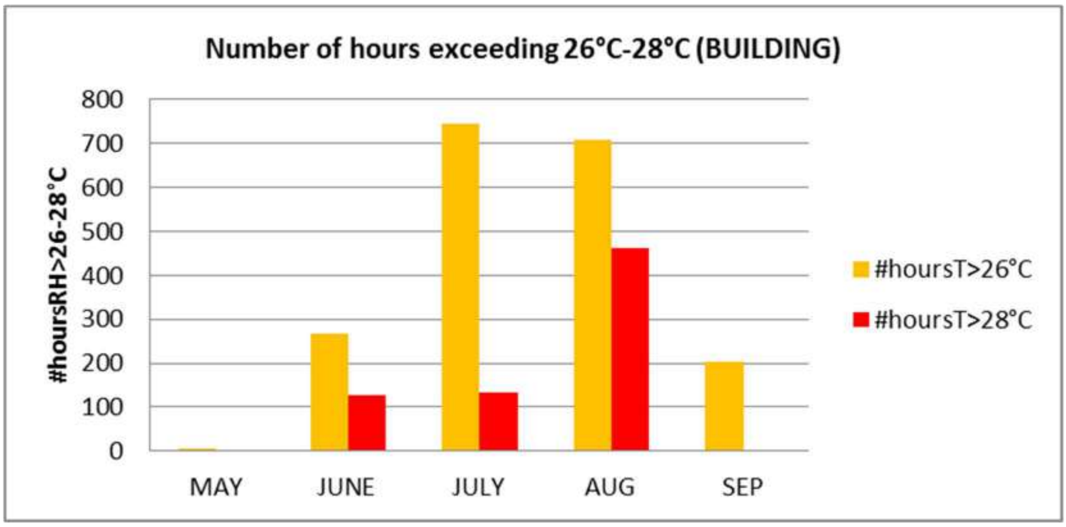


Figure 3.121: BUILDING B. #hoursT>26-28°C. Values averaged across all the flats.

As regard RH values, if we look at the fig below, the most humid months are May, June, September and October; this case, the first 3 floors present similar values of RH, why the fourth floor is less humid compared to the others. (see table 3.27).

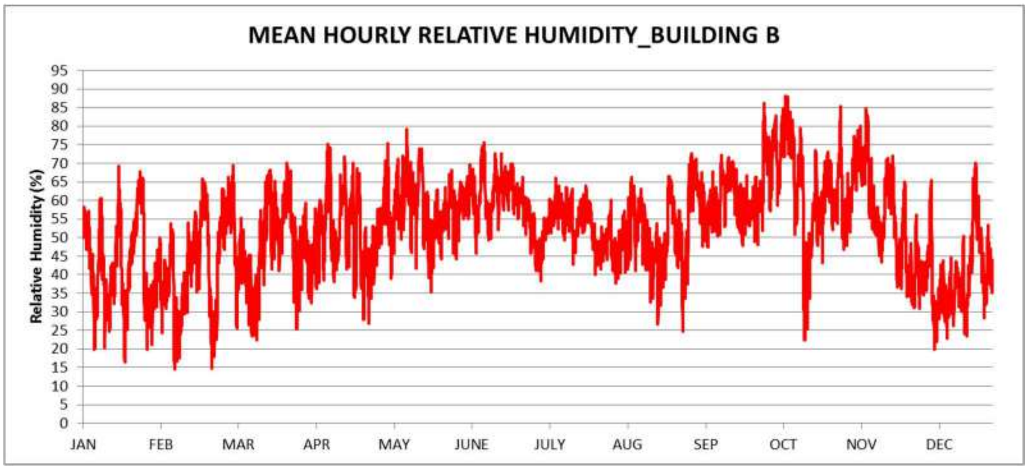


Figure 3.122: BUILDING B. Mean Relative Humidity trend during the year.

	FLOOR_MEAN RH (%)				BUILDING MEAN RH (%)
	1	2	3	4	
MAY	58.33	58.58	59.10	55.69	57.92
JUNE	61.83	61.78	61.63	58.18	60.85
SEPT	53.98	53.67	53.35	50.58	52.90
OCT	50.04	49.59	49.69	47.59	49.23

Table 3.27: BUILDING B. Mean RH value in the most humid months.

The figure below on the right shows what we already underlined before: May, June, September and October are the most humid months, and the last one presents almost half month with RH above 70%.

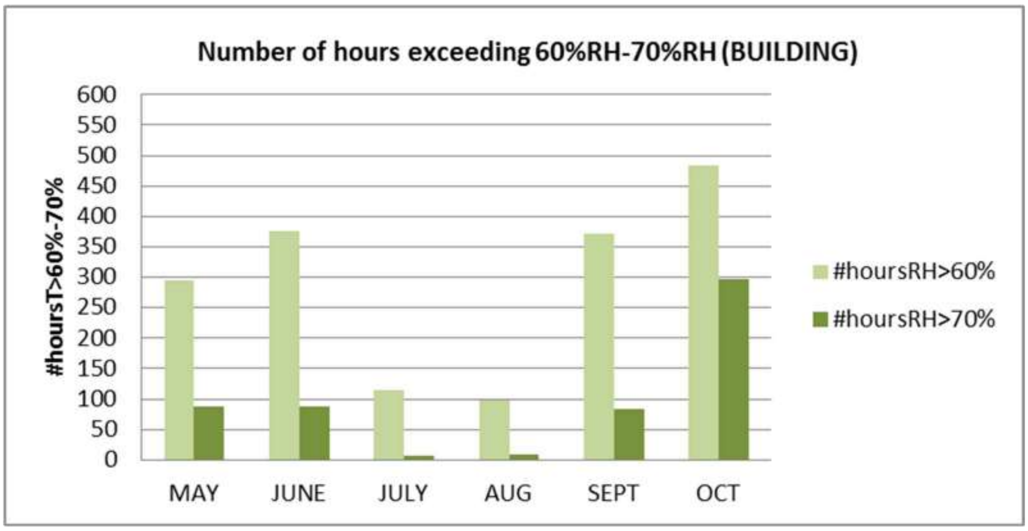


Figure 3.123: BUILDING B. #hoursRH>60-70%. Values averaged across all the flats.

As in BUILDING A, we will analyse the internal conditions of some flats, taken as sample cases. At the 1° floor the worst flat is still located at the extremity, while we decided to take into account FLAT 2 at the 3° floor, leaving out the second floor (it behaves like FLAT 2-FLOOR 3). At the 4° floor we will consider the warmest flat:

FLOOR 1	FLOOR 3	FLOOR 4
FLAT 6	**FLAT 2**	**FLAT 2**

Table 3.28: BUILDING B. Flats with the worst internal conditions chosen as sample flats to be monitored

FLATS

FLOOR 1: FLAT 6

TEMPERATURES:

- MAY: The temperatures are acceptable and the min temperature value is 22.08°C;
- JUNE: The #hours>28°C are about 150 (720 total hours) °C;
- JULY: All the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and almost 500 exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (15.74°C).

The 3.124 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	25.83	29.25	28.44
MAX T (°C)	30.17	30.97	31.17
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.08	24.78	20.02
MAX T (°C)	25.49	27.22	23.41
MIN T (°C)	19.08	21.87	15.74

Table 3.29: BUILDING B. Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 1-FLAT 6).

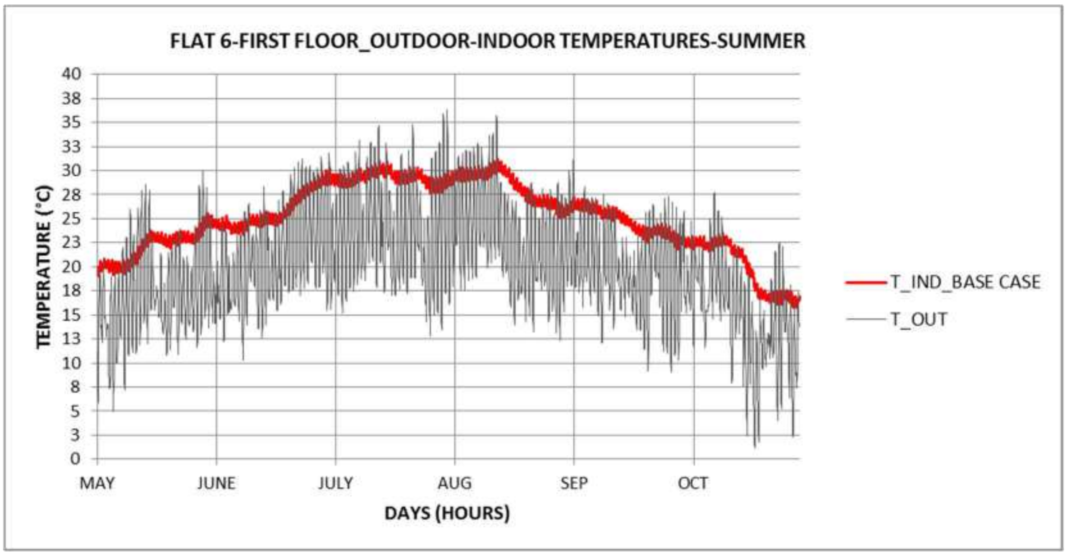


Figure 3.124: BUILDING B. Hourly trend of temperatures in Summer (FLOOR 1-FLAT 6).

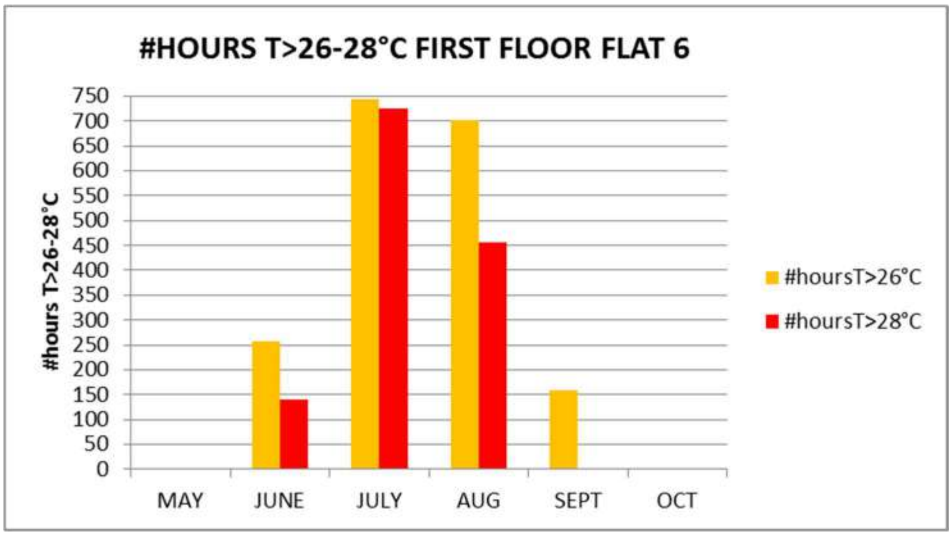


Figure 3.125: BUILDING B. Number of hours exceeding 26-28°C during Summer months (FLOOR 1-FLAT 6).

RELATIVE HUMIDITY (RH):

The Relative Humidity is lower where indoor temperatures are higher.

- MAY: About half month has hours above 60% of RH and 150h exceeding 70%;
- JUNE: More than half month (450h) presents hours above 60% of RH and almost 200h exceeding 70%;
- JULY: Few hours exceed 70% of RH, but about 300 hours present RH>60%
- AUGUST: Few hours exceed 70% of RH, but about 300 hours present RH>60%;
- SEPTEMBER: The flat behaves like in June;
- OCTOBER: It’s the most humid month. It has about 500 hours above 60% of RH, of whom 350h present RH>70%.

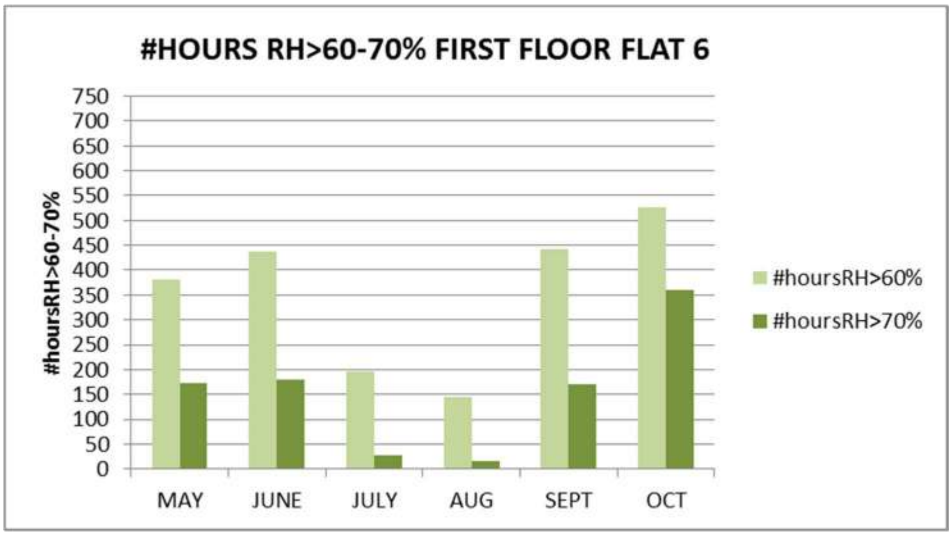


Figure 3.126: BUILDING B. Number of hours exceeding 60-70% of RH during Summer months (FLOOR 1-FLAT 6).

COMFORT INDEX (PPD VALUES):

The figure below shows that in July and in August there are no PPD<6-10-15% and this means that the percentage of dissatisfied in these months is high. In September almost all the month presents PPD<15%; in May and in June about 500 hours has PPD<15%. In October the comfort conditions are quite low, probably due to the low temperatures and high levels of RH.

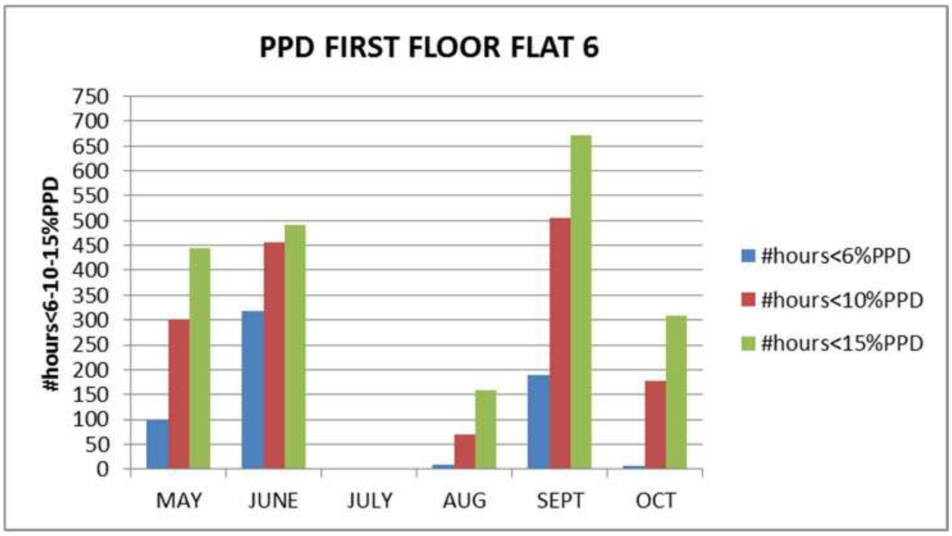


Figure 3.127: BUILDING B. Number of hours with PPD<6-10-15% (FLOOR 1-FLAT 6).

FLOOR 3: FLAT 2

TEMPERATURES:

- MAY: The temperatures are acceptable and the min temperature value is 19.22°C;
- JUNE: The #hours>28°C are about 100 (720 total hours) °C;
- JULY: All the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and 450h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.56°C).

The fig. 3.128 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	26.06	29.42	28.76
MAX T (°C)	30.09	31.03	31.43
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.31	25.25	20.66
MAX T (°C)	25.55	27.43	23.99
MIN T (°C)	19.29	22.55	16.56

Table 3.30: BUILDING B. Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 3-FLAT 2).

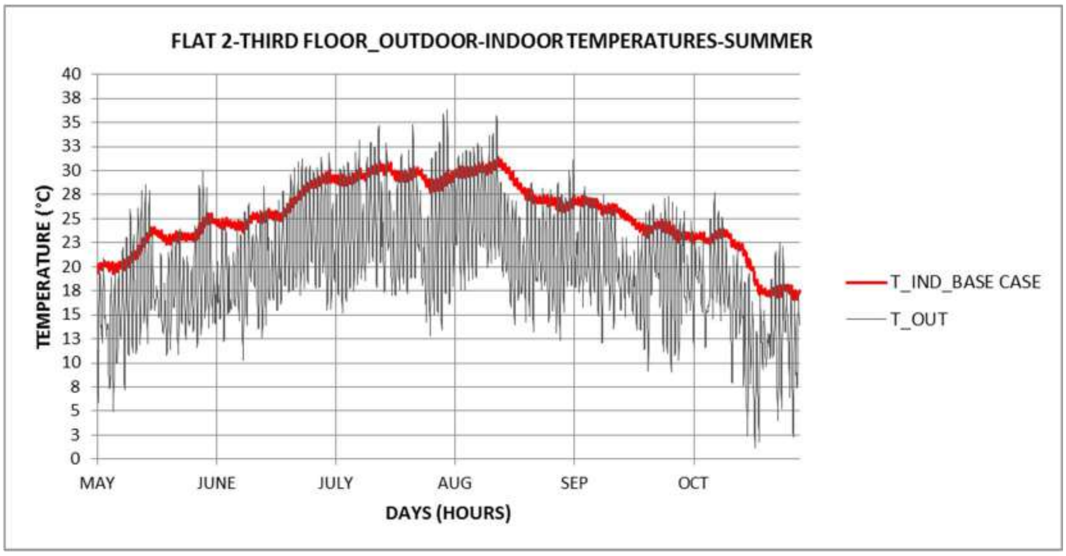


Figure 3.128: BUILDING B. Hourly trend of temperatures in Summer (FLOOR 3-FLAT 2).

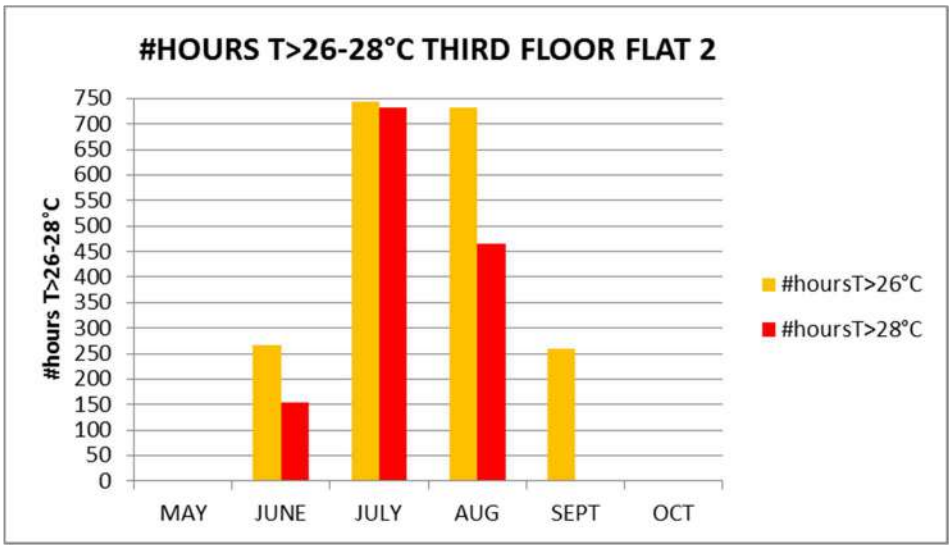


Figure 3.129: BUILDING B. Number of hours exceeding 26-28°C during Summer months (FLOOR 3-FLAT 2).

RELATIVE HUMIDITY (RH):

- MAY: About half month has hours above 60% of RH and 150h exceeding 70%;
- JUNE: More than half month (400h) presents hours above 60% RH and 150h>70%;
- JULY: No hours above 70%RH;
- AUGUST: Few hours above 70%RH;
- SEPTEMBER: The flat behaves like in May;
- OCTOBER: It is the most humid month also in this case, because 350h present RH>70%.

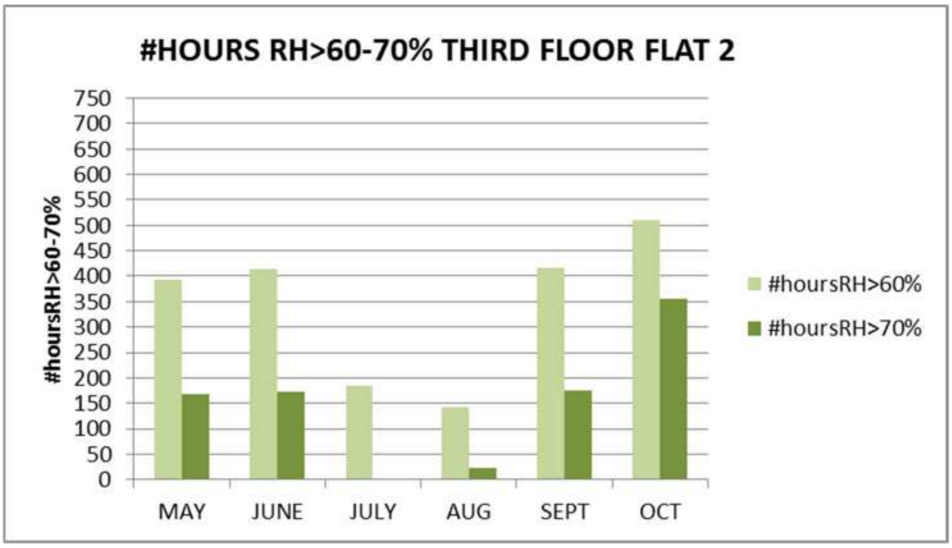


Figure 3.130: BUILDING B. Number of hours exceeding 60-70% of RH during Summer months (FLOOR 3-FLAT 2).

COMFORT INDEX (PPD VALUES):

As in the previous flat, in July and in August there are no PPD<6-10-15% and this means that the percentage of dissatisfied in these months is high. In September, there is a decrease of comfort levels, due to the increase of indoor temperatures compared to the previous flat. In May and in June about 500 hours has PPD<15%. In October, the flat for a half of the month has low levels of indoor comfort, even if the best value of PPD (<6%) is improved compared to the flat at first floor, and this improvement is due to higher values of temperatures, useful in October.

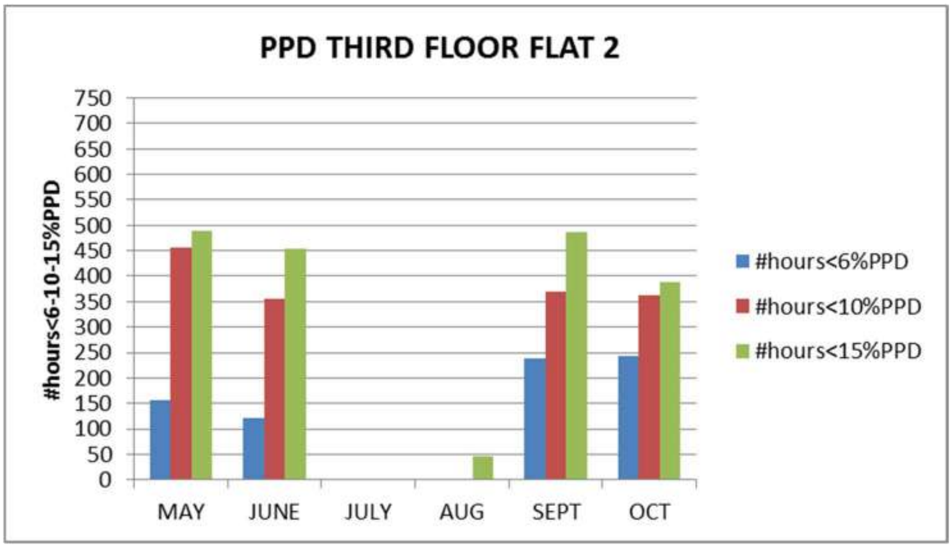


Figure 3.131: BUILDING B. Number of hours with PPD<6-10-15% (FLOOR 3-FLAT 2).

FLOOR 4: FLAT 2

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 19.22°C;
- JUNE: The #hours>28°C are about 200 (720 total hours) °C;
- JULY: All the month presents hours above 28°C (744 total hours);
- AUGUST: All the month presents hours above 26°C (744 total hours) and 450h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.06°C).

The fig. 3.132 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	**JULY**	**AUG**
MEAN T (°C)	26.58	29.93	29.02
MAX T (°C)	30.88	31.59	31.82
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.74	25.27	20.32
MAX T (°C)	26.23	27.68	23.89
MIN T (°C)	19.22	22.18	16.06

Table 3.31: BUILDING B. Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 4-FLAT 2).

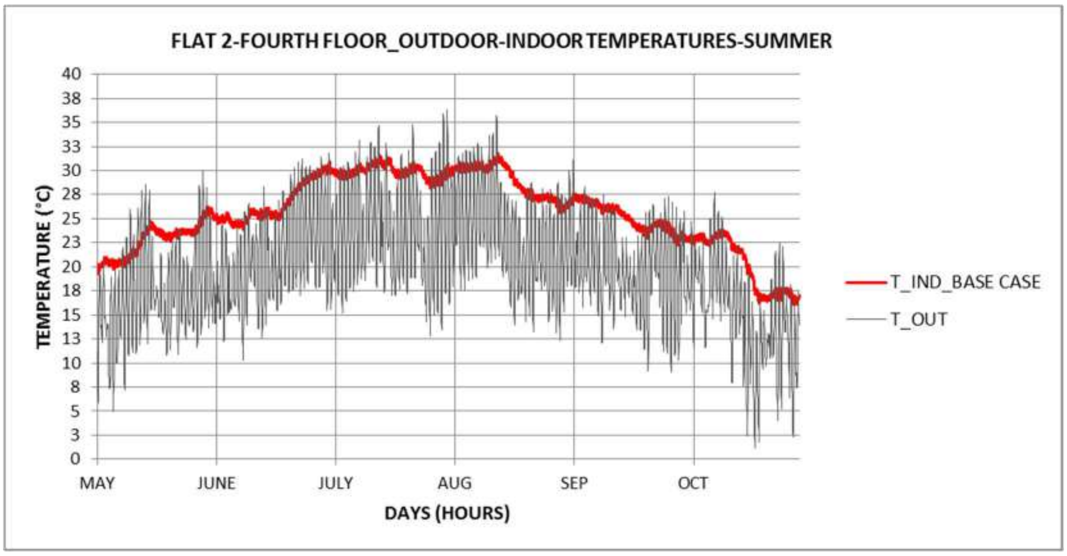


Figure 3.132: BUILDING B. Hourly trend of temperatures in Summer (FLOOR 4-FLAT 2).

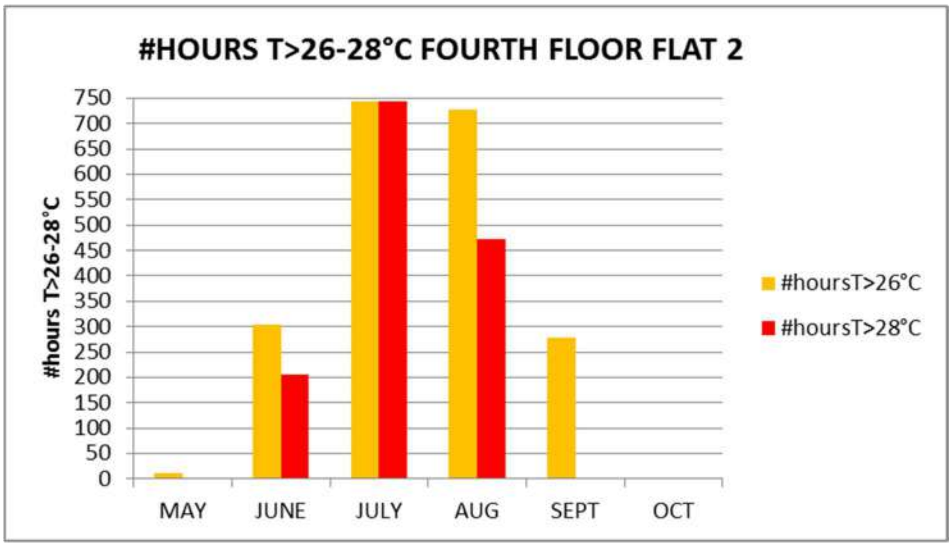


Figure 3.133: BUILDING B. Number of hours exceeding 26-28°C during Summer months (FLOOR 4-FLAT 2).

RELATIVE HUMIDITY (RH):

- MAY: About half month has hours above 60% of RH and 100h exceeding 70%;
- JUNE: About half month (350h) presents hours above 60% of RH and 100h exceeding 70%;
- JULY: The levels of RH are negligible;
- AUGUST: JULY: The levels of RH are negligible;
- SEPTEMBER: Almost 400 hours exceed 60% of RH, of whom 150h are above 70% of RH;
- OCTOBER: It is the most humid month also in this case. The flat has 500 hours exceeding the 60% and for half month it presents RH>70%.

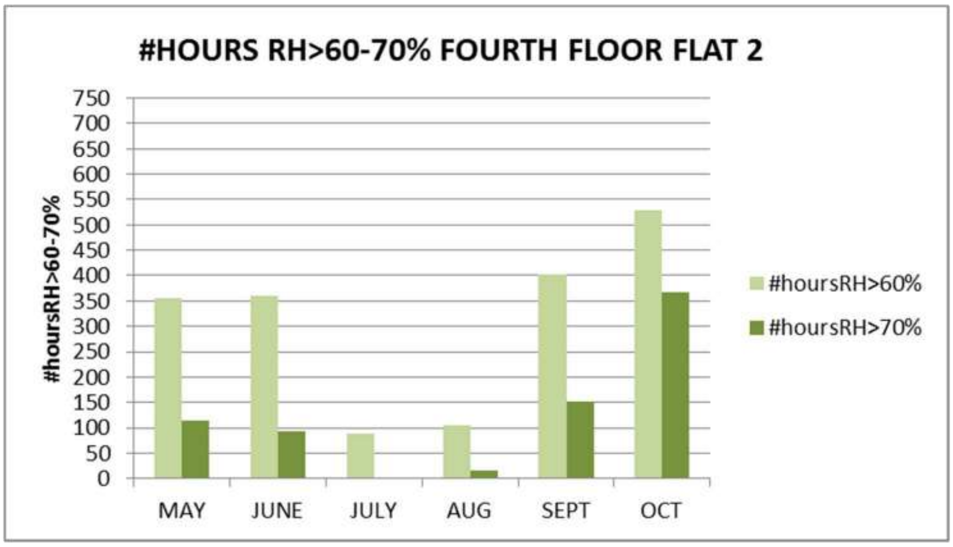


Figure 3.134: BUILDING B. Number of hours exceeding 60-70% of RH during Summer months (FLOOR 4-FLAT 2).

COMFORT INDEX (PPD VALUES):

In July and in August there are no hours with PPD<6-10-15% and this means that the percentage of dissatisfied in these months is high. In May this flat presents the highest mean temperature value compared to the other flats and a slight improve of comfort levels.

In June FLAT 2 is the warmest flat and for this cause, it is the worst apartment for what concerns the comfort levels, even though the RH values are lower compared to the other cases. In September the flat behaves like FLAT 2 at the 3° floor. Both present lower levels of comfort compared to the flat at first floor, due to the increase of indoor temperatures. In October internal comfort conditions are better than at the 1° floor, but slightly lower compared to the flat at the 3° floor, which, being surrounded by other flats, present higher temperatures.

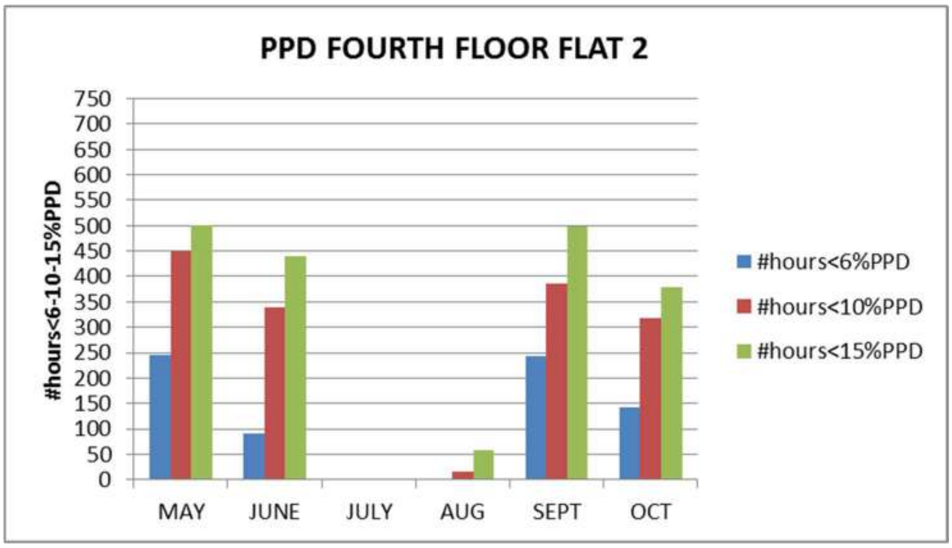


Figure 3.135: BUILDING B. Number of hours with PPD<6-10-15% (FLOOR 4-FLAT 2).

SYNTHESIS

Summarizing the results of the BASE CASE in BUILDING B

WHOLE BUILDING:

Winter Season

- Low quality of the envelope;
- Heat losses;
- Energy class: E;

Summer Season

- Low quality of the envelope;
- Overheating in the flats during the central months: temperatures above 28°C all the month in July and in August;
- Elevated levels of RH in June, September and October.

FLATS:

We can say that the warmest flat are located at the 1° floor (FLAT 6) and at the 4° floor (FLAT 2) except in October when all the flats present almost the same mean temperature values. The warmest flat in this month is FLAT 2 at 3° floor.

All the flats present similar levels of RH, even if FLAT 2 at the 3° floor is slightly more humid.

In July and August all the flats have low levels of internal comfort, due to the high values of temperatures and the RH has no effects on the final result in terms of comfort.

In June the flat with better comfort conditions is FLAT 6 at the first floor. The increase of temperatures, lowers the indoor comfort. Indeed the flat at the 4° floor presenting the highest temperatures values, is the worst apartment in this month, even if RH levels decrease.

Instead in May, the flat located at the 4° floor, presents better comfort conditions, due to higher temperatures, acceptable for this month.

In September the flats at the 3°-4° floor have similar behaviours. The flat at the first floor has higher levels of comfort in comparison to the others, due to lower temperatures.

In October the “best” flat is FLAT 2 at the 4°floor.

Summarizing we can say that in the central months, the higher temperatures lead to low levels of indoor comfort and this is a common characteristic of all the flats. As regards the shoulder months, the flats which in general are the warmest, behave better in May and in October (the increase of temperatures lead to positive results). Conversely, in September, better conditions occur when the flat presents lower temperatures (FLAT 6-FLOOR 1).

3.2.2 COMPLEX B: Firenze-Via Canova

First of all, it is necessary to define the Climate Zone of interest:

PRATO-IOLO	
Elevation	50m
HDD	1821
Climate Zone	D
Latitude	43°47’
Longitude	11°14’
Outdoor temperature (project)	0°C
Indoor temperature (project)	20°C
Heating period	150 days/year

Table 3.32: Firenze-Climate Data. Values found in (9).

The buildings present 3 different thermal zones: the stairwells, the flats and the cellars/attic. As we already mentioned, the 3 buildings (Qd1, Qa19, Qb16) present the same technological characteristics, so that the energy performance of the building elements surrounding the heated volume will be in common:

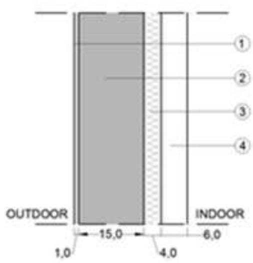
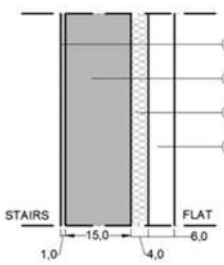
EXTERNAL WALLS			
	STRATIGRAPHY	Width ***s*** (m)	Conductivity ***l*** (W/mK)
	1-External Plaster	0.01	0.75
	2-Reinforced Concrete wall	0.15	1.3
	3-Glass wool	0.04	0.037
	4-Gypsum Panel	0.06	0.36
	Total Transmittance *U* (W/m²K)	**0.550**	
STAIRS WALLS			
	STRATIGRAPHY	Width ***s*** (m)	Conductivity ***l*** (W/mK)
	1-Internal Cladding (toward the stairs)	0.01	0.45
	2-Reinforced Concrete wall	0.15	1.3
	3-Polystyrene	0.04	0.037
	4-Gypsum Panel (toward the flats)	0.06	0.36
	Total Transmittance *U* (W/m²K)	**0.522**	

Table 3.33: COMPLEX B. U-values of the walls. Transmittance Values and thermal resistance calculation are taken from the “Thermal Plant Report” (Folder 163-F).

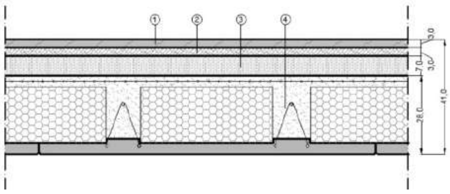
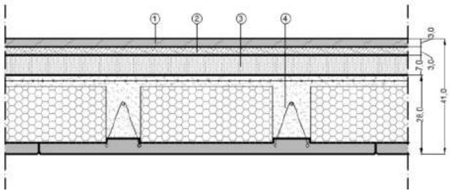
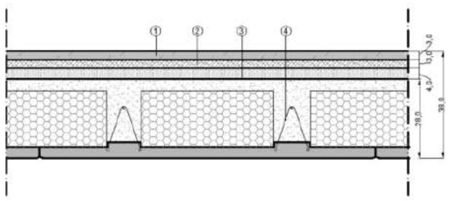
"PILLAR FLOOR" SLAB			
	STRATIGRAPHY	Width ***s*** (m)	Conductivity ***l*** (W/mK)
	1-Marble	0.03	2.9
	2-Mortar	0.03	1.1
	3-Cellular concrete	0.07	0.08
	4-Celerpan Slab	0.28	1.51
	Total Transmittance *U* (W/m²K)	**0.764**	
CELLARS FLOOR SLAB			
	STRATIGRAPHY	Width ***s*** (m)	Conductivity ***l*** (W/mK)
	1-Marble	0.03	2.9
	2-Mortar	0.03	1.1
	3-Cellular concrete	0.07	0.08
	4-Celerpan Slab	0.28	1.51
	Total Transmittance *U* (W/m²K)	**0.695**	
ATTIC FLOOR SLAB			
	STRATIGRAPHY	Width ***s*** (m)	Conductivity ***l*** (W/mK)
	1-Marble	0.03	2.9
	2-Mortar	0.03	1.1
	3-Cellular concrete	0.04	0.08
	4-Celerpan Slab	0.28	1.51
	Total Transmittance *U* (W/m²K)	**1.083**	

Table 3.34: COMPLEX B. U-values of the slabs. Transmittance Values and thermal resistance calculation are taken from the "Thermal Plant Report" (Folder 163-F).

The transmittance for the windows is **U_w= 2.7 W/m²K**. The presence of the roll blinds is taken into account in the evaluations of the Energy Performance of the buildings under dynamic conditions in Summer, by considering a control on the closure of the blinds when the Solar Irradiance is above 300W/m² in Summer months.

Qd1

1. **Semi-stationary conditions**

In the table below a summary of necessary data to evaluate the Energy Demand for heating and the final Global Energy Performance *($EP_{gl,nren}$)* are listed:

CANOVA-Qd1	
TOTAL DISPERSANT SURFACES ***(S)***	$5147m^2$
HEATED VOLUME ***(V)***	$10504m^3$
USEFUL AREA ***(A)***	$3245m^2$
SHAPE FACTOR ***(S/V)***	$0.49m^{-1}$
WINDOWS AREA/*S*	0.17

The figure below shows the thermal zones of Qd1: 8 flats/floor for a total of 6 floors. Accordingly, we will have 48 thermal zones. In this case the number of thermal zones is equal to the number of flats (one thermal zone for each flat). This splitting is used both in the semi-stationary model and in the dynamic one.

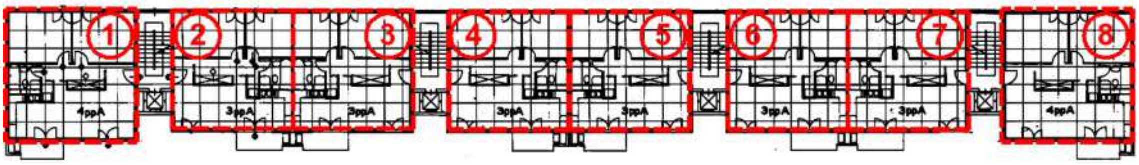


Figure 3.136: thermal zones in Qd1 typical plan.

The Global Energy Performance index (**$EP_{gl,nren}$**) is:

$EP_{gl,nren}$= 130.94kWh/m^{2}y

$EP_{gl,nren,rif}$(2019,2021)= 49.58kWh/m^{2}y

The building Energy Class is **F**, in fact:

2.60* $EP_{gl,nren,rif}$(2019,2021) < **$EP_{gl,nren}$** ≤ 3.50* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K

H'_T= 1.30 W/m^{2}K

$H'_T > H'_{Tlim}$ **UNVERIFIED**

b. Envelope Energy Performance in Winter through the calculation of ***$EP_{H,nd}$***

$EP_{H,nd}$ = 64.65kWh/m^{2}y

$EP_{H,nd,lim}$(2019,2021)= 13.42kWh/m^{2}y

The result is:

$EP_{H,nd}$ > 1.7*$EP_{H,nd,lim}$(2019,2021) → **LOW QUALITY OF THE ENVELOPE**

c. Envelope Energy Performance in Summer through the evaluation of ($\boldsymbol{A_{sol,est}}$) and ($\boldsymbol{Y_{IE}}$)

$A_{sol,est}/S$= 0.063

Y_{IE}=0.29W/m^{2}K

The thresholds are:

$(A_{sol,est}/S)_{lim}$= 0.03

$(Y_{IE})_{lim}$= 0.14W/m^{2}K

The result is:

$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ and $Y_{IE} > (Y_{IE})_{lim}$ → **LOW QUALITY OF THE ENVELOPE**

2. **Dynamic conditions**

From the results of the dynamic simulations we obtained the sensible energy demand for heating, called in the model *Q_heat* which corresponds to $Q_{H,nd}$ in the semi-stationary conditions and *Q_heat/S* corresponds to $EP_{H,nd}$.

If we analyse the behaviour of the floors, from the figure below, we can note that the most "energy-hungry" flats are located at the first and sixth floor.

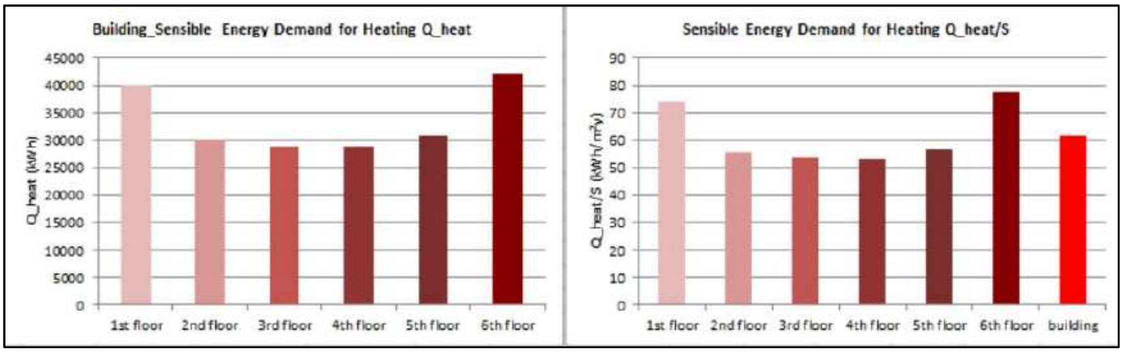


Figure 3.137: Qd1-Sensible Energy Demand for Heating. (On the left) the average values of *Q_heat* per month averaged across all the flats. (On the right) The average values of *Q_heat/S* per floor.

- From the analysis in semi-stationary conditions we found:

$EP_{H,nd}$ = 64.65 kWh/m^{2}y

- From the analysis in dynamic conditions we found:

Q_heat/S= 61.84 kWh/m^{2}y

The 2 values differ of about 5%.

WHOLE BUILDING

As in IOLO, we analysed the mean temperatures of the building as a whole, by making an average of all the flats values.

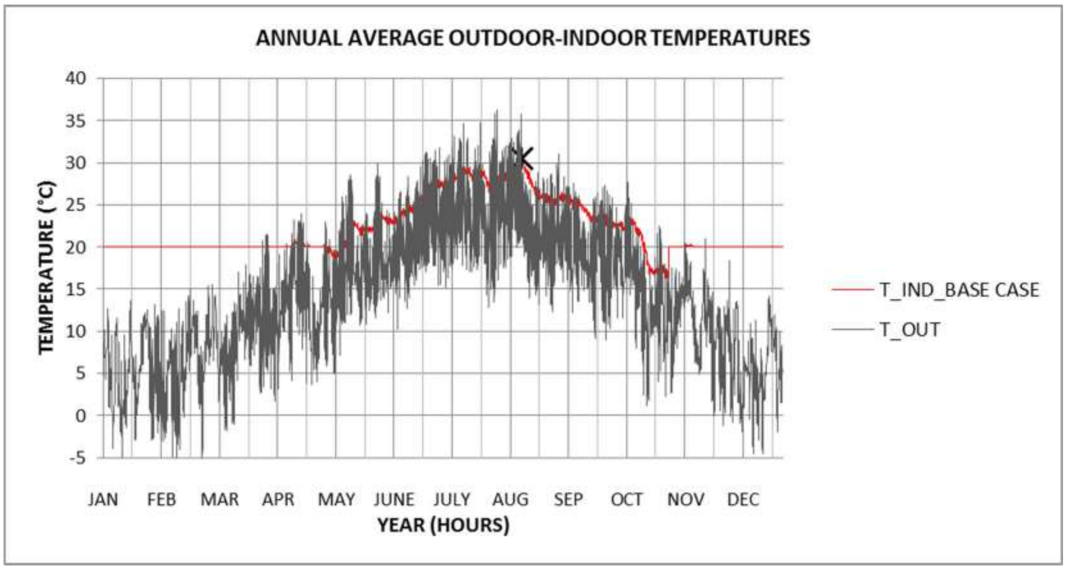


Figure 3.138: Qd1-Hourly trend of mean temperatures during all the year and the outdoor temperature hourly trend (T_out). These are values averaged across all the flats.

Obviously, the temperatures in Winter are always steady to 20°C, that is the set-point temperature for the heating system.

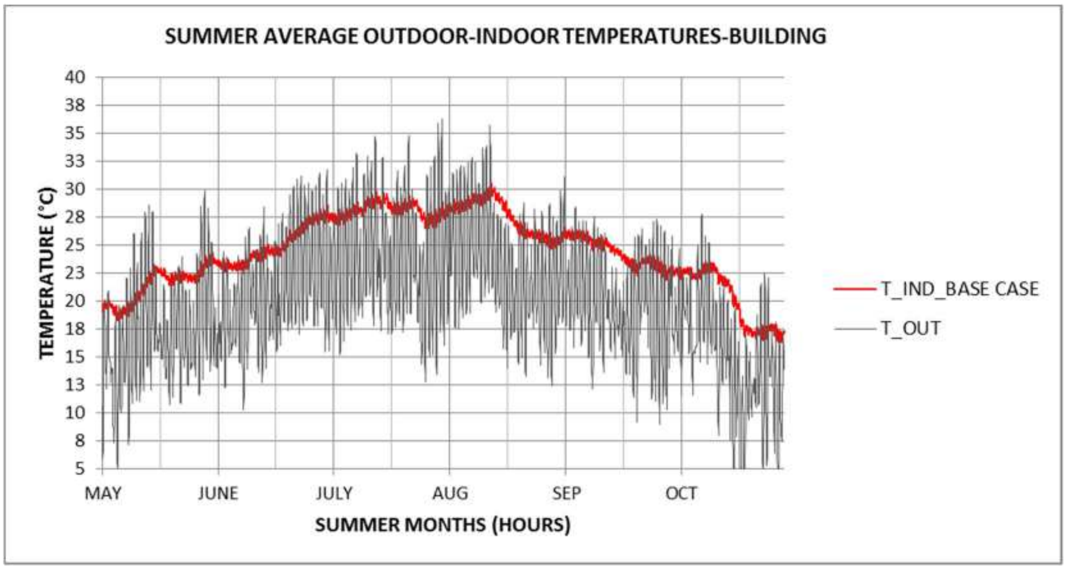


Figure 3.139: Qd1-Hourly trend of mean temperatures in Summer (average values of the whole building). Comparison between BASE CASE and outdoor temperatures.

The max value of temperatures occurs in August and at the 6° floor in the flat 4, while the min value is in October still at the fourth floor, but in FLAT 1. This trend is shown in the figure below, where the warmest floor is the 6° (red line).

SUMMER	CENTRAL MONTHS	JUNE	JULY	AUGUST
		BASE CASE	BASE CASE	BASE CASE
	MEAN T (°C)	24.97	28.16	27.70
	MAX T (°C)	30.18	31.40	31.74
	SHOULDER MONTHS	MAY	SEPTEMBER	OCTOBER
		BASE CASE	BASE CASE	BASE CASE
	MEAN T (°C)	21.44	24.51	20.26
	MAX T (°C)	25.72	27.65	24.16
	MIN T (°C)	17.46	21.02	15.20

Table 3.35: Qd1-Characteristic mean temperature values averaged across all the flats.

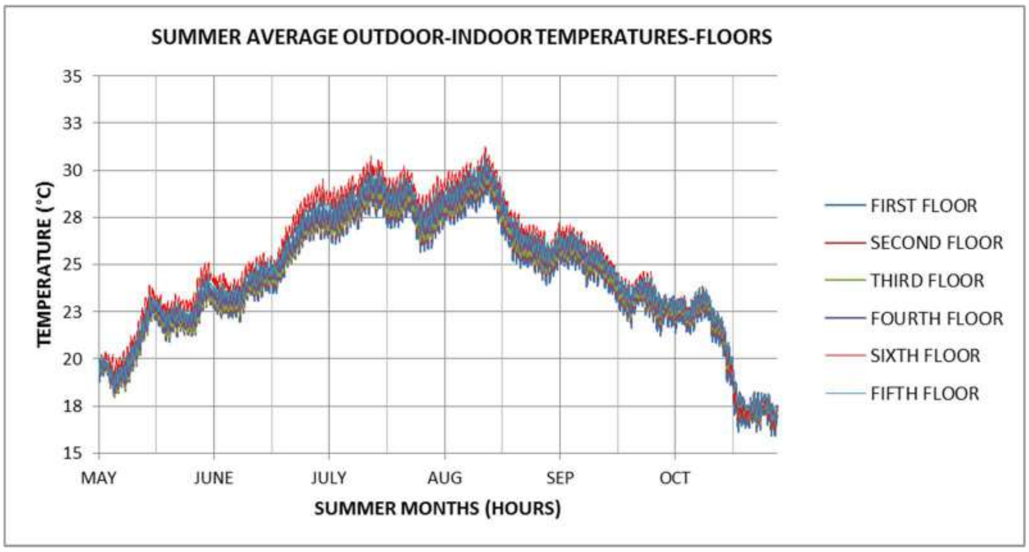


Figure 3.140: Qd1-Hourly trend of mean temperatures during Summer months per each floor.

From the figure below we can note that July and August present almost all the month temperatures above the comfort limit value (26°C) and in August more than half month has hours with temperature above 28°C.

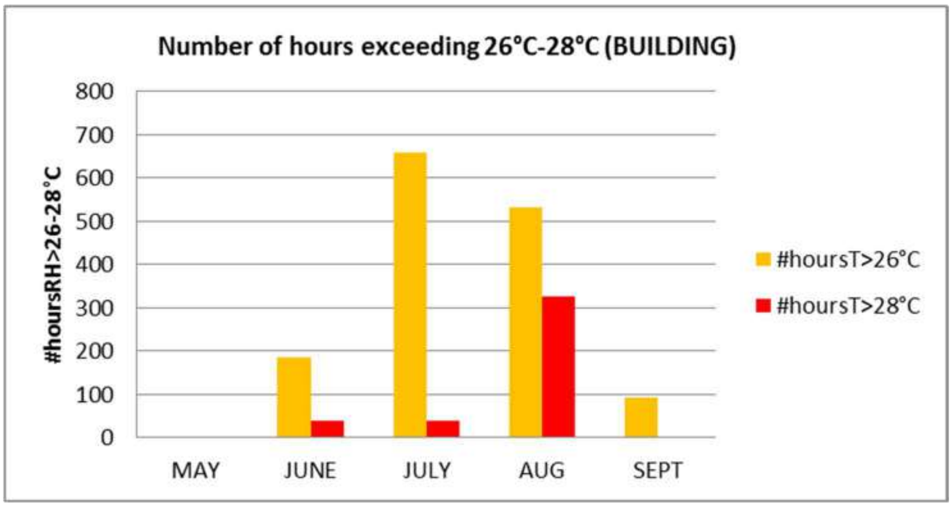


Figure 3.141: Qd1-#hoursT>26-28°C. Values averaged across all the flats.

As regard RH values, if we look at the fig below, the most humid months are May, June, September and October; in this case, the first 2 floors are the most humid, why the sixth floor is less humid compared to the others. (see table 3.36).

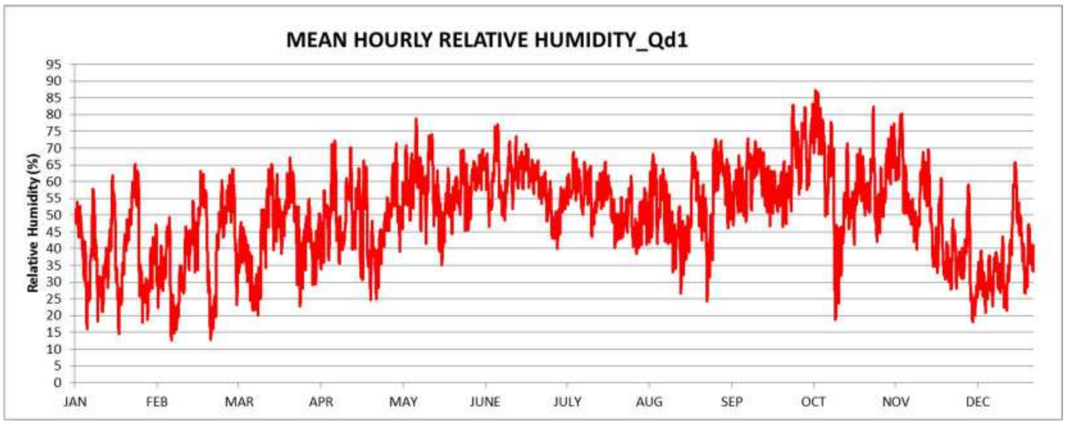


Figure 3.142: Qd1-Mean Relative Humidity trend during the year.

	FLOOR_MEAN RH (%)						**BUILDING MEAN RH (%)**
	1	2	3	4	**5**	**6**	
may	58.20	58.20	57.94	57.57	56.81	55.34	57.34
june	63.27	62.79	62.29	61.73	60.78	59.08	61.66
sep	61.79	60.85	60.17	59.67	59.08	58.34	59.98
oct	63.29	62.31	61.66	61.35	61.24	61.49	61.89

Table 3.36: Qd1-Mean RH value in the most humid months.

The fig. below shows what we already underlined before: May, June, September and October are the most humid months, and the last one presents almost half month with RH above 70%.

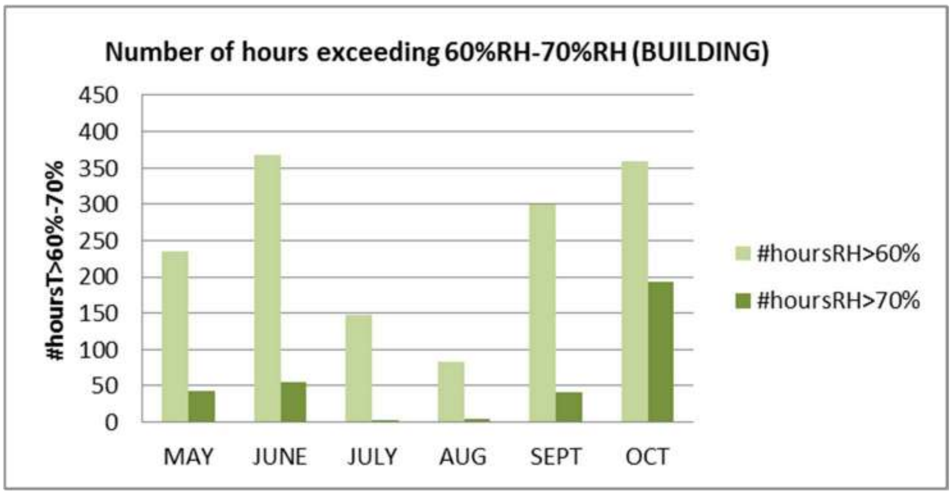


Figure 3.143: Qd1-#hoursRH>60-70%. Values averaged across all the flats.

As in IOLO, we will analyse the internal conditions of some flats, taken as sample cases. At the 1° floor the worst flat is still located at the extremity, while we decided to take into account FLAT 6 at the 4° floor, leaving out the other central floors (it behaves like FLOOR 2, 3 and 5 do not present particular differences compared to the other floors). At the 6° floor we will consider the warmest flat:

FLOOR 1	FLOOR 4	FLOOR 6
FLAT 1	FLAT 6	FLAT 4

Table 3.37: Qd1-Flats with the worst internal conditions chosen as sample flats to be monitored.

FLATS

FLOOR 1: FLAT 1

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 19.06°C;
- JUNE: The #hours>28°C are about 150 (720 total hours) °C;
- JULY: All the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and almost 400 exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (15.84°C).

The 3.144 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	25.83	28.82	28.03
MAX T (°C)	29.94	30.72	31.09
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.20	24.62	20.10
MAX T (°C)	25.64	27.17	23.67
MIN T (°C)	19.06	21.58	15.84

Table 3.38: Qd1-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 1-FLAT 1).

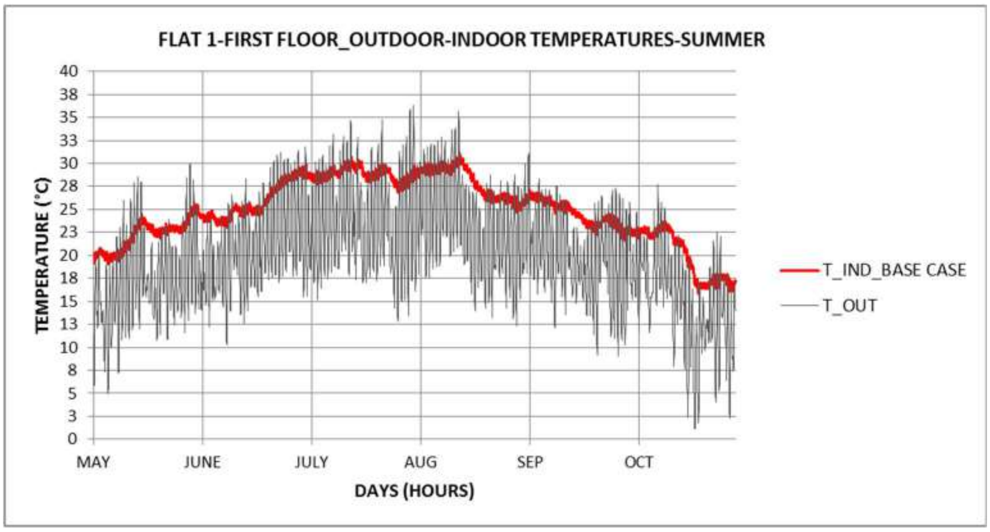


Figure 3.144: Qd1-Hourly trend of temperatures in Summer (FLOOR 1-FLAT 1).

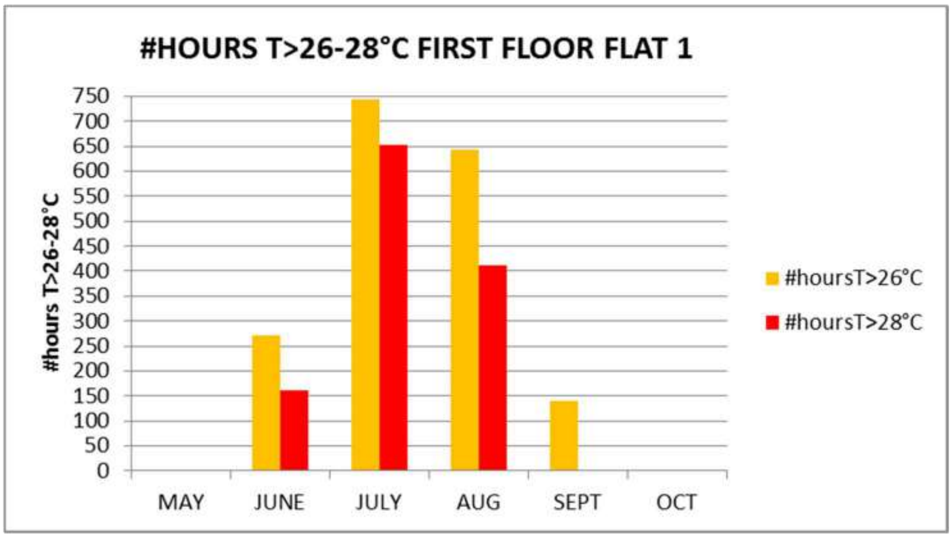


Figure 3.145: Qd1-Number of hours exceeding 26-28°C during Summer months (FLOOR 1-FLAT 1).

RELATIVE HUMIDITY (RH):

- MAY: About half month has hours above 60% of RH and 150h exceeding 70%;
- JUNE: About 250 hours above 60%RH; it does not have hours above 70%RH;
- JULY: No relevant levels of RH;
- AUGUST: No relevant levels of RH;
- SEPTEMBER: It presents about 300 hours>60%, while it does not have hours>70%;
- OCTOBER: It is the most humid month. It has about 400 hours above 60% of RH, of whom 200h present RH>70%.

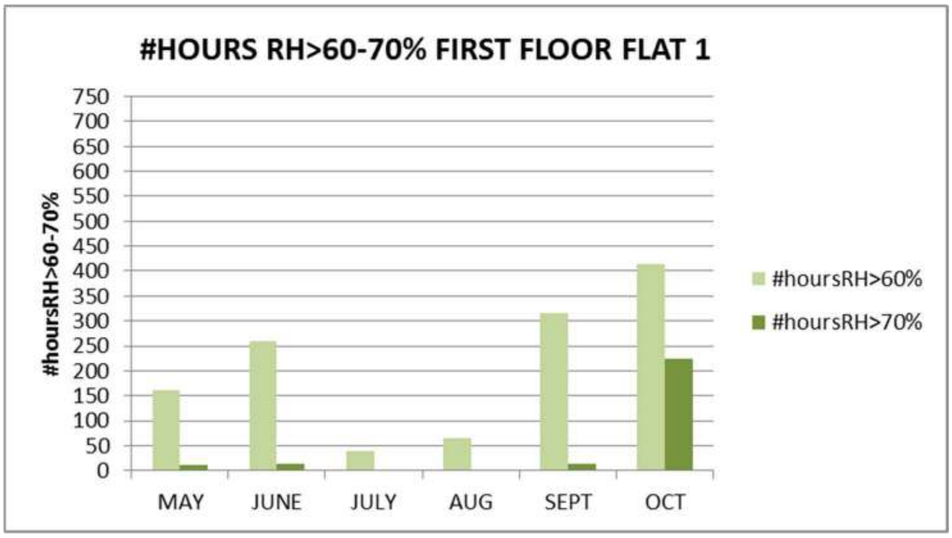


Figure 3.146: Qd1-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 1-FLAT 1)..

COMFORT INDEX (PPD VALUES):

The figure below shows that in July there are no hours with PPD<6-10-15%, while in August the level of comfort is improved with respect to IOLO results. In September almost all the month presents hours with PPD<15% and a good percentage of hours with PPD<10%; in May and in June about 450 hours has PPD<15%. In October the comfort conditions are quite low, probably due to the low temperatures and high levels of RH.

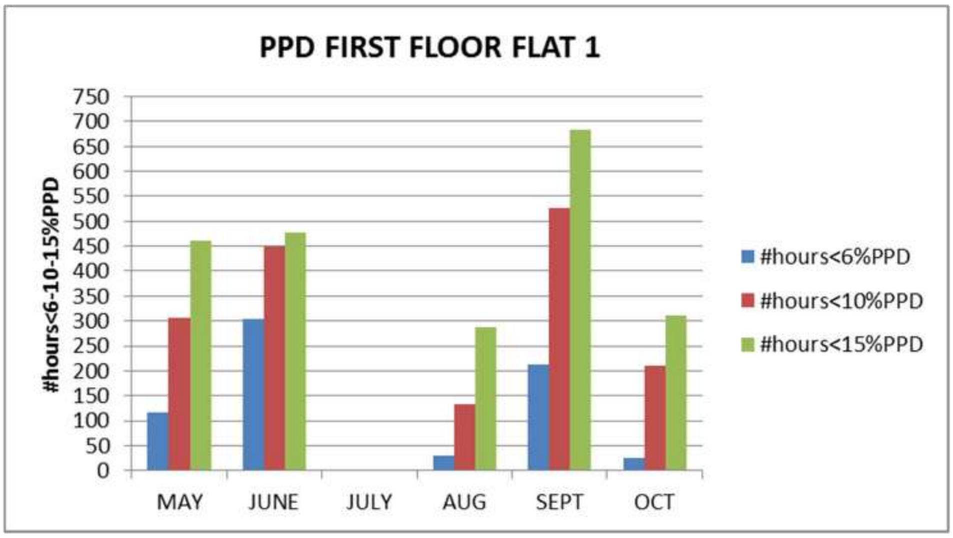


Figure 3.147: Qd1-Number of hours with PPD<6-10-15% (FLOOR 1-FLAT 1).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 18.49°C;
- JUNE: The #hours>28°C are about 50 (720 total hours) °C;
- JULY: All the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and 450h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.51°C).

The fig. 3.148 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	25.39	28.74	28.28
MAX T (°C)	28.93	30.48	31.11
	MAY	**SEP**	**OCT**
MEAN T (°C)	21.86	25.03	20.75
MAX T (°C)	24.65	27.13	23.97
MIN T (°C)	18.49	22.26	16.51

Table 3.39: Qd1-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 4-FLAT 6).

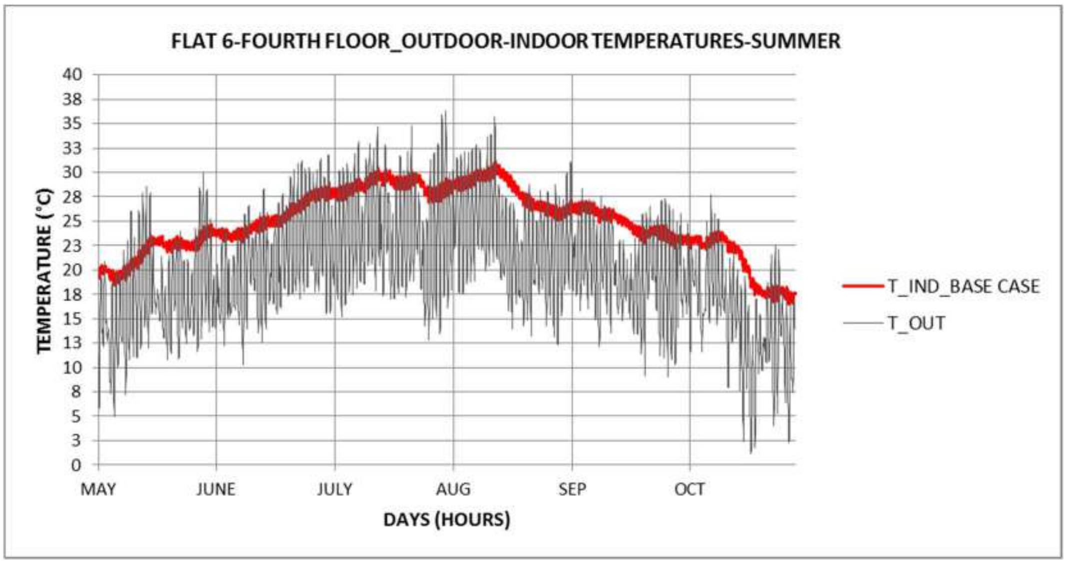


Figure 3.148: Qd1-Hourly trend of temperatures in Summer (FLOOR 4-FLAT 6).

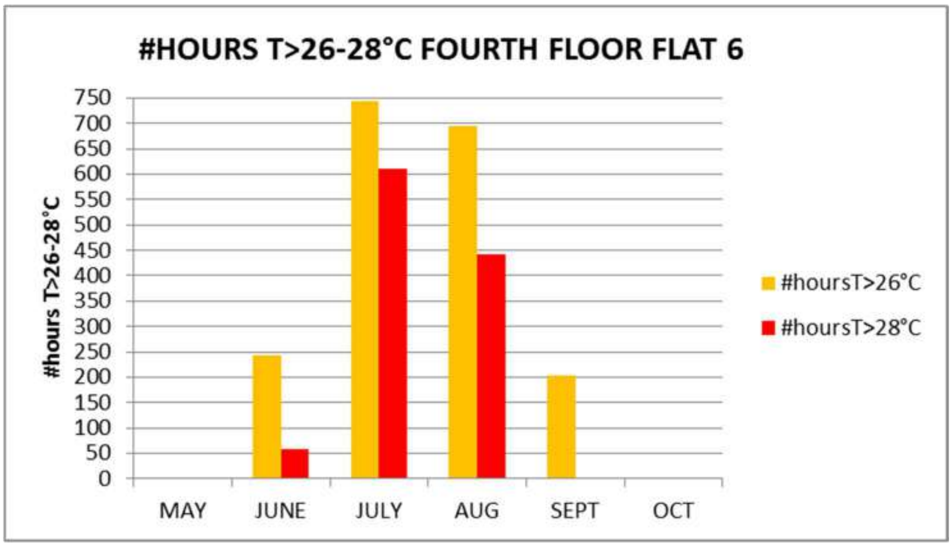


Figure 3.149: Qd1-Number of hours exceeding 26-28°C during Summer months (FLOOR 4-FLAT 6).

RELATIVE HUMIDITY (RH):

The most humid months are May, June, September and October, even if the hours above 70% are not relevant. Indeed:

- MAY: 200 hours above 60% of RH no relevant hours with Relative Humidity above 70%;
- JUNE: Half month (350h) presents hours above 60%, but no relevant hours above 70%RH;
- JULY: No hours above 70%RH; in general we can say that the flat does not have humidity problems;
- AUGUST: No hours above 70%RH; in general we can say that the flat does not have humidity problems;
- SEPTEMBER: 250 hours exceeding 60% of RH;
- OCTOBER: It is the most humid month also in this case, it presents about 400 hours with RH above 60% and of these about 150 hours exceed 70%RH.

This flat does not have particular humidity problems.

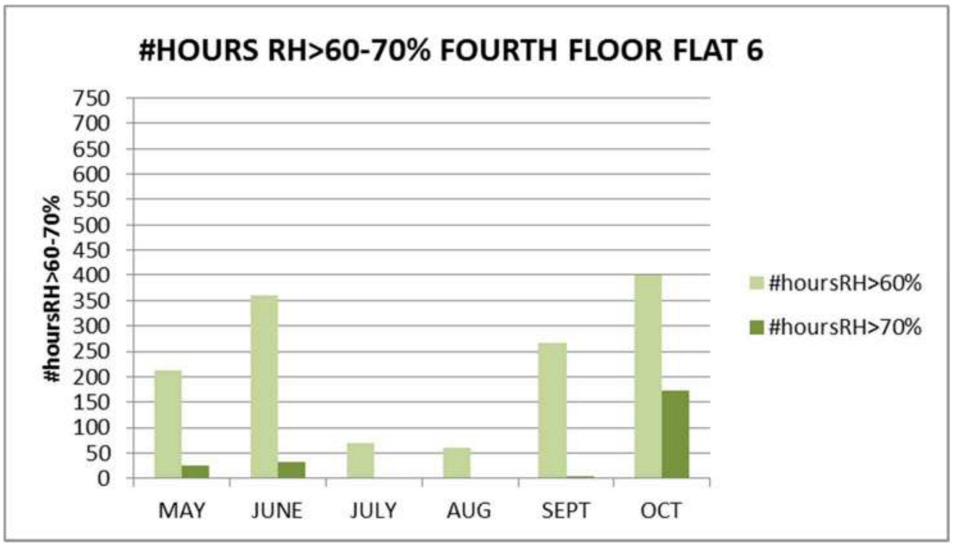


Figure 3.150: Qd1-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 4-FLAT 6).

COMFORT INDEX (PPD VALUES):

As in the previous flat, in July there are no hours with PPD<6-10-15%, while in August there is a little improvement compared to IOLO buildings. In May the comfort levels decrease compared to the previous flat because the mean indoor temperatures are slightly lower. In June the 2 flats behave the same as well as in September, when the flat demonstrates a good level of comfort with the right levels of RH and temperatures. Conversely in October there is an improvement compared to the previous flat, due to a slight increase of indoor temperature values.

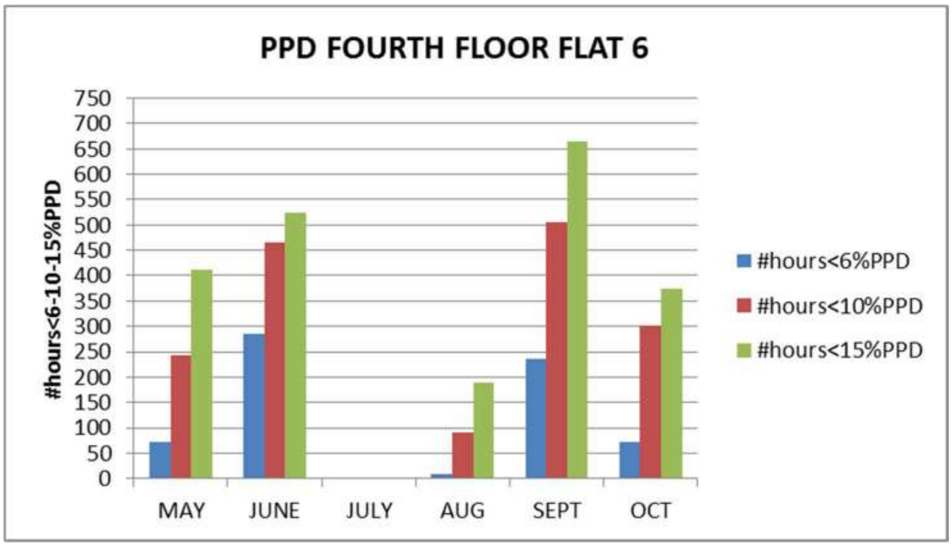


Figure 3.151: Number of hours with PPD<6-10-15% (FLOOR 4-FLAT 6).

FLOOR 6: FLAT 4

This is the warmest flat in the building.

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 19.12°C;
- JUNE: The #hours>28°C are about 200 (720 total hours) °C;
- JULY: All the month presents hours above 28°C (744 total hours);
- AUGUST: All the month presents hours above 26°C (744 total hours) and 500h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The mean temperature value is close to the threshold of comfort range (20.63°C).

The fig. 3.152 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	26.22	29.64	28.93
MAX T (°C)	30.18	31.40	31.74
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.56	25.41	20.63
MAX T (°C)	25.72	27.65	24.16
MIN T (°C)	19.12	22.25	16.22

Table 3.40: Qd1-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 6-FLAT 4).

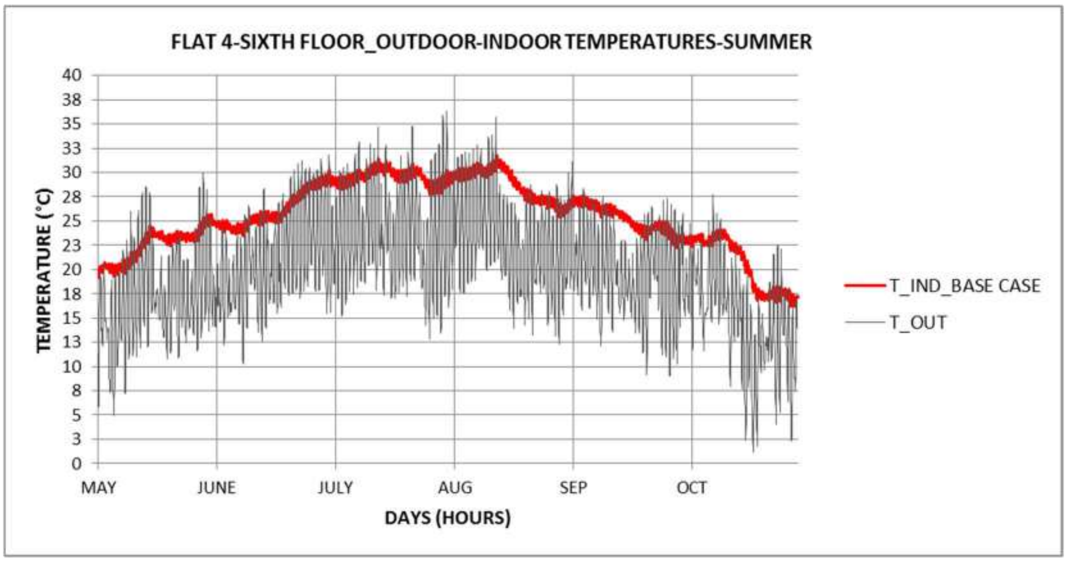


Figure 3.152: Qd1-Hourly trend of temperatures in Summer (FLOOR 6-FLAT 4).

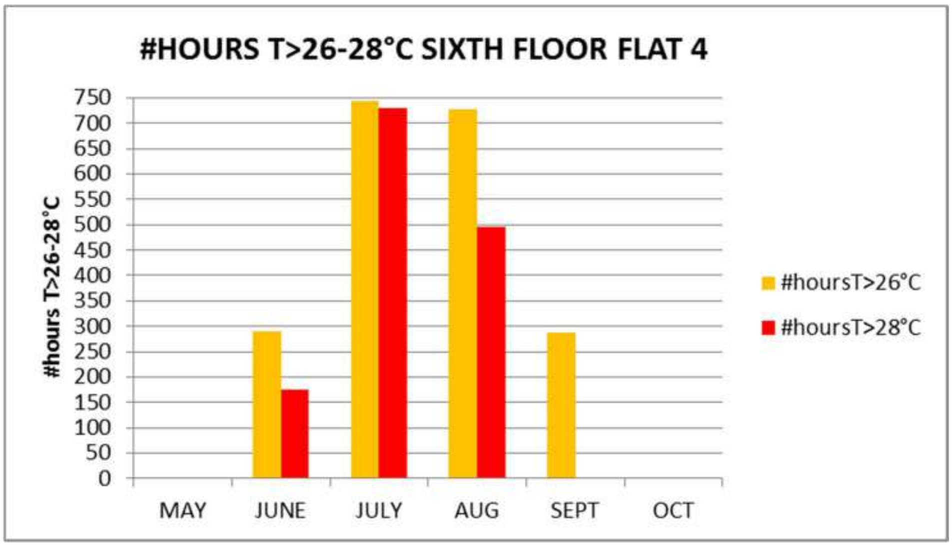


Figure 3.153: Qd1-Number of hours exceeding 26-28°C during Summer months (FLOOR 6-FLAT 4).

RELATIVE HUMIDITY (RH):

Also this flat does not present high levels of Relative Humidity:

- MAY: About 150 hours have RH above 60%; No hours above 70%RH;
- JUNE: About 200 hours have RH above 60%; No hours above 70%RH;
- JULY: The levels of RH are negligible;
- AUGUST: The levels of RH are negligible;
- SEPTEMBER: 200 hours exceed 60% of RH;
- OCTOBER: It is the most humid month also in this case. The flat has 400 hours exceeding the 60% and 150h with RH>70%.

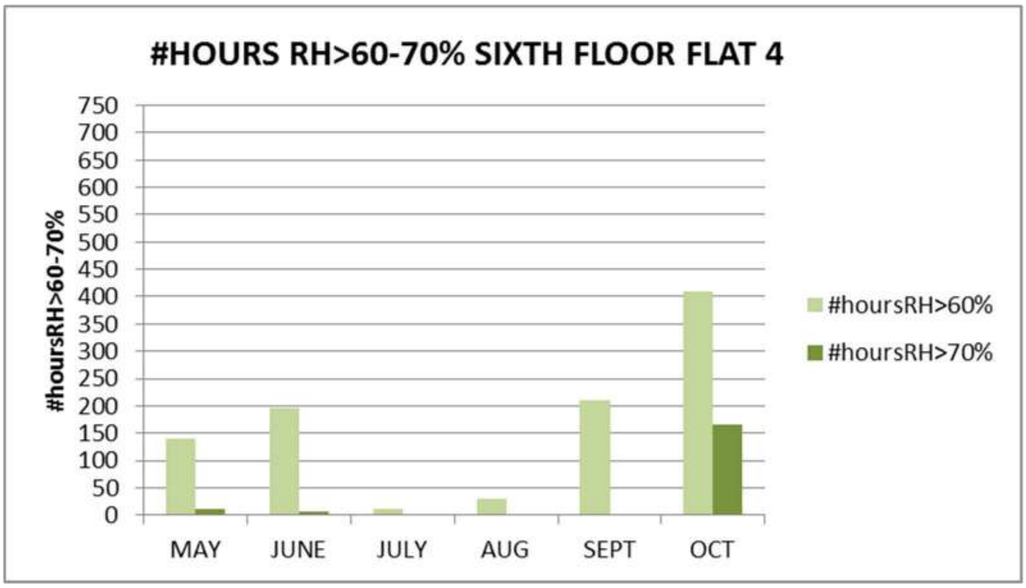


Figure 3.154: Qd1-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 6-FLAT 4).

COMFORT INDEX (PPD VALUES):

In July and in August there are no hours with PPD<6-10-15%, due to the high values of indoor temperatures.

Since this flat is the warmest compared to the other flats analysed in this section, also in May the temperatures are higher; this leads to an increase of comfort levels and in comparison with the other flats, as regards this month, the flat behave the best.

Conversely, the increase of temperatures in June, leads to a decrease of comfort levels with respect to the FLAT 1-FLOOR 1. It has the same behaviour than the previous flat.

In October the results are similar to the other apartments, except a slight improvement compared to FLAT 1-FLOOR 1 (it presents a mean value of temperature of 20.10°C, the lowest value making a comparison between all the flats).

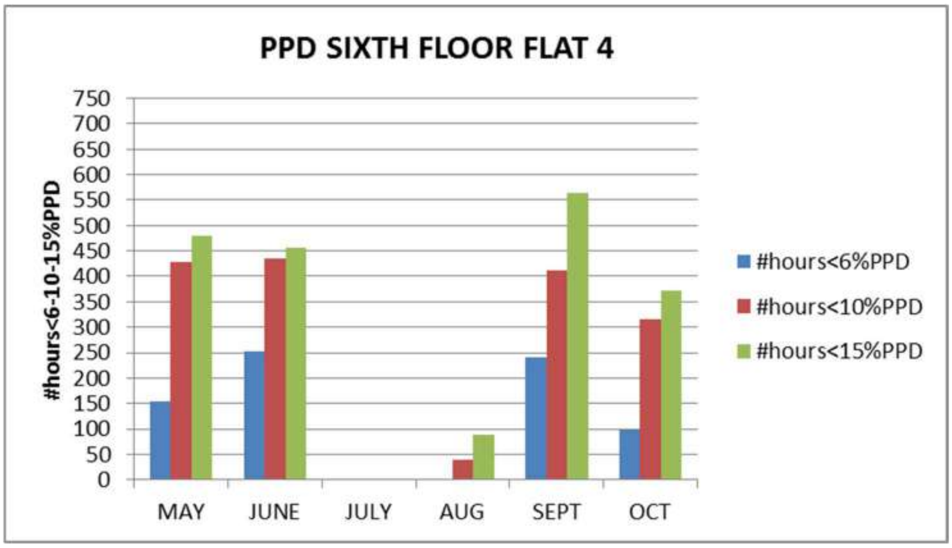


Figure 3.155: Qd1-Number of hours with PPD<6-10-15% (FLOOR 6-FLAT 4).

SYNTHESIS

Summarizing the results of the BASE CASE in Qd1

WHOLE BUILDING:

Winter Season

- Low quality of the envelope;
- Heat losses;
- Energy class: F;

Summer Season

- Low quality of the envelope;
- Overheating in the flats during the central months: temperatures above 28°C all the month in July and in August;
- High levels of RH in June, September and October.

FLATS:

We can say that the warmest flats are located at the 1° floor (FLAT 1) and at the 6° floor (FLAT 4) except in October when all the flats present almost the same mean temperature values. The warmest flat in this month is FLAT 6 at 4° floor.

All the flats present similar levels of RH and do not present particular humidity issues.

In July and August all the flats have low levels of internal comfort, due to the high values of temperatures.

In June the flat with better comfort conditions is FLAT 1 at the first floor. The increase of temperatures, lowers the indoor comfort. Conversely, the flat at the 6° floor presenting the highest temperatures values, is the worst apartment in this month, even if RH levels decrease.

Instead in May, the flat located at the 6° floor, presents better comfort conditions, due to higher temperatures, acceptable for this month.

The flat at the first floor has higher levels of comfort in comparison to the others, due to lower temperatures.

In October the “best” flat is FLAT 4 at the 6° floor, because, compared to FLAT 1 at 1° floor, it has higher temperatures values, while in comparison with the flat at 4° floor lower RH levels.

Summarizing we can say that in the central months, the higher temperatures lead to low levels of indoor comfort and this is a common characteristic of all the flats. As regards the shoulder months, the flats which in general are the warmest, behave better in May and in October (the increase of temperatures leads to positive results). Conversely, in September, better conditions occur when the flat presents lower temperatures (FLAT 1-FLOOR 1).

Qa19

1. Semi-stationary conditions

In the table below a summary of necessary data to evaluate the Energy Demand for heating and the final Global Energy Performance *($EP_{gl,nren}$)* are listed:

CANOVA-Qa19	
TOTAL DISPERSANT SURFACES ***(S)***	2107m^2
HEATED VOLUME ***(V)***	3764m^3
USEFUL AREA ***(A)***	1125m^2
SHAPE FACTOR ***(S/V)***	0.56m^{-1}
WINDOWS AREA/*S*	0.15

The figure below shows the thermal zones of Qa19: 6 flats/floor for a total of 4 floors. Accordingly, we will have 24 thermal zones. Each thermal zone corresponds to a flat, both in the semi-stationary conditions and in dynamic ones.

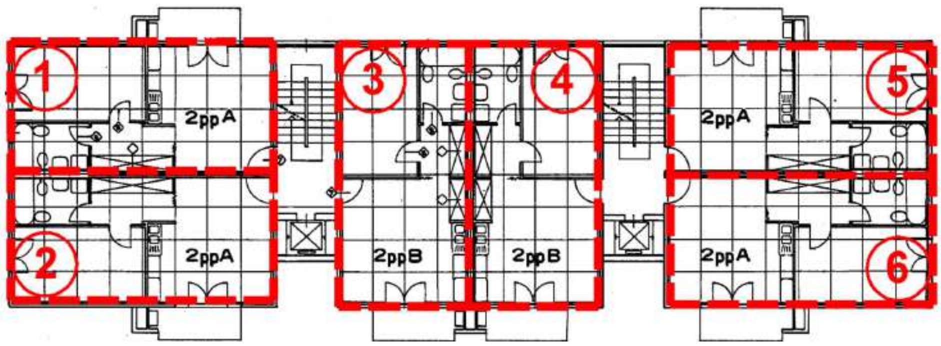


Figure 3.156: Thermal zones in Qa19 typical plan.

The Global Energy Performance index (***$EP_{gl,nren}$***) is:

$EP_{gl,nren}$= 136.70kWh/m^{2}y
$EP_{gl,nren,rif}$(2019,2021)= 49.76kWh/m^{2}y

The building Energy Class is **F**, in fact:

2.60* $EP_{gl,nren,rif}$(2019,2021) < **$EP_{gl,nren}$** ≤ 3.50* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K
H'_T= 1.14 W/m^{2}K
$H'_T > H'_{Tlim}$ **UNVERIFIED**

b. Envelope Energy Performance in Winter through the calculation of ***$EP_{H,nd}$***

$EP_{H,nd}$ = 68.27kWh/m^{2}y

$EP_{H,nd,lim}$(2019,2021)= 11.94kWh/m^{2}y

The result is:

$EP_{H,nd}$ > 1.7*$EP_{H,nd,lim}$(2019,2021) → **LOW QUALITY OF THE ENVELOPE**

c. Envelope Energy Performance in Summer through the evaluation of (***$A_{sol,est}$***) and (***Y_{IE}***)

$A_{sol,est}/S$= 0.082

Y_{IE}=0.19W/m^{2}K

The thresholds are:

$(A_{sol,est}/S)_{lim}$= 0.03

$(Y_{IE})_{lim}$= 0.14W/m^{2}K

The result is:

$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ *and* $Y_{IE} > (Y_{IE})_{lim}$ → **LOW QUALITY OF THE ENVELOPE**

2. Dynamic conditions

From the results of the dynamic simulations we obtained the sensible energy demand for heating, called in the model *Q_heat* which corresponds to $Q_{H,nd}$ in the semi-stationary conditions and *Q_heat/S* corresponds to $EP_{H,nd}$.

If we analyse the behaviour of the floors, from the figure below, we can note that the most "energy-hungry" flats are located at the first and fourth floor.

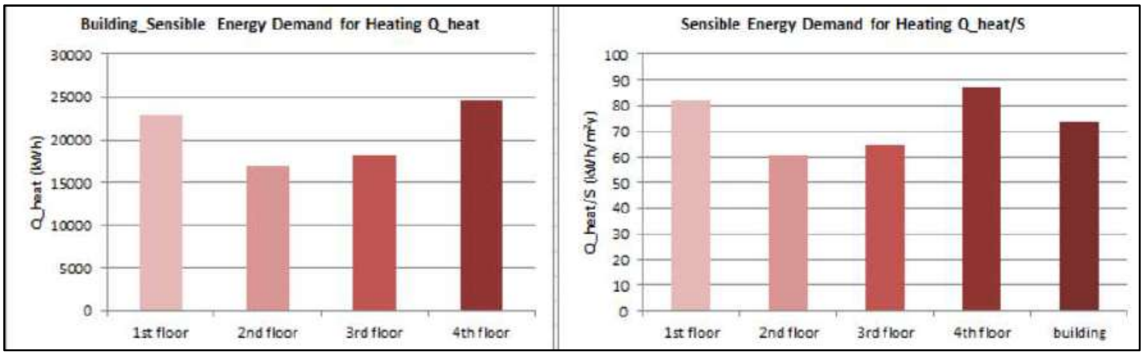


Figure 3.157: Qa19-Sensible Energy Demand for Heating. (On the left) the average values of *Q_heat* per month averaged across all the flats. (On the right) The average values of *Q_heat/S* per floor.

- From the analysis in semi-stationary conditions we found:

$EP_{H,nd}$ = 68.27 kWh/m^{2}y

- From the analysis in dynamic conditions we found:

Q_heat/S= 73.57 kWh/m^{2}y

The 2 values differ of about 10%.

WHOLE BUILDING

As in Qd1, we analysed the mean temperatures of the building as a whole, by making an average of all the flats values. Obviously, the temperatures in Winter are always steady, around 20°C, that is the set-point temperature for the heating system.

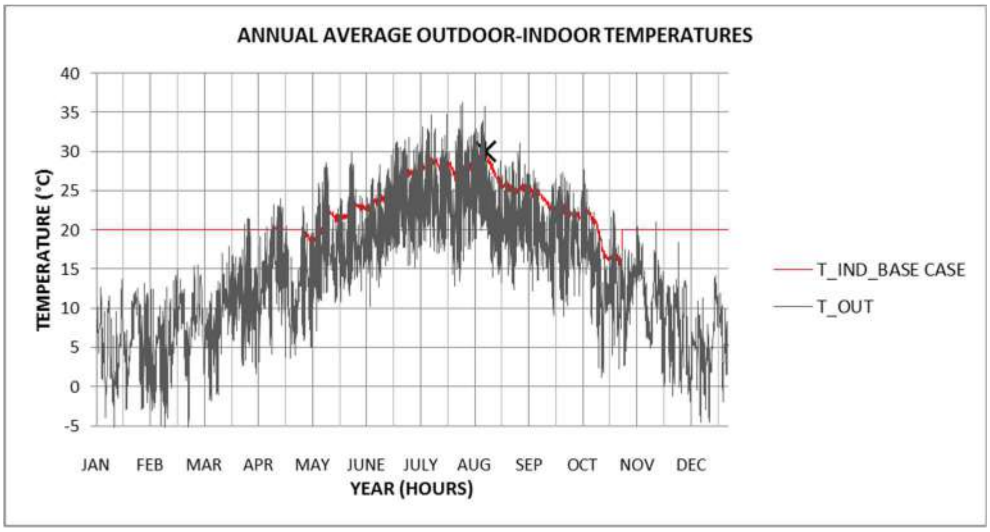


Figure 3.158: Qa19-Hourly trend of mean temperatures during all the year and the outdoor temperature hourly trend (T_out). These are values averaged across all the flats.

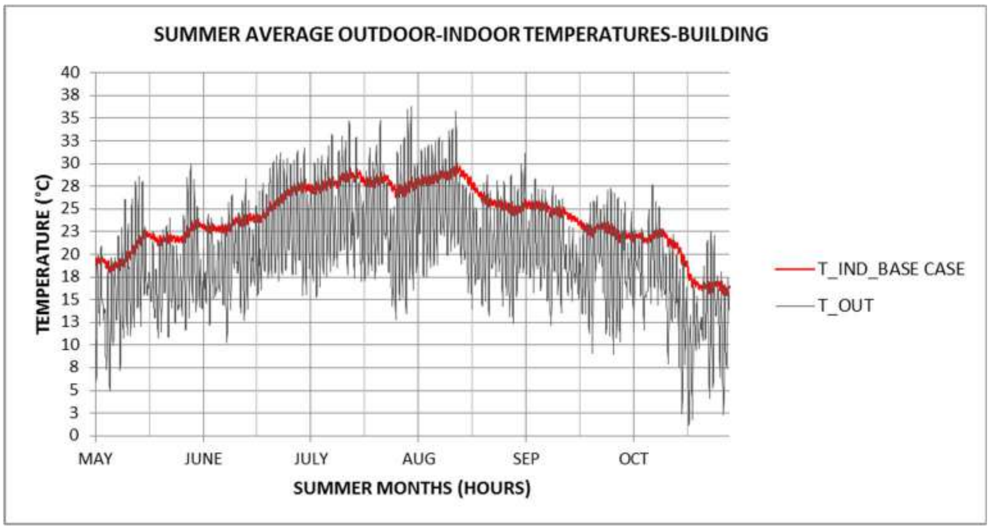


Figure 3.159: Qa19-Hourly trend of mean temperatures in Summer (average values of the whole building). Comparison between BASE CASE and outdoor temperatures.

The maximum value of temperatures occurs in August and at the 4° floor in the FLAT 4, while the minimum value is in October still at the third floor, but in FLAT 6. This trend is shown in the figure below, where the warmest floor is the 6° (violet line).

SUMMER	**CENTRAL MONTHS**	**JUNE**	**JULY**	**AUGUST**
		BASE CASE	**BASE CASE**	**BASE CASE**
	MEAN T (°C)	24.59	27.91	27.36
	MAX T (°C)	29.82	30.90	31.13
	SHOULDER MONTHS	**MAY**	**SEPTEMBER**	**OCTOBER**
		BASE CASE	**BASE CASE**	**BASE CASE**
	MEAN T (°C)	21.04	24.04	19.65
	MAX T (°C)	25.17	27.07	23.40
	MIN T (°C)	16.88	20.12	14.76

Table 3.41: Qa19-Characteristic mean temperature values averaged across all the flats.

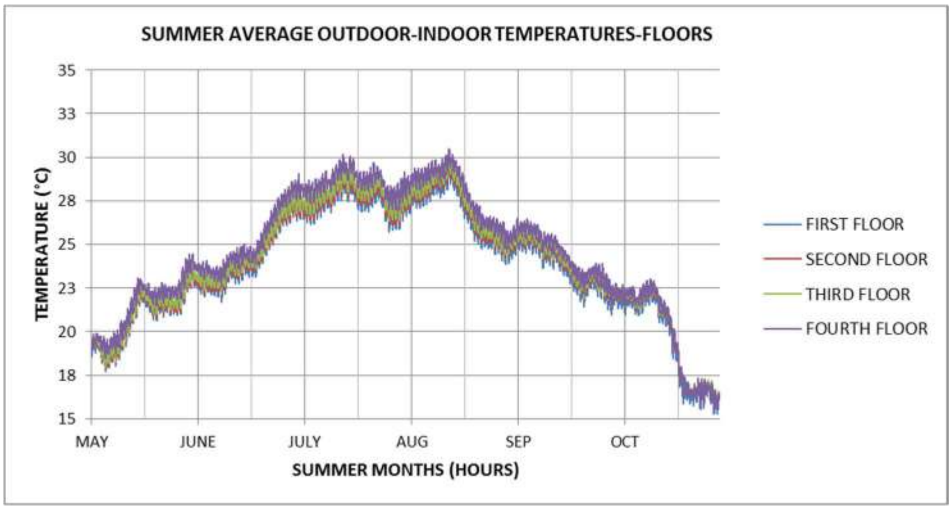


Figure 3.160: Qa19-Hourly trend of mean temperatures during Summer months per each floor.

From the figure below, that represents the behaviour of the whole building, the warmest months are July and August, even if the percentage of hours exceeding 28°C is not high, but being an average across all the flats, a more detailed study of some flats is needed.

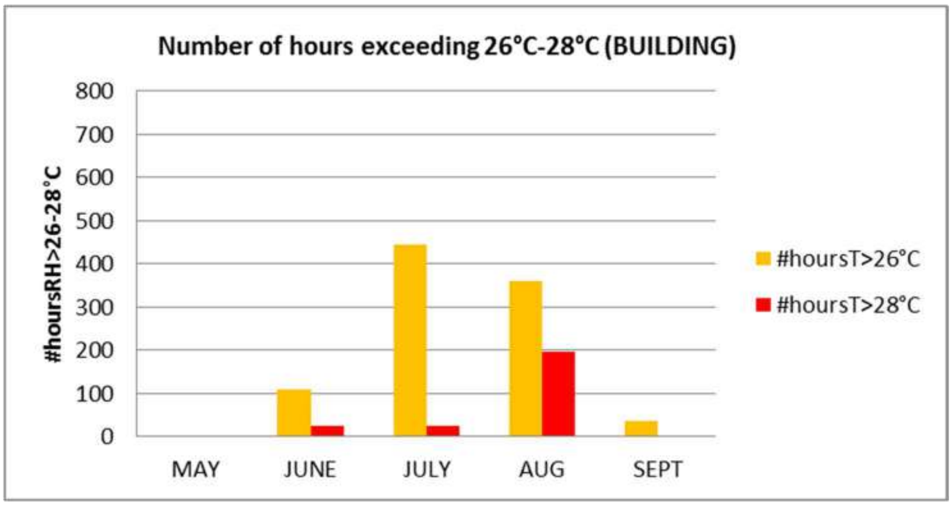


Figure 3.161: Qa19-#hoursT>26-28°C. Values averaged across all the flats.

As regards RH values, if we look at the figure below, as in the previous buildings, the most humid months are May, June, September and October. In July and in August the Relative Humidity is low, while the indoor temperatures are high.

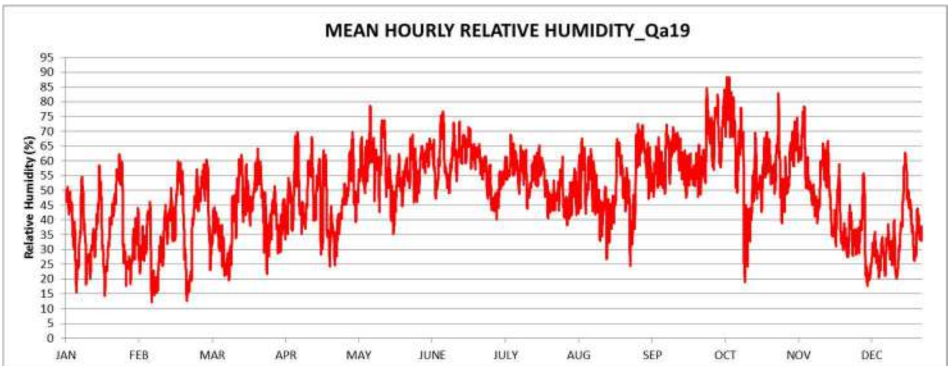


Figure 3.162: Qa19-Mean Relative Humidity trend during the year.

According to the table 3.42, the most humid floor is the 1°, while among the central floors of the building (2° and 3° floor), the most humid is the second floor. The flats present the highest humidity levels in October, regardless of the floor.

	FLOOR_MEAN RH (%)				**BUILDING MEAN RH (%)**
	1	2	3	4	
may	57.51	57.18	56.53	55.12	56.59
june	62.70	62.03	61.10	59.31	61.29
sep	61.22	60.21	59.51	58.55	59.87
oct	63.00	62.01	61.64	61.59	62.06

Table 3.42: Qa19-Mean RH value in the most humid months.

The figure below confirms what we said before. May June, September and October are the most humid months, but the number of hours exceeding the 70% of Relative Humidity is not high: the building does not present particular humidity issues. Nevertheless, it is necessary to study more in detail the indoor conditions of the flats.

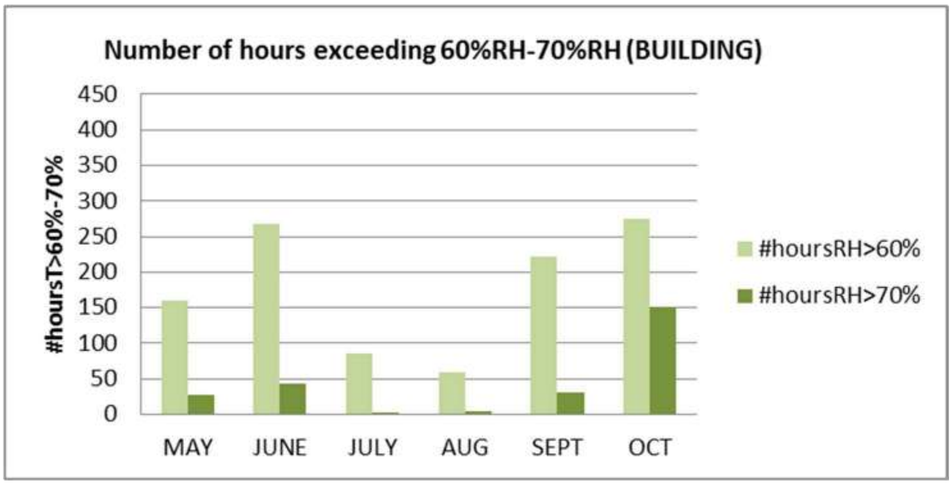


Figure 3.163: Qa19-#hoursRH>60-70%. Values averaged across all the flats.

As in the other buildings, we will analyse the internal conditions of some flats, taken as sample cases. The typical plan of the building, divided into 3 precise blocks, leads to consider the flats according to their location.

As in the previous examples, it was worth to choose at least one flat at the extremity in the 1° or 4° floor. As regards the first floor, the warmest flat is FLAT 4, but for taking into account the more external flat, we have chosen FLAT 1, while at the fourth floor the warmest flat, in the central box (FLAT 4). Among the central floors we have chosen the second floor (the most humid), taking into account the warmest flat (FLAT 4):

FLOOR 1	**FLOOR 2**	**FLOOR 4**
FLAT 1	**FLAT 4**	**FLAT 4**

Table 3.43: QFlats with the worst internal conditions chosen as sample flats to be monitored.

FLATS

FLOOR 1: FLAT 1

The flat does not present high temperature values as in the other examples, but it is worth to study the behaviour of this apartment in order to understand if the strategies we will apply can match also the needs of flats like this, with less severe indoor conditions.

TEMPERATURES:

- MAY: The mean temperature value is close to 20°C (the minimum value in order to be within the comfort range) and the minimum value is around 17°C;
- JUNE: The flat has indoor temperature values under 26°C for almost all the month;
- JULY: All the month presents hours above 26°C (744 total hours), but temperatures do not exceed 28°C;
- AUGUST: Almost 500 hours (744 total hours) are above 26°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (15.34°C). The mean value is under the low threshold for comfort range (20°C).

	JUNE	JULY	AUG
MEAN T (°C)	23.52	26.63	26.24
MAX T (°C)	27.00	28.18	28.82
	MAY	**SEP**	**OCT**
MEAN T (°C)	20.22	23.30	19.32
MAX T (°C)	22.83	25.23	22.45
MIN T (°C)	17.41	20.81	15.34

Table 3.44: Qa19-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 1-FLAT 1).

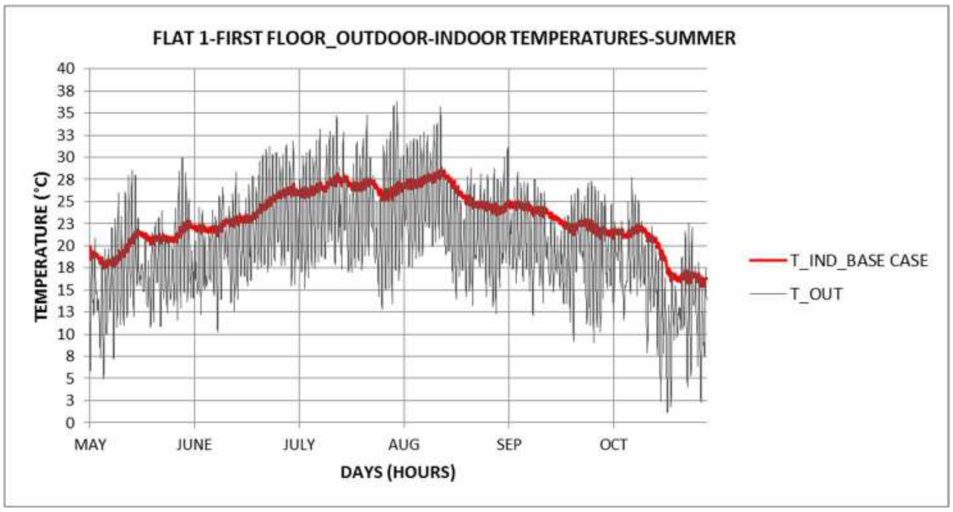


Figure 3.164: Qa19-Hourly trend of temperatures in Summer (FLOOR 1-FLAT 1).

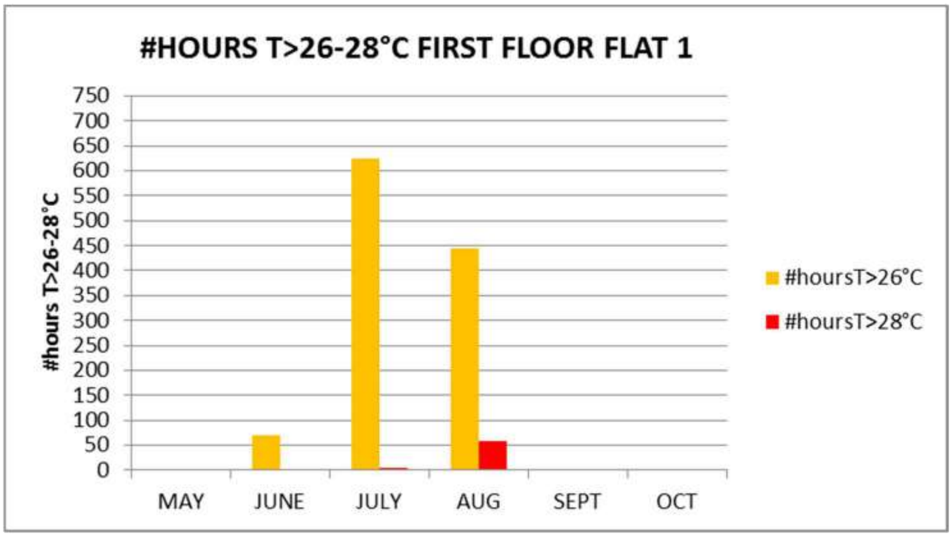


Figure 3.165: Qa19-Number of hours exceeding 26-28°C during Summer months (FLOOR 1-FLAT 1).

RELATIVE HUMIDITY (RH):

- MAY: About half month has hours above 60% of RH and 100h exceeding 70%;
- JUNE: About 600 hours above 60%RH; 150 hours above 70%RH;
- JULY: No relevant levels of RH;
- AUGUST: No relevant levels of RH;
- SEPTEMBER: It presents about 450 hours>60%, 100 hours>70%;
- OCTOBER: It is the most humid month along with June. It has about 450 hours above 60% of RH, of whom 250h present RH>70%.

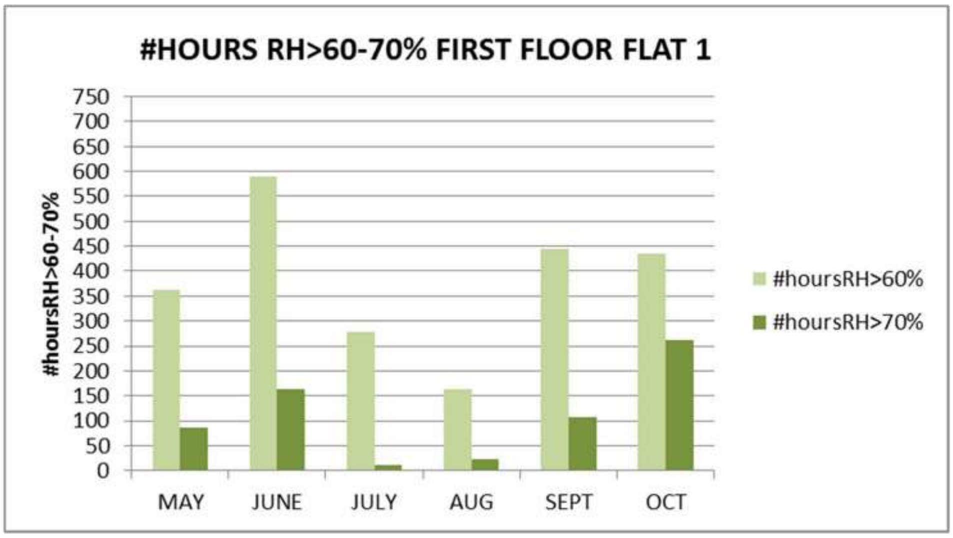


Figure 3.166: Qa19-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 1-FLAT 1)..

COMFORT INDEX (PPD VALUES):

As I mentioned before, this flat presents differences in the internal conditions compared to the other examples. Indeed, as it is shown in the figure below, the flat in July and August presents better comfort conditions, compared to all the examples explained in the previous sections, due to temperature values more acceptable. The worst months are May and October, when the too low temperature values lead to indoor discomfort. In September and in June the comfort conditions are in line with the flats in Iolo or with Qd1.

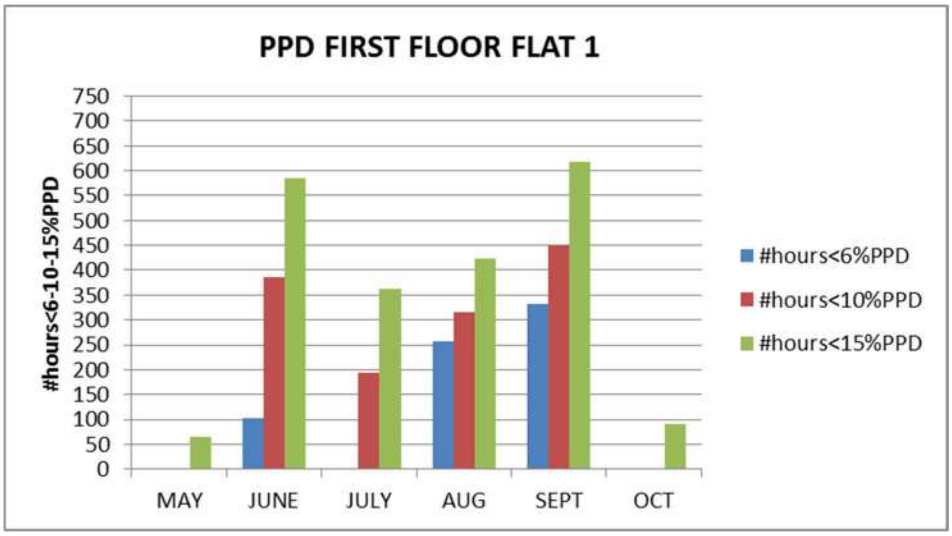


Figure 3.167: Qa19-Number of hours with PPD<6-10-15% (FLOOR 1-FLAT 1).

FLOOR 2: FLAT 4

This flat is the warmest flat located at the second floor, it has therefore high indoor temperatures, especially during the central months.

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 18.45°C;
- JUNE: The #hours>28°C are about 50 (720 total hours);
- JULY: All the month presents hours above 26°C (744 total hours) and almost all of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and 450h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (15.91°C).

The fig. 3.168 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months, while in October there is a steep decrease.

	JUNE	JULY	AUG
MEAN T (°C)	25.45	28.96	28.34
MAX T (°C)	29.20	30.59	30.96
	MAY	**SEP**	**OCT**
MEAN T (°C)	21.77	24.85	20.24
MAX T (°C)	24.68	26.94	23.40
MIN T (°C)	18.45	22.06	15.91

Table 3.45: Qa19-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 2-FLAT 4).

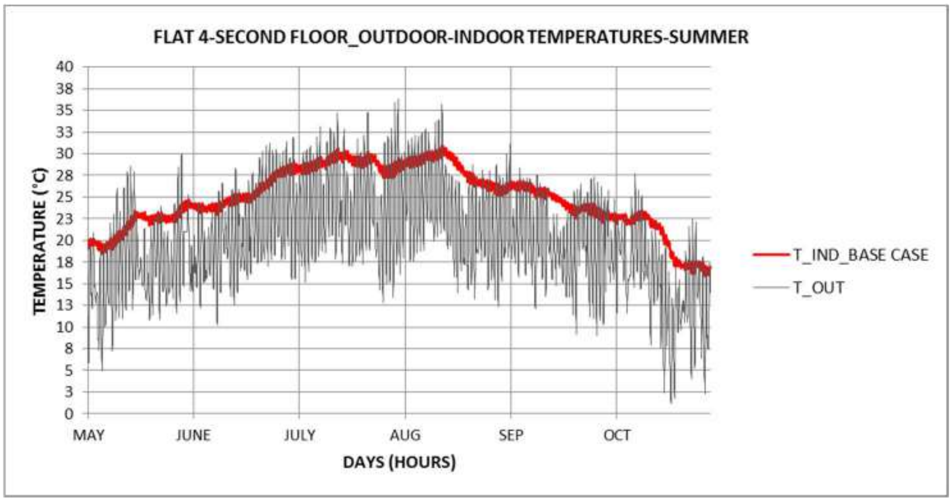


Figure 3.168: Qa19-Hourly trend of temperatures in Summer (FLOOR 2-FLAT 4).

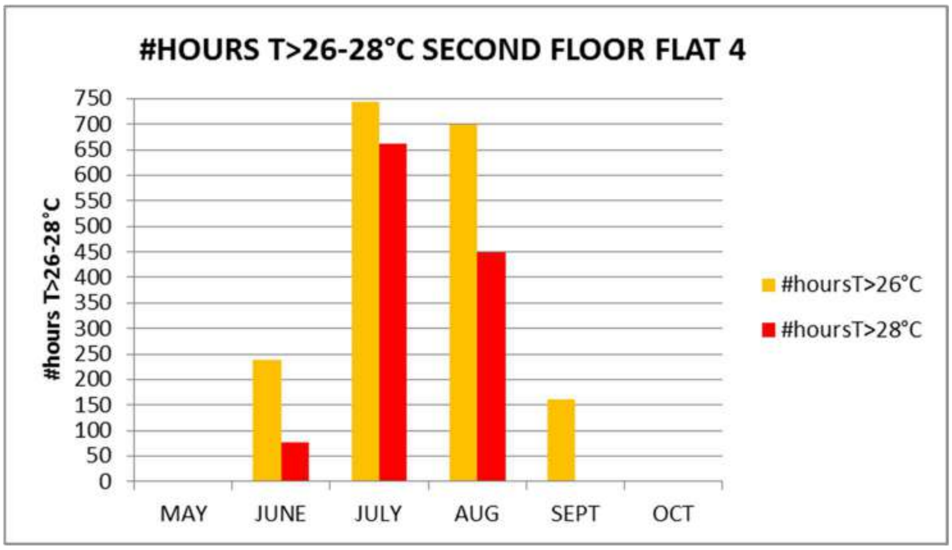


Figure 3.169: Qa19-Number of hours exceeding 26-28°C during Summer months (FLOOR 2-FLAT 4).

RELATIVE HUMIDITY (RH):

The most humid months are May, June, September and October, even if the hours above 70% are not relevant. Indeed:

- MAY: 150 hours above 60% of RH; no relevant hours with Relative Humidity above 70%;
- JUNE: 250 hours above 60%, but no relevant hours above 70%RH;
- JULY: No hours above 70%RH; in general we can say that the flat does not present humidity problems in this month;
- AUGUST: No hours above 70%RH; in general we can say that the flat does not present humidity problems;
- SEPTEMBER: 200 hours exceeding 60% of RH, no hours above 70%RH;
- OCTOBER: It is the most humid month also in this case, it presents about 400 hours with RH above 60% and of these about 150 hours exceed 70%RH.

This flat does not have particular humidity problems.

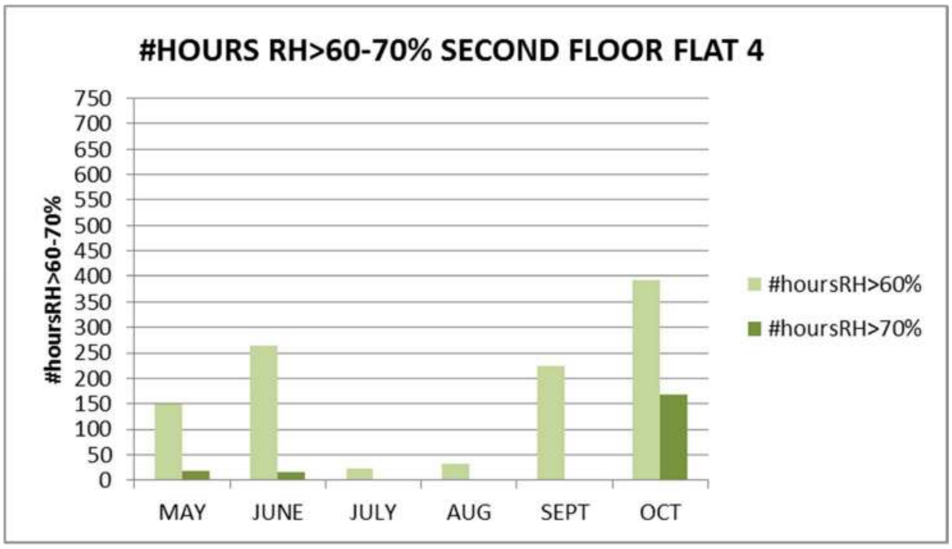


Figure 3.170: Qa19-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 2-FLAT 4).

COMFORT INDEX (PPD VALUES):

As in the previous flat, in July there are no hours with PPD<6-10-15%, while in August there is a little improvement compared to IOLO buildings. In May the comfort levels increase compared to the previous flat because the mean indoor temperatures are slightly higher. In June, the temperatures are acceptable (mean value under 26°C), but in this case the comfort levels are better than in the previous flat. This due to a difference in the Relative Humidity. In fact in FLAT 1-FLOOR 1, the RH in June is higher than in this flat, and with lower temperatures (mean value FLAT 1=23.52°C) the effects of the RH are greater. In September the comfort levels are similar in this flat and in FLAT 1. Conversely in October there is an improvement compared to the previous flat, due to a slight increase of indoor temperature values.

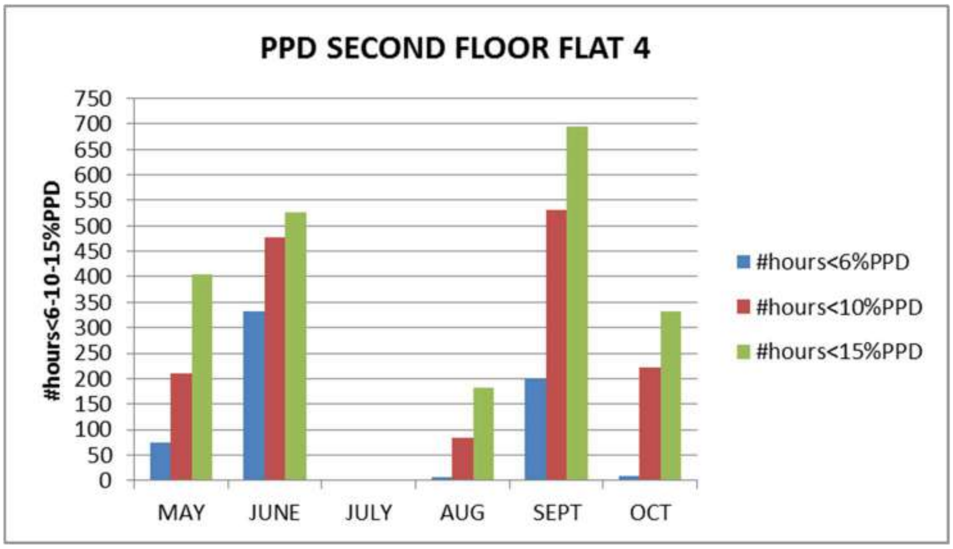


Figure 3.171: Qa19-Number of hours with PPD<6-10-15% (FLOOR 4-FLAT 6).

FLOOR 4: FLAT 4

This is the warmest flat in the building.

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 18.76°C;
- JUNE: The #hours>28°C are about 100 (720 total hours) ;
- JULY: Almost all the month presents hours above 28°C (744 total hours);
- AUGUST: All the month presents hours above 26°C (744 total hours) and almost 500h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The mean temperature value is close to the threshold of comfort range (20.11°C).

The fig. 3.172 shows the hourly trend of temperatures during Summer months. The highest temperatures occur in the central months.

	JUNE	JULY	AUG
MEAN T (°C)	25.71	29.27	28.55
MAX T (°C)	29.59	30.90	31.09
	MAY	**SEP**	**OCT**
MEAN T (°C)	21.99	24.93	20.11
MAX T (°C)	25.02	27.07	23.32
MIN T (°C)	18.76	21.95	15.67

Table 3.46: Qa19-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 4-FLAT 4).

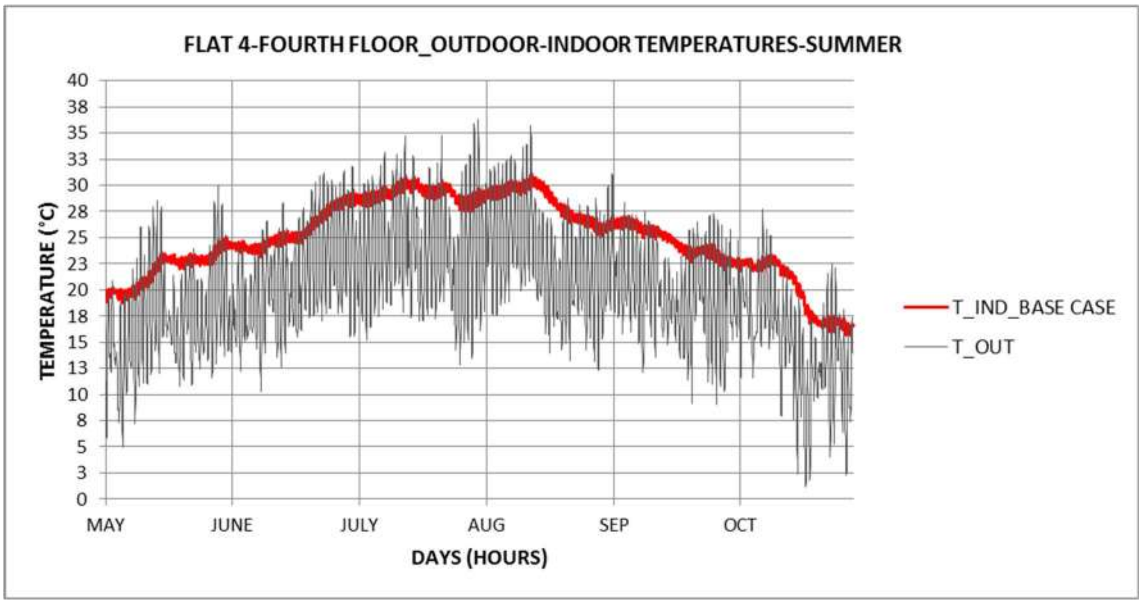


Figure 3.172: Qa19-Hourly trend of temperatures in Summer (FLOOR 4-FLAT 4).

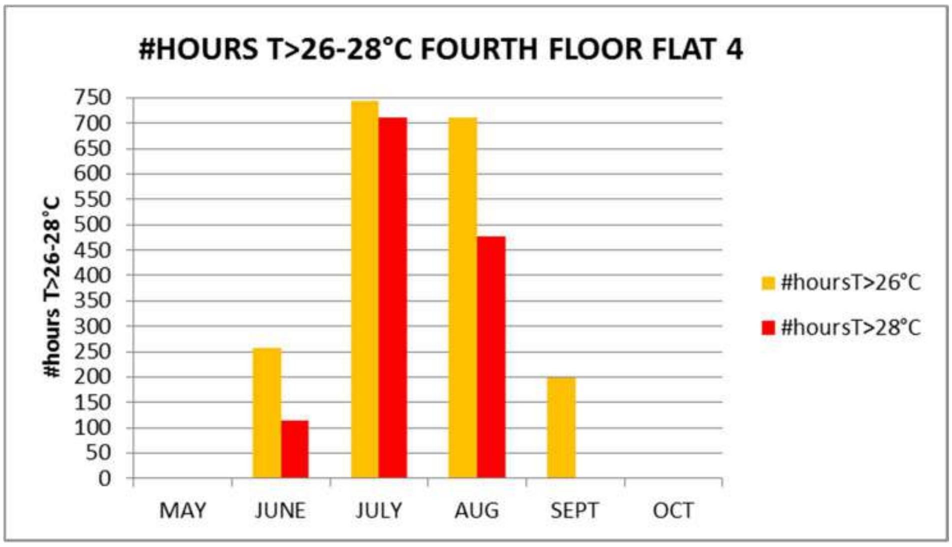


Figure 3.173: Qa19-Number of hours exceeding 26-28°C during Summer months (FLOOR 4-FLAT 4).

RELATIVE HUMIDITY (RH):

Also this flat does not present high levels of Relative Humidity:

- MAY: About 150 hours have RH above 60%; No hours above 70%RH;
- JUNE: About 200 hours have RH above 60%; No hours above 70%RH;
- JULY: The levels of RH are negligible;
- AUGUST: The levels of RH are negligible;
- SEPTEMBER: 200 hours exceed 60% of RH;
- OCTOBER: It is the most humid month also in this case. The flat has 400 hours exceeding 60% of RH and 150h with RH>70%.

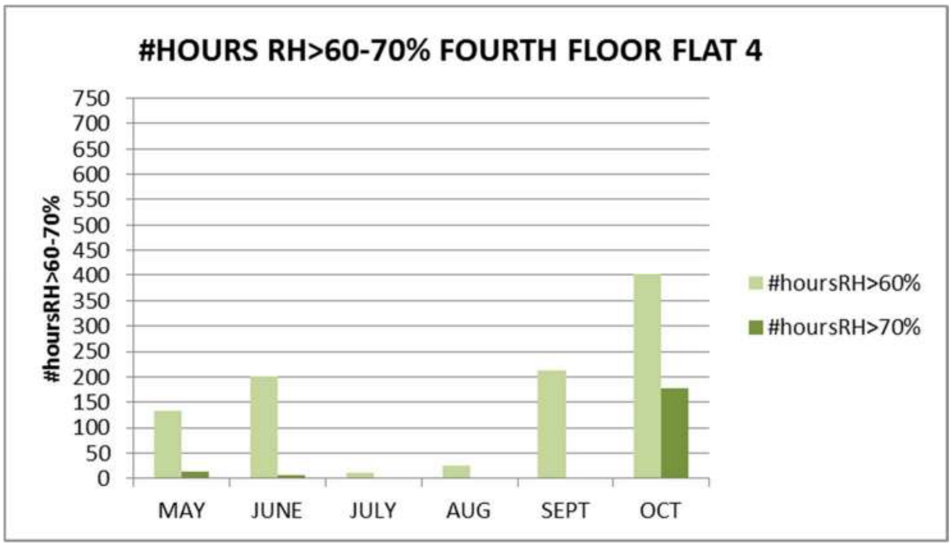


Figure 3.174: Qa19-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 4-FLAT 4).

COMFORT INDEX (PPD VALUES):

In July there are no hours with PPD<6-10-15%, due to the high values of indoor temperatures. In August it is the same even if there is a small improvement.

Since this flat is the warmest compared to the other flats analysed in this section, also in May the temperatures are higher; this leads to an increase of comfort levels and in comparison with the other flats, as regards this month, the flat behaves the best.

Conversely, the increase of temperatures in June, leads to a decrease of comfort levels with respect to the FLAT 1-FLOOR 1. It has the same behaviour than the previous flat.

In September the apartment has good levels of comfort, as well as the other flats.

In October this flat behaves like the flat at the second floor (FLAT 4), because of the increase of temperatures.

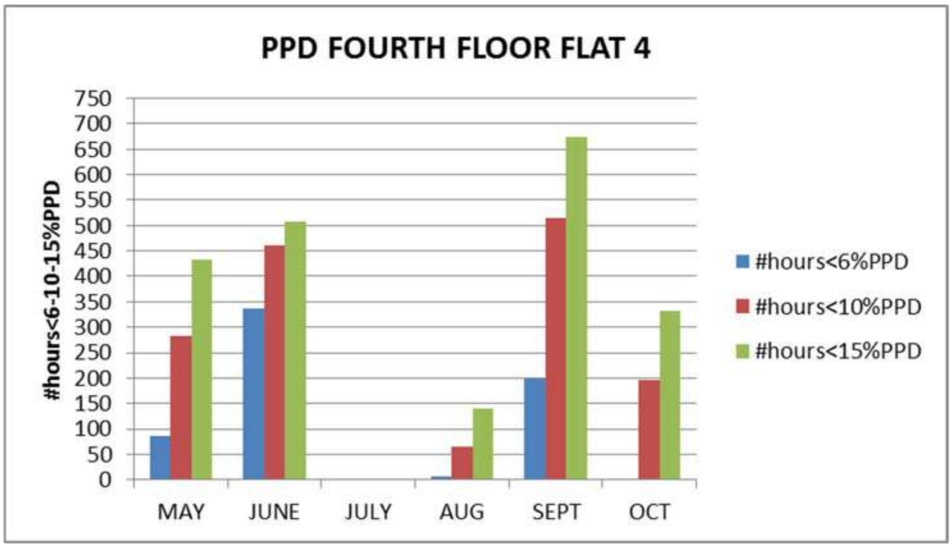


Figure 3.175: Qa19-Number of hours with PPD<6-10-15% (FLOOR 4-FLAT 4).

SYNTHESIS

Summarizing the results of the BASE CASE in Qa19

WHOLE BUILDING:

Winter Season

- Low quality of the envelope;
- Heat losses;
- Energy class: F;

Summer Season

- Low quality of the envelope;
- Overheating in the flats during the central months: temperatures above 28°C all the month in July and in August;
- High levels of RH in June, September and October.

FLATS:

We can say that the warmest flats are located at the 4° floor (FLAT 4) except in October when all the flats present almost the same mean temperature values. The warmest flat in this month is FLAT 4 at 2° floor.

All the flats present similar levels of RH and do not present particular humidity issues.

In July and August all the flats have low levels of internal comfort, due to the high values of temperatures, except for FLAT 1-FLOOR 1, where the mean temperature values in these months are close to 26°C.

In June all the flats present good levels of comfort, because the mean temperature values is below 26°C.

Instead in May, the flat located at the 4° floor, presents better comfort conditions, due to higher temperatures, acceptable for this month.

Summarizing, in the central months, the higher temperatures lead to low levels of indoor comfort and this is a common characteristic of all the flats. As regards the shoulder months, the flats which in general are the warmest, behave better in May and in October (the increase of temperatures leads to positive results). The relative humidity can modify the comfort levels when the temperatures are not so high (shoulder months).

Qb16/Qb40

1. **Semi-stationary conditions**

In the table below a summary of necessary data to evaluate the Energy Demand for heating and the final Global Energy Performance *($EP_{gl,nren}$)* are listed:

CANOVA-Qb16/Qb40s	
TOTAL DISPERSANT SURFACES ***(S)***	$2107m^2$
HEATED VOLUME ***(V)***	$3764m^3$
USEFUL AREA ***(A)***	$1125m^2$
SHAPE FACTOR ***(S/V)***	$0.56m^{-1}$
WINDOWS AREA/*S*	0.15

The figure below shows the thermal zones of Qb16: 4 flats/floor for a total of 6 floors. Accordingly we will have 24 thermal zones. Each thermal zone corresponds to a flat, both in the semi-stationary conditions and in dynamic ones.

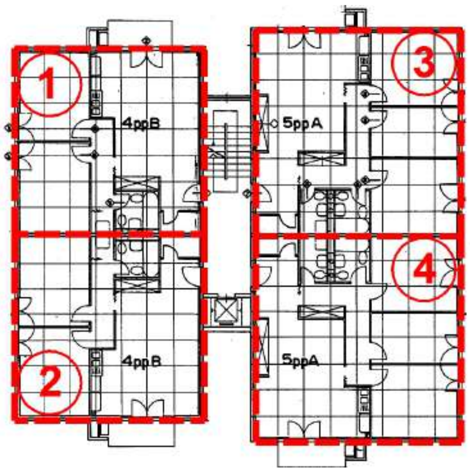


Figure 3.176: Thermal zones in Qa19 typical plan.

The Global Energy Performance index (**$EP_{gl,nren}$**) is:

$EP_{gl,nren}$= 114kWh/m^{2}y

$EP_{gl,nren,rif}$(2019,2021)= 46.89kWh/m^{2}y

The building Energy Class is **E**, in fact:

2.00* $EP_{gl,nren,rif}$(2019,2021) < **$EP_{gl,nren}$** ≤ 2.60* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:

d. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K

H'_T= 1.26 W/m^{2}K

H'_T>H'_{Tlim} **UNVERIFIED**

e. Envelope Energy Performance in Winter through the calculation of $EP_{H,nd}$

$EP_{H,nd}$ = 57.54kWh/m^{2}y

$EP_{H,nd,lim}$(2019,2021)= 12.73kWh/m^{2}y

The result is:

$EP_{H,nd}$ > 1.7*$EP_{H,nd,lim}$(2019,2021) → **LOW QUALITY OF THE ENVELOPE**

f. Envelope Energy Performance in Summer through the evaluation of ($A_{sol,est}$) and (Y_{IE})

$A_{sol,est}/S$= 0.082

Y_{IE}=0.19W/m^{2}K

The thresholds are:

$(A_{sol,est}/S)_{lim}$= 0.03

$(Y_{IE})_{lim}$= 0.14W/m^{2}K

The result is:

$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ and $Y_{IE} > (Y_{IE})_{lim}$ → **LOW QUALITY OF THE ENVELOPE**

2. Dynamic conditions

From the results of the dynamic simulations we obtained the sensible energy demand for heating, called in the model *Q_heat* which corresponds to $Q_{H,nd}$ in the semi-stationary conditions and *Q_heat/S* corresponds to $EP_{H,nd}$.

If we analyse the behaviour of the floors, from the figure below, we can note that the most "energy-hungry" flats are located at the first and sixth floor.

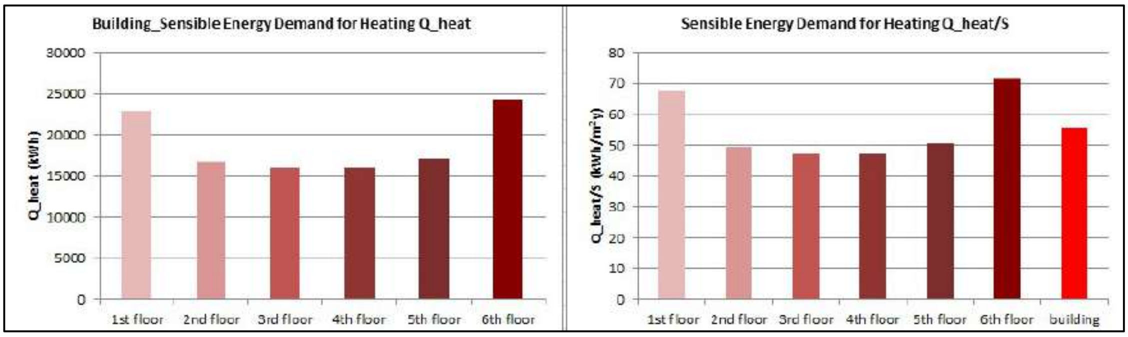


Figure 3.177: Qb16-Sensible Energy Demand for Heating. (On the left) the average values of *Q_heat* per month averaged across all the flats. (On the right) The average values of *Q_heat/S* per floor.

From the analysis in semi-stationary conditions we found:

$EP_{H,nd}$ = 57.54 kWh/m^{2}y

- From the analysis in dynamic conditions we found:

Q_heat/S= 55.61 kWh/m^{2}y

The 2 values differ of about 5%.

WHOLE BUILDING

As in the previous buildings, we analysed the mean temperatures of the building as a whole, by making an average of all the flats values. Obviously, the temperatures in Winter are always around 20°C, that is the set-point temperature for the heating system.

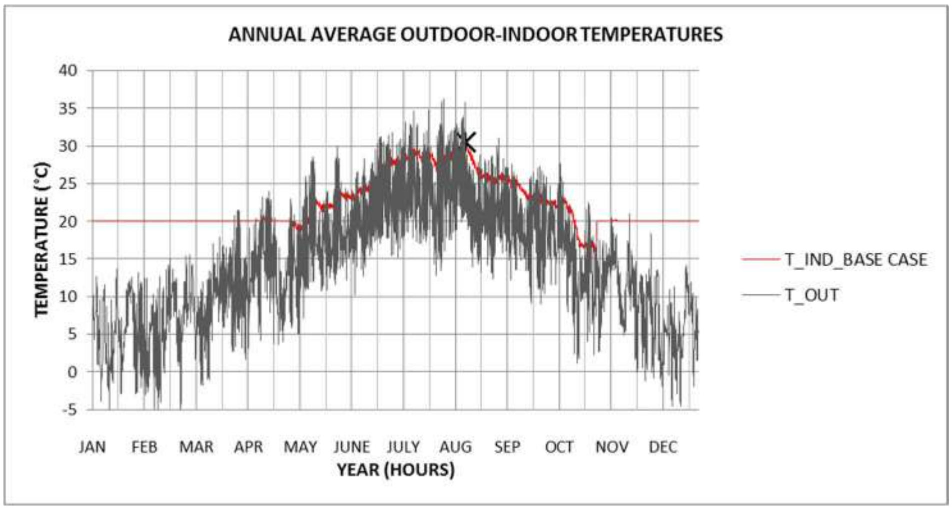


Figure 3.178: Qb16-Hourly trend of mean temperatures during all the year and the outdoor temperature hourly trend (T_out). These are values averaged across all the flats.

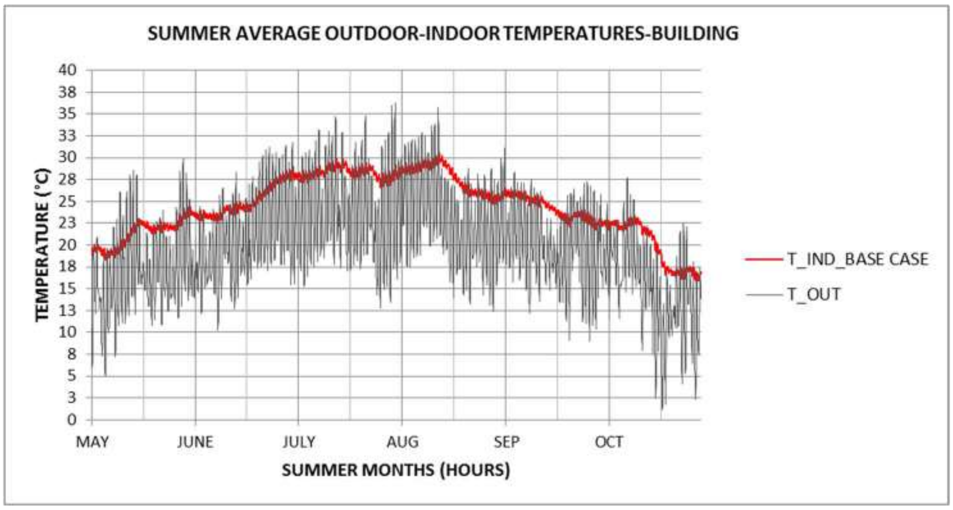


Figure 3.179: Qb16-Hourly trend of mean temperatures in Summer (average values of the whole building). Comparison between BASE CASE and outdoor temperatures.

The max value of temperatures occurs in August at the 1° floor in flat 2, while the min value is in October still at the first floor, but in flat 4. Even if the max value occurs at the first floor, on average the warmest floor is the last one (red line fig.3.180).

SUMMER	**CENTRAL MONTHS**	**JUNE**	**JULY**	**AUGUST**
		BASE CASE	**BASE CASE**	**BASE CASE**
	MEAN T (°C)	25.03	28.33	27.78
	MAX T (°C)	30.51	31.36	31.53
	SHOULDER MONTHS	**MAY**	**SEPTEMBER**	**OCTOBER**
		BASE CASE	**BASE CASE**	**BASE CASE**
	MEAN T (°C)	21.36	24.41	20.03
	MAX T (°C)	25.71	27.57	24.02
	MIN T (°C)	17.19	20.39	14.93

Table 3.47: Qb16-Characteristic mean temperature values averaged across all the flats.

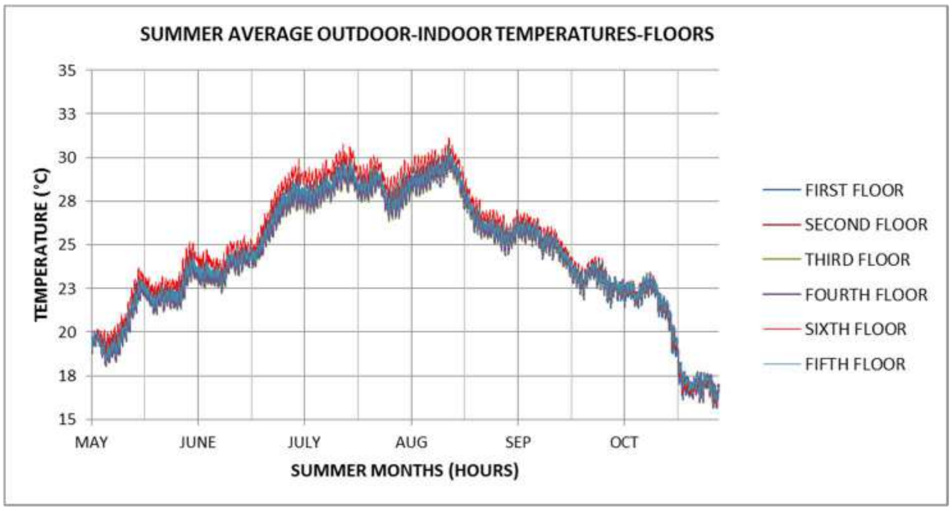


Figure 3.180: Qb16-Hourly trend of mean temperatures during Summer months per each floor

From the figure below, that represents the behaviour of the whole building, the warmest months are July and August, even if the percentage of hours exceeding 28°C is negligible in July and low in August, but being an average across all the flats, a more detailed study of some flats is needed.

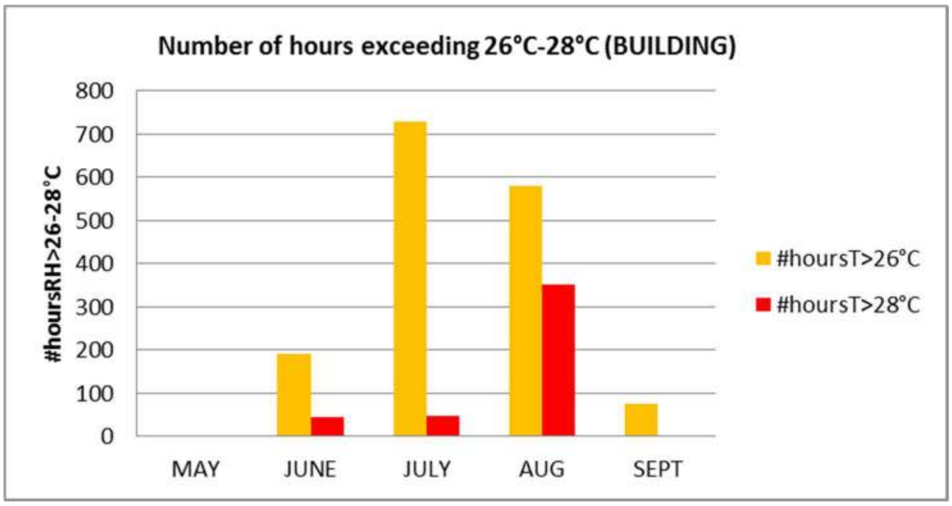


Figure 3.181: Qb16-#hoursT>26-28°C. Values averaged across all the flats.

As regard RH values, if we look at the fig. below, as in the previous buildings, the most humid months are May, June, September and October.

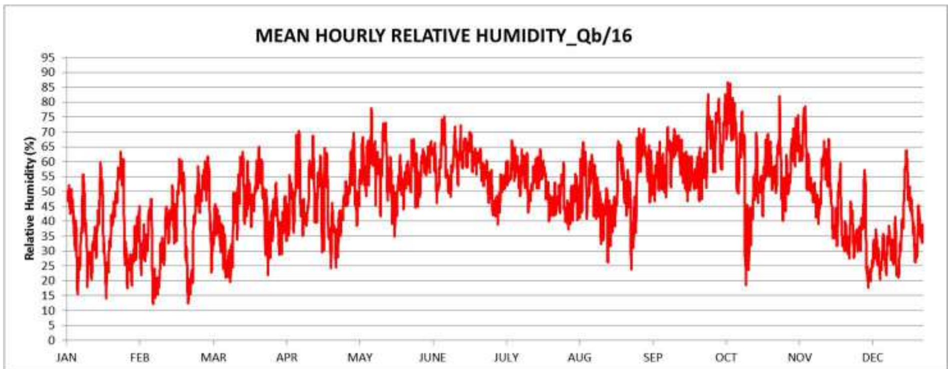


Figure 3.182: Qb16-Mean Relative Humidity trend during the year.

According to the table 3.48, the most humid floor is the 3°. The flats present the highest humidity levels in October, regardless of the floor.

	FLOOR_MEAN RH (%)						**BUILDING MEAN RH (%)**
	1	2	3	4	**5**	**6**	
may	55.63	56.79	57.13	56.95	56.24	54.52	56.21
june	60.11	61.11	61.36	61.04	60.07	57.99	60.28
sep	59.67	59.68	59.52	59.24	58.80	57.93	59.14
oct	62.03	61.52	61.15	61.00	61.08	61.30	61.35

Table 3.48: Qb16-Mean RH value in the most humid months.

The fig. below confirms what we said before. May June, September and October are the most humid months, but the number of hours exceeding the 70% of Relative Humidity is not high: the building does not present particular humidity issues. Nevertheless, it is necessary to study more in detail the indoor conditions of the flats.

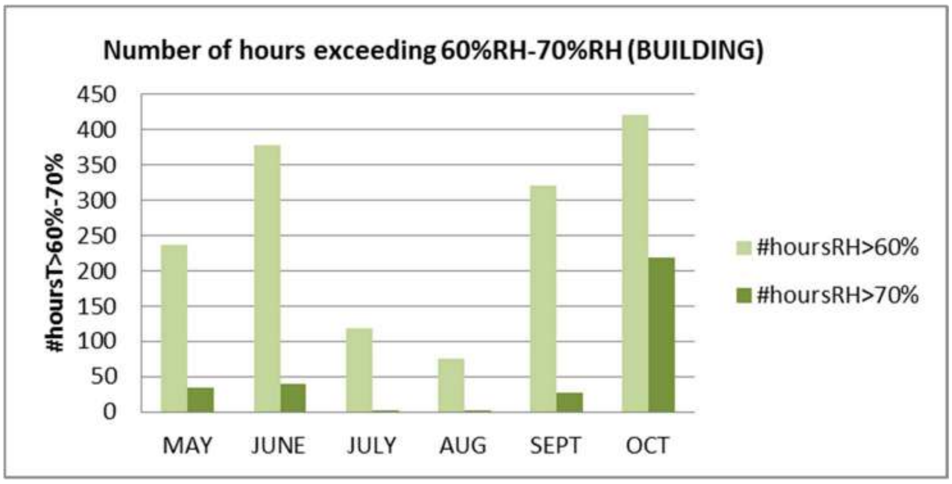


Figure 3.183: Qb16-#hoursRH>60-70%. Values averaged across all the flats.

As in the other buildings, we will analyse the internal conditions of some flats, taken as sample cases. The typical plan of the building is divided in 4 blocks surrounding a stairwell (the dimensions are different: 2 blocks are larger than the other 2 blocks. Each block contains a thermal zone and because of the building type configuration (tower), the dispersant surfaces are equal in each thermal zone

We have chosen the warmest flat at the first floor (FLAT 1). Among the central floors we have chosen the third floor (the most humid), taking into account the warmest flat (FLAT 1). At the last floor we choose the warmest flat as well.

FLOOR 1	**FLOOR 3**	**FLOOR 6**
FLAT 1	**FLAT 1**	**FLAT 1**

Table 3.49: Qb16-Flats with the worst internal conditions chosen as sample flats to be monitored.

FLATS

FLOOR 1: FLAT 1

The flat does not present high temperature values as in the other examples, but it is worth to study the behaviour of this apartment in order to understand if the strategies we will apply can match also the needs of flats like this, with less severe indoor conditions.

TEMPERATURES:

- MAY: The temperatures are acceptable.
- JUNE: The mean value of temperatures overcomes 26°C. 150 hours are above 28°C;
- JULY: All the month presents hours above 28°C (744 total hours);
- AUGUST: All the month presents hours above 26°C (450h>28°C);
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.66°C). The mean value is close to the threshold for comfort range (20.77°C).

	JUNE	JULY	AUG
MEAN T (°C)	26.25	29.51	28.76
MAX T (°C)	30.36	31.10	31.34
	MAY	**SEP**	**OCT**
MEAN T (°C)	22.51	25.31	20.77
MAX T (°C)	25.71	27.57	24.02
MIN T (°C)	18.90	22.46	16.66

Table 3.50: Qb16-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 1-FLAT 1).

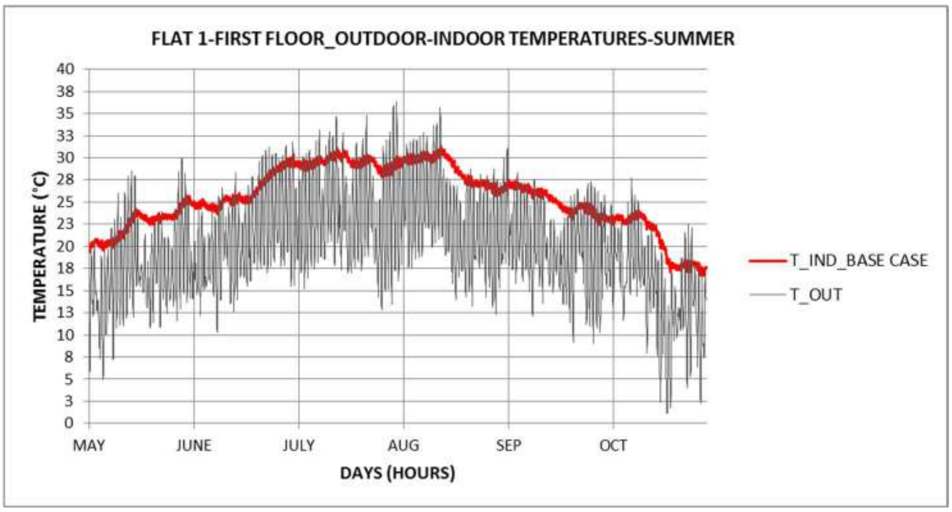


Figure 3.184: Qb16-Hourly trend of temperatures in Summer (FLOOR 1-FLAT 1).

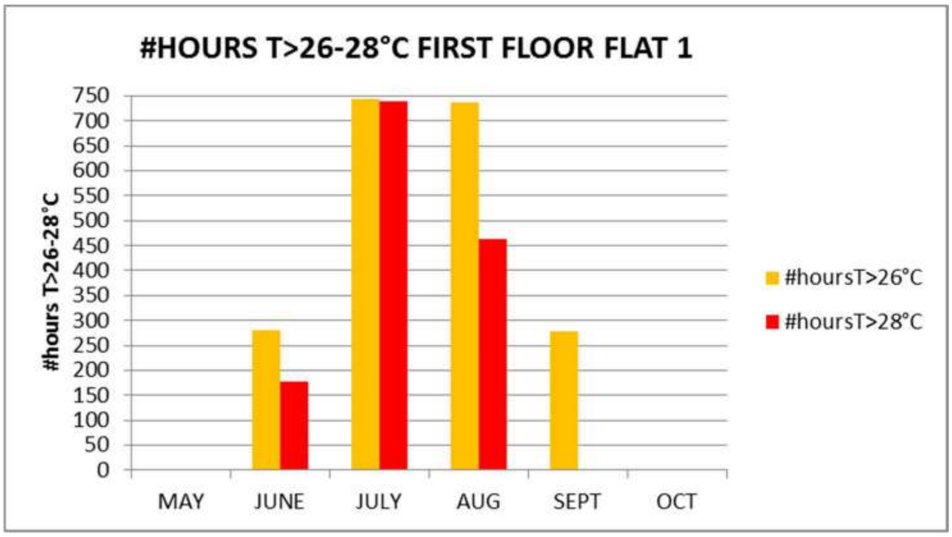


Figure 3.185: Qb16-Number of hours exceeding 26-28°C during Summer months (FLOOR 1-FLAT 1).

<u>RELATIVE HUMIDITY (RH):</u>

This flat does not present high values of Relative Humidity:

- MAY: 150 hours above 60% of RH. No hours above 70%RH;
- JUNE: About 200 hours above 60%RH; No hours above 70%RH;
- JULY: No relevant levels of RH;
- AUGUST: No relevant levels of RH;
- SEPTEMBER: It presents about 200 hours>60%, No hours above 70%RH;
- OCTOBER: It is the most humid month along with June. It has about 400 hours above 60% of RH, of whom 150h present RH>70%.

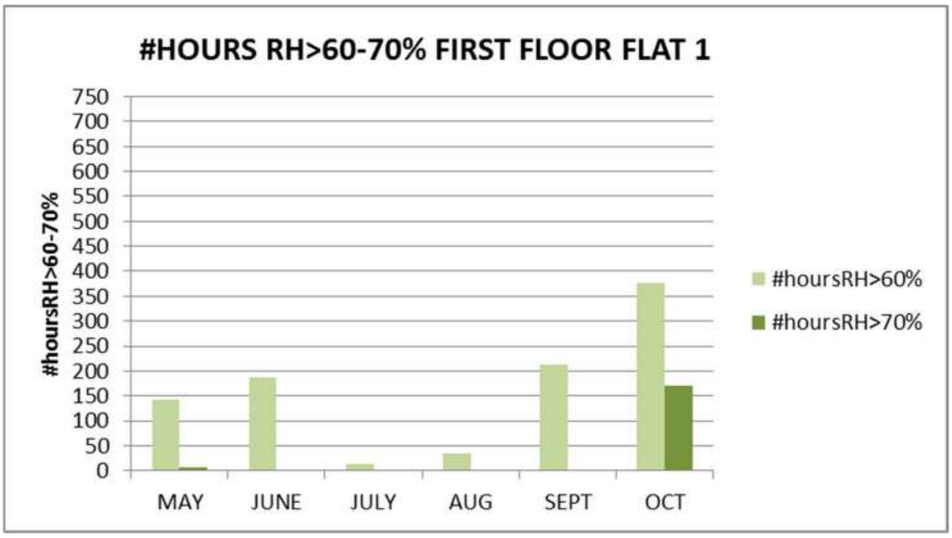


Figure 3.186: Qb16-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 1-FLAT 1).

COMFORT INDEX (PPD VALUES):

As regards July and August, the flat behaves as the majority of the flats analysed so far. The high indoor temperatures lead to low comfort levels inside the flat. The best month is September, when both the temperatures and RH values are acceptable.

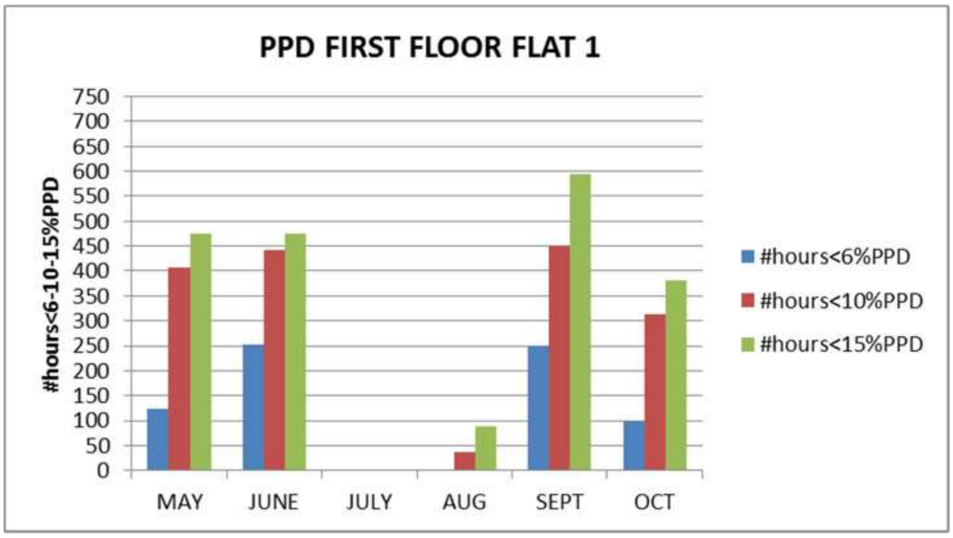


Figure 3.187: Qb16-Number of hours with PPD<6-10-15% (FLOOR 1-FLAT 1).

FLOOR 3: FLAT 1

TEMPERATURES:

- MAY: The temperatures are acceptable and the minimum temperature value is 18.39°C;
- JUNE: The #hours>28°C are about 50 (720 total hours);
- JULY: All the month presents hours above 26°C (744 total hours) and about 550 of these exceeding 28°C;
- AUGUST: Almost all the month presents hours above 26°C (744 total hours) and 400h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The minimum value is low (16.48°C).

	JUNE	JULY	AUG
MEAN T (°C)	25.07	28.41	27.95
MAX T (°C)	28.90	29.98	30.64
	MAY	**SEP**	**OCT**
MEAN T (°C)	21.37	24.75	20.57
MAX T (°C)	24.24	26.84	23.72
MIN T (°C)	18.39	22.25	16.48

Table 3.51: Qb16-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 3-FLAT 1).

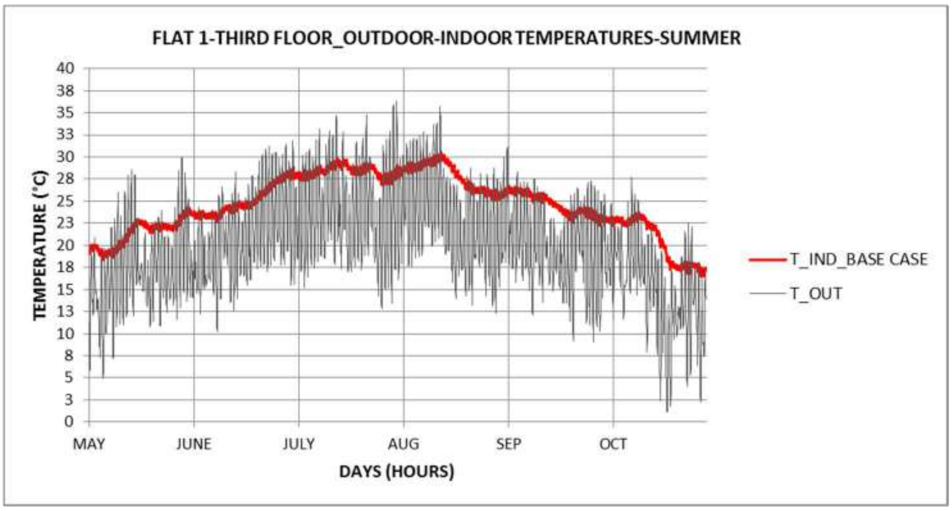


Figure 3.188: Qb16-Hourly trend of temperatures in Summer (FLOOR 3-FLAT 1).

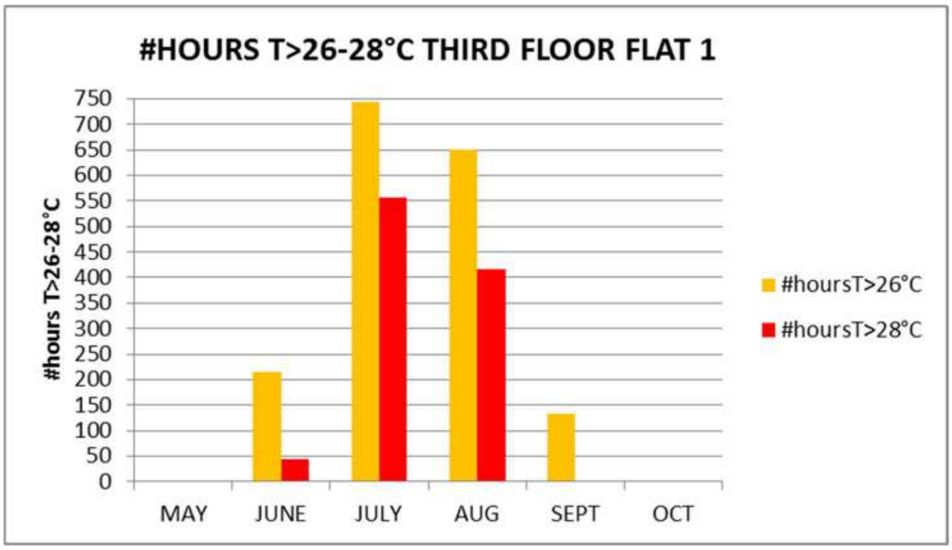


Figure 3.189: Qb16-Number of hours exceeding 26-28°C during Summer months (FLOOR 3-FLAT 1).

RELATIVE HUMIDITY (RH):

The most humid months are May, June, September and October, even if the hours above 70% are not relevant. Indeed:

- MAY: 250 hours above 60% of RH, no relevant hours with Relative Humidity above 70%;
- JUNE: The flat presents 400 hours above 60%, but no relevant hours above 70%RH;
- JULY: No hours above 70%RH; in general we can say that the flat does not have humidity problems;
- AUGUST: No hours above 70%RH; no humidity issues.
- SEPTEMBER: 300 hours exceeding 60% of RH;
- OCTOBER: It is the most humid month also in this case, it presents about 400 hours with RH above 60% and of these about 200 hours exceeds 70%RH.

This flat does not have relevant humidity problems.

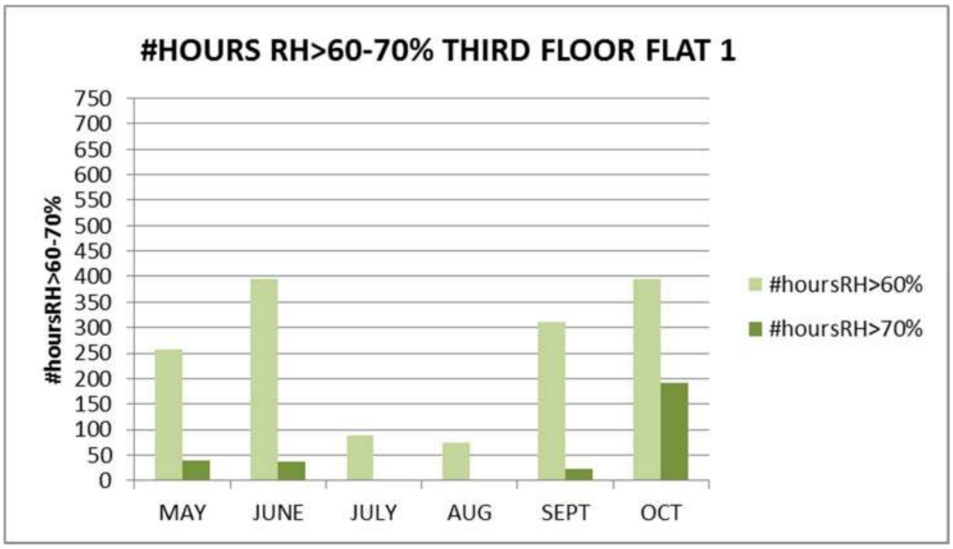


Figure 3.190: Qb16-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 3-FLAT 1).

COMFORT INDEX (PPD VALUES):

As in the previous flat, in July there are no hours with PPD<6-10-15%, while in August there is a modest improvement, compared to IOLO buildings and to the previous flat, because of the decrease of indoor temperatures. In May and in October the comfort levels decrease compared to the previous flat, due to the decrease of indoor temperature mean values.

Conversely in June, the decrease of temperature values leads to better comfort conditions inside the flat, in comparison with the previous flat, as well as in September.

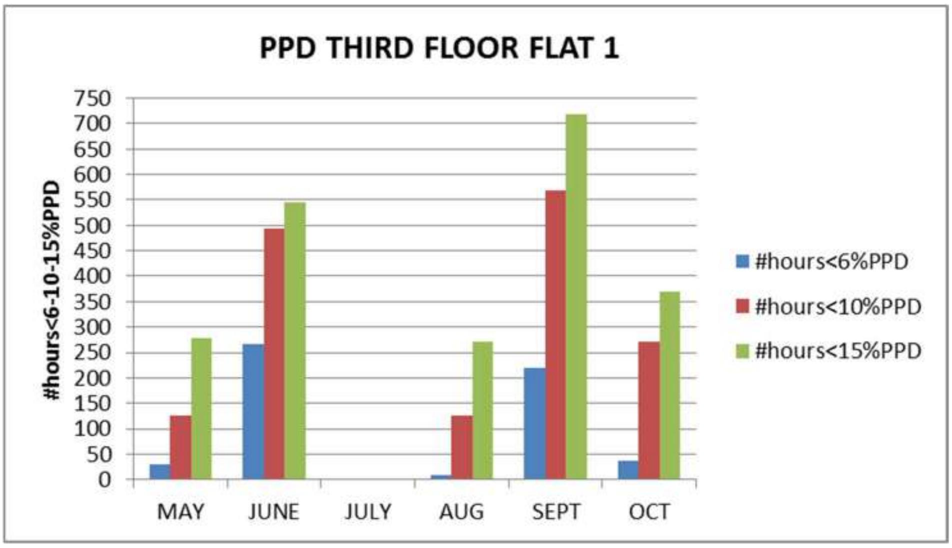


Figure 3.191: Qb16-Number of hours with PPD<6-10-15% (FLOOR 3-FLAT 1).

FLOOR 6: FLAT 1

TEMPERATURES:

- MAY: The temperatures are acceptable and the min temperature value is 18.93°C;
- JUNE: The #hours>28°C are about 150 (720 total hours) °C; The mean temperatures value is below 26°C
- JULY: Almost all the month presents hours above 28°C (744 total hours);
- AUGUST: All the month presents hours above 26°C (744 total hours) and 450h of these exceeding 28°C;
- SEPTEMBER: The temperatures are acceptable;
- OCTOBER: The mean temperature value is close to the threshold of comfort range (20.30°C).

	JUNE	JULY	AUG
MEAN T (°C)	25.79	29.23	28.49
MAX T (°C)	30.02	30.86	31.18
	MAY	**SEP**	**OCT**
MEAN T (°C)	21.97	24.96	20.30
MAX T (°C)	25.17	27.18	23.69
MIN T (°C)	18.93	22.06	15.99

Table 3.52: Qb16-Temperature values during the worst months in Summer and during the shoulder season (BASE CASE/FLOOR 6-FLAT 4).

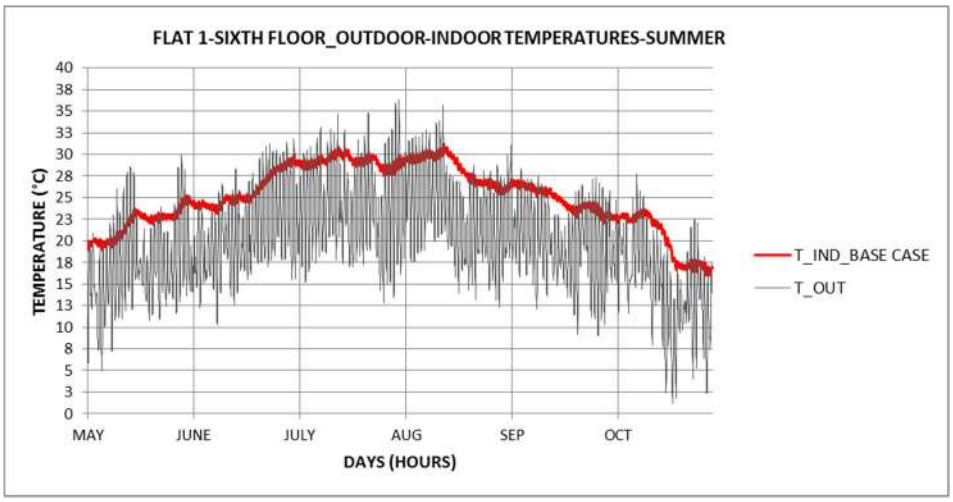


Figure 3.192: Qb16-Hourly trend of temperatures in Summer (FLOOR 6-FLAT 1).

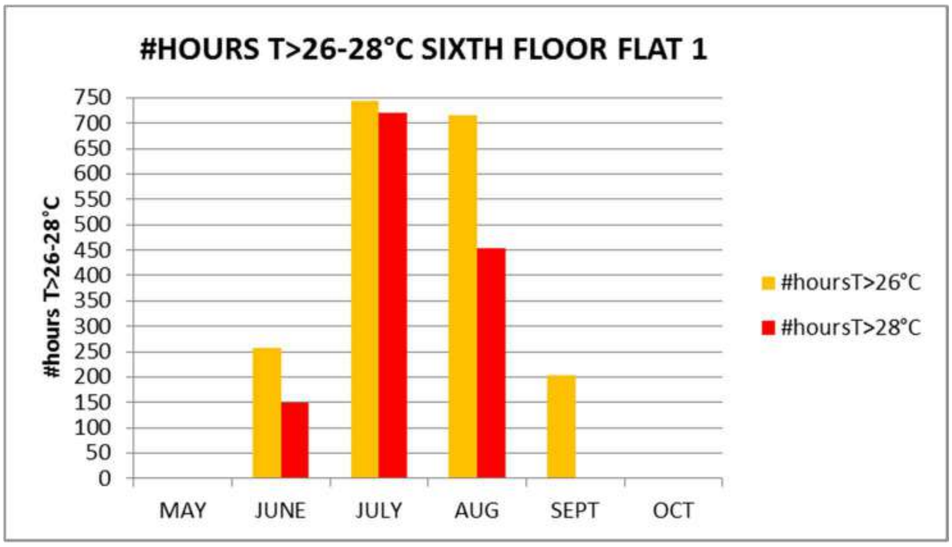


Figure 3.193: Qb16-Number of hours exceeding 26-28°C during Summer months (FLOOR 6-FLAT 1).

RELATIVE HUMIDITY (RH):

Also this flat does not present high levels of Relative Humidity:

- MAY: About 200 hours have RH above 60%; No relevant hours above 70%RH;
- JUNE: About 250 hours have RH above 60%; No relevant hours above 70%RH;
- JULY: The levels of RH are negligible;
- AUGUST: The levels of RH are negligible;
- SEPTEMBER: 250 hours exceed 60% of RH; No relevant hours above 70%RH;
- OCTOBER: It is the most humid month also in this case. The flat has 400 hours exceeding the 60%RH and 200h have RH>70%.

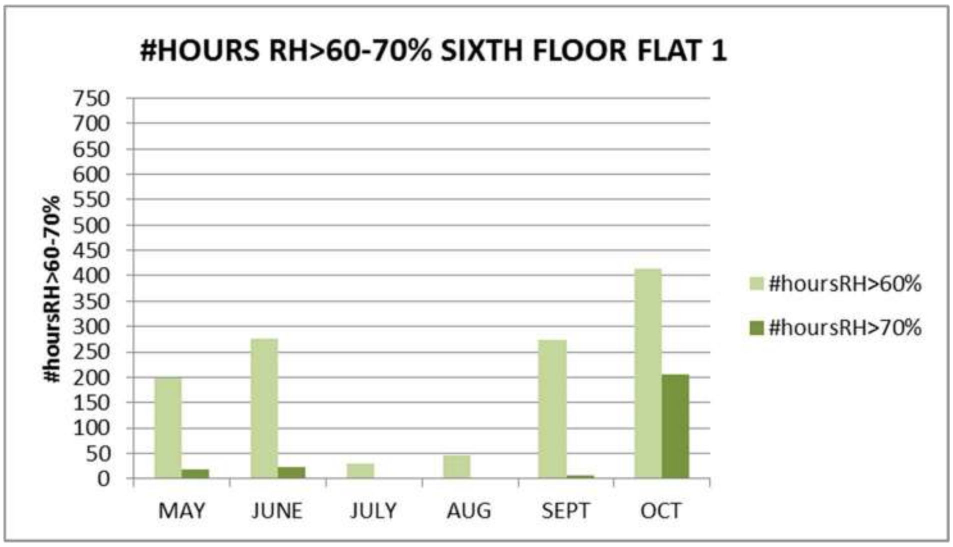


Figure 3.194: Qb16-Number of hours exceeding 60-70% of RH during Summer months (FLOOR 6-FLAT 1).

COMFORT INDEX (PPD VALUES):

In July there are no hours with PPD<6-10-15%, due to the high values of indoor temperatures. In August there is a small improvement, compared to FLAT 1-FLOOR 1 (the warmest flat). In May the higher temperature values in comparison with those of the previous flat, lead to an increase of indoor comfort conditions. In June, temperatures are higher than in FLAT 1-FLOOR 3, but still below 26°C. The higher levels of RH of the previous flat makes the difference, by decreasing the internal comfort conditions compared to this flat which presents lower RH values. In September the apartment has good levels of comfort, as well as the other flats. In October this flat behaves like the previous apartment with lower indoor comfort conditions in comparison with the flat at the first floor.

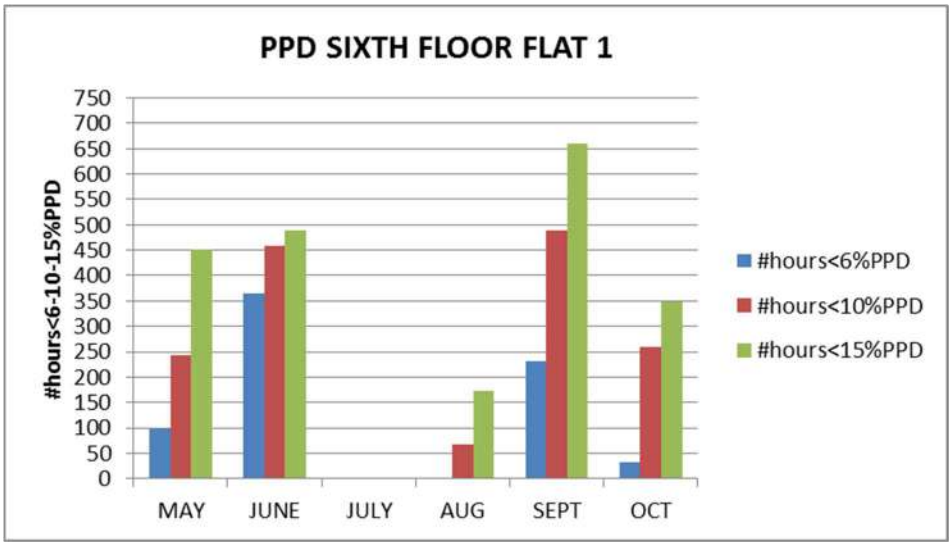


Figure 3.195: Qb16-Number of hours with PPD<6-10-15% (FLOOR 6-FLAT 1).

SYNTHESIS

Summarizing the results of the BASE CASE in Qa19

WHOLE BUILDING:

Winter Season

- Low quality of the envelope;
- Heat losses;
- Energy class: E;

Summer Season

- Low quality of the envelope;
- Overheating in the flats during the central months: temperatures above 28°C all the month in July and in August;
- High levels of RH in June, September and October.

FLATS:

The warmest flat is located at the 1° floor (FLAT 1). All the flats present low temperatures in October and in May; the internal comfort conditions improve with the increase of indoor temperatures and the worst flat in these months is FLAT 1-FLOOR 1. The worst comfort conditions occur in July and August for all the flats. In June the analysed flats, do not present high levels of indoor temperatures; the Relative Humidity plays an important role in these cases: with similar values of temperature, the flat presenting higher RH levels has the worst indoor comfort conditions.

All the apartments have good levels of indoor comfort in September, because the temperatures and RH levels are within the comfort range.

3.2.3 COMMON ISSUES IN THE ENERGY PERFORMANCE

From the previous analyses it was possible to establish the current energy performance of the buildings under study, along with their behaviour in terms of thermal comfort. They present similar characteristics which can be summarised, by dividing the results according to the two main seasons:

WINTER SEASON

The Energy class, deriving from the analyses under semi-stationary conditions, is low in all the sample cases, according to the National Standards: This fact is due to the high U-values of the elements constituting the heated volume of the buildings, that lead to high heat losses for transmission through the envelope (external walls, floors, roof and windows):

ENERGY CLASS (D.M. 26/06/2015 (7))				
COMPLEX A: Prato-Iolo		COMPLEX B: Firenze-Via Canova		
BUILDING A	BUILDING B	Qd1	Qa19	Qb16
E	E	F	F	E

The Sensible (ideal) energy demand for heating, deriving from the dynamic simulations through the use of Trnsys differs from that calculated in semi-stationary conditions in the range 5-10%.

The buildings on average do not present high levels of Relative Humidity during the heating season, but the problem, already underlined in the first part of the chapter, is the presence of thermal bridges which can lead, along with the actual Relative Humidity levels, to mold growth.

In order to verify the possibility of mold growth a finite elements analysis was performed through the use of the software THERM[54], in order to evaluate the surface temperatures of the building elements, starting from threshold values imposed from the Law, for avoiding the possibility of mold growth.[55]

The surveys carried out on site, showed the existence of mold in correspondence of the external walls of the flats located at the "pillar-floor", as regards the buildings in Prato, while on the ceiling of the flats located at the last floor for what concerns the buildings located in Florence. These are the zones where there is a discontinuity of the insulation layer and the internal surfaces can present superficial low temperatures on the building element (wall or slab) such as to create condensation phenomena.

[54] THERM is "a state-of-the-art computer program developed at Lawrence Berkeley National Laboratory (LBNL) for use by building component manufacturers, engineers, educators, students, architects, and others interested in heat transfer. Using THERM, you can model two-dimensional heat-transfer effects in building components such as windows, walls, foundations, roofs, and doors, appliances; and other products where thermal bridges are of concern". (https://windows.lbl.gov/software/therm/therm.html)

[55] According to the Law UNI EN ISO 13788:2003 (21), the minimum surface temperature to avoid the condensation phenomenon for Firenze and Prato is 16.68°C. The boundary conditions for the system are: T_ind=20°C (set-point heating system) and HR=65%. The mold growth depends also on the actual Relative Humidity levels. In our cases, even though on average the buildings do not present high level of Relative Humidity there are anyway periods with worse conditions. For instance, in October or in November the Relative Humidity overcomes 65%, in such a way further increasing the possibility of mold growth.

The heat flow trend on the connection between "pillar floor" and external walls (fig.3.196 on the left) shows that the interruption of the insulation layer located on the internal side of the wall creates surface temperatures below the threshold value (15.4°C<16.68°C). This demonstrates the presence of mold inside the flats at the bottom of the wall.

The heat flow trend on the connection between "attic floor" and external walls (fig.3.196 on the right) shows that the interruption of the insulation layer located on the internal side of the wall creates surface temperatures below the threshold value (14°C<16.68°C). This demonstrates the presence of mold inside the flats at the top of the wall.

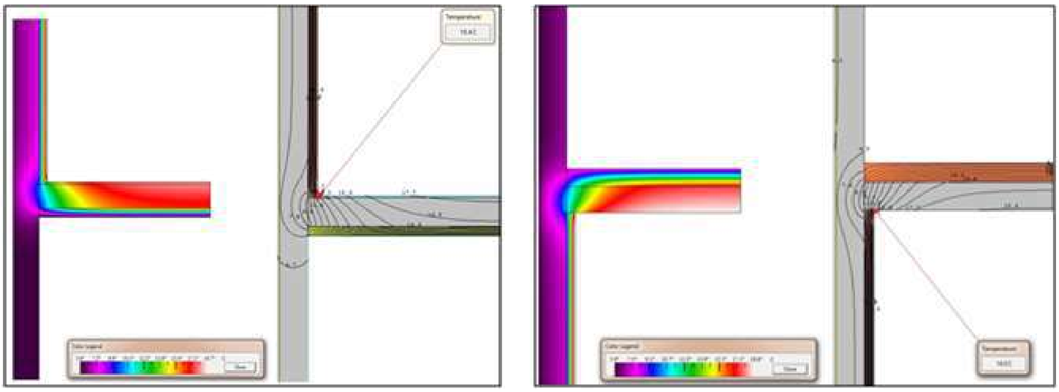


Figure 3.196: (On the left-PRATO COMPLEX) Heat flow trend on the connection between "pillar floor" and external walls. (On the right-FIRENZE COMPLEX) Heat flow trend on the connection between "attic floor" and external walls.

<u>SUMMER SEASON</u>

After the analysis of the building behaviour as a whole, for what concerns the indoor temperatures and the Relative Humidity, the common results among all the buildings are:

<u>WHOLE BUILDING:</u>

- Mean temperature values above 28°C in July and in August;
- The warmest flats are located at the "pillar floor" and at the attic floor;
- In May and in October all the buildings present an average value of temperatures around 20°C with minimum values around 16°C;
- The mean temperature values in June are around 25÷26°C;
- The mean temperature values in September are around 25÷26°C;
- All the buildings present higher values of Relative Humidity in May, June, September and October; the highest levels of RH occur in October.
- The central floors in the building are the most humid.

<u>FLATS:</u>

The flats taken as sample cases have demonstrated what we found making an average of all the values calculated for each flat aiming at estimating the behaviour of the whole building. Moreover, the analysis of these flats allowed us to understand the thermal comfort under particular conditions, in order to evaluate what is the main causes of discomfort

- The warmest flats are located at the "pillar floor" and at the attic floor;
- The most humid flats are located among the central floors of the building;
- All the flats present high temperature values in July and August (above 28°C);

- All the flats present low values of temperatures in May and in October (the mean temperature values are around 20°C, but peaks with low temperatures may occur (≈16°C));
- All the flats present the highest levels of RH in May, June, September and October.
- The best comfort conditions are shown in September, when all the flats present acceptable values of temperature;
- The worst comfort conditions are shown in July and August because of the indoor temperatures and the RH does not have effects on shifting these conditions towards an improvement or a worsening of such conditions;
- In May and in October the comfort levels decrease as much as temperatures are lower, but in this case we highlighted that flats with similar temperatures, but with different levels of RH, can have different levels of indoor comfort.
- In June the flats behave more or less in the same way. The temperatures are not so high as in July and August, but very high peaks can occur anyway. Even in this month the Relative Humidity has effects on shifting the comfort levels.

Concluding, the main issues found in the analysis of the buildings' BASE CASE are:
- HIGH ENERGY DEMAND FOR HEATING;
- THERMAL BRIDGES: POSSIBILITY OF MOLD GROWTH;
- HIGH TEMPERATURE VALUES. The windows opening by the users (considered in the model as a mean value of 0.5 air changes) is not sufficient to ensure a good level of comfort, especially during the central months in Summer; once further it is worth to underline that there are no air-conditioning systems;
- LOW TEMPERATURE VALUES IN SHOULDER MONTHS (May and October). We consider these two months within the Summer season for making a simplification, justified by the fact that in May and in October the heating system is turned-off, but in reality, as we noticed, the temperatures can reach very low temperatures without the help of a heating system, especially in October.

APPENDIX A

BUILDING PROCESS COMPLEX A[56]

In 19/10/1978 the Residential Building Committee assigned to the Tuscany Region, in accordance with Law 457 of 08/05/1978, the sum of L.67.118 million for subsidised housing during the years 1978/'79. By resolution 153 of 27.03.1979, the Tuscany Region assigned the sum of L.1.296.000.000 for the construction of 54 residential units in the Municipality of Prato, establishing also the places of interventions. The Tuscany Region announced with a letter delivered in 04/23/1979, that construction-works would be committed to the Institute of Independent Public Housing in Florence (IACP), and from that date they would have 10 months for the delivering and opening of the construction yard. Besides, the Region also engaged itself to enact the legislation for the actions implementation within 30 days. In 10/04/1979 Oliviero Cardinale, President of the IACP Florence, required the City to priory propose one or more areas for the realization of works and to prepare the necessary documentation including: the planning regulations, the costs of primary and secondary urbanisation, the plans for determining the area size and the location of the sewer system. In 26/06/1979, further to the Institute request dated 06/06/1979 for the formal area location, the Municipality informed IACP about the official assignment of the area E of Iolo Master Plan, setting the maximum volume of construction in 27.080 m^3.

On 13/08/1979, IACP requested the City of Prato indications as: Lot Dimensions, height dimensions for the building and landscape settings, location and type of sewer system with sections and base dimensions as well as type of fractionation. On 09/03/1979 the City provided the communication of cadastral data of the lot in question, indicating 7.728mq as total land area.

As can be seen from the report prepared by the IACP Technical Coordinator, Eng. Silvio Viezzoli, dated 09/05/1979, during a meeting at the headquarters of the Consortium between IACP members in 31/07/1979, the Administration Council indicated the will of assigning the works through an open-ended tender competition, in accordance with the most advantageous offer.

On 09/01/1980 the IACP proclaimed the tender competition to which no offer has been made. The Institute therefore, decided to set up its own design office to be offered as a private bidding. On 03/17/1980 the IACP presented the project, prepared by the Technical Department of the Institute, represented by an internal engineer, as indicated on the statement of President Oliviero Cardinali, dated 23/06/1980, to the City of Prato for the issuance of the Building Permit.

The Municipality answered in 17/05/1980 with the approval of the project, requiring the presentation, to the Technical Bureau administrative services, of various documents, including the affidavit, the permit from the hygiene office, clearance under Law 1497 / '39, the confirmation that the thermal power plant would not exceed 20.000Kcal / h and the storage would not be more than 500lt, the deposit of a sum (L.8.344.000) as a guarantee for the landscape, the infrastructure costs to be paid (primary L.22.386.052 and secondary L.51.307 .256) within 60 days upon receipt of such information from the Institute. The project was discussed and approved by the IACP Council of Directors on 04/23/1980. It consisted of 19 drawing tables, the Special Tender Document, the General Tender Document (edition 04/1967), the General Tender Documents for the works pertaining to the Minister of Public Works and Pricing List.

[56] The reconstruction of the Building Process has been made through the consultation of the folders 105-109 about COMPLEX A that are collected at the Casa SpA Archive.

On 06/05/1980 a new Tender Competition has been issued and again the result was negative because there were no offers. Only the Berti Sabatino Company proposed solutions of variants concerning mainly the structural construction system. Because of the results of the bidding process, and in order to generate interest from the building sector companies, during the meeting of 06.12.1980, the Institute decided to integrate and expand the Tender Document with some specifications and alternative solutions chosen and approved during the Institute Administration Council meeting on 09.06.1980 (score n.446). The new Tender Competition, in abbreviated terms and with the criterion of the best offer based on the price and deadline for the conclusion of works, was launched on 19.06.1980 by a letter of invitation dated 12.06.1980. The tender announcement was published on 06.10.1980, specifying that the parties concerned would have to send the request to participate within 5 days from the date of publication of the same. The tender competition was issued with the restricted invitation system, in accordance with the modalities provided in article 24, letter 'b', Law 584 of 08/08/1977.

Only one offer was done within the time allowed by the letter of invitation. In the presence of the above-mentioned persons it was analysed the documentation issued by EDILPROGRESS, the only offer arrived, which was declared as regular and, therefore, the Company was admitted to the bidding process. It was then opened the sealed envelope with the offer:

- *The amount sum was increased of 21.50%*
- *Time deadline 600 days*

After that, President Oliviero Cardinali assigned temporarily and verbally the contract to EDILPROGRESS Srl, specifying that if the offer should be considered immediately valid for this company, for the Institute it would have been considered only at the time of the approval and ratification by the Council of Administration in accordance to paragraph 24) of the invitation letter.

The Building Permit n.6721 was released the 23/06/1980. The design of the Concrete structures was assigned by the Company to Eng. Maximum Crozzoli and reported to the office of Civil Engineers on 14.11.1980 (dossier 5040) regarding to the foundation structures, the 14.12.1980 (dossier 5453) for the elevation structures and finally the 24/03/1982 for the static test (dossier 1576) the practice test certificate was issued by Eng. Mauro Camels, appointed by the IACP in 12/22/1981, among other experts suggested by the Company, as evidenced in the registered mail sent on 28/11/1981 from the Company to the Institute.

On 07.03.1980 Geom. Rolando Neri was appointed as Site Supervisor on behalf of the Building Company. Works began on 23/06/1980, as confirmed by a certificate of commencement of works and the minutes of delivery, signed by representatives of the IACP and the Company, on which is formally specified the delivery of the area to EDILPROGRESS and the identification of the intervention boundaries. In the same document, the Work Supervisor pointed out that the particles # 645 and # 162 were not yet available due to the physical opposition of the owners and other persons present on the site. In addition, the company was invited to start the work immediately. On 07.07.1980 the representative of the City, Arch. Paolo Vannucchi, in the presence of Eng. Checcucci , on behalf of the IACP, indicated the definitive Site boundaries, plan and height levels position of buildings and the road height level used as reference, delivering the area permanently to the Company, after having obtained the availability of the particles still occupied.

The Tender Contract between the company and the IACP was signed on 11.27.1980, after having received the tender offer approval by the Regional Council with act n.8546 dated 08/27/1980. The works were completed on 29/10/1982 ,43 days in advance and delivered to the Institute on

21.12.1982. During the works, under the contractor request, 20 work suspensions were ordered due to adverse weather conditions for a total of 155 days.

The residential units were finally delivered to the beneficiaries on 10/02/1983.

On 10/24/1984 Arch. W. Di Salvo and Arch. A. Alessi, experts appointed by the Regional Council with resolution n.4285 dated 27/04/1983, issued the static test certificate. The test experts, with a registered mail sent to the Company on 18/07/1984, required some interventions to be brought to the buildings, imposing their execution within 30 days after receiving the above-mentioned letter. The 17/10/1984 IACP General Manager, Luigi Dilillo, answered to the experts informing the requested interventions have been completed, so they could issue the mentioned static test certificate.

That document shows that technicians found no discrepancies with respect to the draft contract. The only variations concerned the non-execution of the basement for 2 autoclaves, since, as shown on the registered mail sent from the Company to the Institute on 10.20.1980, their installation was not necessary due to the immediate vicinity of the buildings regarding the central aqueduct. Anyway, some rooms were predisposed under the stairs on the basement floor of each building for a future installation of tanks and autoclaves. Besides, even if not required by the Contract, a basement compartment, padded wood for the kitchens, pressure reducer and finally thermoelectric heaters (this last one by F.lli Cramini Company) were installed.

APPENDIX B

BUILDING PROCESS COMPLEX B[57]

Following the request presented on 19/03/1980 by IACP, on 10/06/1980 the Municipality of Florence released Building License no. 622 for the construction of 4 buildings for public residential housing for a total of 120 housing units. The tender contract (no.7779 of 02/07/1980) was signed at the Institute. In the contract, the bidding discount was established to be brought from 2.57% to 2.845%. The company then undertook to perform construction works within 535 days from the handover report dated 19/06/1980.

The Construction Management was assigned to the engineer Luciano Checcucci on behalf of Technical Service of IACP. On 04/06/1982, the Company requested an extension that was granted for 95 days from the C.d.A. (Board of Directors), with resolution of 07/09/1982. Previous works were suspended 14 times, followed by the same number of recoveries.

Due to these extensions and suspensions for a total of 272 days, the completion of the works was extended to 03/09/1982. Despite repeated verbal solicitations, the construction company increasingly slowed down the production of the building site and ended up suspending it. This circumstance was pointed out by the D.L. (construction management) on 8/9/1982, 17/9/1982 and 28/9/1982, with drafting reports on the state of consistency of works and abandoned sites. At the meeting on 30/9/1982, the Board of Directors noticed that the works had been completed for about 51% and decided to terminate the contract due to the conduct of the company.

The announcement of termination of contract was drafted on 01/10/1982 and on 04/10/1982 it was notified to the administration of the Capece company by bailiff.

With resolution no.10800 of 11/10/1982 of the Regional Council of Tuscany, the working group composed by the engineers Giorgio Croppi, Francesco Lardani and Vittorio De Sanctis was commissioned to undertake the acceptance of work, and after the visit on 11/01/1984, they drafted the test report on 08/03/1984. On 08/11/1982, the Region of Tuscany decided to once again contract out unfinished works. Due to the different progress of work, the IACP decided to separately contract the building of lot Qb40, as only the foundations and part of the ground floor structures were completed.

With resolution 15/03/1984 the Board approved the tender documentation for the contract work of the 96 housing units left out, and decided to carry out a new tender. The maximum time given for carrying out and completing the works was 300 days.

Following the private bid which took place on 10/04/1984, the contract was awarded to COS.MA S.p.A., company of Florence that offered a bidding discount of 18.65%, based on the reference amount of L.1,676,000,000, and agreed to complete the works in 200 consecutive and continuous days.

The contract agreement was signed on 27/04/1984, while works were delivered on 09/05/1984, and the construction management (Direzione Lavori) was entirely given to the IACP and to the surveyor Sergio Bianchini. The completion of the works was originally programmed for the 24/11/1984, but then ended on 24/12/1984, 30 days later.

[57] The reconstruction of the Building Process has been made through the consultation of the folders 162-173 about COMPLEX B that are collected at the Casa SpA Archive.

During the period between the submission of the offer by the companies and the award of works, an arson occurred in the building lot Qb16, which damaged partitions, bathroom wall units, and blackened walls and ceilings in some apartments. Therefore, a survey took place in order to decide on the cost for recovery works of the damaged building, which had to be added to the total contract cost. After the handover of the housing units, defects were found on thermal water and electric systems, as well as on some frames.

The COS.MA company did not carry out the required repair works, thus IACP had to hand them over to the company Massini & Gori Montevarchi (AR). On 30/11/1985 COS.MA announce to the IACP to have ceased every operation, and with the order of 25/03/1986, the Court of Florence declared its bankruptcy. The inspection committee, after having examined the buildings on 30/12/1985 and 21/01/1986, drafted a test report on 02/02/1987.

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4. CHOICE OF THE RECOVERY STRATEGIES AND DEFINITION OF THE - REFURBISHMENT METHOD FOR THE CASE STUDIES

According to the BASE CASE results (Chapter 3), the next sections will be focused on the strategies suitable to solve the energy issues of the buildings and the final definition of criteria according to the building type and the common features found in chapter 3.

As we have mentioned, the most suitable strategies will have to:

- During the Winter season: minimize heat losses, due to both the transmission through the envelope (for example because of a poor insulation or windows with low performance) and due to the ventilation (natural opening of the windows and air leakage due to the poor tightness of the buildings);
- During the Summer season: ensure a good cooling in order to improve the thermal-hygrometric internal comfort.

4.1 CHOICE OF THE RENOVATION STRATEGIES AND APPLICATION ON A SAMPLE CASE: IOLO A

As we already mentioned in chapter 2, a great amount of renovation strategies does exist. This work aims at applying simple and low-cost strategies because of the residential building class analysed that is social housing. For this cause the objective is to maintain as much as possible the existing building characteristics, such as:

- the building shape;
- the building volume;
- the internal organization of the flats;
- the technical implants, if they still work.

Accordingly, the best strategies will have to be effective with the minimum impact on the building and on the inhabitants' life. At the same time, the chosen measures will have to lead to acceptable comfort levels inside the apartments together with good levels of energy saving in order to reduce costs and to have less impact on the environment.

The first step of the recovery criteria will analyse measures for the envelope recovery in order to reduce the heat losses and the second step will take into account measures for improving the internal comfort inside the flats, by avoiding the installation of an air-conditioning system.

4.1.1 ENVELOPE RECOVERY (STEP A)

The first step (STEP A) was the application of an insulation layer on the facades, on the attic and arcade/cellar slabs and the substitution of the windows. The choice of this strategy depended on the simplicity of the recovery intervention due to the possibility to let the occupants live inside the flat still during the recovery works and the low price, considering the fact we are analyzing public residential buildings. The insulation chosen for the external walls and for the arcade/cellar slabs was an EPS (expanded polystyrene) panel 8cm of thickness. This material is the most common insulation used in the recovery intervention by Casa S.p.A. in the recovery of Social Housing in the Florence area for the good energy performance and for its low cost compared to other insulation materials (1). For the attic floor we choose the mineral wool insulation, simply to lay on the slab (10cm thick). The thickness of the insulation both on the walls/slabs and the windows type were chosen according to the actual Legislative Standards[1].

The building model was updated with the new type of external walls, slabs and windows:

	Before the recovery	After the recovery	Standards
External walls	U-value: 0.698 W/m^{2}K	U-value: 0.25 W/m^{2}K	U-value: 0.29 W/m^{2}K
Stairs walls	U-value: 0.798 W/m^{2}K	U-value: 0.26 W/m^{2}K	U-value: 0.29 W/m^{2}K
Windows	U_w-value: 2.83 W/m^{2}K	U_w value: 1.70 W/m^{2}K[2]	U_w value: 1.80 W/m^{2}K
Arcade/Cellar slab	U-value: 0.83 W/m^{2}K	U-value: 0.28 W/m^{2}K	U-value: 0.29 W/m^{2}K
Attic slab	U-value: 0.92 W/m^{2}K	U-value: 0.28 W/m^{2}K	U-value: 0.29 W/m^{2}K

Table 4.1: BUILDING A-U-values of the building elements before and after the intervention.

The presence of Roll blinds is still considered in the evaluation of the energy performance of the building in order to limit the solar gains during the Summer months (see Chapter 3).

The number of air change rates (ACH) considered in the model is still 0.5/h, taking into account an average value for a good indoor air quality inside the apartments (according to the European legislative Standards). This first strategy has solved the issues of heat losses and has enhanced the performance of the buildings envelope.

The results under semi-stationary conditions and dynamic ones are showed in the next paragraphs.

1. **Semi-stationary conditions**

We will apply the same verifications conducted in Chapter 3.

The Global Energy Performance index ($\boldsymbol{EP_{gl,nren}}$) is:

$EP_{gl,nren}$= 55.69 kWh/m^{2}y

$EP_{gl,nren,rif}$(2019,2021)= 46.85 kWh/m^{2}y

The NEW building Energy Class is **B**, in fact:

[1] We refer to the "Reference building" introduced by the National Standards (see par.3.2). According to the Climate Zone this "building" has limit values for the transmittance. We choose the minimum thickness for the insulation layer in order to obtain the same or lower values for the transmittance of the walls/slabs than those defined for the "Reference Building". The same considerations were made for the windows.

[2] We consider the glass transmittance U_g= 1.5W/m^2 and a shading factor g=0.75 (SGG CLIMAPLUS-SAINT GOBAIN GLASS) (25). For the frame transmittance U_f= 1.3W/m^2 (GENIUS window-Sudtirol FENSTER www.suedtirol-fenster.com/it/).

$1.00^* EP_{gl,nren,rif}(2019,2021) < \mathbf{EP_{gl,nren}} \leq 1.20^* EP_{gl,nren,rif}(2019,2021)$

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient ($\boldsymbol{H'_T}$)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K

H'_T = 0.36 W/m^{2}K→ $H'_T < H'_{Tlim}$ **VERIFIED**

In BASE CASE this verification was not satisfied, because of the high values of Transmittance of the building elements.

b. Envelope Energy Performance in Winter through the calculation of $\boldsymbol{EP_{H,nd}}$

$EP_{H,nd}$ = 16.59 kWh/m^{2}y

$EP_{H,nd,lim}$(2019,2021)= 11.14 kWh/m^{2}y

The result is:

$1^*EP_{H,nd,lim}(2019,2021) < EP_{H,nd} \leq 1.7^*EP_{H,nd,lim}(2019,2021)$

→ **MEDIUM QUALITY OF THE ENVELOPE**

In BASE CASE the quality of the envelope was LOW. It means that the envelope recovery led to a decrease of heat losses through the envelope.

c. Envelope Energy Performance in Summer through the evaluation of ($\boldsymbol{A_{sol,est}}$) and ($\boldsymbol{Y_{IE}}$)

$A_{sol,est}/S$= 0.061

Y_{IE}=0.02W/m^{2}K

The thresholds are:

$(A_{sol,est}/S)_{lim}$= 0.03

$(Y_{IE})_{lim}$= 0.14W/m^{2}K

The result is:

$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ and $Y_{IE} < (Y_{IE})_{lim}$ → **MEDIUM QUALITY OF THE ENVELOPE**

In BASE CASE the quality of the envelope was LOW. The addition of the insulation layer increased the thermal mass of the building elements, improving then the thermal inertia.

2. Dynamic conditions

From the results of the dynamic simulations, the fig.4.1 shows the Energy Balance of the flats during the year, highlighting a decrease of almost the 40% of the total Energy Demand for heating for the entire building, compared to BASE CASE.

REDUCTION (%)	
	STEP A/BASE CASE
JAN	32%
FEB	32%
MARCH	39%
APR	59%
NOV	36%
DEC	32%
TOTAL	**37%**

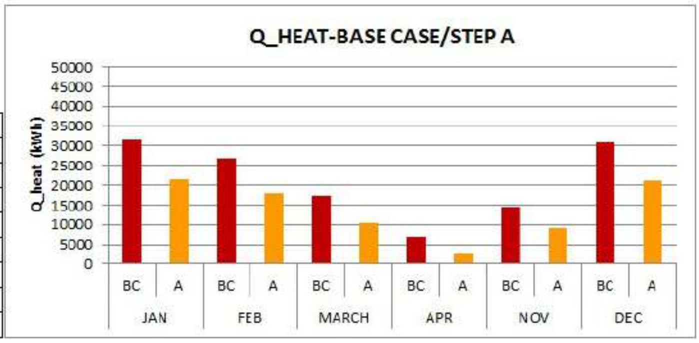

Figure 4.1: BUILDING A-Monthly Sensible Energy Demand for heating in BASE CASE and STEP A.

This energy improvement is due to the decrease of heat losses due to the transmission through the envelope (Q_trans). As it is shown in fig. 4.2, this reduction is about 35% in comparison with BASE CASE.

REDUCTION (%)	
	STEP A/BASE CASE
JAN	46%
FEB	36%
MARCH	39%
APR	42%
MAY	37%
JUNE	27%
JULY	10%
AUG	7%
SEP	19%
OCT	35%
NOV	37%
DEC	36%
TOTAL	34%

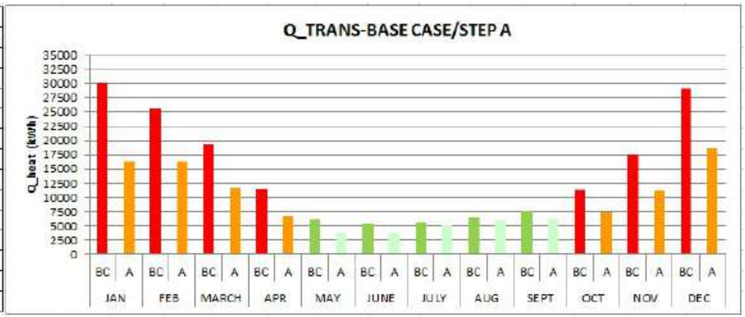

Figure 4.2: BUILDING A-Monthly average heat losses due to the transmission through the envelope (Q_trans). Comparison between BASE CASE and STEP A.

<u>WHOLE BUILDING</u>

For what concerns the internal comfort, the addition of an insulation layer on the facades leads to an increase of indoor temperatures, in Summer, of almost 2°C and a consequent decrease of Relative Humidity.

The improved thermal inertia of the envelope has increased the attenuation of the heat flow, but the heat accumulated during the warmer hours of the day is not able to go out from the house during the cooler hours (if on one hand the insulation layer stops the entering of the heat, on the other hand, it obstructs it from its leaving).

The warmest floor is still the fourth floor.

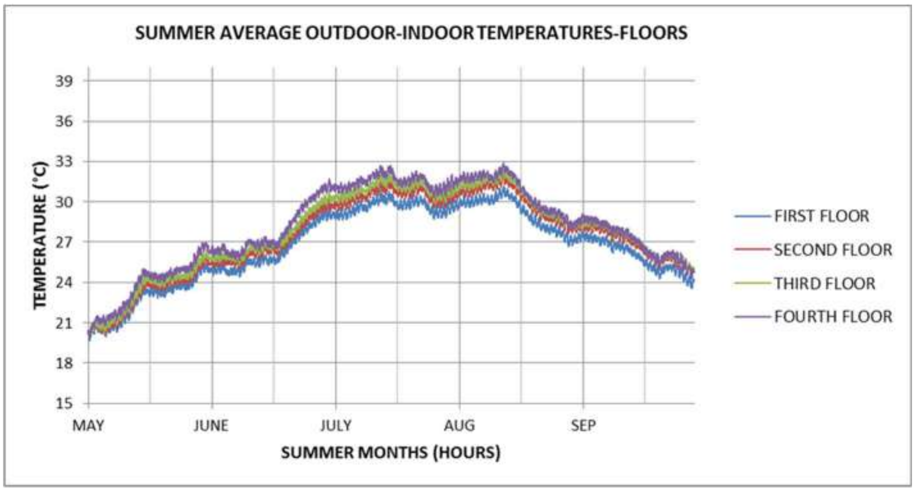

Figure 4.3: BUILDING A-Hourly trend of temperatures during Summer months, averaged across all the apartments per floor.

The warmest flat is FLAT 6 at the fourth floor, as well as in BASE CASE, but the maximum value of temperatures is almost 34°C in August against 32.63°C.

MONTHS	BASE CASE					STEP A				
	MEAN T (°C)	MAX T (°C)	FLOOR	FLAT (ZONE)	DAY	MEAN T (°C)	MAX T (°C)	FLOOR	FLAT (ZONE)	DAY
MAY	21.98	26.92	4	Z-8/F-6	29th	23.16	27.91	4	Z-8/F-6	29th
JUNE	25.61	31.47	4	Z-8/F-6	30th	27.08	32.54	4	Z-8/F-6	30th
JULY	28.92	32.36	4	Z-8/F-6	13th	30.62	33.57	4	Z-8/F-6	13th
AUGUST	28.29	32.63	4	Z-8/F-6	13th	30.15	33.77	4	Z-8/F-6	13th
SEPTEMBER	24.84	28.87	4	Z-8/F-6	2nd	26.68	30.28	4	Z-8/F-6	2nd

Table 4.2: BUILDING A-Comparison between temperature values averaged across all the apartments for each floor during Summer in BASE CASE and STEP A.

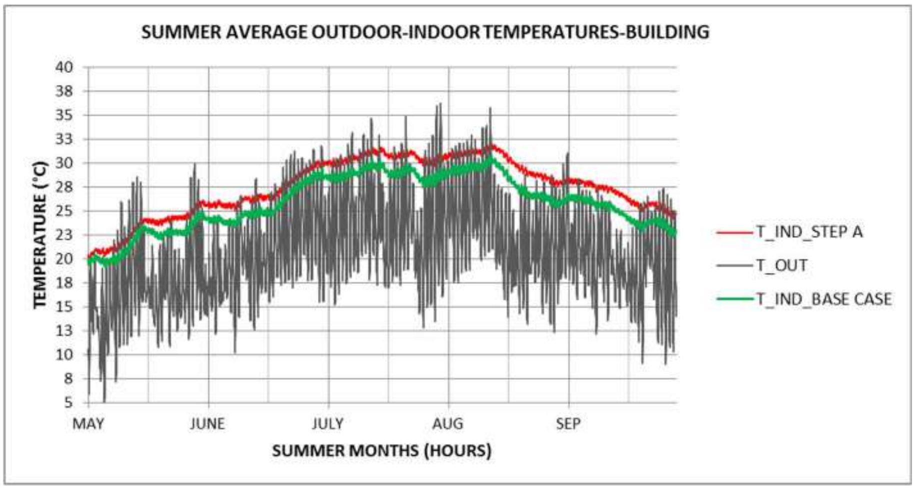

Figure 4.4: BUILDING A-Hourly trend of mean temperatures in Summer (average values of the whole building). Comparison between STEP A, BASE CASE and outdoor temperatures.

The number of hours exceeding 26°C and 28°C is increased in all the analysed months, except in May and in October, because already in BASE CASE these months did not present this problem. The table located on the left in the fig.4.5 represents the reduction in terms of percentage of hours exceeding 26-28°C during each month between BASE CASE and STEP A, calculated as follows:

$$R_{T,26\text{-}28}=\%h_{bc,26\text{-}28}-\%h_{A,26\text{-}28}\text{, where} \qquad (4.1)$$

$R_{T,26\text{-}28}$= percentage reduction of hours exceeding 26°C or 28°C during the month;

$\%h_{bc,26\text{-}28}$= percentage of hours exceeding 26°C or 28°C in BASE CASE ($\%h_{bc,26\text{-}28}=\#h_{26\text{-}28}/H_m$) in the month;

$\%h_{A,26\text{-}28}$= percentage of hours exceeding 26°C or 28°C in STEP A ($\%h_{A,26\text{-}28}=\#h_{26\text{-}28}/H_m$) in the month;

$\#h_{26\text{-}28}$= number of hours exceeding 26°C or 28°C in the month;

H_m= number of hours in the month.

The negative sign of the percentage in the table represents the increase of temperatures. In August, hours exceeding 28°C increase of about the 30%, while in September hours above 26°C enhance of about the 40% in comparison with BASE CASE.

$R_{T,26\text{-}28}$ (%) STEP A/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-	-
JUNE	-12%	-12%
JULY	-2%	-12%
AUG	-8%	-33%
SEP	-42%	-21%
OCT	-	-

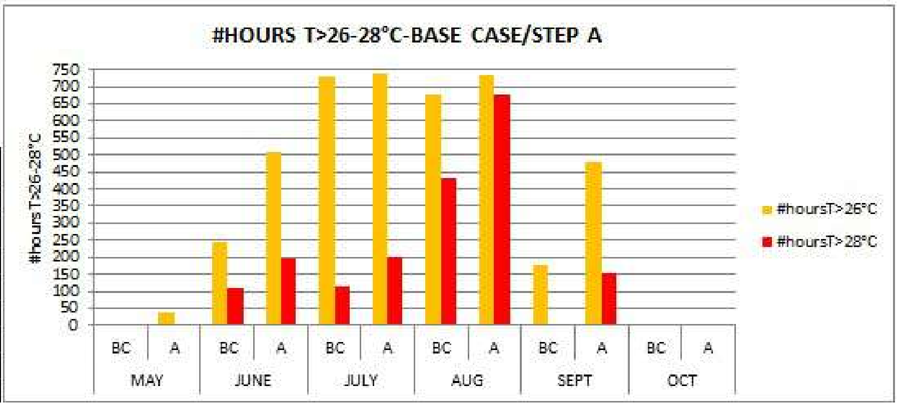

Figure 4.5: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP A and BASE CASE during Summer months.

We have to specify that we are still dealing with values averaged across all the apartments for the whole building, but they are useful in order to understand the general behaviour of the building and the effects of the application of the strategy on the global performance.

The increase of temperatures, especially during the worst months in Summer (July and August) leads to a decrease of Relative Humidity inside the apartments.

The fig.4.6 shows the comparison of the hours number of RH above 60% and 70% between BASE CASE and STEP A, and the table, as in the previous case, represents the reduction between the 2 cases in terms of percentage of hours exceeding these thresholds of Relative Humidity, calculated as follows:

$$R_{RH,60\text{-}70}=\%h_{bc,60\text{-}70}-\%h_{A,60\text{-}70}\text{, where} \qquad (4.2)$$

$R_{RH,60\text{-}70}$= percentage reduction of hours with RH exceeding 60% or 70% during the month;

$\%h_{bc,60\text{-}70}$= percentage of hours with RH exceeding 60% or 70% in BASE CASE ($\%h_{bc,60\text{-}70}=\#h_{60\text{-}70}/H_m$) in the month;

$\%h_{A,60\text{-}70}$= percentage of hours with RH exceeding 60% or 70% in STEP A ($\%h_{A,60\text{-}70}=\#h_{60\text{-}70}/H_m$) in the month;

$\#h_{60\text{-}70}$= number of hours with RH exceeding 60% or 70% in the month;

H_m= number of hours in the month.

$R_{RH,60-70}$ (%)		
STEP A/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	15%	8%
JUNE	32%	13%
JULY	28%	7%
AUG	19%	6%
SEP	34%	13%
OCT	18%	23%

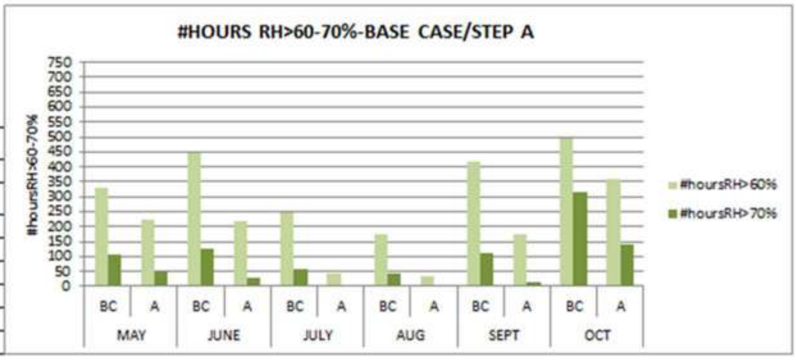

Figure 4.6: BUILDING A-Comparison between the number of hours exceeding 60%-70% of Relative Humidity in STEP A and BASE CASE during Summer months.

Hours exceeding 70% of RH are almost completely eliminated in June, July, August and September. Hours above 60% of RH in STEP A decrease in all months compared to BASE CASE, up to reach a reduction of 30% in June, July and September.

After a previous analysis of the global building behaviour after the envelope recovery, we will study in detail the answer of the flats with the worst indoor conditions taken as sample flats to be monitored in BASE CASE.

FLATS

FLOOR 1: FLAT 8

The flat 8, as well as the whole building, suffered an increase of temperatures.

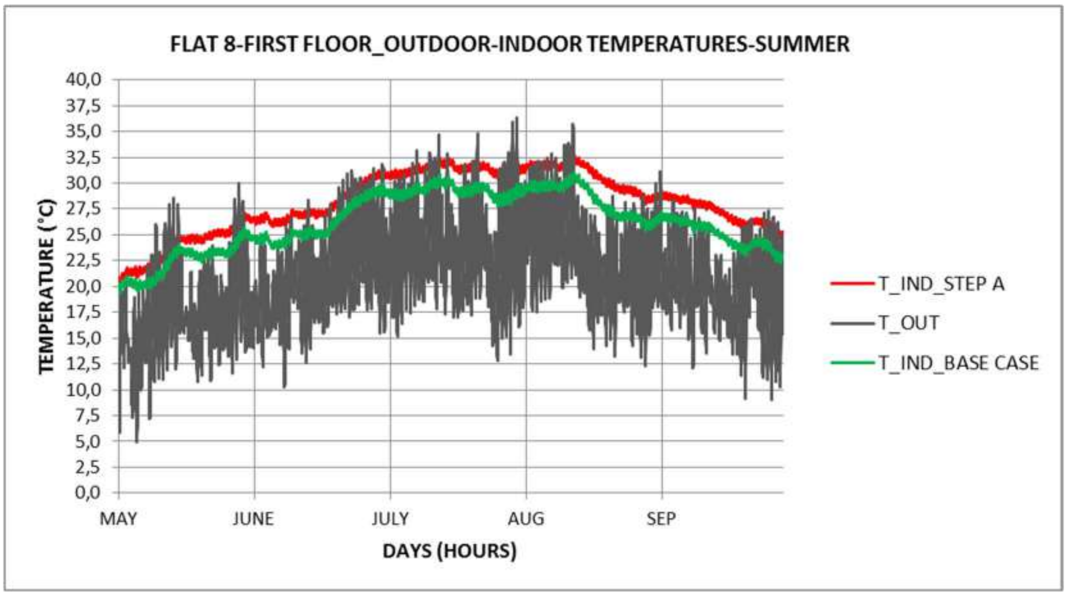

Figure 4.7: BUILDING A. Hourly trend of temperatures in Summer. Comparison between STEP A, BASE CASE and outdoor temperatures (FLOOR 1-FLAT 8).

The tab. 4.3 shows some representative temperature values during the central months in Summer and the "shoulder" months. The maximum value of temperature is reached in August (32.66°C), almost 2°C higher than in BASE CASE. The minimum value of temperature is in October (16.57°C).

	JUNE		JULY		AUGUST	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	26.05	27.84	29.23	31.30	28.50	30.71
MAX T (°C)	30.00	31.49	30.78	32.49	31.04	32.66

	MAY		SEPTEMBER		OCTOBER	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	22.42	23.87	22.73	25.05	20.50	27.20
MAX T (°C)	25.65	27.11	25.51	27.25	23.73	29.26
MIN T (°C)	19.40	20.17	18.94	22.31	16.57	24.62

Table 4.3: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (FLOOR 1-FLAT 8).

The number of hours exceeding 28°C increases in almost all the months, worsening the internal comfort conditions especially in June, July and August.

$R_{T,26-28}$ (%)	
STEP A/BASE CASE	
$R_{T,26}$	$R_{T,28}$
MAY	-	-
JUNE	-59%	-14%
JULY	0%	-2%
AUG	-4%	-40%
SEP	-50%	-36%
OCT	-	-

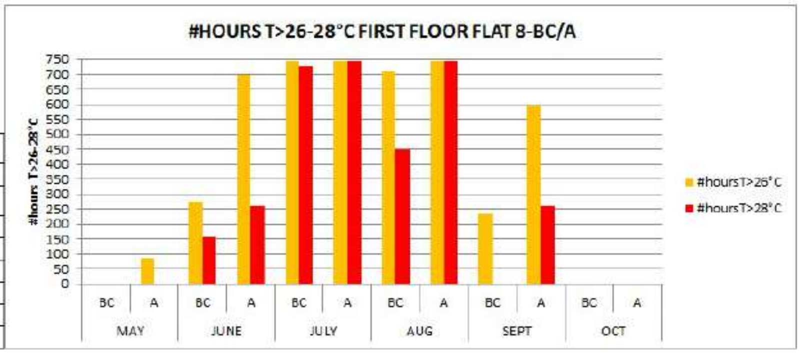

Figure 4.8: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP A and BASE CASE during Summer months (FLOOR 1-FLAT 8).

In September the fig. 4.8 highlights that hours above 26°C double and hours above 28°C increase, going from 0 in BASE CASE up to about 260 in STEP A (increase of 36%). The other relevant months are June and August. The first one presents an increase of almost the 60% of hours exceeding 26°C, while for the second one hours above 28°C rise of the 40%. All the month of July has hours above 28°C. The Relative Humidity decreases as we could aspect because of the increase of temperatures. During the warmest months we have the greatest reduction of RH (June, July, August and September).

$R_{RH,60-70}$ (%)		
STEP A/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	11%	11%
JUNE	20%	23%
JULY	34%	5%
AUG	22%	7%
SEP	24%	24%
OCT	15%	22%

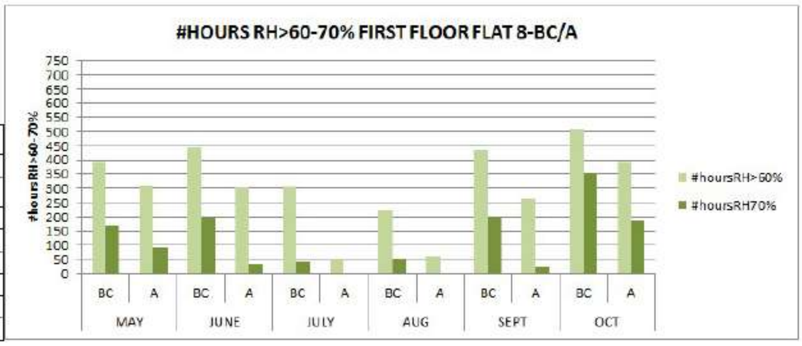

Figure 4.9: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and BASE CASE during Summer months (FLOOR 1-FLAT 8).

For a better evaluation of the internal comfort conditions it is useful to analyse the PPD index, by evaluating the percentages of hours with PPD<6-10-15%. The greater these values, the better will be the internal comfort conditions. The table in fig.4.10 represents the reduction between BASE CASE and STEP A in terms of percentage of hours with PPD<6-10-15%, calculated as follows:

$$R_{PPD,6\text{-}10\text{-}15}=\%h_{bc,6\text{-}10\text{-}15}-\%h_{A,6\text{-}10\text{-}15}, \text{where} \tag{4.3}$$

$R_{RH,60\text{-}70}$= percentage reduction of hours with PPD<6-10-15% during the month;

$\%h_{bc,6\text{-}10\text{-}15}$= percentage of hours with PPD<6-10-15% ($\%h_{bc,6\text{-}10\text{-}15}=\#h_{6\text{-}10\text{-}15}/H_m$) in the month;

$\%h_{A,6\text{-}10\text{-}15}$= percentage of hours with PPD<6-10-15% in STEP A ($\%h_{A,6\text{-}10\text{-}15}=\#h_{6\text{-}10\text{-}15}/H_m$) in the month;

$\#h_{6\text{-}10\text{-}15}$= number of hours with PPD<6-10-15% in the month;

H_m= number of hours in the month.

When this reduction is negative, STEP A led to an improvement to the internal comfort in the flat. In this case we have an improvement of the internal conditions in May and in October, while in the other months, according to the decrease of the percentage of PPD, the situation worsens. This depends on the fact that the decrease of RH does not improve the indoor comfort conditions, because PPD values decrease with high levels of temperature even if the RH levels are lower than those of BASE CASE. In June, July, August, as we could aspect, we have a relevant reduction of number of hours with PPD<6-10-15%. Indeed, in these months the indoor temperatures increase and this aspect is more relevant than the decrease of RH.

In September, despite the mean temperature value inside the flat is acceptable (25.05°C), the increase of temperatures worsens the indoor comfort. This is likely outdoor temperatures depending. In fact, the external mean temperature value in September is 19.82°C, so that temperatures measured in the flat in BASE CASE where more comfortable than the STEP A ones.

On the contrary in May and in October we still have an increase of temperatures, but for the first month this is useful to rise the too low mean temperature value in BASE CASE, still compared with the outdoor temperatures. Indeed, in this case the outdoor mean temperature in May is 17.17°C, lower than in September, so that the increase of temperatures makes the flat more comfortable. In October the effect of the outdoor temperature is more relevant, since the external mean value is even lower (15.09°C). Therefore, the rise of temperatures, together with the decrease of RH helped to improve the internal comfort in the flat.

$R_{PPD,6\text{-}10\text{-}15}$ (%)			
STEP A/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-25%	-3%	-7%
JUNE	37%	53%	31%
JULY	-	-	-
AUG	-	8%	19%
SEP	26%	32%	46%
OCT	-33%	-13%	-9%

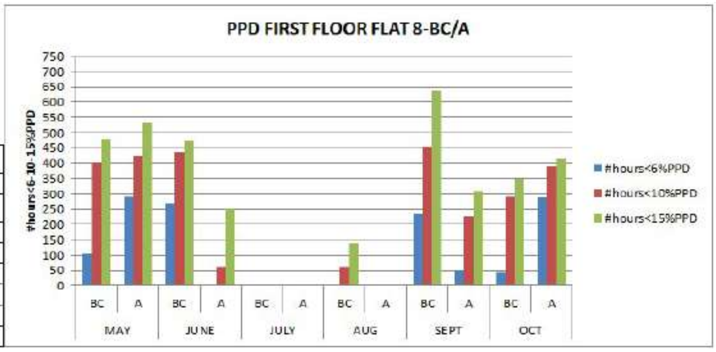

Figure 4.10: BUILDING A-Comparison between the PPD index values in BASE CASE and STEPA (FLOOR 1-FLAT 8).

FLOOR 2: FLAT 6

The FLAT 6 suffered an increase of temperatures as in the previous case with a maximum value of 32.33°C in August.

	JUNE		JULY		AUGUST	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	25.64	27.06	28.98	30.62	28.47	30.28
MAX T (°C)	29.31	30.52	30.43	31.82	30.99	32.33

	MAY		SEPTEMBER		OCTOBER	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	22.01	23.16	25.10	26.89	20.79	22.64
MAX T (°C)	24.83	26.09	27.12	28.82	23.80	25.56
MIN T (°C)	19.07	19.94	22.60	24.48	16.80	18.74

Table 4.4: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (FLOOR 2-FLAT 6).

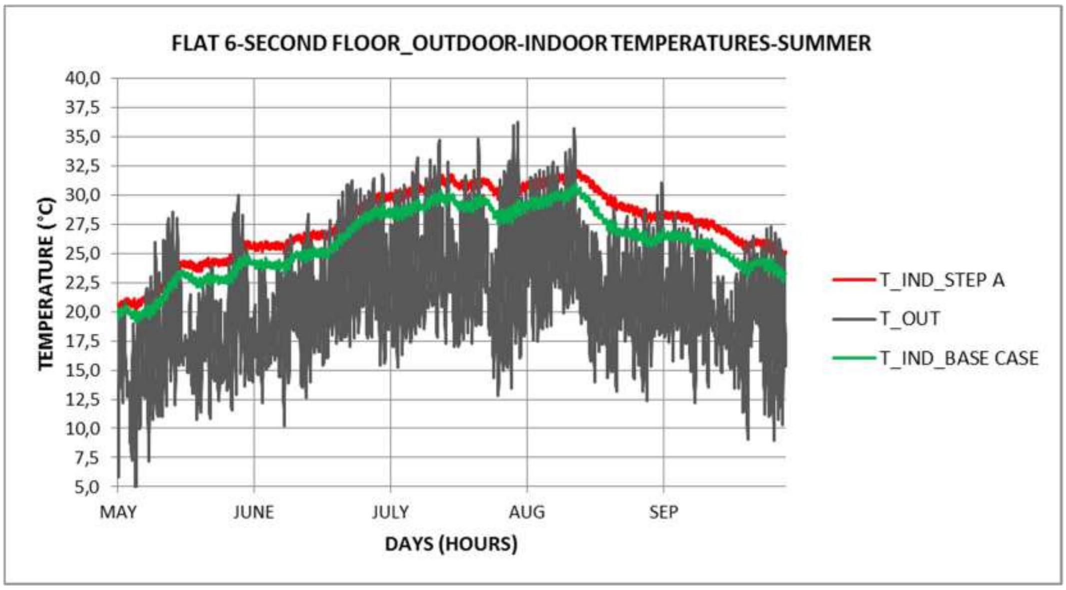

Figure 4.11: BUILDING A-Hourly trend of temperatures in Summer Comparison between STEP A, BASE CASE and outdoor temperatures (FLOOR 2-FLAT 6).

Also in this flat the mean temperature values in May and in October are too low in BASE CASE compared to STEP A (the minimum value reaches almost 16°C in October), so that the increase of temperatures provides better comfort conditions. In September this flat reaches higher levels of temperatures than in BASE CASE ones. The results are highlighted in fig.4.12: in October the number of hours with PPD<6% is almost 300, while in BASE CASE around 60 hours; in May we have almost 300 hours with PPD<6%, against 80 hours in BASE CASE.

$R_{PPD,6\text{-}10\text{-}15}$ (%)			
STEP A/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-25%	-30%	-8%
JUNE	45%	35%	18%
JULY	-	-	-
AUG	-	9%	22%
SEP	28%	33%	51%
OCT	-30%	-13%	-7%

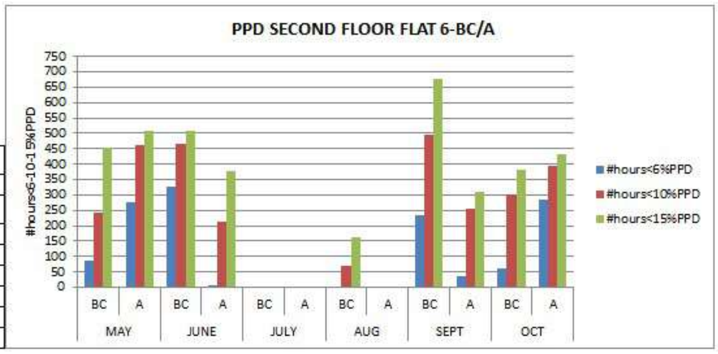

Figure 4.12: BUILDING A-Comparison between the PPD index values in BASE CASE and STEPA (FLOOR 2-FLAT 6).

Obviously, the worst conditions occur during the central months in Summer (June, July and August) when the number of hours above 28°C increases of almost 40% in August, so that all the month presents hours above 28°C. In June hours exceeding 26°C double (from 247 in BASE CASE to 504 in STEPA, increase of almost 40%). September has almost 200 hours exceeding 28°C. July is completely above 28°C.

$R_{T,26\text{-}28}$ (%)		
STEP A/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-	-
JUNE	-36%	-13%
JULY	0%	-6%
AUG	-3%	-37%
SEP	-37%	-22%
OCT	-	-

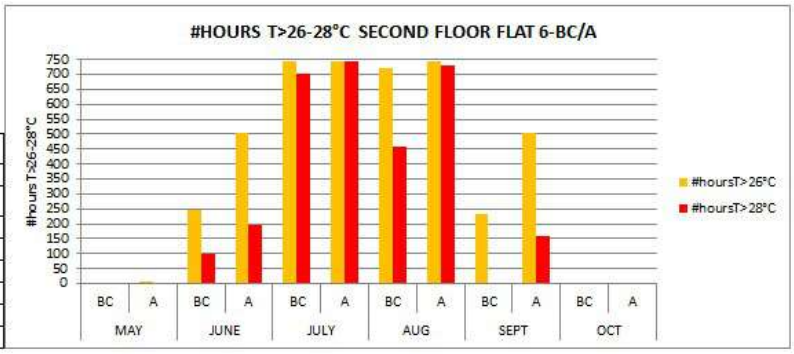

Figure 4.13: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP A and BASE CASE during Summer months (FLOOR 2-FLAT 6).

Also in this case the Relative Humidity decreases (fig.4.14), especially in July and August, when the reduction is around 60% for the first one and 40% for the second one, but the high levels of temperatures reached in this flat during these months make it uncomfortable.

$R_{RH,60\text{-}70}$ (%)		
STEP A/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	10%	12%
JUNE	26%	26%
JULY	63%	38%
AUG	40%	23%
SEP	23%	24%
OCT	14%	21%

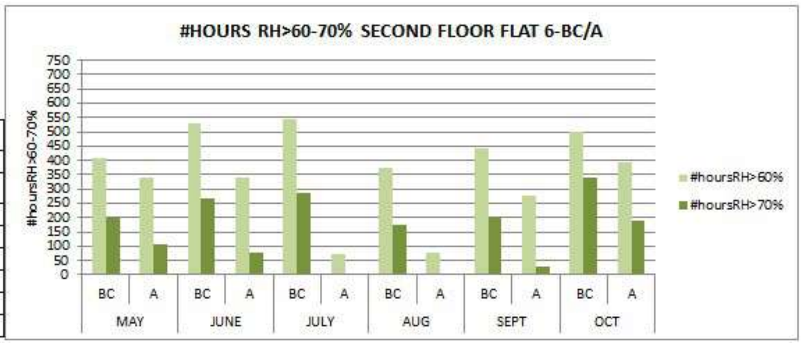

Figure 4.14: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and BASE CASE during Summer months (FLOOR 2-FLAT 6).

FLOOR 3: FLAT 2

Similar considerations of the previous flats can be made for this apartment. The results of the envelope recovery on the internal comfort are: the improvement of temperatures during all the analysed months and the consequent decrease of Relative Humidity.

The PPD indices vary according to the different months. For what concerns the central months in Summer (June, July and August) the PPD index highlights (fig.4.16) a discomfort in the flat, as well as in September when the temperatures reach too high levels compared to the actual comfort standards, while in May and in October the increase of temperatures improves the internal comfort conditions inside the flat (increase of number of hours with PPD<10-15%), because in the BASE CASE the temperatures of the flats were too low.

	JUNE		JULY		AUGUST	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	26.29	27.93	29.64	31.54	29.02	31.07
MAX T (°C)	30.26	31.67	31.28	32.86	31.73	33.25

	MAY		SEPTEMBER		OCTOBER	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	22.56	26.07	25.54	27.53	21.07	23.10
MAX T (°C)	25.79	27.20	27.74	29.63	24.38	25.86
MIN T (°C)	19.50	20.25	22.82	24.94	16.97	19.11

Table 4.5: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (FLOOR 3-FLAT 2).

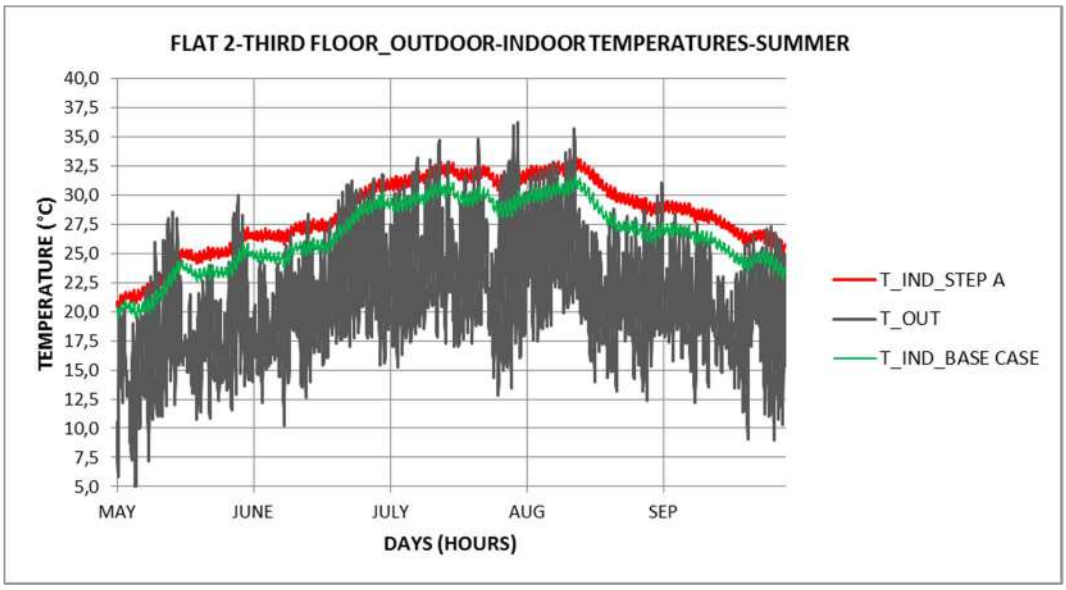

Figure 4.15: BUILDING A-Hourly trend of temperatures in Summer. Comparison between STEP A, BASE CASE and outdoor temperatures (FLOOR 3-FLAT 2).

$R_{PPD,6-10-15}$ (%)		
STEP A/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-17%	3%	-6%
JUNE	23%	51%	38%
JULY	-	-	-
AUG	-	1%	8%
SEP	28%	38%	33%
OCT	9%	-5%	-8%

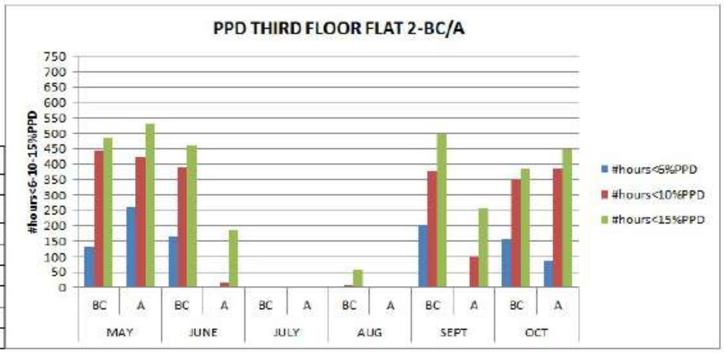

Figure 4.16: BUILDING A-Comparison between the PPD index values in BASE CASE and STEPA (FLOOR 3-FLAT 2).

The fig.4.17 demonstrates the results obtained with the PPD values. June presents an increase of 60% of hours above 26°C compared to BASE CASE (indeed the percentage of PPD decreases). In September 300 hours have temperatures exceeding 28°C (33%/month) compared to no hours in BASE CASE and the hours above 26°C double (increase of almost 50%). In July all the hours show temperatures above 28°C. In August all the hours exceed 26°C both in BASE CASE and STEP A, but hours above 28°C increases of about 30% in the last case, increasing the mean temperature value.

$R_{T,26-28}$ (%)		
STEP A/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-	-
JUNE	-58%	-13%
JULY	0%	0%
AUG	0%	-33%
SEP	-46%	-43%
OCT	-	-

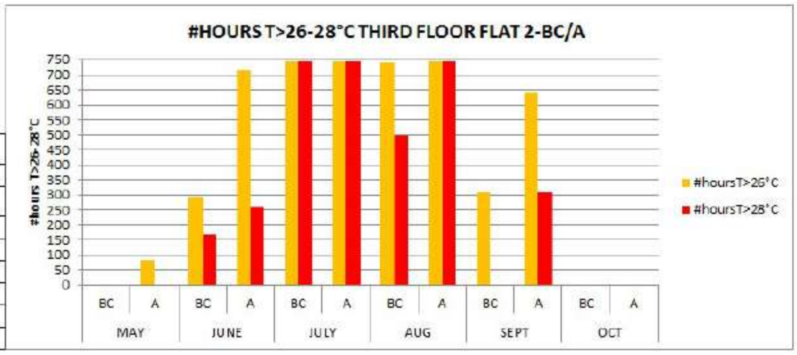

Figure 4.17: BUILDING A-Comparison between the number of hours 26-28°C in STEP A and BASE CASE during Summer months exceeding (FLOOR 3-FLAT 2).

According to the raise of temperatures, Relative Humidity decrease. The most important aspect to underline, as in the other flats, is the removal of hours above 70% of RH in July and August and the reduction of almost the 50% in June and September (fig.4.18).

$R_{RH,60-70}$ (%)		
STEP A/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	13%	25%
JUNE	12%	46%
JULY	43%	12%
AUG	27%	11%
SEP	22%	47%
OCT	8%	26%

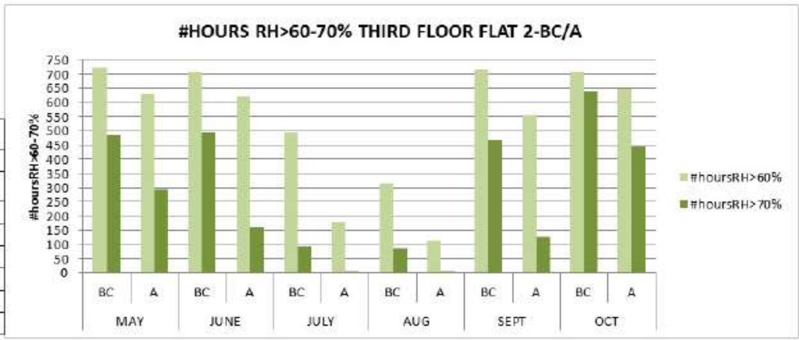

Figure 4.18: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and BASE CASE during Summer months (FLOOR 3-FLAT 2).

FLOOR 4: FLAT 6

This flat presents the highest levels of temperature of the entire building. The intervention on the envelope leads to an increase of the indoor temperatures and a consequent decrease of RH as well as in the other flats. The comfort conditions improve during the "shoulder" months (May and October), while in September temperatures reach too high values (fig.4.19).

	JUNE		JULY		AUGUST	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	26.85	28.24	30.33	31.95	29.52	31.27
MAX T (°C)	31.02	32.18	31.85	33.14	32.10	33.34

	MAY		SEPTEMBER		OCTOBER	
	BASE CASE	STEP A	BASE CASE	STEP A	BASE CASE	STEP A
MEAN T (°C)	23.07	24.18	25.80	27.48	20.84	22.55
MAX T (°C)	26.36	27.42	28.15	29.65	24.59	25.75
MIN T (°C)	19.45	20.13	22.69	24.54	16.45	18.31

Table 4.6: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (FLOOR 4-FLAT 6).

$R_{PPD,6-10-15}$ (%)			
STEP A/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-18%	5%	-3%
JUNE	25%	56%	38%
JULY	-	-	-
AUG	-	3%	9%
SEP	30%	36%	38%
OCT	-15%	-10%	-5%

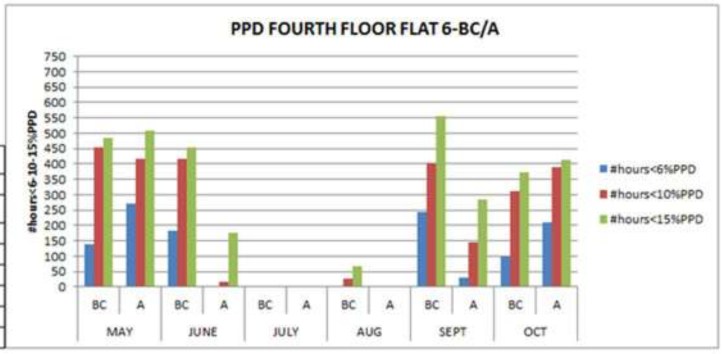

Figure 4.19: Comparison between the PPD index values in BASE CASE and STEP A (FLAT 6).

As in the other flats, July has hours above 28°C all the month. In August hours exceeding 28°C increase of almost 30%, with the result of reaching hours above 28°C all the month. In June almost all the month presents hours above 26°C, doubled compared to BASE CASE. September has about 600 hours exceeding 26°C, of which about the half part is above 28°C.

$R_{T,26-28}$ (%)		
STEP A/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-	-
JUNE	-51%	-8%
JULY	0%	0%
AUG	0%	-26%
SEP	-37%	-42%
OCT	-	-

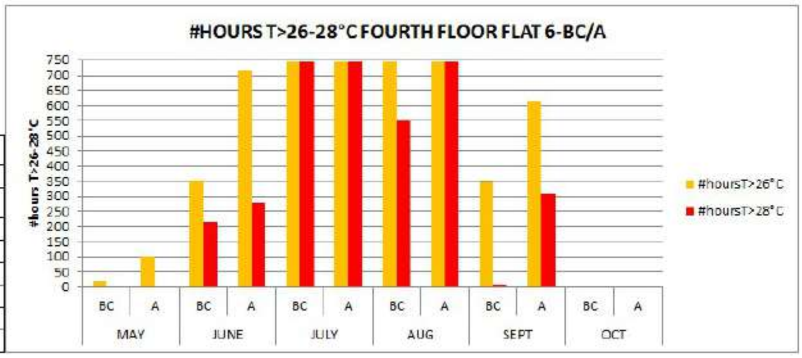

Figure 4.20: BUILDING A- Comparison between the number of hours 26-28°C in STEP A and BASE CASE during Summer months exceeding (FLOOR 4-FLAT 6).

As regards the Relative Humidity, it decreases as in the other cases along with the rise of temperatures. The most relevant effects can be highlighted in the central Summer months (June, July and August). September has no longer hours with RH above 70% and hours exceeding 60% of RH decrease of almost 20% (fig.4.21).

$R_{RH,60-70}$ (%)		
STEP A/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	15%	6%
JUNE	20%	12%
JULY	31%	1%
AUG	19%	5%
SEP	20%	15%
OCT	12%	18%

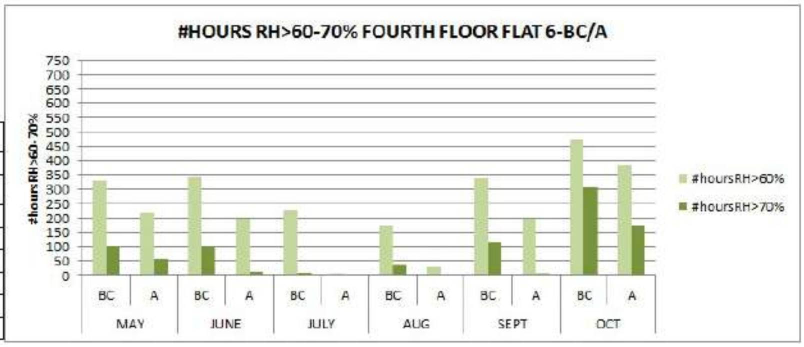

Figure 4.21: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and BASE CASE during Summer months (FLOOR 4-FLAT 6).

4.1.1.1 SYNTHESIS OF THE RESULTS

Summarizing the results of the previous paragraph, we can say that the Envelope Recovery of the building (insulation layer on the façade and slabs + substitution of the windows) led to:

WHOLE BUILDING:

- decrease of the Energy Demand for heating (almost 40% compared to STEP A);
- increase of indoor temperatures of almost 2°C compared to STEP A, taking into account the mean temperature values averaged across all the flats;
- decrease of Relative Humidity: almost total removal of hours above 70% of RH in June, July, August and September; decrease of hours exceeding the 60% of RH in all months.

FLATS:

FLOOR 1-FLAT 8: Increase of number of hours exceeding 26-28°C. Decrease of Relative Humidity.

- May: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;
- June: temperatures above 26°C almost all the month;
- July: temperatures above 28°C all the month;
- August: temperatures above 28°C all the month;
- September: Increase of almost the 60% of hours above 26°C and the half part of these presents temperatures exceeding 28°C;
- October: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;

The worst months from the internal comfort point of view are June, July and August. The internal conditions worsen in September, while are better in May and in October;

FLOOR 2-FLAT 8: Increase of number of hours exceeding 26-28°C. Decrease of Relative Humidity.

- May: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;
- June: increase of 40% of hours above 26°C;
- July: temperatures above 28°C all the month;
- August: temperatures above 28°C all the month;
- September: increase of almost the 40% of hours above 26°C and the 50% of these presents temperatures exceeding 28°C;
- October: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;

The worst months from the indoor comfort point of view are June, July and August. The internal conditions worsen in September. In October and in May the increase of temperatures arise the mean indoor temperatures which were too low in BASE CASE, improving the comfort conditions;

FLOOR 3-FLAT 2: Increase of number of hours exceeding 26-28°C. Decrease of Relative Humidity.

- May: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;
- June: temperatures above 26°C almost all the month;
- July: temperatures above 28°C all the month;
- August: temperatures above 28°C all the month;
- September: increase of almost the 50% of hours above 26°C and the half part of these presents temperatures exceeding 28°C;
- October: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;

The worst months from the internal comfort point of view are June, July and August. The internal conditions worsen in September, while in October and in May the mean indoor temperatures increase compared to those of BASE CASE;

FLOOR 4-FLAT 6: Increase of number of hours exceeding 26-28°C. Decrease of Relative Humidity.

- May: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;
- June: temperatures above 26°C almost all the month;
- July: temperatures above 28°C all the month;
- August: temperatures above 28°C all the month;
- September: increase of almost the 40% of hours above 26°C and the half part of these presents temperatures exceeding 28°C;
- October: no effects on the number of hours exceeding 26-28°C, but increase of the mean temperature value compared to BASE CASE;

The worst months from the internal comfort point of view are still June, July and August. The internal conditions worsen in September, while in October and in May the internal comfort improves.

From these considerations, the FLAT 8 at the first floor and the FLAT 6 at the last one have the worst comfort conditions, taking into account the indoor temperatures. Indeed, the Relative Humidity improves in all cases, but without improving the PPD index.

While STEP A increased the Energy Performance of the building by decreasing the Energy Demand for heating, it has also worsened the internal comfort inside the flats, by increasing the indoor temperatures of almost 2°C compared to BASE CASE.

Thus, the next strategies will have to improve the indoor comfort, by decreasing the internal temperatures and by maintaining acceptable levels of Relative Humidity with the aim at obtaining a good indoor air quality (IAQ). The strategy directly connected with these just showed issues, is to cool the space, by exploiting specific techniques aiming at avoiding the use of air-conditioning system. Obviously, the next strategies will be applied on the "recovered" envelope as obtained in STEP A. In fact, this is the first step, in any case, to be applied on these buildings because Winter issues of heat losses are not negligible in the Florence area.

It is necessary to make clear that an air-conditioning system has a set-point temperature (usually 26°C), so that system turns on only when indoor temperatures exceed this threshold.

The aim is to improve the current indoor comfort conditions (BASE CASE), even worsened by the envelope recovery described in STEP A and to do that it is necessary to cool the space, without introducing air-conditioning systems into the building.

Having stated this, the aim of this work is to more closely match the comfort range, taking into consideration the climate and the building type we are dealing with.

The next paragraphs will analyse the common techniques used to cool the space without the use of air-conditioning systems, aiming at finding the most suitable strategy to be applied on our case studies.

4.1.2 APPLICATION OF VENTILATION TECHNIQUES

Global climatic change and the consequent increase of temperatures, increases the cooling energy performance, along with the peak electricity demand for air-conditioning systems (2). Besides energy issues, air-conditioning can cause indoor air quality problems. Cooling coils may be polluted by organic dust, causing mold growth into the fans. Dirty filters and cooling towers may cause Legionella growth (3). In this scenario, passive techniques for cooling are increasingly developing. Santamouris et al. (4) make an exhaustive summary of the main passing cooling techniques, by defining the most important strategies to apply them:

- by repelling the heat from outside or by reducing the heat quantity generated within the building (thermal control). This can be done by controlling the solar gains, the internal gains and through the increase of thermal capacity;
- by dissipating excess heat through the use of natural thermal sinks (dissipative cooling); the sink can be the air, the earth, the water or the sky. According to these different sinks, different techniques are available:

  SINK: AIR-MICROCLIMATE COOLING: realised with air at lower temperature compared to the environment to be cooled. It can be divided into other 3 categories depending on the relationship between the occupants:

  a. body ventilative cooling (comfort ventilation): through the convective exchange between air and skin due to both the temperature difference and air velocity. The air velocity lowers the felt air temperature up a maximum of 3°C (v=1m/s), but followed by an increase of discomfort due to uncomfortable air movement as well[3];
  b. environmental ventilative cooling (free-cooling): temperature decrease due to the introduction of lower values of air temperature from outside;
  c. structural ventilative cooling: due to the convective exchange between envelope surfaces (walls, ceilings, floors, etc.) and the air at a lower temperature.

  All these three microclimate cooling techniques are obtained through the introduction of cooler outdoor air than the indoor one. The 3 sub-categories differ from each other for the relationship with the occupants: the first occurs when there are occupants inside the environment, the third one when there are no people[4], while the second one in either cases;

  SINK: GROUND-GEOTHERMAL COOLING: realised through the contact between the ground and the building;

  WATER: EVAPORATIVE COOLING: realised through the heat subtraction from the inlet air by means its transition through either nebulized jets or systems able to induce the evaporation mechanism. It is often used for buildings with great height (min. 9m).

[3] it is recommended to keep the air velocity under 0.8m/s. p.46 (26).

[4] It is used in non-residential buildings (not occupied during the night), consisting of introducing air during the night from openings in order to cool the internal surfaces of the building elements with great thermal mass (slabs, walls).

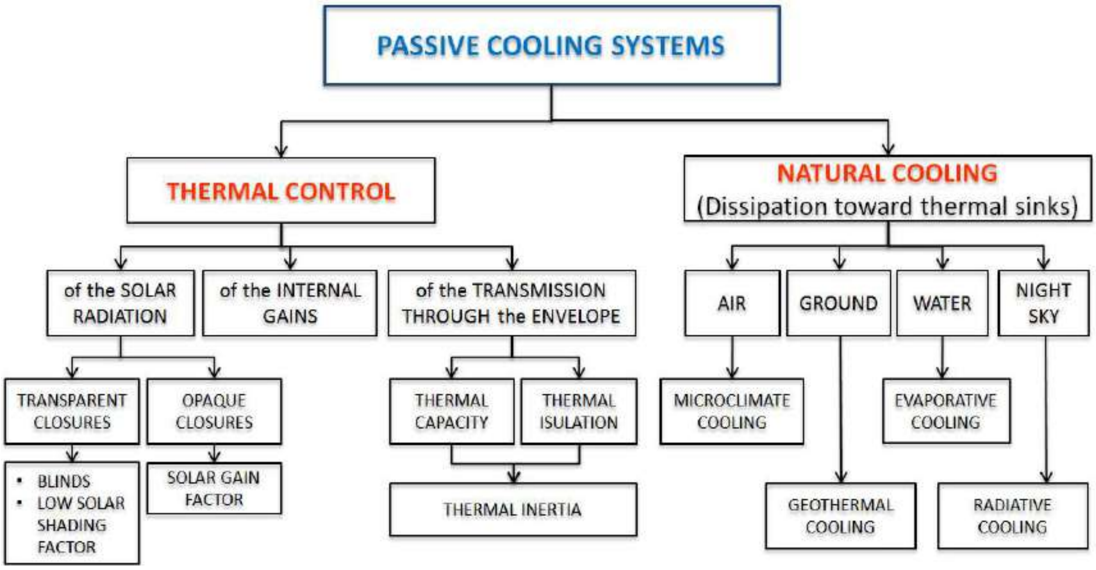

Figure 4.22: Scheme of the main Passive Cooling Techniques. Re-elaboration of the scheme p. 241 (5).

As regards our case study, a thermal control was already applied with the addition of the insulation layer and the substitution of the windows, as it is demonstrated by the increase of the thermal inertia. What we can apply in our buildings is the micro-climate cooling, that as we mentioned before provides cooler air from outside. The way to introduce air inside a building can be obtained by different ventilation techniques.

The ventilation is a process of introducing and/or extracting air from and to a space with the aim at controlling the pollutants levels, the humidity or the temperature (6).

Three main techniques for ventilation do exist:

1. *Natural Ventilation*: it is obtained by means natural forces due to the wind and to temperature differences between outdoors and indoors, which lead to the inlet of external air into the internal space through openings on the building envelope (windows, doors or openings realised for ventilation purpose). Natural ventilation systems are related to the variable outdoor climate conditions; therefore, the ventilation flow rate is not easily to calculate. The installation of natural system is relatively easy: inlet openings for the air and openings connected to chimneys with natural draft are needed (7);
2. *Mechanical Ventilation*: air inlet or/and extraction through the use of fans; in this case the ventilation rate is set directly on the system. The installation is more complicated because of the necessity to install several ducts;
3. *Hybrid Ventilation*: system that combines natural and mechanical ventilation. It uses different features of these systems at different times of the day, the season or the year (8).

The next paragraph will analyse the micro-climate cooling, that it is also called VENTILATIVE COOLING.

4.1.2.1 Ventilation for Cooling

Ventilative cooling systems use Natural or Mechanical Ventilation (or both) strategies to cool indoor spaces (9). The use of outside air reduces the energy consumption of cooling system and it guarantees the thermal comfort at the same time. These mechanisms mainly depend on the difference between outdoor and indoor air temperature. During Summer, outdoor air is not useful to cool the space, because it usually presents higher temperatures compared to the indoor air ones. Thus, the application of ventilative cooling is often limited to the night period (night-cooling). Furthermore, the system efficiency depends on the air flow rate, the thermal capacity of the building and the capacity of transferring heat from the building construction to the air flow and vice-versa.

Artmann et al..- (10) developed a method to determine the climatic potential for passive cooling of buildings by night-time ventilation. This method uses an approach for computing degree-hours based on a variable building temperature that varies within a temperature range of thermal comfort, without taking into account any building-specific parameters. It has been applied to climatic data of 259 stations all over Europe. The results show that night cooling potential is high in Northern Europe. In Central, Eastern and in some regions of Southern Europe, the climatic cooling potential is still significant, but due to the random weather conditions, several warmer nights can occur and passive night cooling might not be sufficient to guarantee thermal comfort. In certain regions, such as Spain, Italy and Greece, climatic cooling potential is restricted. In these particular climate conditions hybrid systems might be the best solutions to be applied.

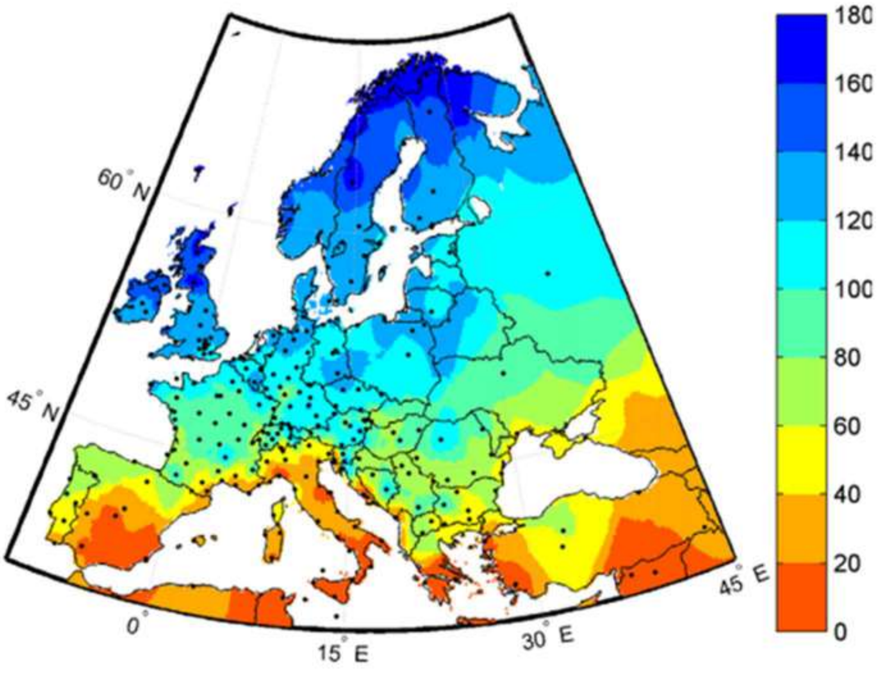

Figure 4.23: Map of mean climatic cooling potential (Kh/night) in July (10).

These considerations imply that cooling by ventilation in Italy is restricted to the night-period and this is likely not enough to keep the building within the comfort range. However, the method does not take into account the building features, so that this work aims at finding the implications of ventilative cooling in the building type analysed in the thesis, as well as the particular climate conditions in the Florence area.

As I mentioned before, ventilative cooling can be achieved through the use of both Natural and Mechanical ventilation. Natural ventilation techniques lead to pollution and acoustic problems, especially in urban area, such as in the area where the chosen buildings are located. Besides the architectural design of a building determines its ventilation and passive cooling potential (11).

Many techniques to improve the possibility of exploiting natural ventilation have been studied. Among these, Martin (12) describes studies different ventilation arrangements through the use of wind chimneys, atria, advanced windows etc. The location of the openings, balconies and internal partition play a fundamental role in the exploitation of natural driving forces in order to achieve the indoor comfort conditions. Besides the shape of the building is another essential aspect to be taken into account. Rosenbaum (13) has listed the most favorite positions of the walls in a building, defining strategies to improve the airflow rates. He gave some indications, such as: irregularly shaped buildings can improve cross-ventilation; it is better that the building is faced at an oblique angle to the main wind, than it is faced perpendicularly to the wind; windows developed along the horizontal direction rather than in the vertical one, can enhance the air movement.

In the building cases, the exploitation of different strategies of natural ventilation techniques is more difficult due to the already existing openings and shape. Besides the construction type (great panels), does not allow interventions on the structure. It would be necessary the creation of additional systems or the exploitation of particular technological systems (for example solar chimneys or wind towers, suggested by the presence of stairwells which run along all the eight of the buildings in all the sample cases) that, in this case, would be preferred to avoid in order to intervene as less as possible on the existing structure and because of the expensive price. Other techniques used for ventilative cooling are connected with the use of fans and mechanical ventilation systems, able to better achieve the air-flow rates needed for the achievement of the internal comfort. Air circulating fans, such as ceiling, oscillating or box fan create air movement that can improve the internal comfort (14). An alternative solution is to use ceiling fans to create both airflow and airspeed. Operable ceiling vents are created above the ceiling fans. The vents are kept closed during the day. Another system is to use a whole house fan which can ventilate and cool buildings where the ventilation cannot be obtained solely by windows opening. It works by pulling air in through windows and exhausting it through the attic. The system can work even in the convers sense, that is by introducing air from the attic and exhausting it from windows (15) .

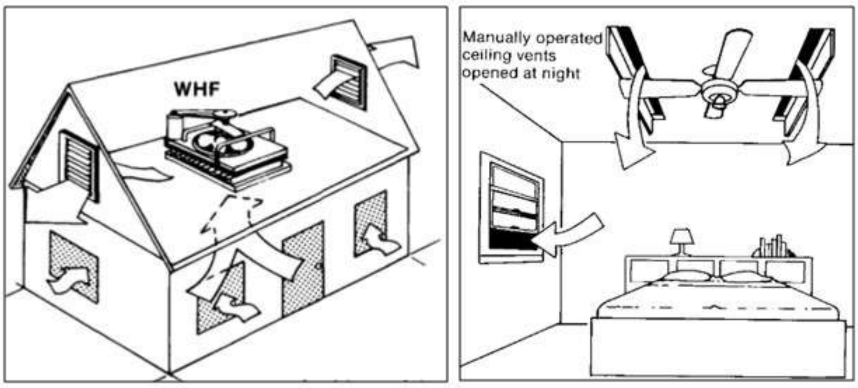

Figure 4.24: (On the left) Whole house fan. (On the right) Operable ceiling vents (15).

Apart from the use of fans or natural ventilation strategies, for achieving the indoor comfort conditions through the ventilative cooling technique (fresh outdoor air) it is necessary to increase the air change rates of the inlet air. The next paragraph analyses the effect of this increase on temperatures and Relative Humidity in BUILDING A.

4.1.2.2 EFFECTS OF THE VARIATION OF AIR CHANGE RATES NUMBER

We already mentioned the cause of imposing the value of 0.5/h ACH (air change rates) in the building simulations. In this section, the effects of the variation of the number of ACH will be analysed. The results of the previous analyses have highlighted that considering 0.5/h ACH, both in BASE CASE and in STEP A, leads to reduced levels of RH, but it does not decrease the internal temperatures with the result of low levels of indoor comfort in Summer. The increase of number of air change rates means an increase of outdoor air introduced inside the building, with its thermo-hygrometric characteristics (humidity and temperature).

Two different situations will be analysed:

1. ACH= 1/h (STEP A-1);
2. ACH= 2/h (STEP A-2).

These values are set only in the periods when the heating system is turn off, that is from May to October. The evaluations will be done on the whole building in order to have a preliminary idea on the effects of changing the number of ACH.

1. **<u>ACH= 1/h (STEP A-1)</u>**

The fig.4.24 shows the hourly trend of temperatures in Summer in STEP A and STEP A-1. These values derive from an average of hourly temperatures of all flats in Summer.

The increase of the number of ACH led to a decrease of indoor temperatures of almost 2°C going back to the internal temperature conditions found in BASE CASE. In May, STEP A-1 removes hours above 26°C as well as in September it removes hours above 28°C. In June, July and August there is a reduction respectively of 15%, 15% and 35% of hours above 28°C.

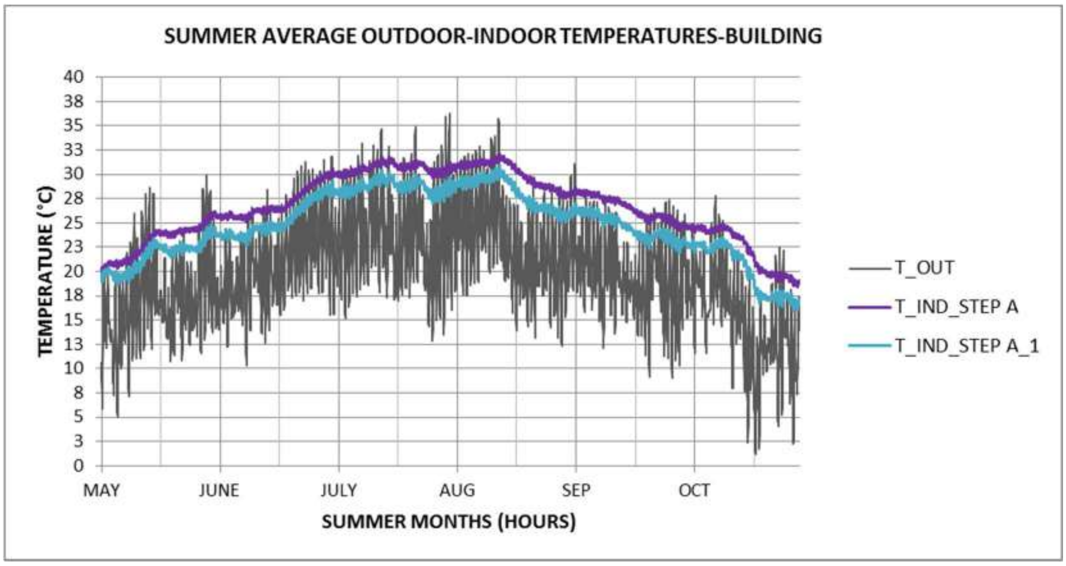

Figure 4.25: BUILDING A-Hourly trend of mean temperatures in Summer (whole building). Comparison between STEP A, STEP A-1 and outdoor temperatures.

The gap between the 2 trends in fig.4.25 is less evident when outdoor temperatures are higher than indoor ones (for example in the central months of Summer). Indeed, if we look at the fig. below, representing the hourly trend of indoor temperatures in STEP A and STEP A-1 on 15th of July, the increase of ACH=1/h leads to a decrease of temperatures of about 2°C until 11:00 a.m..

When outdoor temperatures start to increase and to overcome the indoor temperatures, the gap between STEP A-1 and STEP A values is reduced (indoor temperatures increase from 29°C up to 30°C, in such a way reducing the reduction of temperatures of about 1°C compared to STEP A). This means that, if on one hand there is still a reduction in terms of indoor temperatures even during the warmer hours of the day compared to STEP A, on the other hand increasing the air change rates means introducing more warm air and the result is a discomfort sensation on the human body when this latter would need cooler air. Having said that it is necessary to pay attention when it is useful to increase the ACH without worsening the indoor thermal comfort conditions of the users.

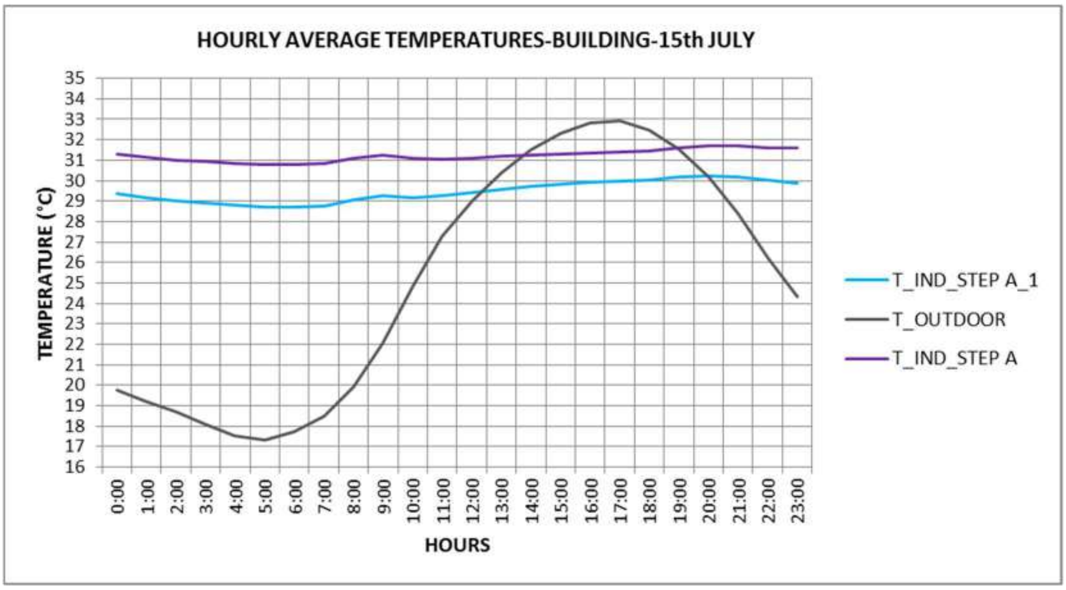

Figure 4.26: BUILDING A-Hourly trend of mean temperature on 15th of July (whole building). Comparison between STEP A, STEP A-1 and outdoor temperatures.

	JUNE		JULY		AUGUST	
	STEP A	STEP A-1	STEP A	STEP A-1	STEP A	STEP A-1
MEAN T (°C)	27.08	25.34	30.62	28.73	30.15	28.18
MAX T (°C)	32.54	31.19	33.57	32.20	33.77	32.58

	MAY		SEPTEMBER		OCTOBER	
	STEP A	STEP A-1	STEP A	STEP A-1	STEP A	STEP A-1
MEAN T (°C)	23.16	21.69	26.68	24.67	22.29	20.18
MAX T (°C)	27.91	26,58	30.28	28.68	31.63	29.42
MIN T (°C)	23.63	18.55	24.35	22.44	16.70	14.51

Table 4.7: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEPA/STEP A-1).

$R_{T,26-28}$ (%)		
STEP A/STEP A-1		
	$R_{T,26}$	$R_{T,28}$
MAY	5%	-
JUNE	39%	15%
JULY	2%	15%
AUG	10%	35%
SEP	46%	21%
OCT	-	-

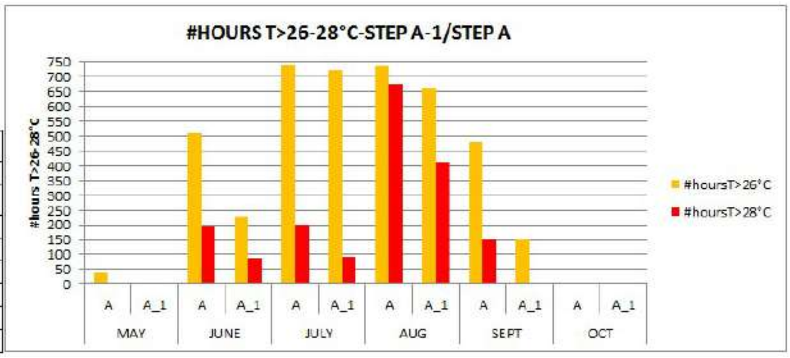

Figure 4.27: BUILDING A-Comparison between the number of hours during Summer months exceeding 26-28°C in STEP A and STEP A-1.

As regards the RH, the increase of ACH led to more air inside the apartments and the consequent introduction of moisture, and a possible rise of the indoor Relative Humidity if Outside is more humid than inside. The graph below shows a moderate increase of number of hours with RH exceeding 60%, while hours above 70% of Relative Humidity are still absent.

The unique exception is represented by the month of May in which a little reduction of RH is highlighted, meaning that the introduction of outdoor air reduces the Relative Humidity of some apartments (hours when it is less humid outside than inside are more relevant in this month), thereby affecting the RH global average of the whole building in this month.

The values shown in the figures are calculated by averaging the RH of all the apartments, therefore this evaluation is an approximation of the building internal comfort.

$R_{RH,60-70}$ (%)		
STEP A/STEP A-1		
	$R_{RH,60}$	$R_{RH,70}$
MAY	4%	3%
JUNE	-11%	0%
JULY	-3%	0%
AUG	-3%	0%
SEP	-12%	0%
OCT	-4%	-5%

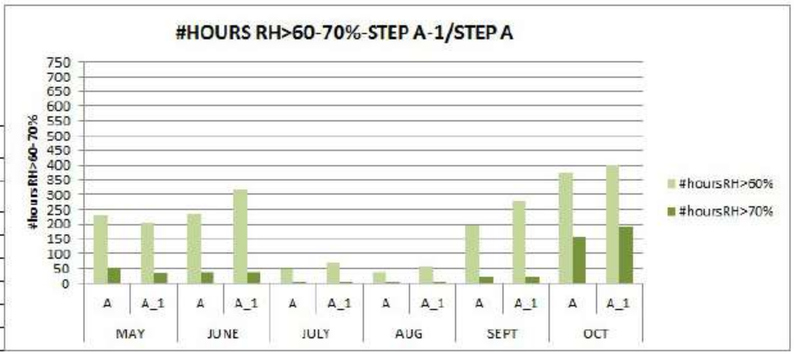

Figure 4.28: BUILDING A-Comparison between the number of hours during Summer months exceeding 60-70% of RH in STEP A and STEP A-1. Values averaged across all the flats in the building.

2. **ACH= 2/h (STEP A-2)**

The increase of ACH up to 2/h led to an even more evident reduction of internal temperatures, about 3.50°C. It is worth to underline that we are still analysing averaged values among all the building flats. This value has been considered steady for all the hours of the day, during Summer months[5]. The same considerations made for the previous example are valid for this case as well; indeed, even though the mean temperatures values seem to suffer a significant decrease, the fact of not decreasing the ACH during the warmer hours of the day lead to an even greater amount of warmer air into the house (double ACH number), causing an unavoidable discomfort sensation on the human body. This section aims at evaluating the effects of increasing ACH, by making a

[5] As we already mentioned, we consider October among Summer season and the value ACH=2/h has been set in this month as well.

preliminary test, at the building scale, before going to analyse each flat in order to understand which value might fit the best depending on the month.

	JUNE		JULY		AUGUST	
	STEP A	STEP A-2	STEP A	STEP A-2	STEP A	STEP A-2
MEAN T (°C)	27.08	23.86	30.62	27.07	30.15	26.49
MAX T (°C)	32.54	30.12	33.57	31.23	33.77	31.87

	MAY		SEPTEMBER		OCTOBER	
	STEP A	STEP A-2	STEP A	STEP A-2	STEP A	STEP A-2
MEAN T (°C)	23.16	20.22	26.68	24.63	22.29	18.44
MAX T (°C)	27.91	25.69	30.28	27.70	31.63	27.70
MIN T (°C)	23.63	16.21	24.35	20.31	16.70	12.10

Table 4.8: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEPA/STEP A-2).

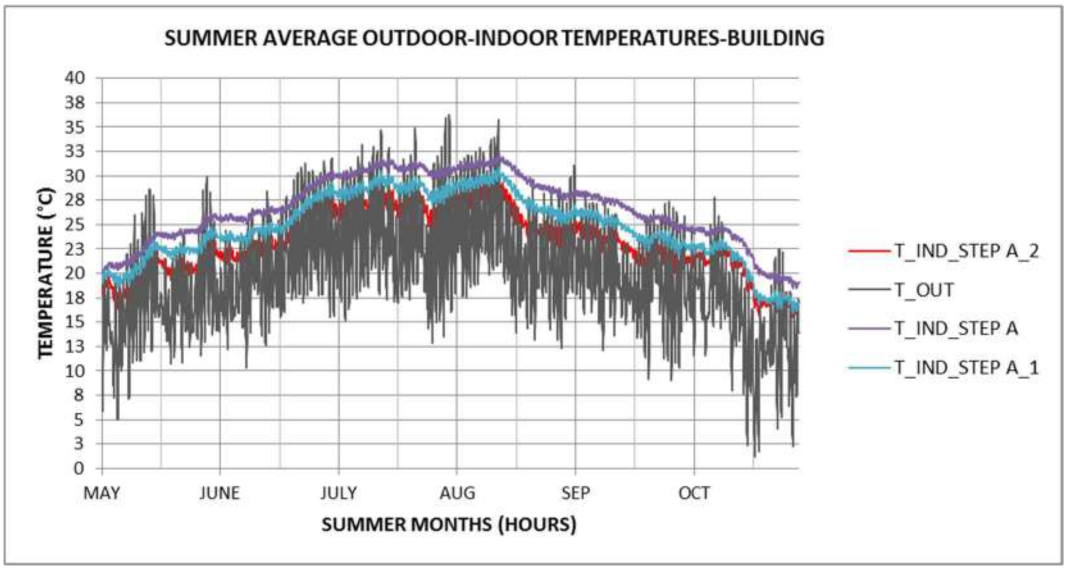

Figure 4.29: BUILDING A-Hourly trend of mean temperatures in Summer (whole building). Comparison between STEP A, STEP A-1, STEP A-2 and outdoor temperatures.

The reduction of number of hours above 28°C is evident in July and August. In September the increase of air change rates led to the elimination of the hours exceeding 26°C. The issue of increasing the ACH up to 2/h is the decrease of the mean temperature values in May and October which become too low.

The value ACH= 2/h increases the Indoor Relative Humidity as we could aspect, going back to the previous situation in BASE CASE.

$R_{RH,60-70}$ (%)		
STEP A/STEP A-2		
	$R_{RH,60}$	$R_{RH,70}$
MAY	-5%	0%
JUNE	-31%	-7%
JULY	-15%	-1%
AUG	-9%	-1%
SEP	-32%	-12%
OCT	-12%	-18%

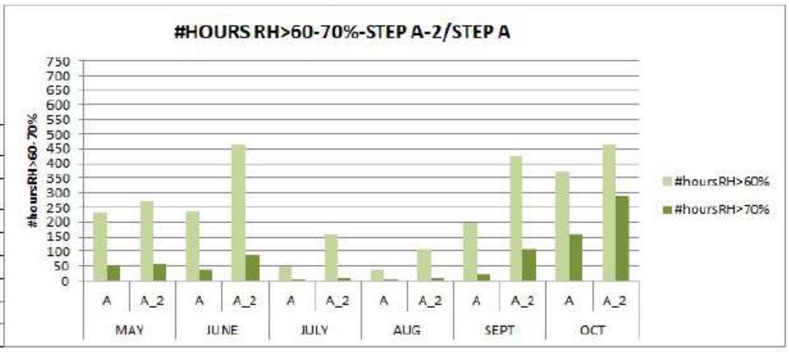

Figure 4.30: BUILDING A-Comparison between the number of hours during Summer months exceeding 60-70% of RH in STEP A and STEP A-2. Values averaged across all the flats in the building.

In conclusion, the increase of the air change rates number (ACH) helps to improve the internal comfort because temperatures get lower, even if the Relative Humidity increases.

From the previous considerations, we can affirm that:

- in May: ACH=1/h is better than ACH=2/h, both from the temperatures point of view and the Indoor Humidity one;
- in June: ACH=1/h reduces the mean temperature value under the comfort threshold (26°C) without worsening the Indoor Relative Humidity;
- in July and in August: ACH= 2/h is the best value because it almost eliminates hours above 28°C without increasing hours exceeding 70% of RH;
- In September ACH=1/h is better than ACH=2/h, both from the temperatures point of view and the Indoor Humidity one;
- In October either the two values make temperatures too low with the increase of hours above 70% of RH.

These are preliminary evaluations. Specific analyses of the flats are needed in order to have a better evaluation of the answer in terms of internal comfort conditions. Moreover, a smart control of the number of ACH during each month is needed, especially during the central months in Summer in order to avoid the introduction of useless warm air as well as great amount of humidity inside the home.

The way to improve air change rates useful to cool the space and to maintain a good indoor air quality (by verifying RH levels) is to ventilate the space, both by means natural and mechanical ventilation. As we mentioned before, the choice of one or the other system depends on the objective of the intervention, on the local climate conditions and on the building type.

4.1.2.3 EFFECTS OF THE USER BEHAVIOUR IN WINDOWS OPENING (STEP B)

In the previous chapter we analysed the effects of improving the air change rates. Before going to analyse the specific techniques used to ventilate the flats, still dealing with the variation of ACH, we want to analyse if considering the real behaviour of the occupants in windows opening (and therefore the influence on ACH) could improve the indoor comfort conditions, instead of setting a consistent value (0.5/h) all over the year, whatever the season.

Many studies were carried out on this field, but there is not a shared approach on the definition of the main factor influencing the actions of the occupants (windows opening and closing). According to Fabi et al. (16) the driving forces for occupants' window opening can be divided into 5 categories: Physical, Environmental, Contextual, Psychological, Physiological and Social. Each category depends upon different parameters, and their influence on the occupants behaviour is difficult to establish, because of the great amount of boundary conditions to be account for. For example, the study of IEA – ECBCS Annex 8 (16) on occupant behaviour with respect to ventilation showed that the type of house (apartment or single house) influences the duration of windows opening and that in living rooms and kitchens windows were open for shorter periods, while in bedrooms were open for longer ones. The study of Dick and D.A. Thomas (17) had shown the relationship between outdoor air, wind speed and windows opening. Erhorn (18) tried to correlate the season with windows opening and found that windows were open for longer periods in Summer than in Winter. Many other factors influence the occupants behaviour in windows opening, such us wind velocity, wind direction and incidence, the indoor air quality and so on. Many models have been performed in order to predict the occupants behaviour in windows openings.

An exhaustive description of these models are shown in the Internal Report of CBE (University of California) (19) and the conclusions were that the best models were based on the probability of observed phenomena because the human behaviour is not deterministic, but a common tendency can be found in the data collected in the various research surveys.

Stated this, we made a series of interviews to the BUILDING A occupants in order to find a common tendency in windows opening, and we found that in general we have 2 different users:

- USER 1: occasionally at home;
- USER 2: always at home.

Accordingly, we created different hourly profiles of number of air exchanges (ACH) for both the users, differentiated according to the seasons and therefore on the different outdoor temperatures, in relation to the fact that outdoor-indoor temperatures are 2 of the most significant factors influencing the occupants behaviour.

The values considered for the users were the same, the variable was only the hour when this value was taken into account, depending on the different occupancy levels. The values for the ACH

-MAX VALUE: ACH= 2/h (in Summer)[6];

-MIN VALUE: ACH= 0.2/h (in Winter and in Summer)[7].

Among these values other intermediate values are considered.

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[6] Value found in the work conducted in Virginia after continuous measurements of air change rates in a occupied house for 1 year (27). Windows were open for shorter periods in Winter, but in Summer, the air change rates vary and increase up to 2/h, consequence of the windows opening more than half the time in this warm season.

[7] Mean value approved by the Building Regulation Document F (28) for air-infiltrations of a building.

In Summer, we considered ACH=1/h for both users to take into account the “less” frequency in windows opening; according to the interviews to the occupants, the max value ACH=2/H was given to the night hours, and in the central hours of the day the value for USER 1 is equal to that given by the Standards (0.5/h), while for USER 2 ACH= 0.2/h (only infiltrations provide ACH, because in these hours the windows are supposed to be closed).

In Winter, we used ACH=0.5/h for the max value (from Standards), consistent for USER 1 almost all day (except during the night, when windows are closed), variable for USER 1 (we consider also the value 0.2/h during the central hours of the day, because the windows are kept closed).

These schedules were assigned to the different apartments in the building model, according to the results of the interviews, so that to simulate a more realistic building usage.

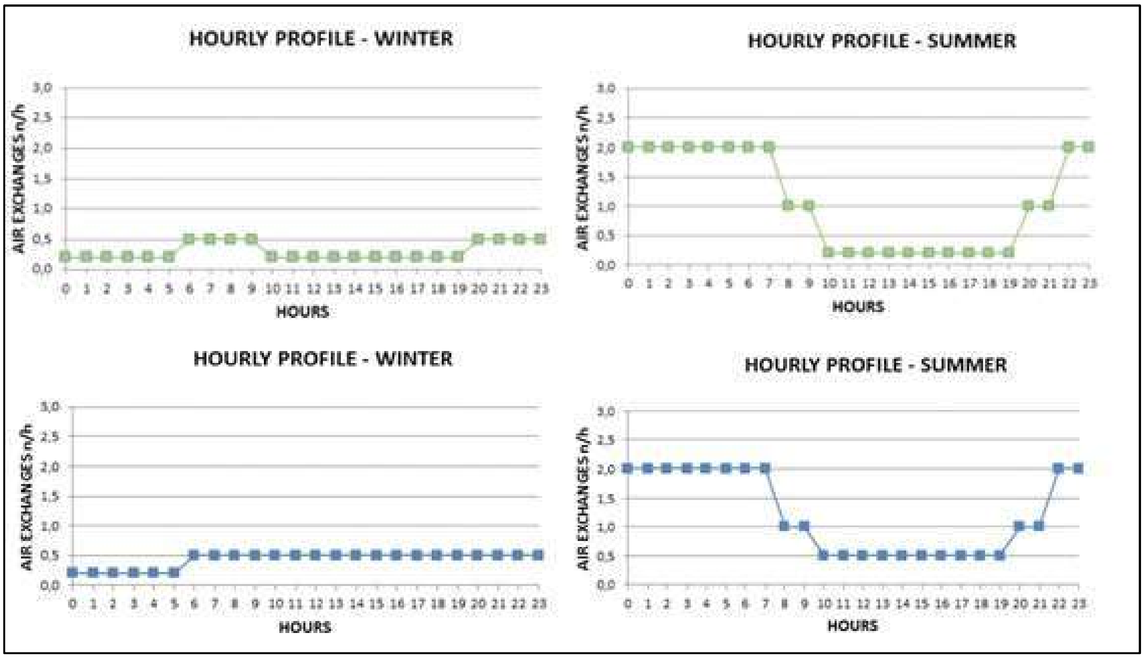


Figure 4.31:BUILDING A-In green hourly profile of ACH for USER 2 and in blue hourly profile of ACH for USER 1.

The average value of air exchanges during the year, considering these hourly profiles, is around 0.7 n/h that is close to the legislative standard (0.5 /h).

	ACH SUMMER (mean value)	ACH WINTER (mean value)	ACH YEAR (mean value)	Global mean ACH value
USER 1	1.15/h	0.43/h	0.79/h	**0.72/h**
USER 2	1.00/h	0.31/h	0.66/h	

Table 4.9: BUILDING A-ACH in relation to the season and users.

In order to evaluate the effects on the indoor comfort of varying both the number of ACH and its different distribution during the day, only the evaluation of the indoor temperatures in Summer is shown along with the evaluation of the mean relative humidity for the whole building[8].

The mean temperatures during Summer decrease of about 1°C compared to STEP A, going back to the BASE CASE conditions. We can say that the use of different values of ACH according to

[8] The aim is to find a general strategy for all the buildings chosen for the research.

different hours of the day as a consequence of the occupant behaviour led to improve the indoor comfort in Summer compared to the results in STEP A.

BUILDING T_VALUES						
	BASE CASE		STEP A		STEP B	
	MEAN T (°C)	MAX T (°C)	MEAN T (°C)	MAX T (°C)	MEAN T (°C)	MAX T (°C)
JUNE	25.6	31.5	27.1	32.5	25.6	32.5
JULY	28.9	32.4	30.6	33.6	28.7	33.2
AUGUST	28.3	32.6	30.1	33.8	28.3	33.3

Table 4.10: BUILDING A-Comparison between average temperature values during the three central months in summer obtained in BASE CASE, STEP A and STEP B.

As regards the RH, there is an increase of the mean value both in Summer and in Winter, because if we look at the figure below, Outdoor Humidity trend (HR_out) presents values always lower than the Indoor ones: the air change rates could lower the HR_out. Conversely, the decrease of ACH (both for USER 1 and USER 2), led to an increase of RH, because of less amount of air entering the building.

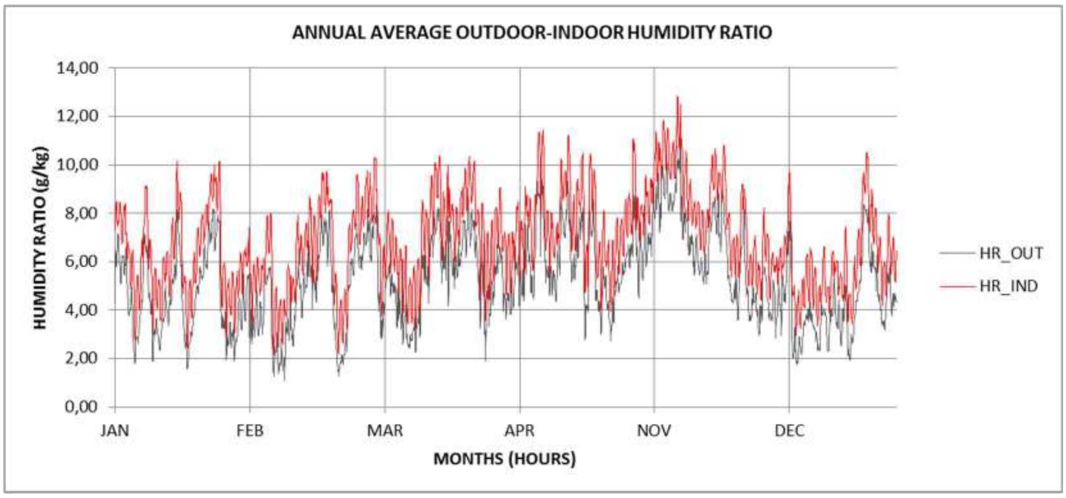


Figure 4.32: BUILDING A-Hourly trend of Outdoor/Indoor humidity In Winter. Averaged related to the whole building, obtained by averaging all the flat values.

		BASE CASE		STEP A		STEP B	
		SUMMER	WINTER	SUMMER	WINTER	SUMMER	WINTER
RH	mean %hours_RH>60%	37.85%	25.76%	17.51%	6.87%	30.31%	40.81%
	mean %hours_RH>70%	9.29%	11.76%	2.34%	7.59%	6.09%	21.31%

Table 4.11: BUILDING A-Comparison between RH and temperature values in BASE CASE, STEPA and STEP B.

As we mentioned before, a common behaviour of the occupant is hardly to be evaluated, depending on several factors and input, strictly connected to one each other.

This is a hypothesis of the behaviour of BUILDING B occupants (derived from interviews), that can find some demonstrations in literature, for example for what concerns the dependence of the windows opening on the outdoor temperature (opening during the night in Summer), or the indoor air quality (opening during some hours of the day in Winter).

Moreover, the values chosen for the hourly profiles of natural air exchanges have been chosen making several assumptions, by verifying that they could have been right if the annual average was around the standards value and by finding some comparable results in literature.

Aiming at establishing the real number of natural air exchanges, it would be necessary to use a multi-zone indoor air quality and ventilation analysis program able to calculate: airflows, pressures and room-to-room airflows and pressure differences in building systems driven by wind pressures acting on the exterior of the building, and buoyancy effects induced by outdoor-indoor temperature differences.

The aim of this section was to evaluate how the indoor comfort can be improved by considering different schedules and consequently different users inside the building, but the improved results in Summer derive from the increase of ACH up to 2/h, as we already demonstrated in Section 4.1.2.2.

The occupants' behaviour in windows opening could be taken into account in the global renovation of existing buildings, by giving some instructions to the building users on the period when it is useful to open the windows. This could be helped by outdoor/indoor temperature sensors, able to alert the occupants when it is time to ventilate. This action can be also made automatically.

Nevertheless, the airflow is still an unknown and variable factor depending on outdoor conditions, pressures and temperatures, differences that should be carefully evaluated.

4.1.2.4 APPLICATION OF MECHANICAL VENTILATION SYSTEMS (STEP C)

In the previous chapters we highlighted the fact that improving the ventilation rates, by using outdoor air in specific periods, could lead to a decrease of indoor temperatures. A method to guarantee the right number of air change rates is to use mechanical fans such as oscillating fans or ceiling fans, through mechanisms explained in the paragraph 4.1.2.1. The use of oscillating fans to move the air inside a room, even if it helps to improve the well-being of the human body (by improving the air-speed) would mean to introduce them in each room of the house in order to create a recirculation of the air itself, helped by windows.

The position of windows is very important because the air movements depend on it. Besides openings have to be positioned according to the direction of the wind; in our cases this is not possible, because the openings are already configured and the type of construction (great panels in reinforced concrete) make this operation very expensive and difficult to realise.

Moreover, despite the buildings in exam present similar characteristics, the windows are not exactly positioned in the same location, and the alternative would be to create a different strategy according to different buildings. Conversely, what we want to do is to create a common strategy to intervene even in other buildings with similar characteristics, but which could have different organizations in the openings or different boundary conditions.

On the other hand, the use of ceiling fans and the creation of vents on the ceiling is not possible in our buildings, because of their conformation: they are apartment buildings, so that the attic could be used only by the last floor flats. The suitable solution could be to use a whole-house fan for each flat, but instead of positioning it in the attic, it could be located in the corridor, in a new plasterboard false-ceiling. Each building analysed in this work obviously presents this corridor/service area, that can be easily linked to outdoors. The difference to the system analysed in the paragraph 4.1.2.1 is that the outdoor air is not taken form vents realised in the attic, but from a duct that would link the corridor to the outdoors. This whole-house fan can be defined as a mechanical ventilation system.

The following part analyses different mechanical ventilation systems.

Mechanical ventilation systems (MVSs) are useful both to improve the indoor air quality and to remove the higher temperatures, by using the ventilation system for cooling (11). In general, these systems use fans to move the air and they therefore consume just the electricity to make them work. These systems do not condition the air[9], they just "change" the air according to the objective they are required to satisfy.

Unlike natural ventilation systems, based exclusively on temperature gradient and on the wind power, through the use of a MVS, the correct ACH number is always guaranteed, by setting it on the mechanical ventilation handling unit. Besides with the use of MVSs air cleaning through filtration might be applied (it depends on the mechanical system), avoiding the introduction of pollutants into the building, along with the reduction of noise that is a common issue in a naturally ventilated building.

Various configurations of Mechanical Ventilation are in use (20). We can divide them into 2 groups: Single Stream and Double Stream.

[9] The primary function of mechanical ventilation systems is ensuring the right number of air change rates, but they can include additional units and battery able to condition the inlet air or dehumidify it.

1. **SINGLE STREAM (SSMVS)**, in turn further divided into other two types:

- **Mechanical Extract Ventilation (MEV)**: a fan is used to mechanically remove air from a space. This strategy includes: Local Extract Systems (LES) and Centralized Ducted Extract Systems (CDES). The first are used to extract pollutants from the source of production. These are typical of windows and cooker hood fans which transfer “dirty” air to outside. CDES allow to vent the whole building in the sense that there is a central fan (whole-house fan), linked to extract grilles through ducts. In residential buildings, extract grilles are positioned in “wet” rooms (bathrooms and kitchens), whereas air inlets are located in “noble” rooms (bedrooms and living-rooms). Extract Ventilation systems work by depressurizing the space and it is more appropriate for cold climates. In fact, in climates with warm humid Summers, this provided suction can suck the humid air from outside into the wall cavities where it can condense; one problem of this system is that it can introduce pollutants inside the home and it might further increase the heating or cooling demand, by introducing air without the possibility to condition it;
- **Mechanical Supply Ventilation (MSV)**: fresh outdoor air is introduced into the house with a fan, forcing indoor air out through openings realised in the building envelope. This system, therefore, works by pressuring the home. This installation, as the previous one, is quite simple and inexpensive to install. The typical scheme of a MSV consists of a fan and a duct system that introduces fresh air into the home. This system is better than the CDES, from the contaminants control. Indeed, it can filter the outdoor air before its entering into the house. It is more suitable for hot climates, because in winter the pressurization can make the indoor water vapor penetrate inside the building envelope with the risk of condensation when outdoor temperatures are low. Besides, as in the previous case, it can increase heating and cooling costs, by introducing outdoor air without any conditioning treatments: too cold air during Winter and too warm air in Summer;

2. **DOUBLE STREAM**, better known as:

- **Mechanical Balanced Ventilation (MBV)**: This system, if it is properly installed, does not lead to any pressurization or depressurization. Indeed, it presents two ducts: one duct for the supply air into living rooms and bedrooms, while the other one extracts exhaust air from kitchens and bathrooms. It is often coupled with a heat recovery (HR), which helps to improve the global energy performance of the building both in Winter and in Summer. During the cold season, it moves heat from the exhaust air to the supply air reducing the need to use the heating system, by heating the cold supply air. Instead during the warm season, a heat recovery unit can keep heat, so that to reduce the air-conditioning system use. Obviously, balanced ventilation systems are usually more expensive to install than the previous two systems, because of the double ducts, but this aspect can be compensated from the reduced costs for heating and cooling systems. Moreover, a better comfort can be achieved; in fact, the absence of pressure differences inside the home, guarantees a lower chance to have water vapor movements and consequently moisture problems.

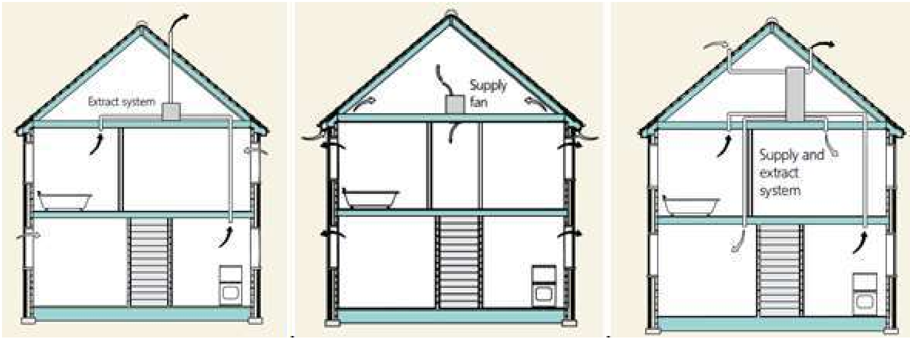


Figure 4.33: The typical configurations of the 3 different mechanical ventilation systems: on the left the MED system, in the middle the MSV system and on the right the MVB system (21).

As we mentioned before, according to the building class analysed in this work (social housing), because of the less expensive costs[10] and the simplicity of the installation, the best system may seem the single stream system (SSMVS), which corresponds to a whole-house fan system. A solution could be to allow the system to operate just in Summer, by providing fresh air (MSV) during cooler hours of the day, by setting the required air flow rate. The system needs openings on the envelope which can be realised on the windows frame and in order to facilitate the air recirculation inside the flat, along with openings on the internal walls to make the air pass from a room to another one. Indeed, the MSV system, because of the pressurization of the house, needs vents to let the air go out in order to balance the internal pressure. Single stream systems, if used in Winter, can drop indoor temperatures, thus causing discomfort conditions, consequently increasing the heating energy demand and energy costs, so that they could be used just in Summer or in the shoulder season to reach better comfort levels by lowering indoor temperatures. The better solution both for improving the comfort conditions and for decreasing the energy demand for heating and enhancing the energy saving, could be the use of the Mechanical Balanced Ventilation (MBV) with heat recovery, but the complexity of the installation (double ducts and double fans, one for the extract air and one for the supply air) and initial costs shift the decision towards single stream systems, more suitable in our sample cases.

Despite these conclusions it is worth to understand the functioning of a MBV+HR and its effect in Winter and in Summer. In addition to heat the cold outdoor air in Winter, this system presents an alternative functioning in which the air flow avoids the heat exchanger (by-pass), that is useful in the warmer season. This system uses the technique of free-cooling, by introducing directly outdoor air without being treated from the heat-recovery.

This occurs when outdoor temperatures are lower than indoor ones; specific temperature sensors, by measuring this temperature condition, send the signal to the mechanical ventilation units that activate the bypass mechanism. The same functioning can work in Winter when outdoor air is warmer then indoor. This mechanism allows to avoid the use of heating system, by exploiting outdoor air which presents characteristics able to keep the comfort conditions (free-heating). All this alternative functioning of the MVS is strictly dependent on the outdoor conditions.

In order to have an idea on the possibility to exploit free-cooling or free-heating by using a Mechanical Ventilation System, an analysis on the percentage of hours in Summer with outdoor

[10] A work conducted in Germany (29) shows that single stream mechanical ventilation systems have investment costs under 50e/m^2 (about 40e/m^2 on average for the example analysed in the work), while the double stream systems with heat recovery reach costs above 70e/m^2.

temperatures lower than indoor ones along with the percentage of hours in Winter with outdoor temperatures greater than indoor ones have been carried out.

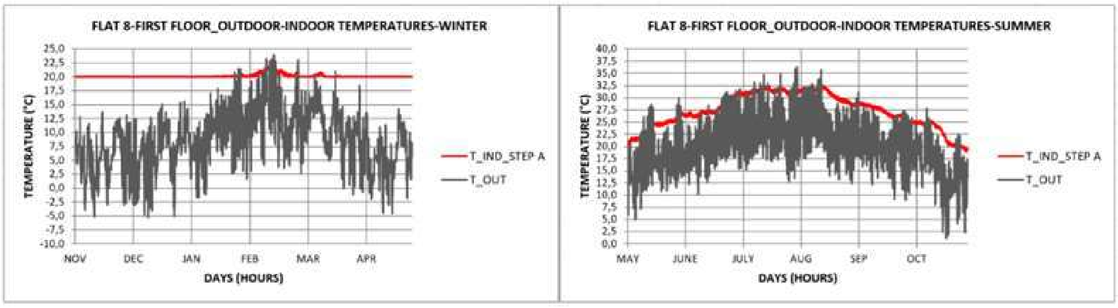


Figure 4.34: BUILDING A-Hourly trend of outdoor/indoor temperatures in FLAT 8-FIRST FLOOR. On the left winter season is shown, while on the right the Summer one.

The figure 4.34 shows an example the outdoor/indoor temperatures hourly trend in FLAT 8 at the first floor (STEP A), both in Summer and in Winter.

The 90% of hours during Summer presents outdoor temperatures lower than indoor ones (almost 4000 hours with T_out<T_ind of a total of 4416 hours in Summer, considering October), so that free-cooling could be applied on this flat, as well as on the other flats taken as sample cases in BASE CASE, because of their similar internal conditions. In Winter, only 1% of hours has outdoor temperatures greater than indoor ones (52 hours/total= 4368 hours in Winter) and therefore free-heating is not exploitable, so that the use of a heat recovery could be useful under these climate conditions.

Some definitions are needed in order to understand to heat recovery functioning:

- air handling unit (AHU): unit with all the components demanded to the system operation (fans, filters, etc);
- heat recovery unit: air handling unit that also contains a heat exchanger;
- heat exchanger: a component inside the heat recovery unit demanded to the heat transfer between the two air flows (exhaust and supply air);

The efficiency of a heat recovery unit has to be known in order to estimate energy savings. Different definitions of heat recovery efficiency exist, depending on the system boundary is considered that can be the either the heat exchanger itself, or the AHU, or the entire ventilation system. The heat exchanger efficiency is usually documented in heat recovery's technical sheets (22).

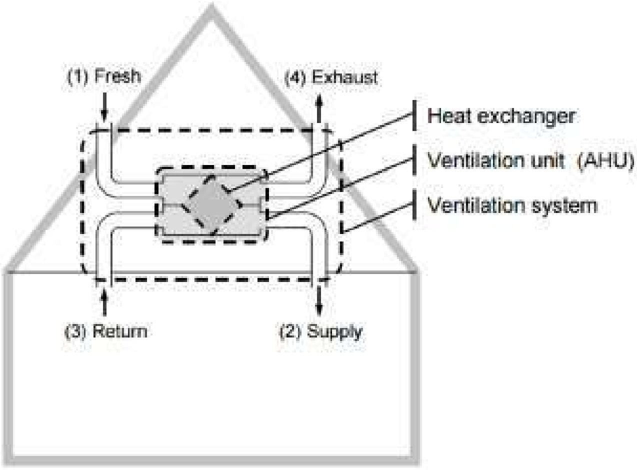


Figure 4.35: Nested System boundaries for a ventilation system for a ventilation system with heat recovery (22)

Efficiency can be measured for temperature (sensible enthalpy) moisture or total enthalpy. The most common definitions of efficiency are:

- Heat Exchanger Sensible Heat Recovery Efficiency (***η_{hx}***):

$$\eta_{hx} = \frac{T_2 - T_1}{T_3 - T_1}, \text{ where} \tag{4.4}$$

T_1= Fresh air stream (°C)

T_2= Supply air stream (°C)

T_3= Return air stream (°C)

- AHU Net Sensible Heat Recovery Efficiency. It considers the sensible heat recovery for the whole AHU, corrected for the system losses (air leakages, recirculation etc., that is lost as heat in the exhaust). It corresponds to the exhaust temperature ratio ***$\eta_{AHU,ex}$***:

$$\eta_{AHU,ex} = \frac{T_3 - T_4}{T_3 - T_1}, \text{ where} \tag{4.5}$$

T_1= Fresh air stream (°C)

T_3= Return air stream (°C)

T_4= Exhaust air stream (°C)

- AHU Supply Temperature Ratio (***$\eta_{AHU,sup}$***). This indicates the thermal comfort properties of the AHU and it is not an accurate measure of the efficiency:

$$\eta_{AHU,sup} = \frac{T_2 - T_1}{T_3 - T_1}, \text{ where} \tag{4.6}$$

T_1= Fresh air stream (°C)

T_2= Supply air stream (°C)

T_3= Return air stream (°C)

UNI EN ISO 13790 (23) indicates the method to calculate the heat losses for ventilation (***Q_v***) of a thermal zone, that can be simplified as follows:

$\mathbf{Q_v} = H_v * (\theta_i - \theta_e) * t$, where (4.7)

H_v = global heat exchange coefficient for ventilation for the thermal zone (W/K)

θ_i = Indoor temperature (K)

θ_e = Outdoor temperature (K)

t = Computing time (h)

$H_v = \dot{V}(1-\eta) * \rho_a c_a$, where (4.8)

$\dot{V}$ = fresh airflow rate (m^3/h)

η= heat recovery efficiency

$\rho_a c_a$ = air thermal capacity: 1200 J/(m^3K)

$\dot{V}$ = V*ACH (4.9)

V = volume of the space (m^3)

ACH= air change rate (h^{-1})

The equation 4.8 shows that the higher the heat recovery efficiency, the lower are heat losses for ventilation (eq. 4.7). The efficiency depends on the temperature difference between outside and inside. The heat recovery will be more efficient with great temperature differences, that is in winter. As we mentioned before, when we deal with heat recovery units, the mostly considered efficiency is the Exchanger Sensible Heat Recovery Efficiency $\boldsymbol{\eta_{hx}}$. This is the efficiency we also refer to in this work. The heat recovery efficiency in Summer and in Winter will be different because of the difference temperature gradients.

For Mechanical Balanced Ventilation + HR, the heat recovery efficiency varies between 0.5 up to 0.9[11]. We decided to set 0.5, the minimum value in the range, that is a common value for the heat recovery efficiency used in the majority of the systems on the market.

The following part of this chapter analyses, from one hand, the effects on the building, by using a MVB+HR system, by comparing the results with those of STEP A, on the other hand the building answer in terms of internal comfort, by introducing a simple single stream MVS allowed to work just in Summer, varying the ACH number.

This analysis will lead to the definition of the correct ACH number after an accurate study on the building/flats answer in terms of internal comfort.

Three different situations will be analysed:

1. MBV+HR-ACH= 0.5/h (STEP C-0);
2. Single stream mechanical ventilation system (MSV)-ACH= 1/h (STEP C-1);
3. Single stream mechanical ventilation system (MSV)-ACH= 2/h (STEP C-2);

The second and third point analyse the effects of setting different number of air change rates when the heating system is turned off (from May to October), while in Winter the mechanical ventilation system is turned off, keeping consistent ACH=0.5/h as required from the Standards, taking into account the fact that this value is not ensured without a system able to control the air change rates.

[11] http://www.agenziacasaclima.it/: list of the main mechanical ventilation systems used in Italy and their heat recovery efficiency.

The choice to not use the system in winter is also justified by the fact that free-heating is not applicable in our climate zone (see fig.4.32) and a continuous activated fan for keeping a good IAQ would increase costs for heating because it too low temperature air would go inside the house, lowering the indoor temperatures.

According to the results obtained in par.4.1.2.2, increasing ACH number is useful especially during the central Summer months (June-July-August); for the shoulder season, it is likely to cause too low temperatures. In October, it is convenient to set ACH=0.5/h and activating the system just when outdoor temperatures are greater than indoor ones.

1. **MBV+HR-ACH= 0.5/h (STEP C-0)**

This value of air change rate is the same considered in STEP A, and as we explained in par.4.1.1, it is not useful to lower the internal temperatures of the flats.

By the way it is worth to analyse the indoor temperatures after the application of the mechanical ventilation system and especially the effect of the mitigation of the temperatures due to the transition of the outdoor air into the heat exchanger. Moreover, the free cooling mechanism is also applied to the system. All this system has been modelled in Trnsys, by introducing specific equations able to describe the MBV+HR mechanism. These equations derive from eq. 4.4.

For each thermal zone in the building the supply air temperature of the MVS has been calculated as follows, making some assumptions:

$T_2 = A * H_s + B * C_s + A * M_o$, where (4.10)

$$A = \left[T_1 - (T_1 - T_3) * \eta_{hx} \right] \quad (4.11)$$

$$B = \left[T_1 * bp + (T_1 - (T_1 - T_3)) * \eta_{hx} (1 - bp) \right] \quad (4.12)$$

T_1= Fresh air stream (°C);
T_2= Supply air stream (°C);
T_3= Return air stream (°C);
η_{hx}= heat recovery efficiency;
H_s= Heating season (from November to April). H_s=1 when we are in the heating season; H_s=0 in the other cases;
C_s= Cooling season (from May to September). C_s=1 when we are in the cooling season; C_s=0 in the other cases;
M_o= October, that is an intermediate month. Obviously, *M_o=1, when the computed month is October, otherwise M_o=0;*
bp= bypass function. *bp*=1, when $T_1 < T_3$; *bp*=0, when $T_1 > T_3$.

In Summer, when outdoor temperatures are lower than indoor ones, from the eq.4.12 (*bp*=1-bypass) $T_2 = T_1$, that is the fresh air introduced from the mechanical ventilation system is directly the outdoor air.

In October mean temperature values are often too low and internal temperatures do not require the free cooling use, so that the functioning is equal to the Winter one.

Since in the building simulation model we did not consider as many thermal zones as the flat's rooms, but each thermal zone corresponds to the single flat, the air volume extracted from the house is equal to supply air.

The results are shown for the whole building, in order to have a global scenario of the building behaviour after the application of a MBV+HR. The figure 4.34 shows the difference between the Energy Demand for Heating (Q_heat) in STEPA and STEP C-0.

The use of the heat recovery in the mechanical ventilation system helps to improve the energy saving during the Winter, by lowering Q_heat of almost the 30%. Moreover, 0.5 ACH are guaranteed, following the aim of keeping or reaching an acceptable IAQ.

REDUCTION (%)	
	STEP A/STEP C-0
JAN	23%
FEB	24%
MARCH	33%
APR	65%
NOV	37%
DEC	23%
TOTAL	**27%**

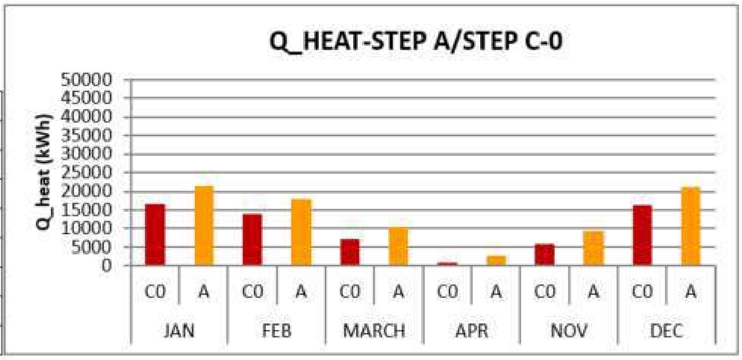


Figure 4.36: BUILDING A-Monthly Sensible Energy Demand for heating in STEP A and STEP C-0.

From the semi-stationary conditions, the introduction of the mechanical ventilation + heat recovery makes the Energy Class improve:

$EP_{gl,nren}$= 44.22 kWh/m^{2}y

$EP_{gl,nren,rif}$(2019,2021)= 46.85 kWh/m^{2}y

<u>The NEW building Energy Class is **A1**, in fact:</u>

0.80* $EP_{gl,nren,rif}$(2019,2021) < $\mathbf{EP_{gl,nren}}$ ≤ 1.00* $EP_{gl,nren,rif}$(2019,2021)

The decrease of the Energy Demand for heating is due to the reduction of Q_inf (heat losses for infiltration through the envelope), because the ACH are guaranteed from the mechanical ventilation system, that through the use of heat recovery, recovers the heat from the exhaust air. The figure below shows the percentage of heat losses for infiltration in STEP A and STEP C0. Q_trans (heat losses for transmission through the envelope) are the same in both cases, but it is worth to highlight the effects of the ventilation system on the reduction of Q_inf up to 15% of the total heat losses.

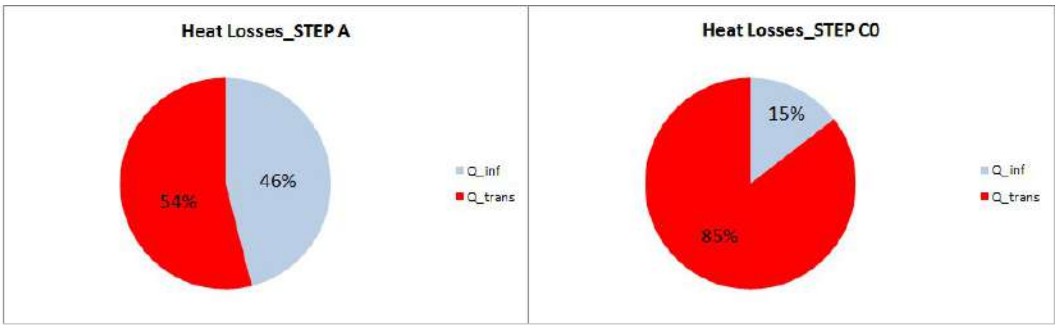


Figure 4.37: BUILDING A-Comparison between heat losses in STEP A and STEP C0.

Despite the improvement during the colder season, in Summer the use of the heat recovery does not have relevant effects on the indoor temperatures.

$R_{T,26-28}$ (%)		
STEP C-0/STEP A		
	$R_{T,26}$	$R_{T,28}$
MAY	2%	-
JUNE	11%	3%
JULY	0%	3%
AUG	0%	6%
SEP	10%	9%
OCT	-	-

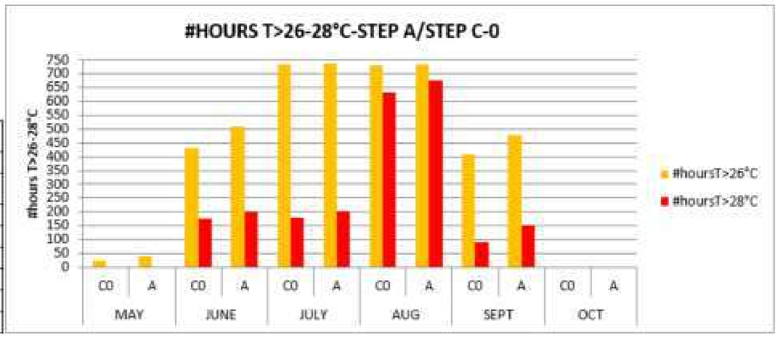


Figure 4.38: BUILDING A-Comparison between the number of hours during Summer months exceeding 26-28°C in STEP A and STEP C-0.

The results are almost equal to those in STEP A, except in October which does not present high internal temperatures. Conversely lower indoor temperatures can occur in this month (see fig. 4.38) so that the use of a heat recovery could increase indoor temperatures.

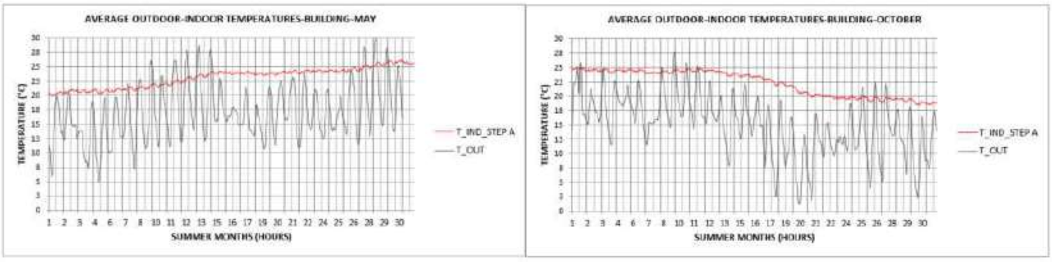


Figure 4.39: BUILDING A-Hourly trend of out/ind temperatures in May and in October (STEP A-values).

In May, indoor temperatures are acceptable and the introduction of outdoor air does not worsen internal comfort, even without the heat recovery. In fact, the majority of the month, the building presents indoor temperatures higher than outdoor ones, but still in the comfort range (20-26°C), so that the continuous operating fan does not decrease or increase indoor temperatures in a relevant way (by-pass functioning), while the use of the heat recovery helps to increase indoor temperatures (when T_out>T_ind), but it is not necessary.

	JUNE		JULY		AUGUST	
	STEP A	STEP C-0	STEP A	STEP C-0	STEP A	STEP C-0
MEAN T (°C)	27.08	26.74	30.62	30.24	30.15	29.76
MAX T (°C)	32.54	32.81	33.57	33.77	33.77	33.67

	MAY		SEPTEMBER		OCTOBER	
	STEP A	STEP C-0	STEP A	STEP C-0	STEP A	STEP C-0
MEAN T (°C)	23.16	22.95	26.68	26.29	22.29	23.25
MAX T (°C)	27.91	28.30	30.28	30.15	31.63	31.36
MIN T (°C)	23.63	20.49	24.35	24.12	16.70	18.24

Table 4.12: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEPA/STEP C-0).

$R_{RH,60-70}$ (%)		
STEP C-0/STEP A		
	$R_{RH,60}$	$R_{RH,70}$
MAY	6%	2%
JUNE	2%	1%
JULY	1%	0%
AUG	1%	0%
SEP	3%	1%
OCT	14%	11%

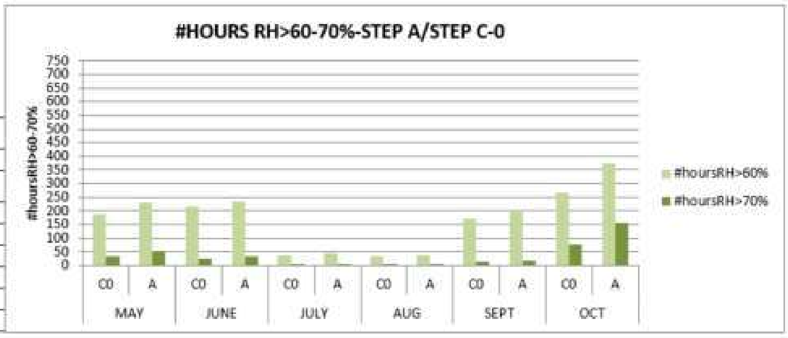


Figure 4.40: BUILDING A-Comparison between the number of hours during Summer months exceeding 60-70% of RH in STEP A and STEP C-0. Values averaged across all the flats in the building.

In Winter mechanical balanced ventilation system + heat recovery makes sense because it saves thermal energy for ventilation, by using the minimum rate of renewal (ACH=0.5/h) because increasing the air flow rate means to increase the ventilation consumption.

Accordingly, in Winter, a benefit from the use of mechanical ventilation can be achieved by using a mechanical balanced ventilation system + heat recovery.

In Summer, outdoor temperatures are almost always lower than the indoor temperatures, the use of a heat recovery is therefore useless, because the mechanical ventilation system would work “in by pass”. Accordingly, from the energy balance point of view a balanced system and a mechanical ventilation single stream would work in the same way in Summer, and an increase of ACH would lead to lower indoor temperatures in both systems (regardless of the heat-recovery). Nevertheless, a mechanical balanced ventilation system + heat recovery will surely offer the possibility to have a more uniform distribution of the air in the apartments (because of the 2 ducts, 1 for the inlet air and the other one for the extract air), but being small apartments, this advantage is slightly amplified.

Having said that, the initial expensive cost for a mechanical balanced ventilation system + heat recovery is not justified[12], because, even if in Winter it decreases the Energy demand for heating, in Summer it works like a simple stream mechanical ventilation system (less expensive and characterized by a simpler installation)

As regards October, the issue of having lower indoor temperatures and the heating system turned off, can be overcome by the use of a simple stream system, by turning it only when outdoor temperatures are capable to not worsen the indoor comfort, or by studying particular controls for the ACH setting. The same system can be used in May for keeping good level of Relative Humidity and Indoor air quality, without particular concerns on outdoor-indoor differences. All these setting measures can be checked through particular outdoor-temperature-humidity sensors.

[12] In relation to the types of residential buildings we are taking into account in this work and the aim at intervening as less as possible both for reducing intervention costs and for not causing uneasiness to the users. Moreover, the envelope recovery has already decreased the Energy Demand for heating, making the Energy Class arise until B.

2. (MSV)-ACH= 1/h (STEP C-1)

The mechanical supply ventilation system is included in the Trnsys building model. This section analyses the effect of doubling the ACH up to 1/h during the central months in Summer. In this system the temperature of the inlet air into the house is equal to the external temperature, because of the absence of any conditioning treatment and the choice to not include the heat recovery. All flats have their own system depending on the outdoor/indoor temperature differences which make the system improve the air change rates when conditions are appropriate. It will be necessary the installation of two sensors: one measuring outdoor temperatures, the other one the indoor ones. The input data given to the new model are summarized in the table below, according to the different months:

MONTH	**ACH (h^{-1})**	**CONDITIONS for SWITCHING ON/OFF**
MAY	**0.5**	Always ON
JUNE	**1**: when T_out<T_ind **0.5:** when T_out>T_ind	Always ON
JULY	**1**: when T_out<T_ind **0.5**: when T_out>T_ind	Always ON
AUGUST	**1**: when T_out<T_ind **0.5**: when T_out>T_ind	Always ON
SEPTEMBER	**1**: when T_out<T_ind **0.5**: when T_out>T_ind	Always ON
OCTOBER	**0.5**	Always ON

Table 4.13: Monthly schedule of the ACH and switching control on the MVS.

For what concerns May and October we decided to keep ACH=0.5/h for all the month because the results in terms of RH and indoor temperatures were acceptable.

WHOLE BUILDING:

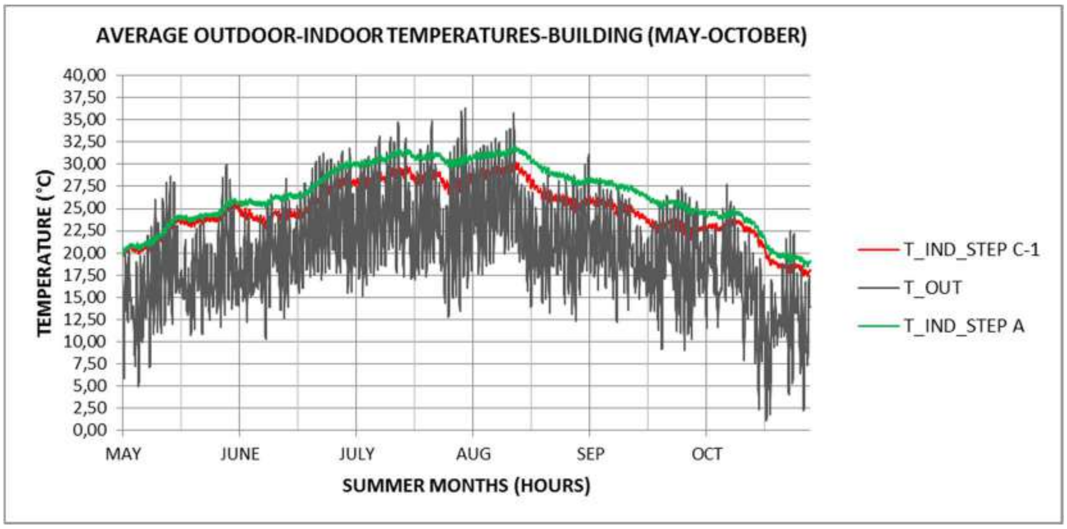


Figure 4.41: BUILDING A-Hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between STEP C-1, STEP A and outdoor temperatures.

The effect of increasing the number of air change rates led to a decrease of indoor temperatures as it is shown in the table below. The effect is more relevant in June and September, rather than in August and July.

	JUNE		JULY		AUGUST	
	STEP A	STEP C-1	STEP A	STEP C-1	STEP A	STEP C-1
MEAN T (°C)	27.08	25.34	30.62	28.45	30.15	27.86
MAX T (°C)	32.54	31.22	33.57	31.99	33.77	32.24
	MAY		SEPTEMBER		OCTOBER	
	STEP A	STEP C-1	STEP A	STEP C-1	STEP A	STEP C-1
MEAN T (°C)	23.16	22.77	26.68	24.31	22.29	21.05
MAX T (°C)	27.91	27.81	30.28	28.09	31.63	24.82
MIN T (°C)	23.63	18.81	24.35	20.30	16.70	16.60

Table 4.14: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEPA/STEP C-1).

For what concerns May and October we decided to keep ACH=0.5/h for all the month because the results in terms of RH and indoor temperatures were acceptable. As it is shown in the table above and in fig.4.41 the results of maintaining 0.5/h in these "shoulder" seasons cause a decrease of indoor temperatures. This is due to the fact that the total number of air change rates is higher than 0.5/h because we have to take into account ACH_{INF}=0.2/h[13] (infiltrations through the envelope). As we already widely expressed, ACH=0.5/h is just a mean value that takes account of both infiltrations through the envelope and air changes due to the windows opening. If we introduce into the flat a mechanical ventilation system, air change rates for infiltration have to be taken into account.

Along with the decrease of temperatures (fig.4.42), we have an increase of Relative Humidity (fig.4.43).

$R_{T,26-28}$ (%)		
STEP C-1/STEP A		
	$R_{T,26}$	$R_{T,28}$
MAY	2%	-
JUNE	41%	17%
JULY	3%	17%
AUG	15%	40%
SEP	53%	21%
OCT	-	-

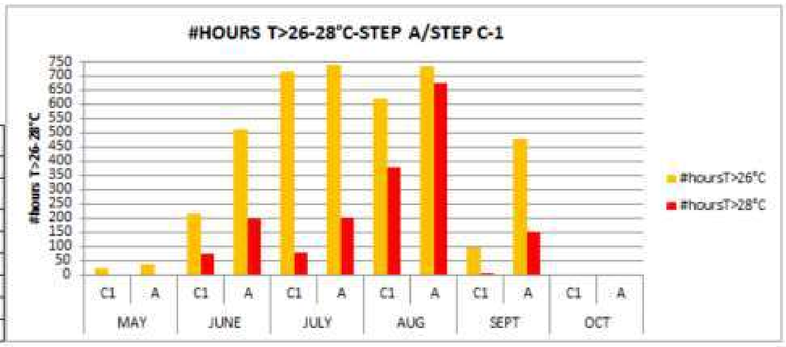


Figure 4.42: Comparison between the number of hours during Summer months exceeding 26-28°C in STEP A and STEP C-1. Values averaged across all the flats in the building.

[13] Mean value approved by the Building Regulation Document F (28) for air-infiltrations of a building.

$R_{RH,60\text{-}70}$ (%)		
STEP C-1/STEP A		
	$R_{RH,60}$	$R_{RH,70}$
MAY	3%	1%
JUNE	-9%	0%
JULY	-5%	0%
AUG	-4%	0%
SEP	-18%	-2%
OCT	-5%	-9%

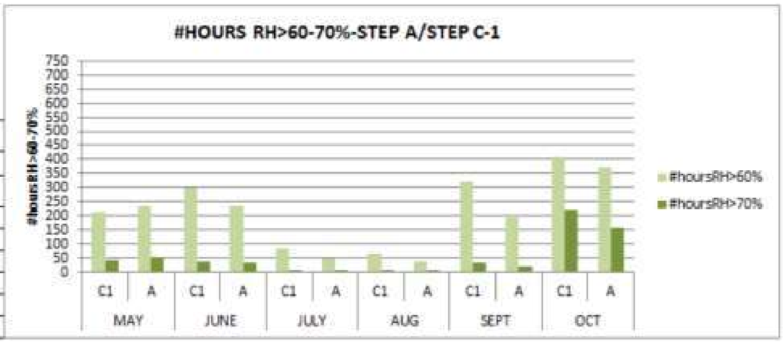


Figure 4.43: Comparison between the number of hours during Summer months exceeding 60-70% of RH in STEP A and STEP C-1. Values averaged across all the flats in the building.

FLATS:

As in STEPA, it is worth to analyse the answer of the single flats taken as reference examples. The analysis will take into account the evaluation of the indoor temperatures, the RH and the PPD index, compared to the STEP A results.

FLOOR 1: FLAT 8

TEMPERATURES:

- MAY: Decrease of number of hours exceeding 26°C. Decrease of the mean temperature values. The minimum value is lower than in STEP A, but still acceptable;
- JUNE: Relevant reduction of #hours>26°C (59%);
- JULY: No relevant effects on the reduction of indoor temperatures (just 3% #hours>28°C) even if the mean temperature value decreases of almost 2°C, but it is still high;
- AUGUST: Decrease of almost 40% of #hours>28°C with a consequent decrease of the mean temperature value of about 2.15°C (still above 28°C);
- SEPTEMBER: No longer hours above 28°C and reduction of almost 60% of #hours>26°C;
- OCTOBER: Decrease of almost 1.20°C of the mean temperature value.

$R_{T,26\text{-}28}$ (%)		
STEP C-1/STEP A		
	$R_{T,26}$	$R_{T,28}$
MAY	5%	-
JUNE	59%	15%
JULY	0%	3%
AUG	3%	39%
SEP	55%	36%
OCT	-	-

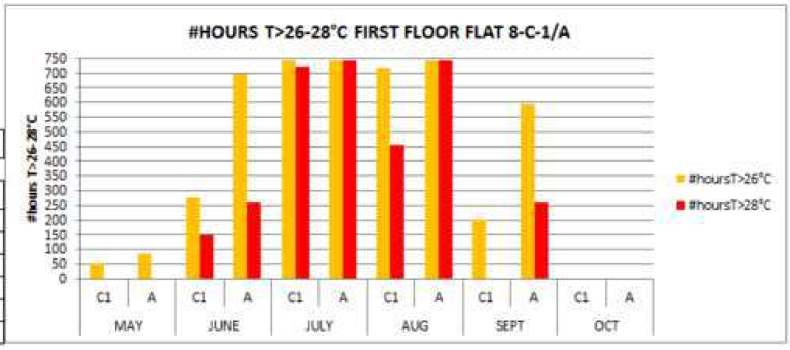


Figure 4.44: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP A and STEP C-1 during Summer months (FLOOR 1-FLAT 8).

	JUNE		JULY		AUGUST	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	27.84	26.18	31.30	29.26	30.71	28.55
MAX T (°C)	31.49	30.12	32.49	30.96	32.66	31.18
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	23.87	23.47	27.20	24.93	22.73	21.52
MAX T (°C)	27.11	26.79	29.26	27.36	25.51	24.21
MIN T (°C)	20.17	19.94	24.62	22.05	18.94	17.86

Table 4.15: Temperature values during the worst months in Summer and during the shoulder season (STEP C-1/FLOOR 1-FLAT 8).

The lower temperatures resulted in May and in October confirm the fact that ACH_{INF} affects the total number of air change rates, lowering the indoor temperatures, compared to the apparent equal value of ACH in STEP A (0.5/h).

RELATIVE HUMIDITY (RH):

- MAY: Decrease of RH, even though indoor temperatures decrease, but just of about 3% (hours above 70%RH);
- JUNE: Reduction of #hoursRH>60-70%, but just of about 3% and 2% respectively;
- JULY: No effects on the RH;
- AUGUST: No effects on the RH;
- SEPTEMBER: Increase of number of hours with RH>60%, according to the decrease of indoor temperatures. No effects on #hoursRH>70%;
- OCTOBER: Increase of both #hoursRH>60% and #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP C-1/STEP A		
	$R_{RH,60}$	$R_{RH,70}$
MAY	5%	3%
JUNE	3%	2%
JULY	0%	-
AUG	1%	-
SEP	-7%	0%
OCT	-6%	-9%

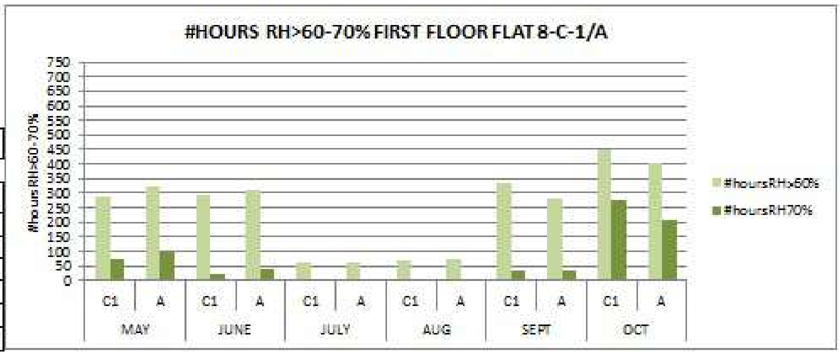


Figure 4.45: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and STEP C-1 during Summer months (FLOOR 1-FLAT 8).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in June and September. In July and in August ACH=1/h does not improve the indoor conditions, even if it contributes to decrease the internal temperatures. In October the decrease of indoor temperatures and the increase of RH worsen the comfort conditions (decrease of #hours%<6%PPD). In May the comfort levels decrease, but not in a relevant way.

$R_{PPD,6-10-15}$ (%)			
STEP C-1/STEP A			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	7%	-2%	2%
JUNE	-22%	-51%	32%
JULY	-	-	-
AUG	-	-7%	-15%
SEP	-21%	-34%	-47%
OCT	21%	1%	3%

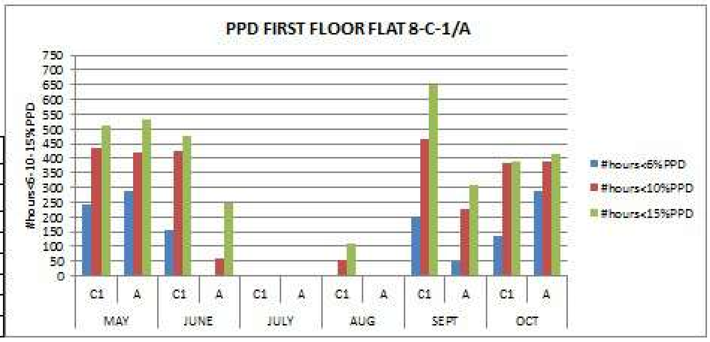


Figure 4.46: BUILDING A-Comparison between the PPD index values in STEP A and STEP C-1 (FLOOR 1-FLAT 8).

FLOOR 2: FLAT 6

The results are similar to the previous flat

TEMPERATURES:

- MAY: No hours with temperatures above the comfort value (26°C). Decrease of the mean temperature value. The minimum value is lower than in STEP A, but still acceptable;
- JUNE: Relevant reduction of #hours>26°C (41%); relevant reduction of hours above 28°C;
- JULY: Reduction of about 30% of hours above 28°C;
- AUGUST: Decrease of about 45% of #hours>28°C;
- SEPTEMBER: No longer hours above 28°C and reduction of about 60% of #hours>26°C;
- OCTOBER: Decrease of almost 1.30°C of the mean temperature value.

	JUNE		JULY		AUGUST	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	27.06	25.21	30.62	28.32	30.28	27.83
MAX T (°C)	30.52	29.02	31.82	30.14	32.33	30.70
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	23.16	22.74	26.89	24.34	22.64	21.36
MAX T (°C)	26.09	25.76	28.82	26.74	25.56	24.06
MIN T (°C)	19.94	19.71	24.48	21.47	18.74	17.58

Table 4.16: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-1/FLOOR 2-FLAT 6).

$R_{T,26-28}$ (%)		
STEP C-1/STEP A		
	$R_{T,26}$	$R_{T,28}$
MAY	-	-
JUNE	41%	21%
JULY	0%	32%
AUG	17%	45%
SEP	60%	22%
OCT	-	-

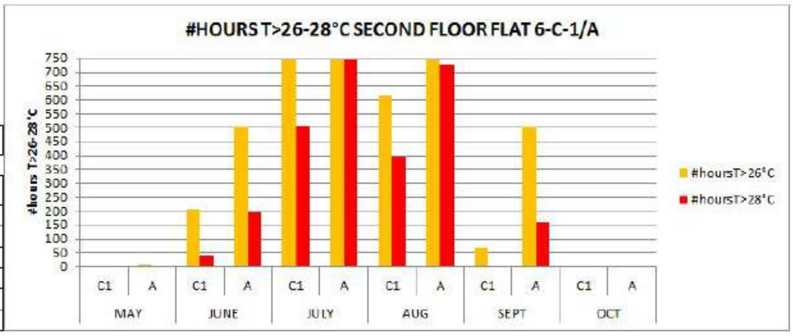


Figure 4.47: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP A and STEP C-1 during Summer months (FLOOR 2-FLAT 6).

RELATIVE HUMIDITY (RH):

- MAY: Decrease of RH, even though indoor temperatures decrease, but just of about 2% (both hours above 70%RH and 60%RH);
- JUNE: Reduction of #hoursRH>60-70%, but just of about 4% and 6% respectively;
- JULY: No effects on #hoursRH>70%; Increase of 3% of #hoursRH>60%;
- AUGUST: No effects on #hoursRH>70%; Increase of 2% of #hoursRH>60%;
- SEPTEMBER: Increase of number of hours with RH>60% (12%), according to the decrease of indoor temperatures. Small increase of #hoursRH>70%;
- OCTOBER: Increase of both #hoursRH>60% and #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP C-1/STEP A		
	$R_{RH,60}$	$R_{RH,70}$
MAY	2%	2%
JUNE	-4%	6%
JULY	-3%	-
AUG	-2%	-
SEP	-12%	-2%
OCT	-6%	-11%

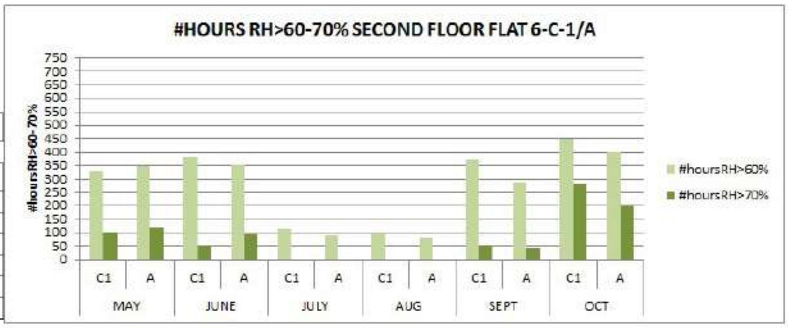


Figure 4.48: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and STEP C-1 during Summer months (FLOOR 2-FLAT 6).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in June and September. In July ACH=1/h does not improve the indoor conditions, even if it contributes to decrease the internal temperatures. In August we have an improve of the comfort level compared to STEP A.

In October the decrease of indoor temperatures and the increase of RH worsen the comfort conditions (decrease of #hours%<6%PPD). In May the comfort levels decrease (decrease of almost 25% of #hours<6%PPD).

$R_{PPD,6-10-15}$ (%)			
STEP C-1/STEP A			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	18%	2%	3%
JUNE	-55%	-39%	23%
JULY	-	-	-
AUG	-	-17%	-36%
SEP	-19%	-45%	-56%
OCT	24%	3%	6%

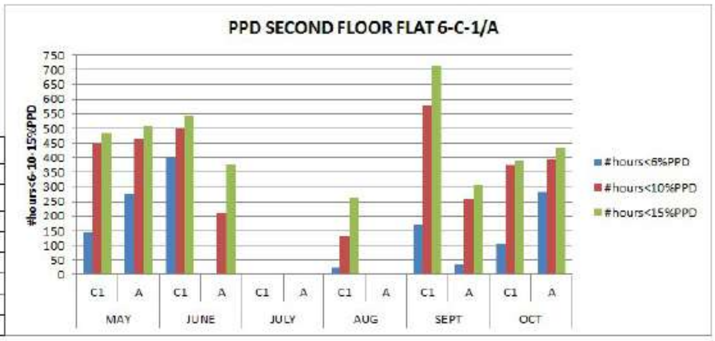


Figure 4.49: BUILDING A-Comparison between the PPD index values in STEP A and STEP C-1 (FLOOR 2-FLAT 6).

FLOOR 3: FLAT 2

TEMPERATURES:

- MAY: No hours with temperatures above the comfort value (26°C). Decrease of the mean temperature values. The minimum value is lower than in STEP A, but still acceptable;
- JUNE: Relevant reduction of #hours>26°C (63%); relevant reduction of hours above 28°C;
- JULY: Reduction of 5% of hours above 28°C;
- AUGUST: Decrease of about 40% of #hours>28°C;
- SEPTEMBER: No longer hours above 28°C and reduction of almost 60% of #hours>26°C;
- OCTOBER: Decrease of about 1.20°C of the mean temperature value.

	JUNE		JULY		AUGUST	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	27.93	26.06	31.54	29.23	31.07	28.65
MAX T (°C)	31.67	30.08	32.86	31.12	33.25	31.58
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	26.07	25.21	27.53	25.05	23.10	21.89
MAX T (°C)	27.20	26.82	29.63	27.55	25.86	24.82
MIN T (°C)	20.25	20.04	24.94	22.13	19.11	18.03

Table 4.17: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-1/FLOOR 3-FLAT 2).

$R_{T,26-28}$ (%)		
STEP C-1/STEP A		
	$R_{T,26}$	$R_{T,28}$
MAY	4%	-
JUNE	63%	18%
JULY	0%	5%
AUG	3%	38%
SEP	58%	43%
OCT	-	-

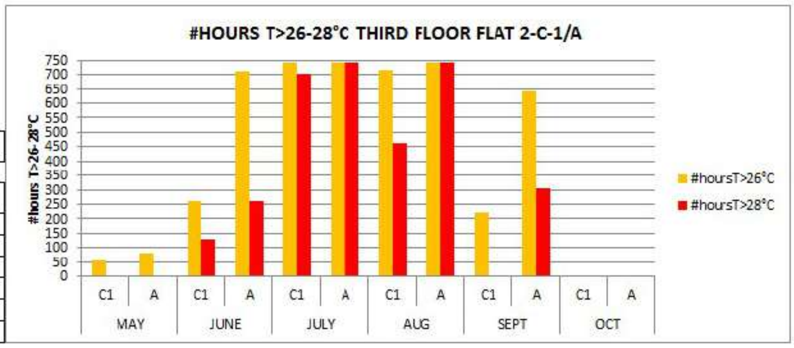


Figure 4.50: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP A and STEP C-1 during Summer months (FLOOR 3-FLAT 2).

RELATIVE HUMIDITY (RH):

- MAY: Decrease of RH. The reduction in this flat is more relevant (reduction of 14% of #hoursRH>70%); The Relative Humidity levels were even high in STEP A;
- JUNE: Reduction of #hoursRH>60-70%, respectively of about 20% and 10% respectively;
- JULY: Small reduction of #hoursRH>60%;
- AUGUST: Small reduction of #hoursRH>60%;
- SEPTEMBER: Decrease of number of hours with RH>60%, as well as a small reduction of #hoursRH>70%;
- OCTOBER: No effects in October.

$R_{RH,60-70}$ (%)		
STEP C-1/STEP A		
	$R_{RH,60}$	$R_{RH,70}$
MAY	12%	14%
JUNE	21%	11%
JULY	4%	-
AUG	3%	-
SEP	12%	8%
OCT	1%	0%

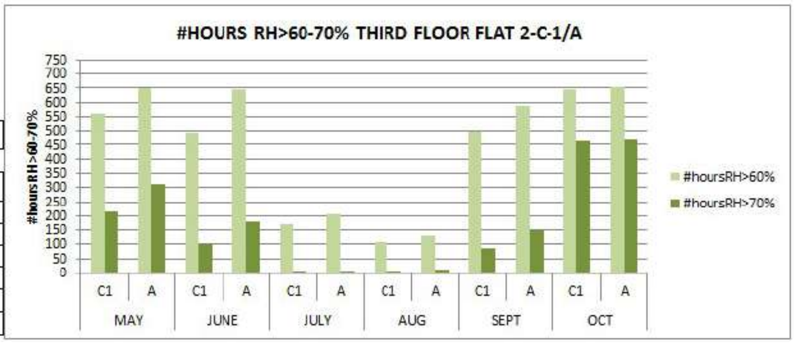


Figure 4.51: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and STEP C-1 during Summer months (FLOOR 3-FLAT 2).

<u>COMFORT INDEX (PPD VALUES):</u>

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in June and September. In July ACH=1/h does not improve the indoor conditions, even if it contributes to decrease the internal temperatures. In August we have an improve of the comfort level. Contrary to the other flats, in October the decrease of indoor temperatures and the increase of RH improve the comfort conditions (increase of #hours%<6%PPD).

$R_{PPD,6-10-15}$ (%)			
STEP C-1/STEP A			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-8%	-2%	1%
JUNE	-25%	-59%	42%
JULY	-	-	-
AUG	-	-5%	-16%
SEP	-30%	-51%	-50%
OCT	-25%	0%	5%

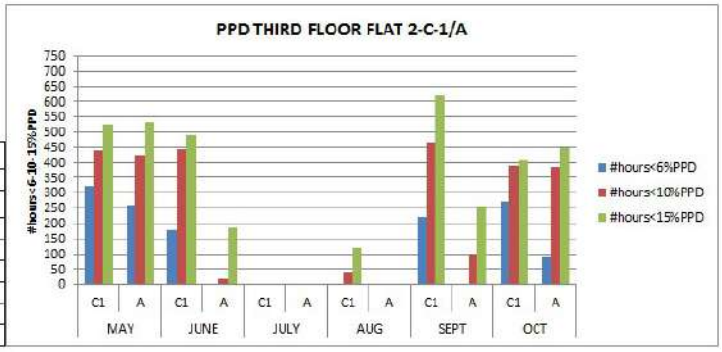


Figure 4.52: BUILDING A-Comparison between the PPD index values in STEP A and STEP C-1 (FLOOR 3-FLAT 2).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: No hours with temperatures above 28°C. Decrease of the mean temperature values. The minimum value is lower than in STEP A, but still acceptable;
- JUNE: Relevant reduction of #hours>26°C (60%); relevant reduction of hours above 28°C;
- JULY: Small reduction of hours above 28°C (3%); the mean temperature value decreases of 2.50°C;
- AUGUST: Decrease of about 40% of #hours>28°C;
- SEPTEMBER: No longer hours above 28°C and reduction of about 60% of #hours>26°C;
- OCTOBER: Decrease of almost 1.30°C of the mean temperature value.

	JUNE		JULY		AUGUST	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	28.24	26.18	31.95	29.40	30.28	28.63
MAX T (°C)	32.18	30.37	33.14	31.21	32.33	31.49
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP C-1**	**STEP A**	**STEP C-1**	**STEP A**	**STEP C-1**
MEAN T (°C)	24.18	23.47	27.48	24.83	22.55	21.24
MAX T (°C)	27.42	26.80	29.65	27.32	25.75	24.21
MIN T (°C)	20.13	19.80	24.54	21.70	18.31	17.30

Table 4.18: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-1/FLOOR 4-FLAT 6).

$R_{T,26-28}$ (%)		
STEP C-1/STEP A		
	$R_{T,26}$	$R_{T,28}$
MAY	6%	-
JUNE	62%	16%
JULY	0%	3%
AUG	4%	39%
SEP	60%	43%
OCT	-	-

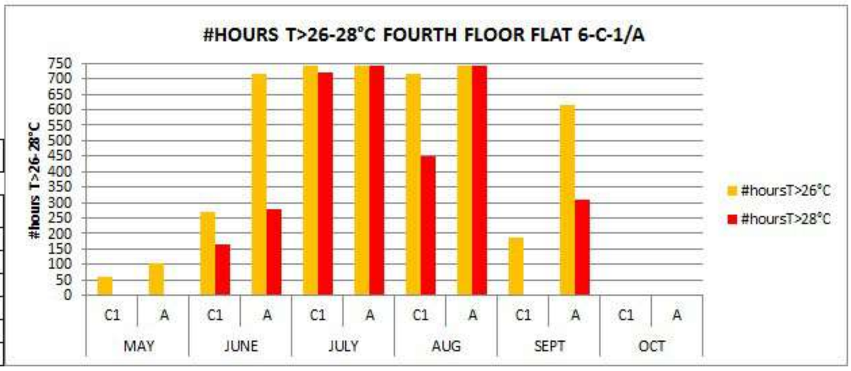


Figure 4.53: Temperature values during the worst months in Summer and during the shoulder season (STEP C-1/FLOOR 4-FLAT 6).

RELATIVE HUMIDITY (RH):

- MAY: The RH is almost the same than in STEP A;
- JUNE: Small reduction of #hoursRH>60%;
- JULY: No effects on the RH levels;
- AUGUST: No effects on the RH levels;
- SEPTEMBER: Increase of number of hours with RH>60% (12%);
- OCTOBER: Increase of #hoursRH>70% (11%).

$R_{RH,60-70}$ (%)		
STEP C-1/STEP A		
	$R_{RH,60}$	$R_{RH,70}$
MAY	0%	1%
JUNE	-4%	1%
JULY	-3%	-
AUG	-1%	-
SEP	-12%	-2%
OCT	-8%	-11%

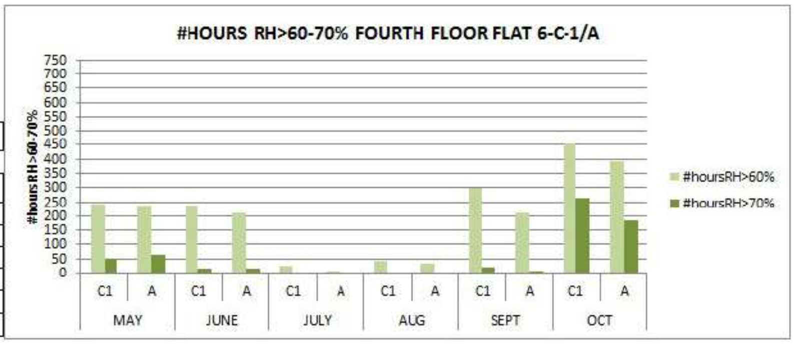


Figure 4.54: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP A and STEP C-1 during Summer months (FLOOR 4-FLAT 6).

COMFORT INDEX (PPD VALUES):

According to the PPD index, the most relevant increase of internal comfort is shown in June and September. In July ACH=1/h does not improve the indoor conditions, even if it contributes to decrease the indoor temperatures, as well as the effects on the comfort conditions are negligible in August even though also in this case the mean temperature value decreases of about 1.60°C (still above 28°C). In October the decrease of indoor temperatures and the increase of RH worsen the comfort conditions (decrease of #hours%<6%PPD).

$R_{PPD,6-10-15}$ (%)			
STEP C-1/STEP A			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-7%	-1%	-1%
JUNE	-31%	-60%	42%
JULY	-	-	-
AUG	-	-8%	-18%
SEP	-25%	-47%	-52%
OCT	9%	2%	3%

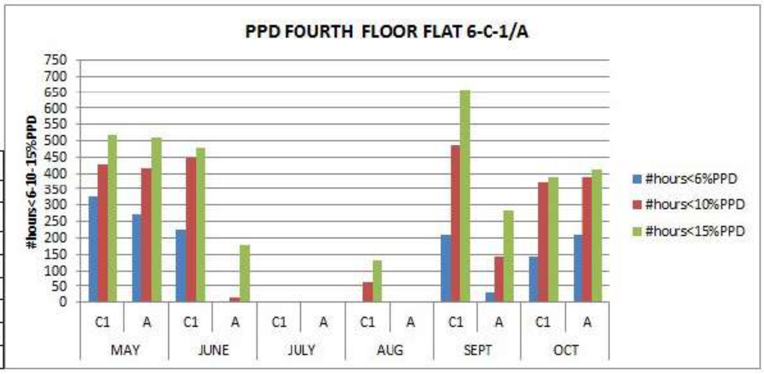


Figure 4.55: BUILDING A-Comparison between the PPD index values in STEP A and STEP C-1 (FLOOR 4-FLAT 6).

SYNTHESIS

Applying ACH=1/h leads to an improvement on indoor comfort conditions in June and in September. For what concerns May and October, keeping ACH=0.5/h worsens (but not in a relevant way) the flats which present lower initial temperature values (STEP A). The flats which present temperatures above 26°C in May (FLOOR 3-FLAT 2 and FLOOR 4-FLAT 6), because of the addition of air change rates due to the infiltration and the consequent decrease of temperatures, have better indoor comfort levels.

In October the comfort conditions improve when the flat present high levels of RH (FLOOR 3-FLAT 2) and the perception of the temperature decrease is attenuated by the indoor humidity.

As regards May and October the different results obtained in comparison with STEP A (ACH=0.5/h) are due to the fact that in the model we consider the heat losses for infiltrations (ACH_{INF}) which increase the total number of ACH.

3. (MSV)-ACH= 2/h (STEP C-2)

This section analyses the results after the application of ACH=2/h. In May and in October the number of air change rates is still ACH=0.5/h, so that comfort level changes will occur mainly in the central months.

MONTH	**ACH (h^{-1})**	**CONDITIONS for SWITCHING ON/OFF**
MAY	**0.5**	Always ON
JUNE	**2**: when T_out<T_ind **0.5:** when T_out>T_ind	Always ON
JULY	**2**: when T_out<T_ind **0.5**: when T_out>T_ind	Always ON
AUGUST	**2**: when T_out<T_ind **0.5**: when T_out>T_ind	Always ON
SEPTEMBER	**2**: when T_out<T_ind **0.5**: when T_out>T_ind	Always ON
OCTOBER	**0.5**	Always ON

Table 4.19: monthly schedule of the ACH and switching control on the MVS.

Also in this case, the mechanical ventilation system was modeled by setting the inlet air equal to the outdoor air. All flats have their own system depending on the outdoor/indoor temperature differences which make the system improve the air change rates when conditions are appropriate.

WHOLE BUILDING:

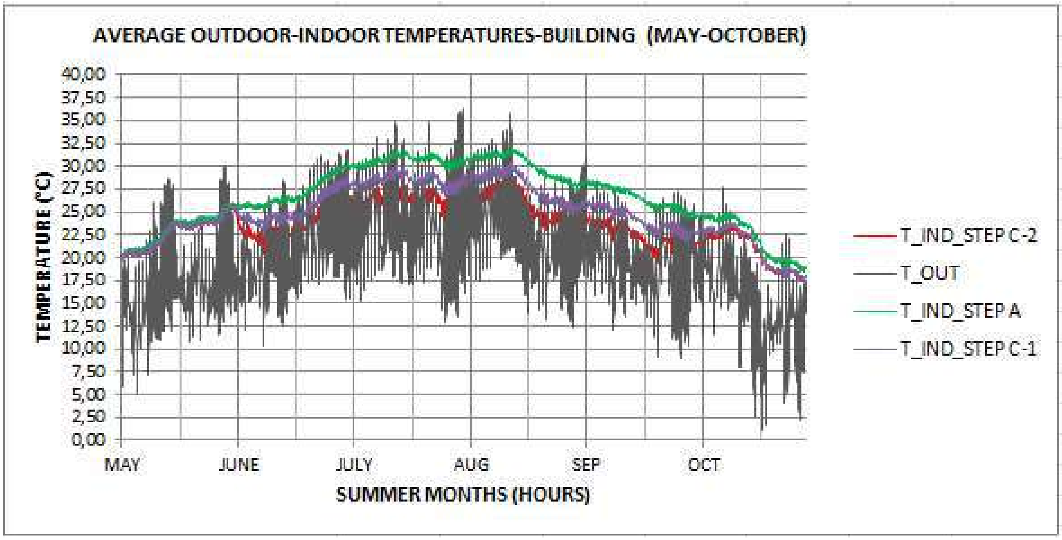


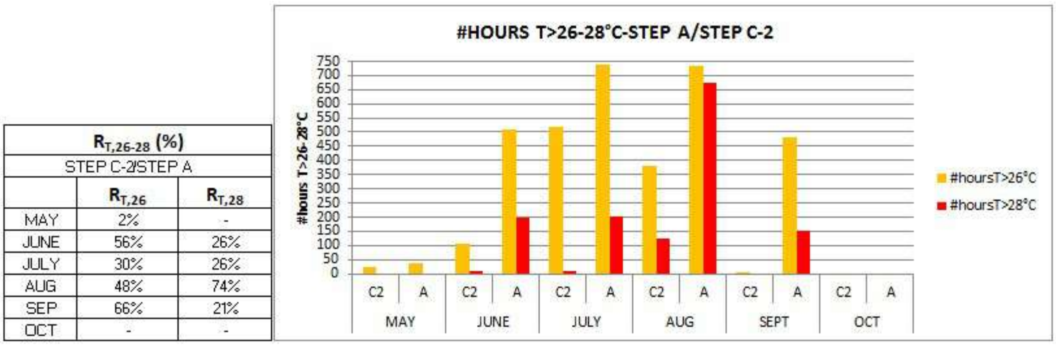
Figure 4.56: BUILDING A-Hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between STEP C-2, STEP C-1, STEP A and outdoor temperatures.

The effect of increasing the number of air change rates led to an even more relevant decrease of indoor temperatures, especially in July and in August. Even in June and in September temperatures suffered a further reduction, but a particular attention has to be paid on the answer in terms of comfort, because to ventilate more means to introduce more moisture inside the house and whenever outdoor temperatures are too low, to decrease indoor temperatures when it is not necessary (for example in September and consequently in the following month-October).

	JUNE		JULY		AUGUST	
	STEP A	STEP C-2	STEP A	STEP C-2	STEP A	STEP C-2
MEAN T (°C)	27.08	23.80	30.62	26.56	30.15	26.00
MAX T (°C)	32.54	29.90	33.57	30.67	33.77	31.09
	MAY		SEPTEMBER		OCTOBER	
	STEP A	STEP C-2	STEP A	STEP C-2	STEP A	STEP C-2
MEAN T (°C)	23.16	22.77	26.68	22.55	22.29	20.70
MAX T (°C)	27.91	27.81	30.28	26.82	31.63	24.49
MIN T (°C)	23.63	18.81	24.35	18.23	16.70	16.57

Table 4.20: Temperature values during the worst months in Summer and during the shoulder season (WHOLE BUILDING).

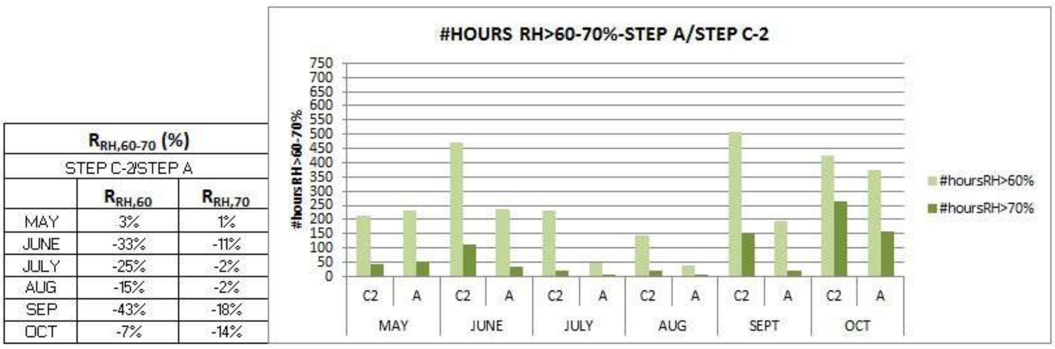
In July ACH=2/h lead to the elimination of number of hours exceeding 28°C and in August the reduction of these hours reaches the 74% compared to those in STEP A.



$R_{T,26-28}$ (%)		
STEP C-2/STEP A		
	$R_{T,26}$	$R_{T,28}$
MAY	2%	-
JUNE	56%	26%
JULY	30%	26%
AUG	48%	74%
SEP	66%	21%
OCT	-	-

Figure 4.57: BUILDING A-Comparison between the number of hours during Summer months exceeding 26-28°C in STEP A and STEP C-2. Values averaged across all the flats in the building.

The increase of the air entering into the house leads to an increase of Relative Humidity in all the central months that is relevant in June and September.



$R_{RH,60-70}$ (%)		
STEP C-2/STEP A		
	$R_{RH,60}$	$R_{RH,70}$
MAY	3%	1%
JUNE	-33%	-11%
JULY	-25%	-2%
AUG	-15%	-2%
SEP	-43%	-18%
OCT	-7%	-14%

Figure 4.58: BUILDING A-Comparison between the number of hours during Summer months exceeding 60-70% of RH in STEP A and STEP C-2. Values averaged across all the flats in the building.

FLATS:

After a previous analysis of the whole building behaviour, it is worth to analyse the answer of each flat in terms of internal comfort. In this case a comparison between STEP C-1 and STEP C-2 will be provided, in order to understand which value is better than the other, according to the different months.

FLOOR 1: FLAT 8

TEMPERATURES:

- MAY: The same results compared to STEP C-1 (ACH=0.5/h[14]);
- JUNE: Reduction of #hours>28°C (18%) in comparison with STEP C-1;
- JULY: Relevant reduction of #hours>28°C (72%);
- AUGUST: Relevant reduction of #hours>28°C (30%);
- SEPTEMBER: No longer hours above 26°C compared to STEP C-1;
- OCTOBER: Decrease of almost 1.50°C of the mean temperature value, more than in STEP C-1 (1.20°C). This reduction is due to the decrease of temperatures in September, compared to STEP C-1.

	JUNE		JULY		AUGUST	
	STEP A	**STEP C-2**	**STEP A**	**STEP C-2**	**STEP A**	**STEP C-2**
MEAN T (°C)	27.84	24.66	31.30	27.40	30.71	26.74
MAX T (°C)	31.49	28.75	32.49	29.58	32.66	29.97
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP C-2**	**STEP A**	**STEP C-2**	**STEP A**	**STEP C-2**
MEAN T (°C)	23.87	23.47	27.20	23.22	22.73	21.20
MAX T (°C)	27.11	26.79	29.26	25.99	25.51	23.92
MIN T (°C)	20.17	19.94	24.62	19.83	18.94	17.84

Table 4.21: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-2/FLOOR 1-FLAT 8).

$R_{T,26-28}$ (%)		
STEP C-2/STEP C-1		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	-
JUNE	13%	18%
JULY	6%	72%
AUG	36%	30%
SEP	28%	0%
OCT	-	-

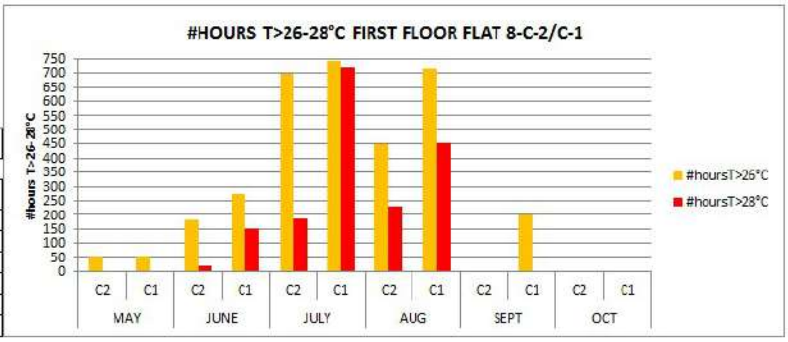


Figure 4.59: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP C-1 and STEP C-2 during Summer months (FLOOR 1-FLAT 8).

[14] In May and in October ACH= 0.5/h.

RELATIVE HUMIDITY (RH):

- MAY: The same results compared to STEP C-1 (ACH=0.5/h);
- JUNE: Increase of almost 20% of #hoursRH>60%; increase of almost 10% of #hoursRH>70%;
- JULY: Increase of #hoursRH>60%;
- AUGUST: Increase of #hoursRH>60%;
- SEPTEMBER: Increase of 20% #hoursRH>60%; increase of about 12% of #hoursRH>70%;
- OCTOBER: Despite the conditions imposed to the MVS are the same than in STEP C-1, the increase for RH in September leads to an increase of RH even in this month, even though not so enhanced.

$R_{RH,60-70}$ (%)		
STEP C-2/STEP C-1		
	$R_{RH,60}$	$R_{RH,70}$
MAY	0%	0%
JUNE	-17%	-6%
JULY	-16%	-
AUG	-9%	-
SEP	-20%	-12%
OCT	-2%	-4%

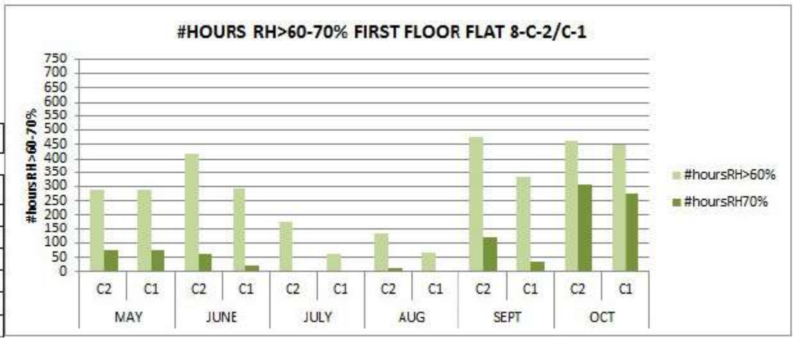


Figure 4.60: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP C-1 and STEP C-2 during Summer months (FLOOR 1-FLAT 8).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in June and September, but the improvement is lower compared to STEP C-1. In July and in August ACH=2/h improves the indoor conditions, even if the indoor temperatures are still above 26°C. In October the decrease of indoor temperatures and the increase of RH worsen the comfort conditions. In May the comfort levels are the same than in STEP C-1 (in Winter ACH=0.5/h, in such a way the starting point conditions in STEP C-1 and STEP C-2 are the same as regards May).

$R_{PPD,6-10-15}$ (%)			
STEP C-2/STEP C-1			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	0%	0%	0%
JUNE	-6%	-8%	12%
JULY	-	-	-
AUG	-	-34%	-30%
SEP	-2%	3%	10%
OCT	9%	16%	1%

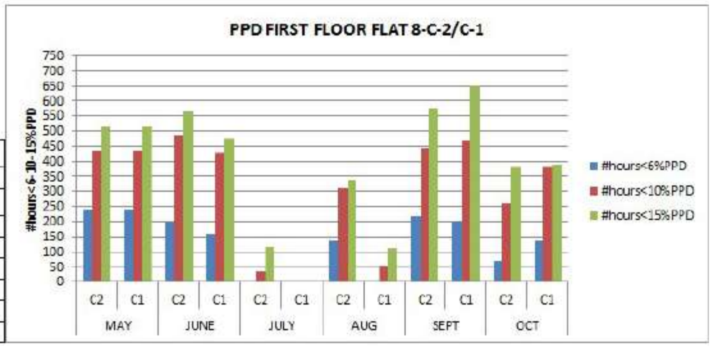


Figure 4.61: BUILDING A-Comparison between the PPD index values in STEP C-1 and STEP C-2 (FLOOR 1-FLAT 8).

FLOOR 2: FLAT 6

The results are similar to the previous flat.

TEMPERATURES:

- MAY: The flat presents the same temperature values as in STEP C-1;
- JUNE: No hours above 28°C;
- JULY: Reduction of almost 70% of hours above 28°C;
- AUGUST: Decrease of about 40% of #hours>28°C;
- SEPTEMBER: This month does not present hours above 26°C;
- OCTOBER: Decrease of the mean temperature value compared to STEP C-1 (21.36°C).

	JUNE		JULY		AUGUST	
	STEP A	STEP C-2	STEP A	STEP C-2	STEP A	STEP C-2
MEAN T (°C)	27.06	23.60	30.62	26.34	30.28	25.87
MAX T (°C)	30.52	27.56	31.82	28.65	32.33	29.36
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP C-2**	**STEP A**	**STEP C-2**	**STEP A**	**STEP C-2**
MEAN T (°C)	23.16	22.74	26.89	22.48	22.64	20.99
MAX T (°C)	26.09	25.76	28.82	25.23	25.56	23.71
MIN T (°C)	19.94	19.71	24.48	18.98	18.74	17.55

Table 4.22: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-2/FLOOR 2-FLAT 6).

$R_{T,26-28}$ (%) STEP C-2/STEP C-1		
	$R_{T,26}$	$R_{T,28}$
MAY	-	-
JUNE	17%	6%
JULY	35%	66%
AUG	32%	41%
SEP	9%	0%
OCT	-	-

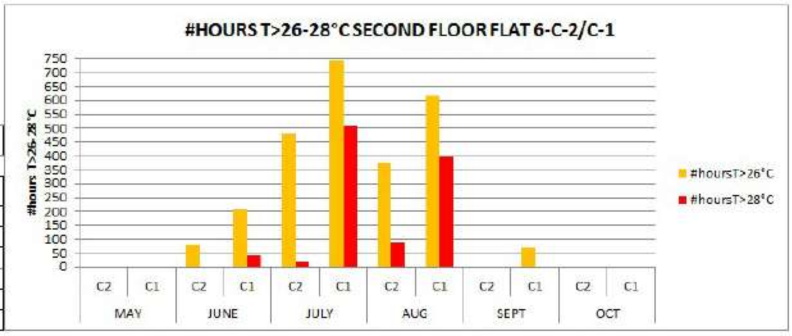


Figure 4.62: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP AC-1 and STEP C-2 during Summer months (FLOOR 2-FLAT 6).

RELATIVE HUMIDITY (RH):

- MAY: The flat presents the same level of Relative Humidity as in STEP C-1;
- JUNE: Increase of 20% of #hoursRH>60% and almost 15% of #hoursRH>70%;
- JULY: Increase of 20% of #hoursRH>60%;
- AUGUST: Small increase of #hoursRH>60%;
- SEPTEMBER: Increase of about 20% of both #hoursRH>60% and #hoursRH>70%;
- OCTOBER: The level of RH increases because of the previous month (September) more humid in STEP C-2 than in STEP C-1.

$R_{RH,60-70}$ (%)		
STEP C-2/STEP C-1		
	$R_{RH,60}$	$R_{RH,70}$
MAY	0%	0%
JUNE	-20%	-13%
JULY	-22%	-
AUG	-8%	-
SEP	-22%	-17%
OCT	-2%	-4%

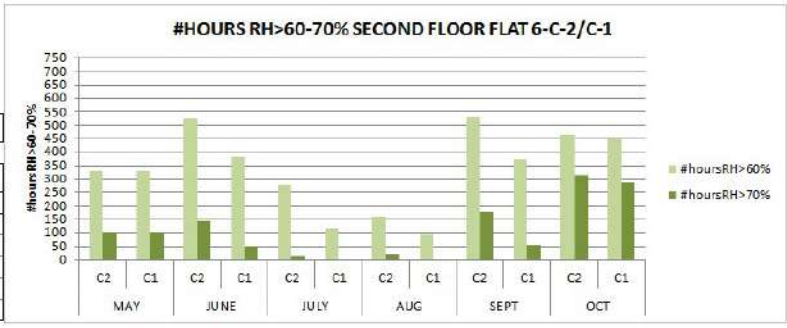


Figure 4.63: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP C-1 and STEP C-2 during Summer months (FLOOR 2-FLAT 6).

<u>COMFORT INDEX (PPD VALUES):</u>

The most relevant increase of internal comfort (compared to STEP C-1) is shown in July and August (the mean temperature values are close 26°C). In the other months ACH=1/h leads to better comfort conditions. Indeed, the decrease of temperatures in September and in June lead to an increase of RH levels, making the comfort levels fall down. In October the decrease of indoor temperatures and the increase of RH worsen the comfort conditions (decrease of #hours%<6%PPD), still depending of the conditions in September.

$R_{PPD,6-10-15}$ (%)			
STEP C-2/C-1			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	0%	0%	0%
JUNE	40%	10%	12%
JULY	-7%	-29%	-29%
AUG	-27%	-29%	-24%
SEP	-6%	32%	35%
OCT	10%	24%	8%

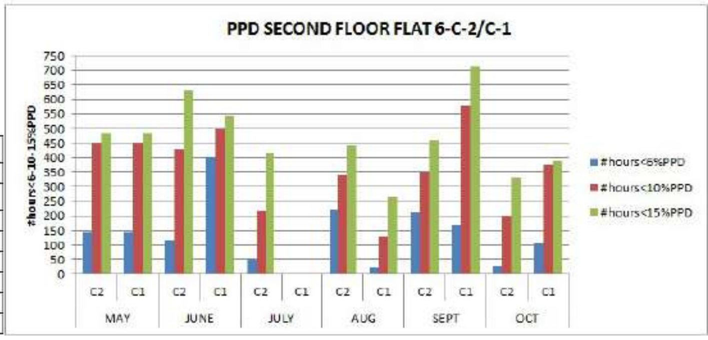


Figure 4.64: BUILDING A-Comparison between the PPD index values in STEP C-2 and STEP C-1 (FLOOR 2-FLAT 6).

FLOOR 3: FLAT 2

TEMPERATURES:

- MAY: No hours with temperatures above the comfort value (26°C);
- JUNE: Reduction of 16% of #hours>28°C;
- JULY: Reduction of almost 75% of hours above 28°C;
- AUGUST: Decrease of about 33% of #hours>28°C;
- SEPTEMBER: No longer hours above 28°C and reduction of almost 30% of #hours>26°C;
- OCTOBER: Decrease of the mean temperature value compared to STEP C-1.

	JUNE		JULY		AUGUST	
	STEP A	STEP C-2	STEP A	STEP C-2	STEP A	STEP C-2
MEAN T (°C)	27.93	24.39	31.54	27.18	31.07	26.64
MAX T (°C)	31.67	28.53	32.86	29.56	33.25	30.21
	MAY		SEPTEMBER		OCTOBER	
	STEP A	STEP C-2	STEP A	STEP C-2	STEP A	STEP C-2
MEAN T (°C)	26.07	25.21	27.53	23.15	23.10	21.53
MAX T (°C)	27.20	26.82	29.63	26.01	25.86	24.49
MIN T (°C)	20.25	20.04	24.94	19.68	19.11	18.01

Table 4.23: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-2/FLOOR 3-FLAT 2).

$R_{T,26-28}$ (%)		
STEP C-2/STEP C-1		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	-
JUNE	16%	16%
JULY	12%	74%
AUG	38%	33%
SEP	30%	0%
OCT	-	-

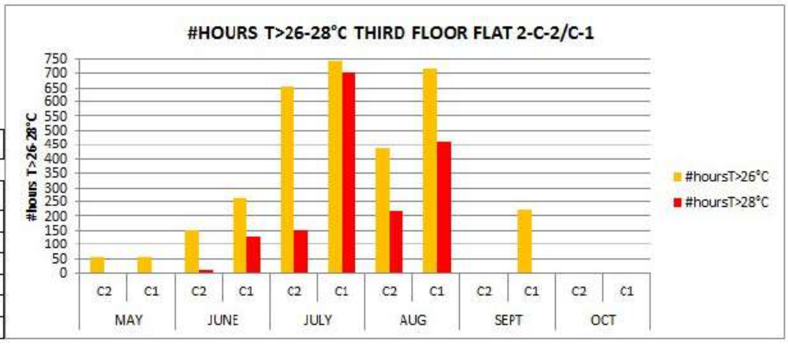


Figure 4.65: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP AC-1 and STEP C-2 during Summer months (FLOOR 3-FLAT 2).

RELATIVE HUMIDITY (RH):

- MAY: The flat presents the same level of Relative Humidity as in STEP C-1;
- JUNE: Increase of about 10% of #hoursRH>60% and 10% of #hoursRH>70%;
- JULY: Increase of about 20% of #hoursRH>60%;
- AUGUST: Increase of about 10% #hoursRH>60%;
- SEPTEMBER: Increase of about 20% of #hoursRH>70%;
- OCTOBER: The level of RH increases as in the previous flat.

$R_{RH,60-70}$ (%)		
STEP C-2/STEP C-1		
	$R_{RH,60}$	$R_{RH,70}$
MAY	0%	0%
JUNE	-9%	-9%
JULY	-17%	-
AUG	-9%	-
SEP	-15%	-19%
OCT	-1%	-3%

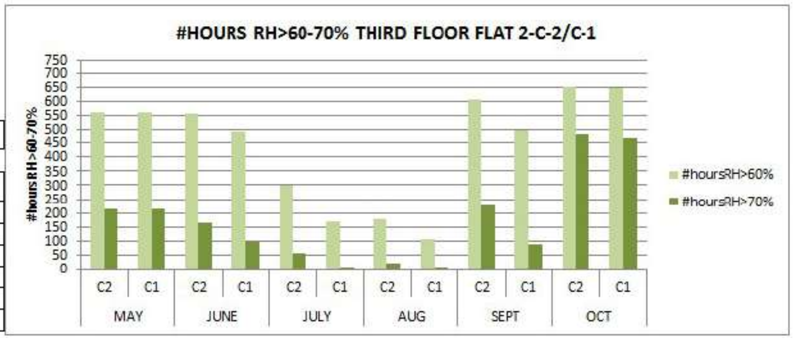


Figure 4.66: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP C-1 and STEP C-2 during Summer months (FLOOR 3-FLAT 2).

<u>COMFORT INDEX (PPD VALUES):</u>

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in July and in August. In September and in October the comfort level is slightly lower than in STEP C-1 because the increase of ACH leads to a decrease of indoor temperatures compared to STEP C-1.

In June ACH=2/h leads to a further decrease of indoor temperatures, but a consequent increase of RH and a small increase of indoor comfort. It is necessary to find a compromise between temperatures-RH-PPD index, because in some cases the increase of RH level can improve indoor comfort levels or viceversa.

$R_{PPD,6-10-15}$ (%)			
STEP C-2/STEP C-1			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	0%	0%	0%
JUNE	-5%	-6%	14%
JULY	-	-	-
AUG	-	-38%	-31%
SEP	0%	2%	6%
OCT	19%	9%	1%

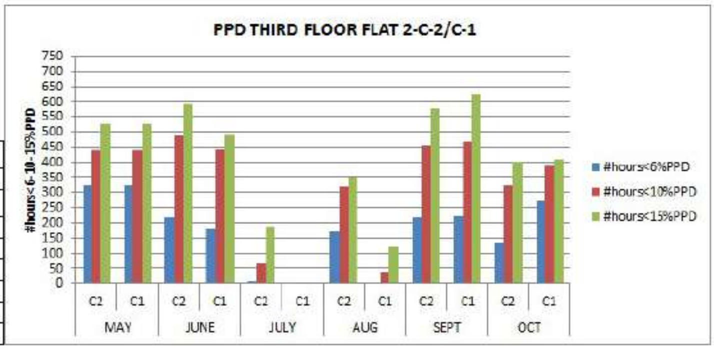


Figure 4.67: BUILDING A-Comparison between the PPD index values in STEP C-1 and STEP C-2 (FLOOR 3-FLAT 2).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: No hours with temperatures above 26°C;
- JUNE: Relevant reduction of #hours>26°C (11%)and >28°C (18%);
- JULY: Reduction of almost 70% of hours above 28°C;
- AUGUST: Decrease of about 30% of #hours>28°C;
- SEPTEMBER: No longer hours above 26°C;
- OCTOBER: Decrease of the mean temperature value in comparison with STEP C-1 (21.24°C).

	JUNE		JULY		AUGUST	
	STEP A	STEP C-2	STEP A	STEP C-2	STEP A	STEP C-2
MEAN T (°C)	28.24	24.61	31.95	27.48	30.28	26.76
MAX T (°C)	32.18	29.01	33.14	29.83	32.33	30.28
	MAY		SEPTEMBER		OCTOBER	
	STEP A	STEP C-2	STEP A	STEP C-2	STEP A	STEP C-2
MEAN T (°C)	24.18	23.47	27.48	23.08	22.55	20.92
MAX T (°C)	27.42	26.80	29.65	25.96	25.75	23.90
MIN T (°C)	20.13	19.80	24.54	19.39	18.31	17.27

Table 4.24: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-2/FLOOR 4-FLAT 6).

$R_{T,26-28}$ (%)		
STEP C-2/STEP C-1		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	-
JUNE	11%	18%
JULY	7%	67%
AUG	37%	26%
SEP	26%	0%
OCT	-	-

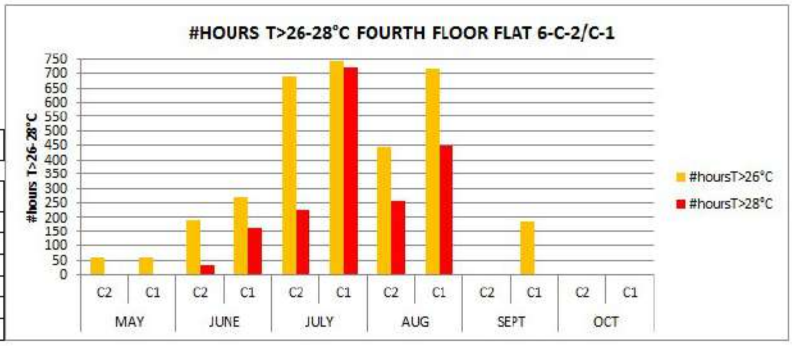


Figure 4.68: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP C-2/FLOOR 4-FLAT 6).

RELATIVE HUMIDITY (RH):

- MAY: The RH is the same than in STEP C-1;
- JUNE: Increase of #hoursRH>60% (16%);
- JULY: Increase of #hoursRH>60% (12%);
- AUGUST: Small increase of #hoursRH>60% (8%);
- SEPTEMBER: Increase of number of hours with RH>60% (20%);
- OCTOBER: Increase of about 5% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP C-2/STEP C-1		
	$R_{RH,60}$	$R_{RH,70}$
MAY	0%	0%
JUNE	-16%	-4%
JULY	-12%	-
AUG	-8%	-
SEP	-20%	-11%
OCT	-2%	-5%

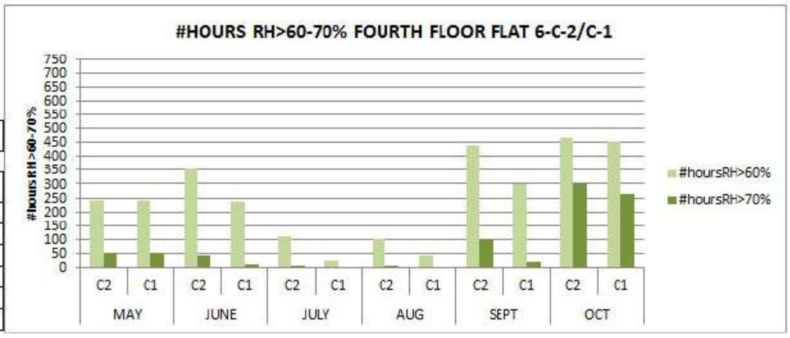


Figure 4.69: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP C-1 and STEP C-2 during Summer months (FLOOR 4-FLAT 6).

COMFORT INDEX (PPD VALUES):

The most relevant increase of internal comfort is shown in July and in August (compared to STEP C-1). Also in this case, the number of hours with PPD<6-10-15% is still low in July, but compared to STEP C-1 in which the results have shown that the decrease of temperatures was not enough, we can say that the indoor comfort got a significant improvement. In September and in October the comfort level is slightly lower than in STEP C-1 because the increase of ACH leads to a decrease of indoor temperatures compared to STEP C-1. In June ACH=2/h leads to a further decrease of indoor temperatures and an increase of comfort conditions (even though not so enhanced).

$R_{PPD,6-10-15}$ (%)			
STEP C-2/STEP C-1			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	0%	0%	0%
JUNE	-1%	-3%	-10%
JULY	0%	-6%	-17%
AUG	-23%	-34%	-28%
SEP	-3%	7%	14%
OCT	8%	17%	2%

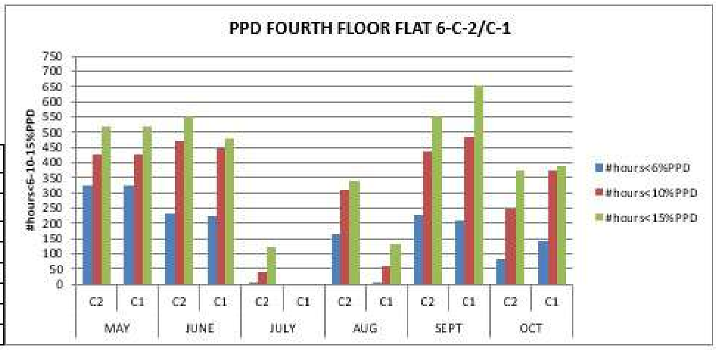


Figure 4.70: BUILDING A-Comparison between the PPD index values in STEP C-1 and STEP C-2 (FLOOR 4-FLAT 6).

SYNTHESIS

Applying ACH=2/h leads to an improvement on indoor comfort conditions in July and in August. For what concerns October, keeping ACH=0.5/h has better effects by setting ACH=1/h in September, instead of ACH=2/h. In September indoor conditions worsen, so that it is convenient to maintain ACH=1/h. In June ACH=2/h improves the comfort conditions inside the flats, especially in FLOOR 1-FLAT 8 and FLOOR 3-FLAT 2; the first one presents a mean temperature value higher than the others, so improving air change rates leads to a further decrease of indoor temperatures, that in its turn leads to an improvement of comfort levels; for the second one, a further decrease of temperatures makes the flat more comfortable because the level of RH is high: decreasing the temperatures, leads to a decrease of the effects of RH on the indoor comfort conditions. In the other two flats STEP C-1 and STEP C-2 lead to similar results. Accordingly, in the shoulder months, the RH pay a fundamental role on the indoor comfort conditions.

4.1.2.5 MECHANICAL VENTILATION SYSTEMS + HUMIDITY CONTROL (STEP D)

From the previous analysis we found the best fitting number of ACH for each month and the attention was paid on the temperature control, by varying the ventilation rates in the system.

As we have found before, the introduction of more air into the house can lead to an increase of RH, and it can cause issues of building durability and human health, even if the human perception of the indoor comfort improves because of the decrease of internal temperatures. Having said that, it is worth maintaining acceptable level of Relative Humidity inside the home. In this section, a smart control of the ventilation system aiming at reducing the indoor Relative Humidity will be analyse.

The comparison with STEP C-1 and STEP C-2 will be useful in order to understand if the humidity control is necessary or the comfort levels are acceptable even without it.

In general, the smart control of household ventilation can reduce interior moisture levels in a number of ways (24):

- Direct removal of moisture at its source through local exhaust fans (i.e., kitchen, bathroom and laundry exhaust).
- Strategic changes in air exchange rates that will increase net-moisture transfer from inside to outside, based on the indoor-outdoor humidity differential.
- Use of the ventilation system to advantageously increase the sensible cooling load and the associated moisture removal of cooling system operation.
- Use of the ventilation system to advantageously increase the interior temperature, which for a given absolute humidity level, will reduce indoor relative humidity.

The second strategy is the primary approach used in our development of a smart ventilation controller for moisture management.

The removal of any indoor contaminant, including moisture, is best achieved by local exhaust before the contaminant disperses throughout the space. This is possible when moisture sources are known and local, as in bathrooms or kitchens. This first strategy listed above is commonly implemented through use of an automatic bathroom exhaust fan, tied to a humidity sensor. Less common, is the automatic control of kitchen exhaust fans to remove moisture generated from cooking activities. While important, these local exhaust approaches are not relevant in control of whole house ventilation systems. Accordingly, local emissions of moisture are not considered in our building simulations, and internal moisture gains are at a constant rate (e.g., they do not vary with time of day, day of week, etc.).

The second strategy listed above uses smart ventilation controls to directly increase net-moisture transport out of the home, or limit net-moisture transport into the home. This is done based on the humidity difference between the house and outside.

As in Equation 4.13, the simple mass balance for moisture suggests that ventilation airflow (translated to mass flow by air densities) will either transport moisture into or out of the home, depending on the sign and magnitude of the humidity ratio difference HRdiff= (w_{house} – $w_{outside}$).

Positive values lead to moisture removal from the house, and negative values lead to moisture transport into the house. Larger values of HRdiff lead to more moisture transport and smaller values lead to little net-transport. Various smart control strategies can be used to take advantage of this, including controls that function by month of the year, time-of-day or in real-time.

$$\dot{m}_{water} = \dot{m}_{air} \times (w_{house} - w_{outside}) \qquad (4.13)$$

m_{water} = mass flow of moisture, kg
m_{air} = mass flow of air, kg
w_{house} = humidity ratio of house, kg/kg
$w_{outside}$ = humidity ratio outside, kg/kg

We then calculated the humidity ratio difference (HRdiff) between the house and outside for every hour of the Summer period, considering values averaged across all the flats from the STEP A results. For each month in Summer there is a net-humidity balance (average of all HRdiff values for the month), which can be either positive or negative. Positive means that on average for the month, it is more humid inside than outside, and more ventilation will provide net-moisture removal. Negative means that on average, it is more humid outside than inside, and more ventilation will provide net-humidification. The fig.4.70 shows the month of May and the sign of HRdiff is positive for the greater part of the month. This means that, on average, it is almost always more humid inside than outside, so that more ventilation can help to decrease the indoor humidity.

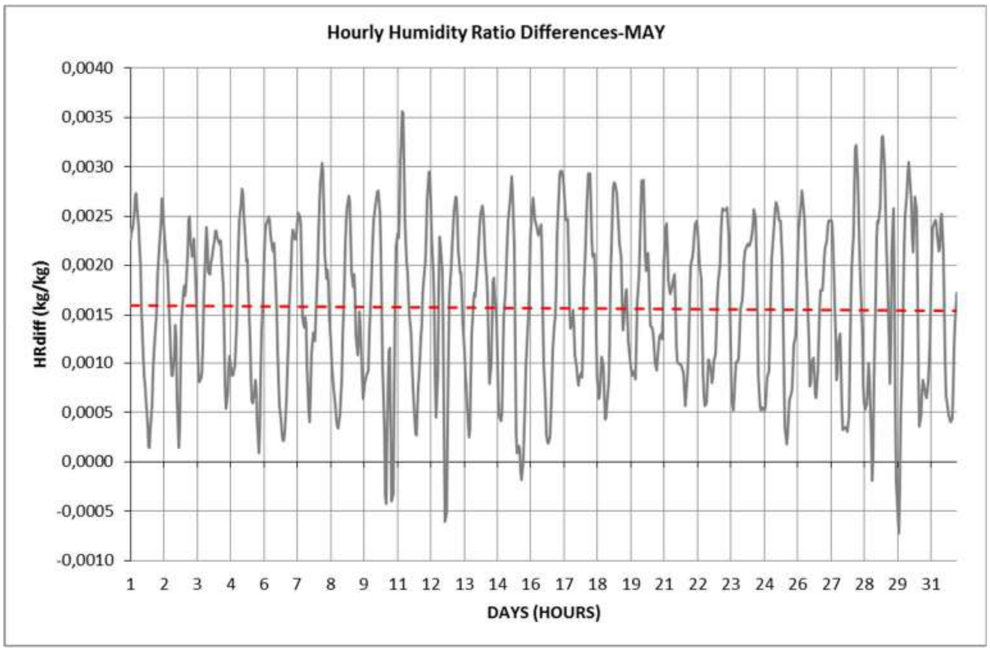


Figure 4.71: Time series plot of hourly Humidity Ratio differences (HRdiff), averaged across all the building. The dashed red line is the monthly average of HRdiff.

The table 4.25 shows the results of HRdiff mean values. According to the previous considerations, the positive sign of these values could allow to ventilate more in order to provide a net-humidity removal.

HRdiff for Summer months (kg/kg)					
MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
0.00156	0.00156	0.00156	0.00157	0.00156	0.00157

Table 4.25: Net-humidity balance for all Summer months.

Obviously, taking into account the season we are dealing with and its high temperatures, it is not possible to increase the ventilation rate all over the month, because together with the removal of moisture there would be an increase of temperatures. Accordingly, it is necessary to evaluate the best compromise between the two parameters (temperature and humidity) able to improve the indoor comfort. To achieve this, a careful analysis of patterns in outdoor/indoor humidity and outdoor/indoor temperatures is needed.

The first step is to analyse month by month temperatures and humidity patterns. We will analyse the average values of these parameters found in STEP A, in order to find a general strategy for the ventilation control assuming that the answer is almost the same for all the flats in the building. This assumption will be verified by examining individually the flats.

MAY

Analyzing the temperatures trend in May, it is worth to note that temperatures starts to arise in the second half of the month, but they do not reach high values. Having said that, in the first part of the month it is not useful to increase the ventilation rate, because more air (when outdoor temperatures are lower than indoor ones) would lower indoor temperatures which are close to 20°C.

Moreover, indoor humidity peaks (HR>12g/kg[15]) occur in the second part of the month, when temperatures are higher and more ventilation could provide a benefit.

From the previous analyses carried out in STEP C-1/2 we noticed that ACH=0.5/h was enough to keep good comfort conditions, so that in order to lower humidity levels, we can verify if increasing ventilation rates just in the periods with high values of indoor HR, could further provide a benefit to the indoor comfort. The condition will be:

ACH=1/h, when HR_IND (Indoor Humidity Ratio)>12g/kg;

ACH=0.5/h, when HR_IND<12g/kg.

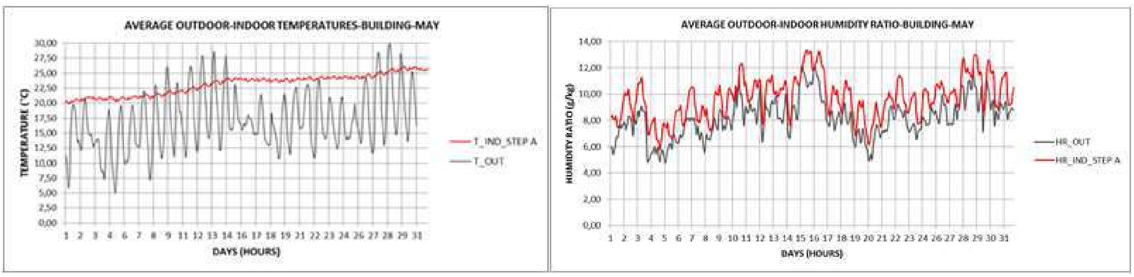


Figure 4.72: On the left: Outdoor/Indoor hourly Temperatures trend in May (WHOLE BUILDING-STEP A); on the right: Outdoor/Indoor hourly Humidity Ratio trend in May (WHOLE BUILDING-STEP A).

[15] 12g/kg of HR correspond to 60% of Relative Humidity, that is the threshold we consider when we deal with comfort levels.

JUNE

The indoor temperatures trend in June highlights that the warmest period occurs in the second part of the month, as well as the most humid one. In the first period we can keep ACH=1/h that is able to maintain good comfort conditions (from STEP C-1 results), while in the second part of the month, when higher temperatures occur, it is convenient to use ACH=2/h (when T_OUT<T_IND) and ACH=1/h (when T_OUT>T_IND). These conditions can ensure, from one hand, the decrease of temperatures (by keeping ACH=2/h when outdoor conditions are suitable), on the other hand, when T_OUT>T_IND, the increase of air change rates (up to 1/h, compared with 0.5/h in STEP C-2) can reduce the RH. The conditions will be:

T_IND>26°C (second half of June):
ACH=2/h, when T_OUT<T_IND;
ACH=1/h, when T_OUT>T_IND.
T_IND<26°C (first half of June):
ACH=1/h, when T_OUT<T_IND[16];
ACH=0.5/h, when T_OUT>T_IND.

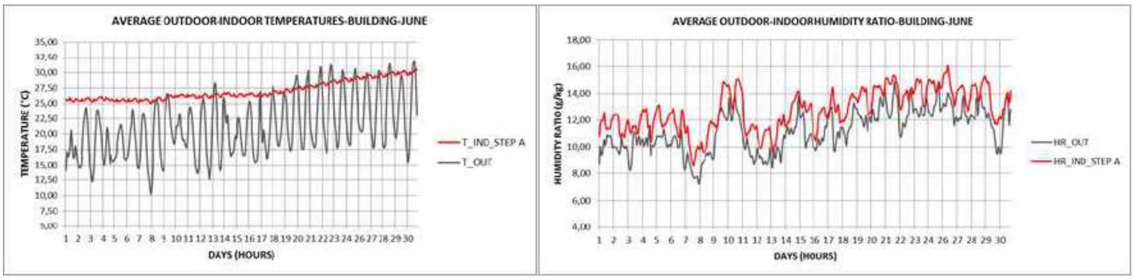


Figure 4.73: On the left: Outdoor/Indoor hourly Temperatures trend in June (WHOLE BUILDING-STEP A); on the right: Outdoor/Indoor hourly Humidity Ratio trend in June (WHOLE BUILDING-STEP A).

JULY

In this month, the building presents temperature values above 30°C. Accordingly, the primary objective is to lower indoor temperatures, by improving the ACH. In the previous paragraphs, we noticed that ACH=2/h can lead to better comfort improvements than ACH=1/h. Together with high temperatures the building presents high values of RH as well. Indoor Humidity Ratio values are always above 12kg/kg. In this case, in order to improve also the Relative Humidity levels, we can increase the ACH number when T_OUT>T_IND, so that the condition will be:

ACH=2/h, when T_OUT<T_IND (Indoor Humidity Ratio);
ACH=1/h, when T_OUT>T_IND (instead of 0.5/h in STEP C-2).

[16] This condition occurs almost always in this month, but since these values are the results of an average made across all the flats, it could be possible that some apartments present indoor temperature values lower than the outdoor ones. Accordingly, we have to consider this possibility and the condition of setting ACH=0.5/h derives from this motivation.

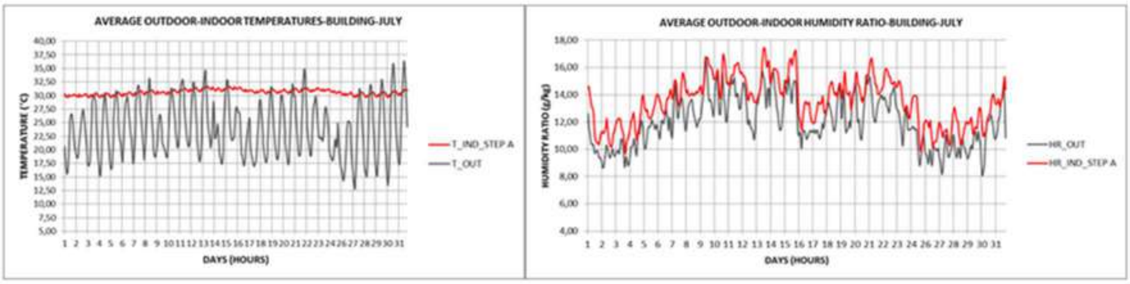


Figure 4.74: On the left: Outdoor/Indoor hourly Temperatures trend in July (WHOLE BUILDING-STEP A); on the right: Outdoor/Indoor hourly Humidity Ratio trend in July (WHOLE BUILDING-STEP A).

AUGUST

The building has temperatures above 30°C in the first half of the month, while in the second part there is a decrease of temperatures, even if they are still above 27.5°C. The humidity level is high, as in July. The strategy to apply in this period is the same than in July, trying to lower the indoor temperatures and the humidity at the same time. The condition will be:

ACH=2/h, when T_OUT<T_IND (Indoor Humidity Ratio);

ACH=1/h, when T_OUT>T_IND (instead of 0.5/h in STEP C-2).

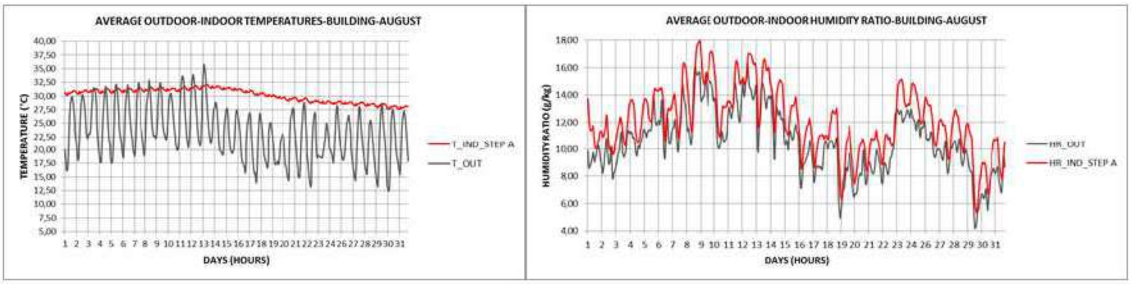


Figure 4.75: On the left: Outdoor/Indoor hourly Temperatures trend in August (WHOLE BUILDING-STEP A); on the right: Outdoor/Indoor hourly Humidity Ratio trend in August (WHOLE BUILDING-STEP A).

SEPTEMBER

The highest values of indoor humidity occur in the first half of the month that is also the warmest period according to indoor temperatures trend. In the second part of the month the humidity tends to decrease as well as indoor temperatures. Having said that, increasing air change rates in this part of September would mean to lower temperatures when they are already under the comfort level (25°C). The condition will be:

T_IND>26°C (first half of September):

ACH=1/h, when T_OUT<T_IND;

ACH=0.5/h, when T_OUT>T_IND.

T_IND<26°C (second half of September):

ACH=0.5/h.

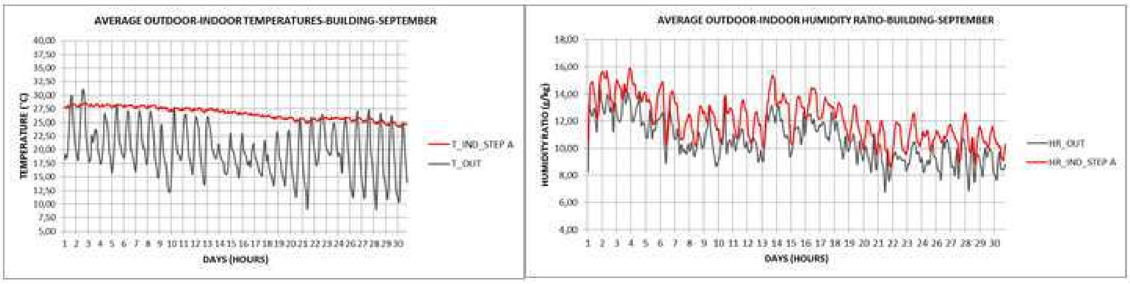


Figure 4.76: On the left: Outdoor/Indoor hourly Temperatures trend in September (WHOLE BUILDING-STEP A); on the right: Outdoor/Indoor hourly Humidity Ratio trend in September (WHOLE BUILDING-STEP A).

<u>OCTOBER</u>

This month represents an intermediate step between Summer and Winter. Indeed, Outdoor temperatures as well as Outdoor Humidity Ratio are higher in the first half of the month than in the second one. This reflects the indoor conditions, in the sense that, since the heating system in October is turned off, indoor temperatures will tend to align to the outdoor ones. So that we have to pay attention on the amount of air entering the house. As we mentioned before, the humidity levels are greater in the first part of October, as well as indoor temperatures, it is therefore convenient to increase the ACH just in this period. Moreover, some hours with too low temperatures can occur in October and therefore it is necessary to check the outdoor temperatures before entering into the home, even though with lower humidity ratio levels. The condition will be:

ACH=1/h, when HR_IND>12kg/kg and T_OUT>20°C;

ACH=0.5/h, when HR_IND<12kg/kg and T_OUT<20°C.

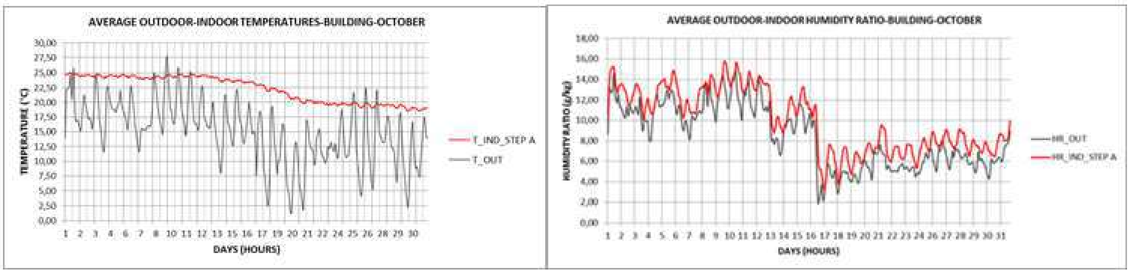


Figure 4.77: On the left: Outdoor/Indoor hourly Temperatures trend in October (WHOLE BUILDING-STEP A); on the right: Outdoor/Indoor hourly Humidity Ratio trend in October (WHOLE BUILDING-STEP A).

After this analysis we can summarize the input to be given to the building model in order to control both the indoor temperatures and the humidity levels:

MONTH	**ACH (h^{-1})**	**CONDITIONS for SWITCHING ON/OFF**
MAY	**2:** when HR_IND>12kg/kg **0.5:** when HR_IND<12kg/kg.	Always ON
JUNE	**T_IND>26°C** **2:** when T_OUT<T_IND **1:** when T_OUT>T_IND **T_IND<26°C** **1:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND	Always ON
JULY	**2:** when T_OUT<T_IND **1:** when T_OUT>T_IND	Always ON
AUGUST	**2:** when T_OUT<T_IND **1:** when T_OUT>T_IND	Always ON
SEPTEMBER	**T_IND>26°C** **1:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND **T_IND<26°C** **0.5:** always	Always ON
OCTOBER	**1:** when HR_IND>12kg/kg and T_OUT>20°C **0.5:** when HR_IND<12kg/kg and T_OUT<20°C	Always ON

Table 4.26: Monthly schedule of the ACH and switching control on the MVS.

<u>WHOLE BUILDING:</u>

The figure below shows the average hourly trend of indoor temperatures in all the analysed cases.

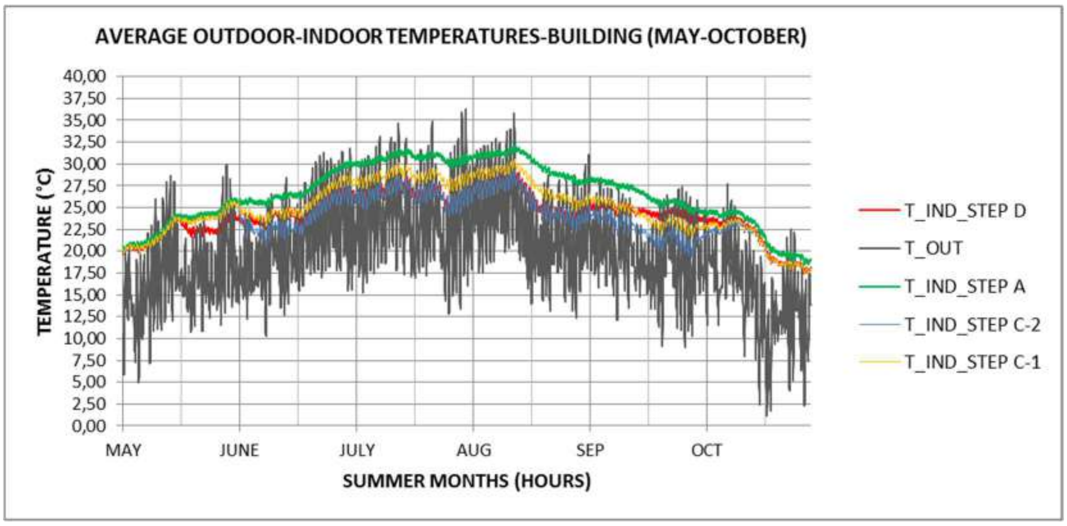


Figure 4.78: BUILDING A-hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between STEP D, STEP C-2, STEP C-1, STEP A and outdoor temperatures.

The STEP D temperatures trend of the central months in Summer (red line) is similar to that in STEP C-2 (blue line), while in June it is quite similar to the STEP C-1 temperatures trend (yellow line). As regards the month of May, temperatures decrease, while September and October highlight a small increase that makes them closer to STEP A hourly trend (green line).

The table below shows some characteristic temperature values. The humidity control strategy leads to intermediate temperature values between STEP C-1 and STEP C-2 in June, July and August, while in May it causes a decrease of the mean value. In September and in October temperatures increase.

	JUNE			**JULY**			**AUGUST**		
	STEP C-1	**STEP C-2**	**STEP D**	**STEP C-1**	**STEP C-2**	**STEP D**	**STEP C-1**	**STEP C-2**	**STEP D**
MEAN T (°C)	25.34	23.80	24.62	28.45	26.56	26.75	27.86	26.00	26.16
MAX T (°C)	31.22	29.90	30.11	31.99	30.67	30.90	32.24	31.09	31.30
	MAY			**SEPTEMBER**			**OCTOBER**		
	STEP C-1	**STEP C-2**	**STEP D**	**STEP C-1**	**STEP C-2**	**STEP D**	**STEP C-1**	**STEP C-2**	**STEP D**
MEAN T (°C)	22.77	22.77	22.17	24.31	22.55	24.65	21.05	20.70	21.29
MAX T (°C)	27.81	27.81	26.72	28.09	26.82	27.39	24.82	24.49	25.02
MIN T (°C)	18.81	18.81	18.81	20.30	18.23	21.72	16.60	16.57	16.61

Table 4.27: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between all the analysed cases.

After this previous analysis of the whole building answer, it is worth to analyse each chosen flat in order to be able to better understand if this strategy is useful to improve indoor comfort.

FLATS:

From the previous STEP (C-1/C-2) we highlighted that for the central months in Summer ACH=2/h is the best fitting value, while for the shoulder months (May, September and October) ACH=1/h lead to better comfort conditions. As regards June the difference between the two values was not so evident. Accordingly, the next analyses will provide a comparison between the STEP D results and either STEP C-1 results or STEP C-2 ones, depending on the month.

FLOOR 1: FLAT 8

TEMPERATURES:

- MAY: Decrease of the mean temperature value, both compared to STEP C-1 and STEP A;
- JUNE: Increase of #hours>28°C (2%) in comparison with STEP C-2; decrease of almost 20% of #hours>28°C compared to STEP C-1;
- JULY: Increase of #hours>28°C (7%) compared to STEP C-2;
- AUGUST: Increase of #hours>28°C (4%) compared to STEP C-2;
- SEPTEMBER: Reduction of almost 20% of #hours>26°C compared to STEP C-1;
- OCTOBER: No effects.

	JUNE		JULY		AUGUST	
	STEP A	STEP D	STEP A	STEP D	STEP A	STEP D
MEAN T (°C)	27.84	25.45	31.30	27.53	30.71	26.85
MAX T (°C)	31.49	29.00	32.49	29.82	32.66	30.21
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP D**	**STEP A**	**STEP D**	**STEP A**	**STEP D**
MEAN T (°C)	23.87	22.91	27.20	25.23	22.73	21.72
MAX T (°C)	27.11	25.77	29.26	26.50	25.51	24.64
MIN T (°C)	20.17	19.94	24.62	23.67	18.94	17.87

Table 4.28: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP D/FLOOR 1-FLAT 8).

$R_{T,26-28}$ (%)				
	STEP C1/STEP D		STEP C2/STEP D	
	$R_{T,26}$	$R_{T,28}$	$R_{T,26}$	$R_{T,28}$
MAY	7%	0%		
JUNE	-9%	-16%	3%	2%
JULY			1%	7%
AUG			0%	4%
SEP	-17%	0%		
OCT	0%	0%		

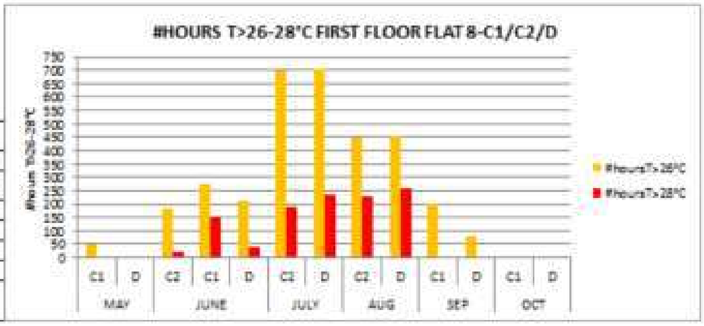


Figure 4.79: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP D and STEP C-2/C-1 depending on the month (FLOOR 1-FLAT 8).

RELATIVE HUMIDITY (RH):

- MAY: Decrease of RH compared to STEP C-1 (6% of #hoursRH>60%);
- JUNE: Increase of almost 10% of #hoursRH>60% compared to STEP C-1; decrease of 10% of #hoursRH>60% compared to STEP C-2;
- JULY: No relevant effects;
- AUGUST: No relevant effects;
- SEPTEMBER: Increase of 8% #hoursRH>70% compared to STEP C-1;
- OCTOBER: Small reduction of #hoursRH>70% (4%) compared to STEP C-1.

$R_{RH,60-70}$ (%)				
	STEP C1/STEP D		STEP C2/STEP D	
	$R_{RH,60}$	$R_{RH,70}$	$R_{RH,60}$	$R_{RH,70}$
MAY	6%	1%		
JUNE	10%	1%	-7%	-5%
JULY			-1%	0%
AUG			-1%	0%
SEP	7%	8%		
OCT	-2%	-4%		

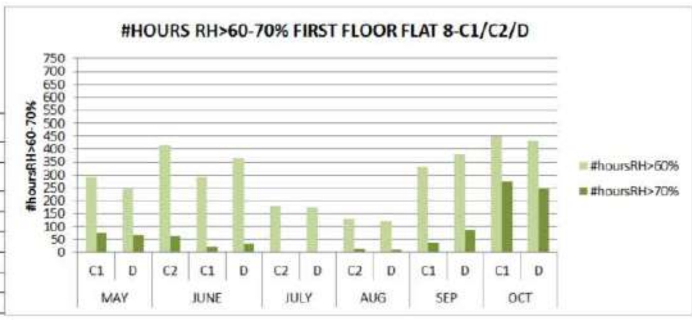


Figure 4.80: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP D and STEP C-2/C-1 depending on the month (FLOOR 1-FLAT 8).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September, when almost all the month presents PPD<15%. In July and in August, despite the strategy reduces the Relative Humidity, at the same time increases indoor temperatures, and the comfort level does not improve compared to STEP C-2. In June the hours with PPD<6% increase of 20% compared to STEP C-1 and almost 15% in comparison with STEP C-2. In May STEP D worsens the comfort conditions, because indoor temperatures decrease (mean value STEP C1=23.47°C; mean value STEP D=22.91°C). Conversely, in October there is an improvement, because the strategy helps to increase indoor temperatures.

$R_{PPD,6\text{-}10\text{-}15}$ (%)						
	STEP C1/STEP D			STEP C2/STEP D		
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	13%	-4%	-1%			
JUNE	-20%	-9%	-9%	-14%	-1%	3%
JULY				0%	0%	-3%
AUG				0%	0%	-1%
SEP	-5%	-20%	-10%			
OCT	-19%	0%	0%			

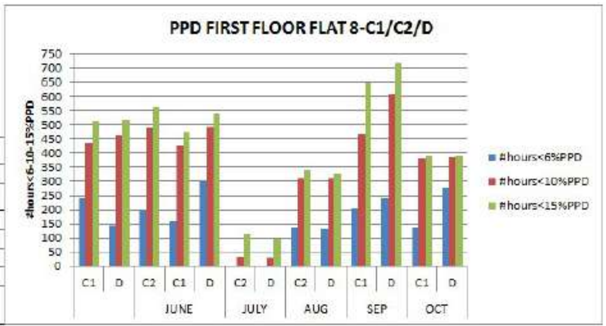


Figure 4.81: BUILDING A-Comparison between the PPD index values in STEP D and STEP C-2/C-1 depending on the month (FLOOR 1-FLAT 8).

FLOOR 2: FLAT 6

TEMPERATURES:

- MAY: The mean temperatures value decreases;
- JUNE: As in the previous flat, this strategy lowers the indoor temperatures compared to STEP C-1, but it increases them in comparison with STEP C-2;
- JULY: Small increase of hours above 28°C (5% compared to STEP C-2);
- AUGUST: Small increase of hours above 28°C (6% compared to STEP C-2);
- SEPTEMBER: No longer hours above 26°C (compared to STEP C-1);
- OCTOBER: Increase of the mean temperatures value.

	JUNE		JULY		AUGUST	
	STEP A	**STEP D**	**STEP A**	**STEP D**	**STEP A**	**STEP D**
MEAN T (°C)	27.06	24.46	30.62	26.55	30.28	26.05
MAX T (°C)	30.52	27.96	31.82	29.05	32.33	29.74
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP D**	**STEP A**	**STEP D**	**STEP A**	**STEP D**
MEAN T (°C)	23.16	22.11	26.89	24.73	22.64	21.60
MAX T (°C)	26.09	24.70	28.82	25.97	25.56	24.62
MIN T (°C)	19.94	19.71	24.48	23.42	18.74	17.59

Table 4.29: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP D/FLOOR 2-FLAT 6).

$R_{T,26-28}$ (%)				
	STEP C1/STEP D		STEP C2/STEP D	
	$R_{T,26}$	$R_{T,28}$	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%		
JUNE	-13%	-6%	4%	0%
JULY			6%	5%
AUG			2%	6%
SEP	-9%	0%		
OCT	0%	0%		

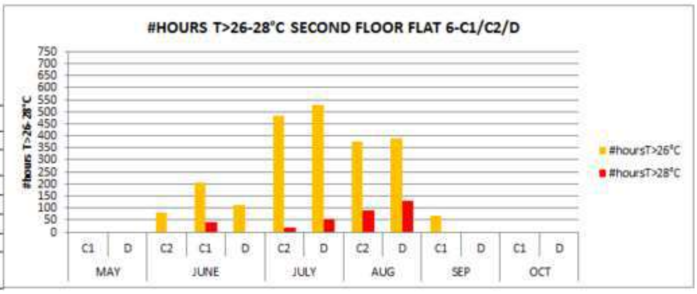


Figure 4.82: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP D and STEP C-2/C-1 depending on the month (FLOOR 2-FLAT 6).

RELATIVE HUMIDITY (RH):

- MAY: The strategy reduces the RH compared to STEP C-1, but just the 5% of #hoursRH>60%;
- JUNE: Increase of about 12% of #hoursRH>60% compared to STEP C-1; decrease of 11% of #hoursRH>70% compared to STEP C-2;
- JULY: No relevant effects;
- AUGUST: No relevant effects;
- SEPTEMBER: Increase of 9% #hoursRH>70% compared to STEP C-1;
- OCTOBER: Small reduction of #hoursRH>70% (5%) compared to STEP C-1.

$R_{RH,60-70}$ (%)				
	STEP C1/STEP D		STEP C2/STEP D	
	$R_{RH,60}$	$R_{RH,70}$	$R_{RH,60}$	$R_{RH,70}$
MAY	5%	1%		
JUNE	12%	2%	-8%	-11%
JULY			-4%	-1%
AUG			-2%	0%
SEP	6%	9%		
OCT	-2%	-5%		

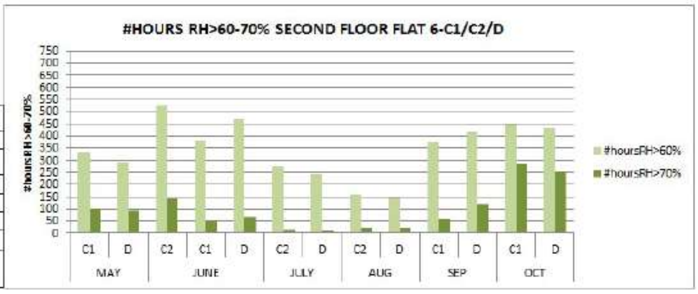


Figure 4.83: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in in STEP D and STEP C-2/C-1 depending on the month (FLOOR 2-FLAT 6).

COMFORT INDEX (PPD VALUES):

The most relevant increase of internal comfort is shown in September, when almost all the month presents PPD<10% and a relevant increase of hours with PPD<6% (42%). In July and in August, despite the strategy reduces the Relative Humidity, at the same time increases indoor temperatures, and the comfort level does not improve compared to STEP C-2. In June the hours with PPD<6% decrease of 12% compared to STEP C-1, but there is an increase of PPD<15% of almost 20%, that lead almost all the month to be within the comfort range (670 hours with PPD<15%). In May STEP D worsens the comfort conditions, because indoor temperatures decrease (mean value STEP C1=22.74°C; mean value STEP D=22.11°C). Conversely, in October there is an improvement, because the strategy helps to increase indoor temperatures (mean value STEP C1=20.99°C; mean value STEP D=21.60°C).

$R_{PPD,6-10-15}$ (%)	STEP C1/STEP D			STEP C2/STEP D		
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	9%	31%	9%			
JUNE	12%	-12%	-16%	-28%	-22%	-4%
JULY				2%	5%	7%
AUG				-2%	1%	3%
SEP	-42%	-20%	-1%			
OCT	-20%	-1%	0%			

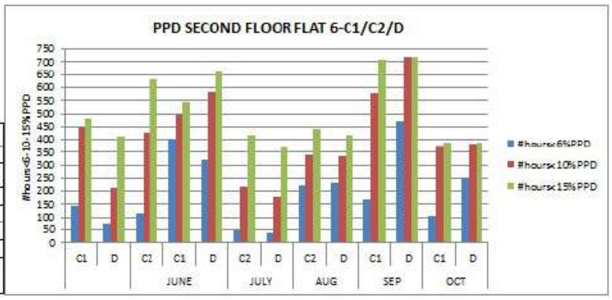


Figure 4.84: BUILDING A-Comparison between the PPD index values in STEP D and STEP C-2/C-1 depending on the month (FLOOR 2-FLAT 6).

<u>FLOOR 3: FLAT 2</u>

<u>TEMPERATURES:</u>

- MAY: The flat presents the same mean temperatures value as in STEP C-1;
- JUNE: As in the previous flat, this strategy lowers the indoor temperatures compared to STEP C-1, but it increases them in comparison with STEP C-2, even if just 5%;
- JULY: Small increase of hours above 28°C (6% compared to STEP C-2);
- AUGUST: Small increase of hours above 28°C (4% compared to STEP C-2);
- SEPTEMBER: Decrease of hours above 26°C (compared to STEP C-1);
- OCTOBER: Increase of the mean temperatures value.

	JUNE		**JULY**		**AUGUST**	
	STEP A	**STEP D**	**STEP A**	**STEP D**	**STEP A**	**STEP D**
MEAN T (°C)	27.93	25.26	31.54	27.34	31.07	26.78
MAX T (°C)	31.67	28.82	32.86	29.84	33.25	30.49
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP D**	**STEP A**	**STEP D**	**STEP A**	**STEP D**
MEAN T (°C)	26.07	22.85	27.53	25.42	23.10	22.12
MAX T (°C)	27.20	25.60	29.63	26.70	25.86	25.02
MIN T (°C)	20.25	20.04	24.94	23.99	19.11	18.05

Table 4.30: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP D/FLOOR 3-FLAT 2).

$R_{T,26-28}$ (%)	STEP C1/STEP D		STEP C2/STEP D	
	$R_{T,26}$	$R_{T,28}$	$R_{T,26}$	$R_{T,28}$
MAY	7%	0%		
JUNE	-11%	-15%	5%	2%
JULY			3%	6%
AUG			1%	4%
SEP	-15%	0%		
OCT	0%	0%		

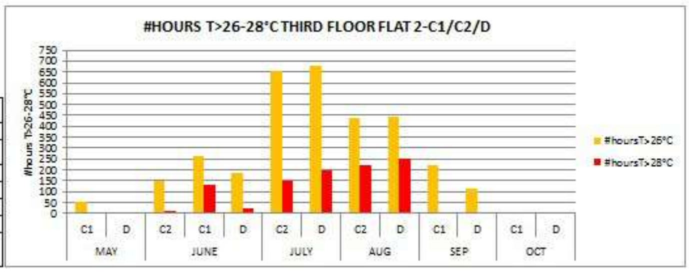


Figure 4.85: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP D and STEP C-2/C-1 depending on the month (FLOOR 3-FLAT 2).

RELATIVE HUMIDITY (RH):

- MAY: The strategy reduces the RH compared to STEP C-1, 14% of #hoursRH>60%;
- JUNE: No relevant effects in comparison with STEP C-1; decrease of 10% of #hoursRH>70% compared to STEP C-2;
- JULY: No relevant effects;
- AUGUST: No relevant effects;
- SEPTEMBER: Increase of 16% #hoursRH>70% compared to STEP C-1;
- OCTOBER: No relevant effects (4% of #hoursRH>70%) compared to STEP C-1.

$R_{RH,60-70}$ (%)				
	STEP C1/STEP D		STEP C2/STEP D	
	$R_{RH,60}$	$R_{RH,70}$	$R_{RH,60}$	$R_{RH,70}$
MAY	14%	3%		
JUNE	5%	-1%	-4%	-10%
JULY			-9%	-6%
AUG			-5%	-1%
SEP	9%	16%		
OCT	-1%	-4%		

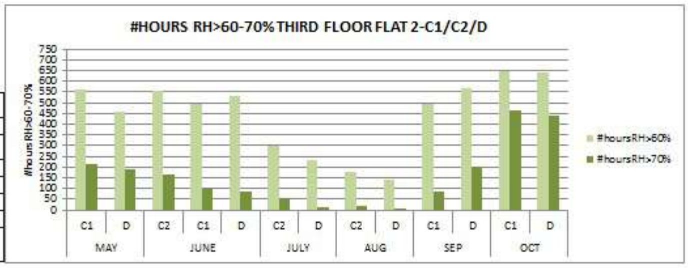


Figure 4.86: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in in STEP D and STEP C-2/C-1 depending on the month (FLOOR 3-FLAT 2).

COMFORT INDEX (PPD VALUES):

In September almost all the month presents PPD<15%, even if there is a decrease of PPD<6% (12%), so that the results of this strategy for this month are equal to those of STEP C-1. In July and in August, despite the strategy reduces the Relative Humidity, at the same time increases indoor temperatures, and the comfort level does not improve compared to STEP C-2.

In June the strategy improves the internal comfort, with the increase of number of hours with PPD<6% in both the two STEP C. In May STEP D worsens the comfort conditions, because indoor temperatures decrease (mean value STEP C1=25.21°C; mean value STEP D=22.85°C). Conversely, in October there is an improvement, because the strategy helps to increase indoor temperatures (mean value STEP C1=21.53°C; mean value STEP D=22.12°C).

$R_{PPD,6-10-15}$ (%)						
	STEP C1/STEP D			STEP C2/STEP D		
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	19%	0%	0%			
JUNE	-20%	-10%	-12%	-15%	-4%	2%
JULY				0%	2%	3%
AUG				0%	1%	1%
SEP	12%	-14%	-13%			
OCT	-4%	0%	0%			

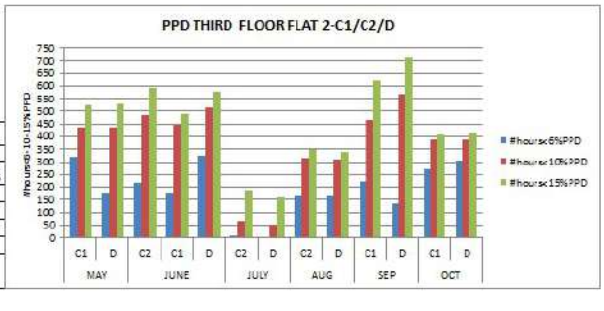


Figure 4.87: BUILDING A-Comparison between the PPD index values in STEP D and STEP C-2/C-1 depending on the month (FLOOR 3-FLAT 2).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: Decrease of the mean temperatures value;
- JUNE: As in the previous flat, this strategy lowers the indoor temperatures compared to STEP C-1, but it increases them in comparison with STEP C-2, even if just 2-3%;
- JULY: Small increase of hours above 28°C (7% compared to STEP C-2);
- AUGUST: Small increase of hours above 28°C (3% compared to STEP C-2);
- SEPTEMBER: Decrease of hours above 26°C (compared to STEP C-1);
- OCTOBER: Increase of the mean temperatures value.

	JUNE		JULY		AUGUST	
	STEP A	**STEP D**	**STEP A**	**STEP D**	**STEP A**	**STEP D**
MEAN T (°C)	28.24	25.43	31.95	27.63	30.28	26.89
MAX T (°C)	32.18	29.27	33.14	30.13	32.33	30.55
	MAY		**SEPTEMBER**		**OCTOBER**	
	STEP A	**STEP D**	**STEP A**	**STEP D**	**STEP A**	**STEP D**
MEAN T (°C)	24.18	22.86	27.48	25.19	22.55	21.45
MAX T (°C)	27.42	25.77	29.65	26.66	25.75	24.64
MIN T (°C)	20.13	19.80	24.54	23.46	18.31	17.31

Table 4.31: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP D/FLOOR 4-FLAT 6).

$R_{T,26-28}$ (%)				
	STEP C1/STEP D		STEP C2/STEP D	
	$R_{T,26}$	$R_{T,28}$	$R_{T,26}$	$R_{T,28}$
MAY	-8%	0%		
JUNE	-8%	-16%	3%	2%
JULY			1%	7%
AUG			0%	3%
SEP	-13%	0%		
OCT	0%	0%		

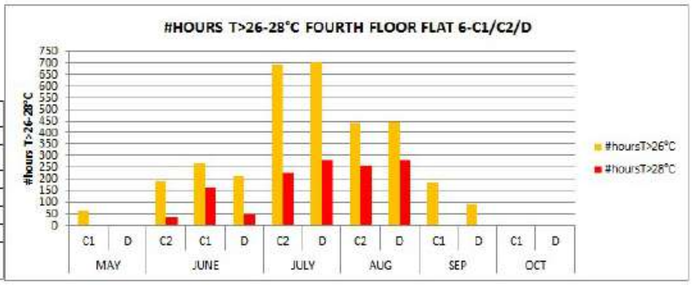


Figure 4.88: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP D and STEP C-2/C-1 depending on the month (FLOOR 4-FLAT 6).

RELATIVE HUMIDITY (RH):

- MAY: No relevant reduction of Relative Humidity;
- JUNE: Reduction of 8% of #hoursRH>60% in comparison with STEP C-1; decrease of 3% of #hoursRH>70% compared to STEP C-2;
- JULY: No relevant effects;
- AUGUST: No relevant effects;
- SEPTEMBER: Increase of 7% #hoursRH>70% compared to STEP C-1;
- OCTOBER: No relevant effects (43% of #hoursRH>70%) compared to STEP C-1.

$R_{RH,60-70}$ (%)				
	STEP C1/STEP D		STEP C2/STEP D	
	$R_{RH,60}$	$R_{RH,70}$	$R_{RH,60}$	$R_{RH,70}$
MAY	-3%	-1%		
JUNE	8%	1%	-8%	-3%
JULY			-2%	0%
AUG			-1%	0%
SEP	7%	7%		
OCT	-2%	-3%		

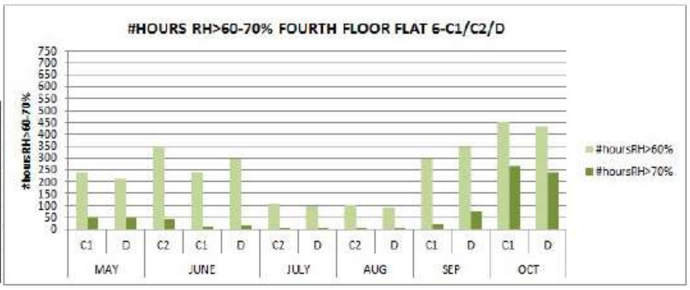


Figure 4.89: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP D and STEP C-2/C-1 depending on the month (FLOOR 4-FLAT 6).

COMFORT INDEX (PPD VALUES):

The most relevant effect of the humidity control strategy is shown in September when almost all the month presents PPD<15%. In July and in August, despite the strategy reduces the Relative Humidity, at the same time increases indoor temperatures, and the comfort level does not improve in comparison with STEP C-2.

In June the strategy improves the internal comfort, with the increase of number of hours with PPD<6% in both the two STEP C. In May STEP D worsens the comfort conditions, because indoor temperatures decrease (mean value STEP C1=23.47°C; mean value STEP D=22.86°C). Conversely, in October there is an improvement, because the strategy helps to increase indoor temperatures (mean value STEP C1=20.92°C; mean value STEP D=21.45°C).

$R_{PPD,6-10-15}$ (%)						
	STEP C1/STEP D			STEP C2/STEP D		
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	21%	-3%	0%			
JUNE	-17%	-7%	-8%	-16%	-3%	2%
JULY				0%	1%	3%
AUG				1%	0%	1%
SEP	-13%	-19%	-9%			
OCT	-18%	-1%	0%			

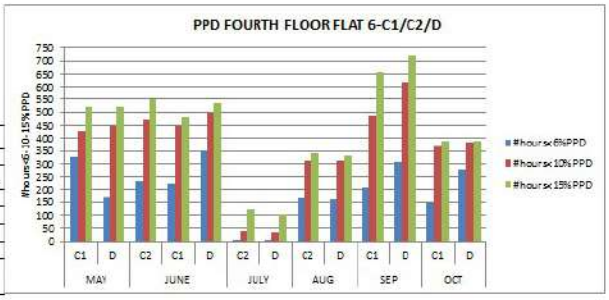


Figure 4.90: BUILDING A-Comparison between the PPD index values in STEP D and STEP C-2/C-1 depending on the month (FLOOR 4-FLAT 6).

SYNTHESIS

According to the previous discussion, the results have shown that:

- MAY: It is convenient to keep ACH=0.5/h all over the month without any controls on the humidity levels, because improving air change rates leads to a decrease of indoor temperatures;
- JUNE: We can affirm that the smart ventilation control of the humidity improves comfort conditions.
- JULY: The humidity control does not improve the indoor conditions. The best solution is to keep STEP C-2 conditions;
- AUGUST: The humidity control does not improve the indoor conditions. The best solution is to keep STEP C-2 conditions;
- SEPTEMBER: The humidity control improves indoor comfort conditions in all the flats;

- OCTOBER: The strategy increases the indoor temperatures and decreases RH, improving the comfort levels.

Obviously, the flats present similar indoor conditions, but not completely, because of the floor in which they are located or the position in the floor as well (in the middle, at the edge).

This work aims at finding a common strategy able to solve all the issues, starting from the assumption that these flats present similar characteristics. From this assumption, we can spread the strategy to the whole building in order to define a recovery method for the building type.

Accordingly, the objective is to achieve or even improve the indoor conditions that the building had before the envelope recovery[17], that is in BASE CASE, without introducing any air-conditioning system.

4.1.2.6 SMART VENTILATION CONTROL (STEP E)

All the analyses led us to define the final Smart Ventilation Strategy to apply in our sample case. The table below shows the ACH to be set on the ventilation system in the building model. The result is the combination between all the steps analysed in the previous paragraphs. In Winter ACH=0.5/h, as in the other cases without exploiting the use of mechanical ventilation systems.

MONTH	**ACH (h^{-1})**	**CONDITIONS for SWITCHING ON/OFF**
MAY (0.5/h)	**0.5**	Always ON
JUNE (STEP D)	**T_IND>26°C** **2:** when T_OUT<T_IND **1:** when T_OUT>T_IND **T_IND<26°C** **1:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND	Always ON
JULY (STEP C-2)	**2:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND	Always ON
AUGUST (STEP C-2)	**2:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND	Always ON
SEPTEMBER (STEP D)	**T_IND>26°C** **1:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND **T_IND<26°C** **0.5:** always	Always ON
OCTOBER (STEP D)	**1:** when HR_IND>12kg/kg and T_OUT>20°C **0.5:** when HR_IND<12kg/kg and T_OUT<20°C	Always ON

Table 4.32: monthly schedule of the ACH and switching control on the MVS.

In this case a comparison between BASE CASE (BC), STEP A and STEP E will be performed, with the aim to verify if the strategy improves or equals the starting comfort conditions.

[17] Indeed the Envelope Recovery (STEP A) has worsened the indoor comfort conditions compared to those in BASE CASE.

WHOLE BUILDING:

The fig. 4.91 shows the average hourly trend of indoor temperatures in the final STEP E compared to BASE CASE and STEP A. In the central months STEP E (red line) lowers temperatures compared to both STEP A (green line) and BASE CASE (violet line).

In May temperatures are higher than in BASE CASE, but lower compared to STEP A.

In the first half of September temperatures decrease according to the higher outdoor temperatures, while in the second part there is an increase in comparison with BASE CASE, still according to the outdoor temperatures starting to get closer to the Winter season. In July and August the mean temperature values decrease of almost 2°C compared to BASE CASE. In May the mean value of temperatures increase of almost 1°C, while in June it decreases of almost 1°C. Indoor temperatures on average are similar to those in BASE CASE in September.

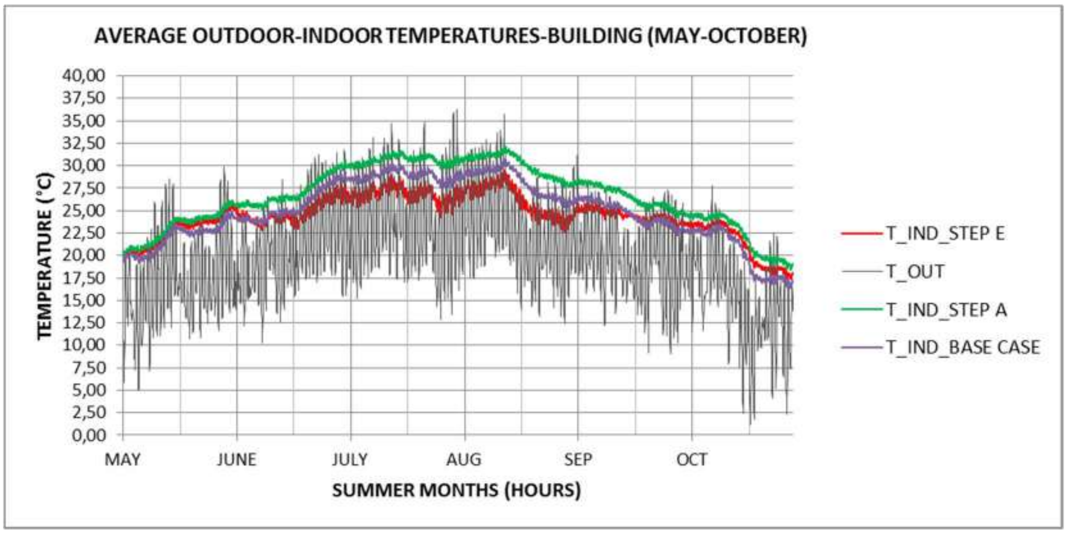


Figure 4.91: BUILDING A-Hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between BASE CASE, STEP A, STEP E and outdoor temperatures.

As it is also shown in the table below, the final Smart Ventilation Control Strategy (STEP E) leads to lower temperatures in the central months (in comparison with STEP A and BASE CASE), while in May and in October it causes an increase.

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.61	27.08	24.91	28.92	30.62	26.91	28.29	30.15	26.32
MAX T (°C)	31.47	32.54	30.11	32.36	33.57	30.69	32.63	33.77	31.15
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	21.98	23.16	22.76	24.84	26.68	24.58	20.31	22.29	21.25
MAX T (°C)	26.92	27.91	27.80	28.87	30.28	27.34	24.59	31.63	25.02
MIN T (°C)	18.26	23.63	18.81	21.26	24.35	20.54	15.24	16.70	16.61

Table 4.33: Temperature values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E.

Taking into account the mean values of Relative Humidity in Summer months, we can note that they decrease compared to BASE CASE. Conversely, they increase in comparison with STEP A, but this is the consequence of the increase of indoor temperatures due to the envelope recovery.

BUILDING MEAN RH VALUES (%)			
	BASE CASE	**STEP A**	**STEP E**
MAY	59.26	55.15	54.57
JUNE	62.56	57.31	59.91
JULY	55.89	49.45	55.80
AUGUST	51.77	45.47	51.71
SEPTEMBER	62.04	55.75	59.54
OCTOBER	65.65	58.81	59.69

Table 4.34: Mean values of Relative Humidity during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E.

FLATS:

The next analyses will be carried out by comparing the results obtained in BASE CASE and those in STEP E, in order to verify if the final strategy can fit for the flats taken as sample cases. Indeed, these flats present the worst indoor conditions in the building, so that if the strategy is able to solve their issues, making them go back to the initial comfort conditions (BASE CASE) or even improving them, it can be spread to all the other flats (that are similar to the flats studied in detail).

FLOOR 1: FLAT 8

TEMPERATURES:

- MAY: Increase of the mean temperature value (≈1°C);
- JUNE: Decrease of #hours>28°C (17%); the mean temperature value is close to the BASE CASE one;
- JULY: Decrease of #hours>28°C (72%); the mean temperature value decreases of 1.8°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (20%); the mean temperature value decreases of almost 1.8°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (20%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1.20°C).

The fig.4.92 shows the hourly trend of temperatures during Summer months. There is a decrease of indoor temperatures in the central month and in the first part of September. Conversely in May, in the second half of September and in October temperatures increase. These results reflect the behaviour of the whole building obtained by averaging all the flats temperature values (see fig.4.90)

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	26.05	27.84	25.64	29.23	31.30	27.43	28.50	30.71	26.74
MAX T (°C)	30.00	31.49	29.00	30.78	32.49	29.60	31.04	32.66	29.97
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	22.42	23.87	23.47	25.05	27.20	25.21	20.50	22.73	21.72
MAX T (°C)	25.65	27.11	26.79	27.25	29.26	26.45	23.73	25.51	24.64
MIN T (°C)	19.40	20.17	19.94	22.31	24.62	23.67	16.57	18.94	17.87

Table 4.35: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP E/FLOOR 1-FLAT 8).

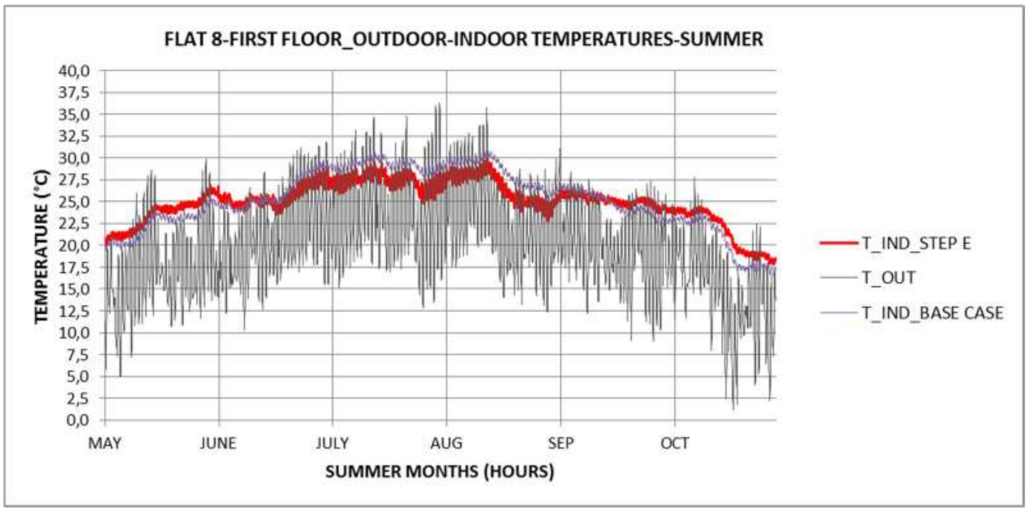


Figure 4.92: BUILDING A-Hourly trend of temperatures in Summer (FLOOR 1-FLAT 8). Comparison between BASE CASE, STEP E and outdoor temperatures.

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-7%	0%
JUNE	8%	17%
JULY	6%	72%
AUG	35%	29%
SEP	22%	0%
OCT	0%	0%

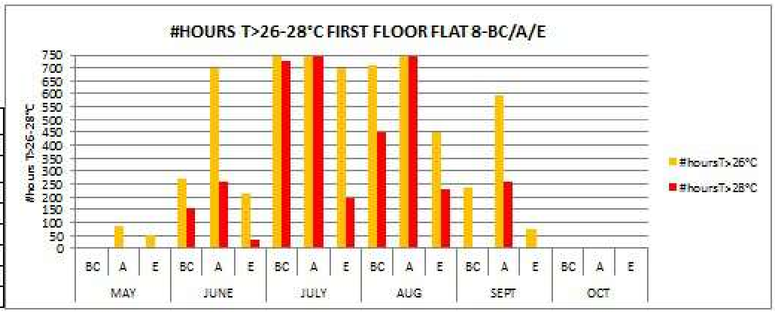


Figure 4.93: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP E and BASE CASE (FLOOR 1-FLAT 8).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 13% #hoursRH>70%;
- JUNE: Decrease of 24% #hoursRH>70%;
- JULY: Decrease of 5% #hoursRH>70%;
- AUGUST: Decrease of 5% #hoursRH>70%;
- SEPTEMBER: Decrease of 15% #hoursRH>70%;
- OCTOBER: Decrease of 14% #hoursRH>70%.

In May, June, September and October, the Relative Humidity falls below 60% of RH.

FLOOR 1-FLAT 8-MEAN RH VALUES (%)		
	BASE CASE	**STEP E**
MAY	58.71	53.47
JUNE	61.65	57.43
JULY	55.38	54.10
AUGUST	51.75	49.97
SEPTEMBER	62.14	58.32
OCTOBER	66.40	59.60

Table 4.36: BUILDING A-Mean values of Relative Humidity during the worst months in Summer and during the shoulder season (FLOOR 1-FLAT 8). Comparison between BASE CASE and STEP E.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	14%	13%
JUNE	16%	24%
JULY	17%	5%
AUG	12%	5%
SEP	8%	15%
OCT	10%	14%

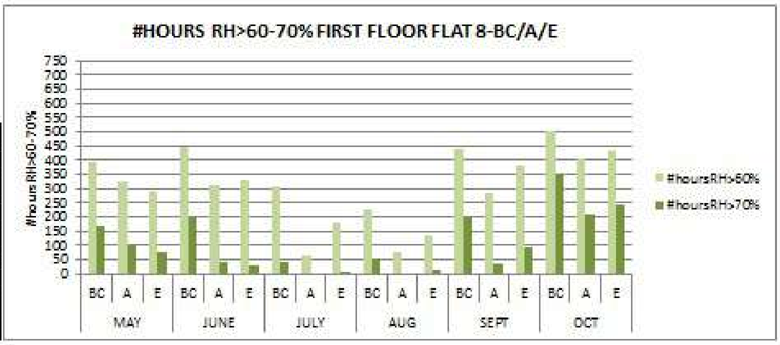


Figure 4.94: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP E and BASE CASE (FLOOR 1-FLAT 8).

<u>COMFORT INDEX (PPD VALUES):</u>

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September, when almost all the month presents PPD<15%. The strategy helps to decrease indoor temperatures In July and in August, and Relative Humidity, improving indoor comfort levels compared to BASE CASE.

In June comfort levels get close to the BASE CASE starting conditions, highlighting an even small improvement. In May the hours with PPD<6% increase of almost 20% compared to BASE CASE as well as October shows a relevant improvement (30% of #hours with PPD<6%).

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-18%	-4%	-5%
JUNE	0%	-6%	-9%
JULY	0%	-5%	-15%
AUG	-19%	-35%	-28%
SEP	-1%	-23%	-12%
OCT	-32%	-13%	-6%

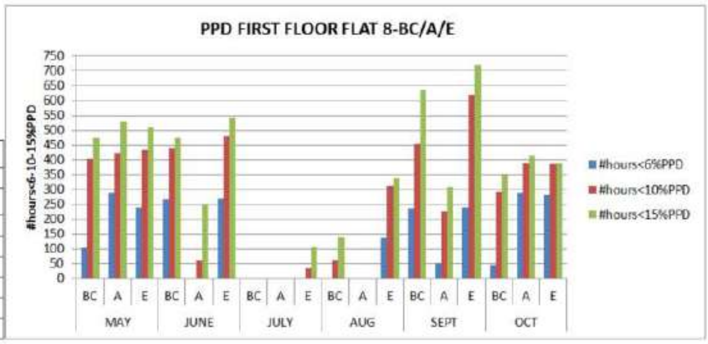


Figure 4.95: BUILDING A-Comparison between the PPD index values in BASE CASE, STEP A and STEP E (FLOOR 1-FLAT 8).

FLOOR 2: FLAT 6

TEMPERATURES:

- MAY: Increase of the mean temperature value (≈1°C);
- JUNE: Decrease of #hours>28°C (13%); Decrease of the mean temperature value (≈1°C);
- JULY: Decrease of #hours>28°C (74%); the mean temperature value decreases of 1.7°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (30%); the mean temperature value decreases of almost 1.7°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (30%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1°C).

The fig. 4.95 shows the hourly trend of temperatures during Summer months. There is a decrease of indoor temperatures in the central month and in the first part of September. Conversely in May, in the second half of September and in October temperatures increase. These results reflect the behaviour of the whole building obtained by averaging all the flats temperature values (see fig.4.88)

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.64	27.06	24.91	28.98	30.62	27.27	28.47	30.28	26.78
MAX T (°C)	29.31	30.52	28.44	30.43	31.82	29.36	30.99	32.33	30.00
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	22.01	23.16	22.74	25.10	26.89	24.57	20.79	22.64	21.47
MAX T (°C)	24.83	26.09	25.76	27.12	28.82	26.27	23.80	25.56	24.17
MIN T (°C)	19.07	19.94	19.71	22.60	24.48	22.56	16.80	18.74	17.58

Table 4.37: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP E/FLOOR 2-FLAT 6).

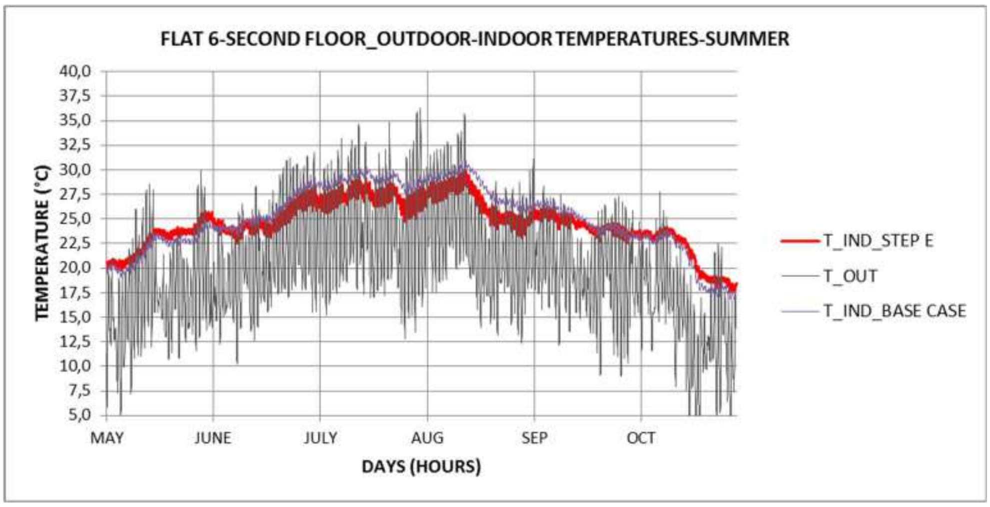


Figure 4.96: BUILDING A-Hourly trend of temperatures in Summer (FLOOR 2-FLAT 6). Comparison between BASE CASE, STEP E and outdoor temperatures.

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%
JUNE	13%	13%
JULY	8%	74%
AUG	35%	32%
SEP	31%	0%
OCT	0%	0%

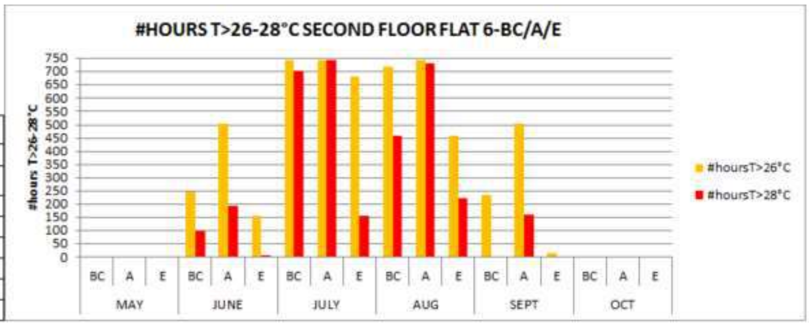


Figure 4.97: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP E and BASE CASE (FLOOR 2-FLAT 6).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 13% #hoursRH>70%;
- JUNE: Decrease of 29% #hoursRH>70%;
- JULY: Decrease of 37% #hoursRH>70%;
- AUGUST: Decrease of 20% #hoursRH>70%;
- SEPTEMBER: Decrease of 11% #hoursRH>70%;
- OCTOBER: Decrease of 12% #hoursRH>70%.

This flat presents high levels of Relative Humidity almost all the Summer months (BASE CASE). The strategy makes the Relative Humidity get closer to the threshold of 60% of RH, while in BASE CASE was always overcome (except in August).

FLOOR 2-FLAT 6-MEAN RH VALUES (%)		
	BASE CASE	**STEP E**
MAY	60.15	55.82
JUNE	64.51	60.89
JULY	63.28	57.61
AUGUST	57.42	52.70
SEPTEMBER	62.43	60.11
OCTOBER	65.30	60.02

Table 4.38: BUILDING A-Mean values of Relative Humidity during the worst months in Summer and during the shoulder season (FLOOR 1-FLAT 8). Comparison between BASE CASE and STEP E.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	11%	13%
JUNE	15%	29%
JULY	37%	37%
AUG	29%	20%
SEP	4%	11%
OCT	9%	12%

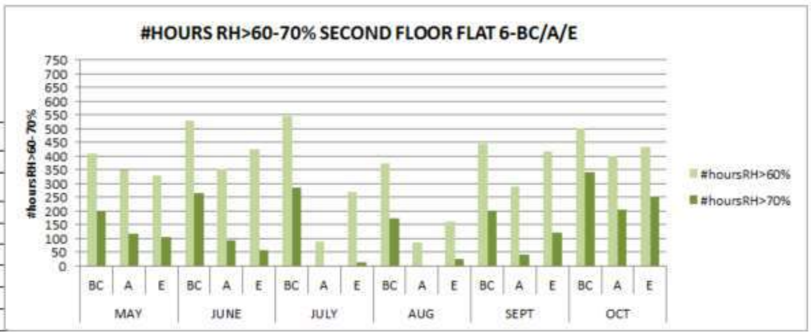


Figure 4.98: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in BASE CASE, STEP A and STEP E (FLOOR 2-FLAT 6).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September and in June.

The strategy, by either decreasing or increasing temperatures depending on the month improves indoor comfort level in all Summer months.

$R_{PPD,6-10-15}$ (%)			
	STEP E/BASE CASE		
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-8%	-28%	-4%
JUNE	-16%	-17%	-21%
JULY	-7%	-28%	-57%
AUG	-31%	-38%	-38%
SEP	-34%	-31%	-6%
OCT	-26%	-11%	-1%

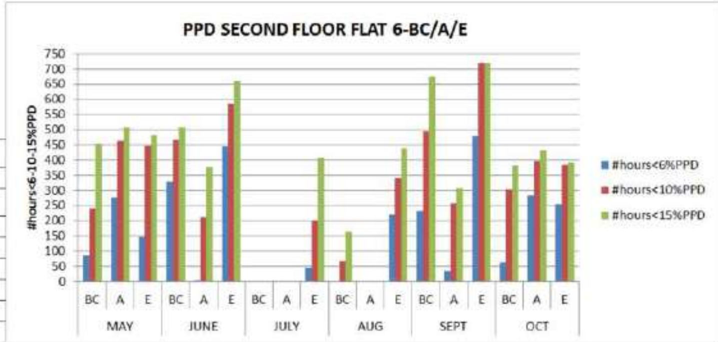


Figure 4.99: BUILDING A-Comparison between the PPD index values in BASE CASE, STEP A and STEP E (FLOOR 2-FLAT 6).

FLOOR 3: FLAT 2

TEMPERATURES:

- MAY: Increase of the mean temperature value (≈1 °C);
- JUNE: Decrease of #hours>28°C (20%); Increase of the mean temperature value (≈1°C);
- JULY: Decrease of #hours>28°C (80%); the mean temperature value decreases of 2.4°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (40%); the mean temperature value decreases of almost 2.4°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (30%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1°C).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	26.29	27.93	25.48	29.64	31.54	27.22	29.02	31.07	26.64
MAX T (°C)	30.26	31.67	28.82	31.28	32.86	29.58	31.73	33.25	30.21
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	22.56	26.07	23.49	25.54	27.53	25.41	21.07	23.10	22.11
MAX T (°C)	25.79	27.20	26.82	27.74	29.63	26.68	24.38	25.86	25.02
MIN T (°C)	19.50	20.25	20.04	22.82	24.94	23.99	16.97	19.11	18.05

Table 4.39: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP E/FLOOR 3-FLAT 2).

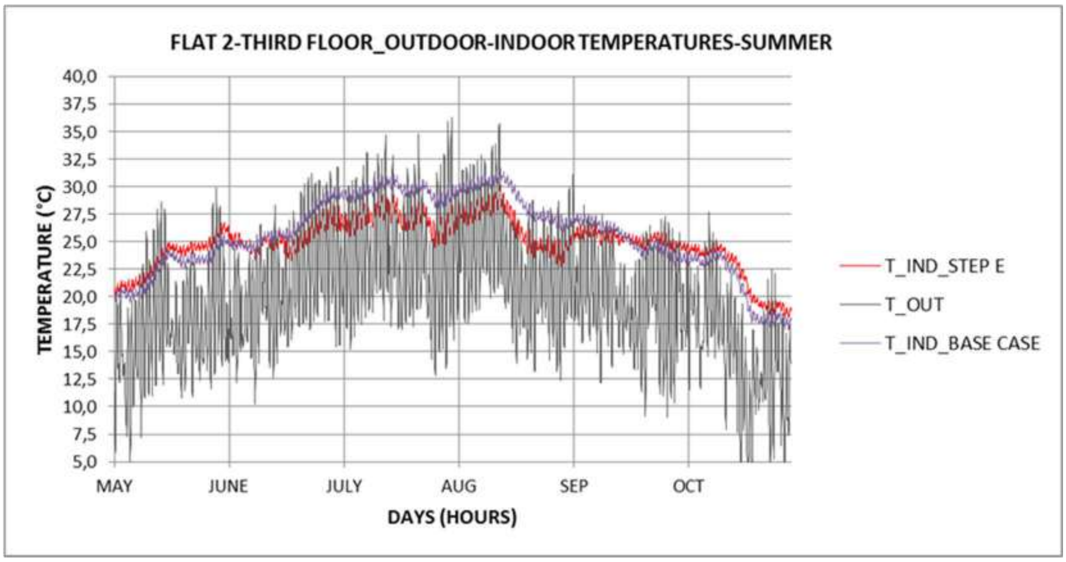


Figure 4.100: BUILDING A-Hourly trend of temperatures in Summer (FLOOR 3-FLAT 2). Comparison between BASE CASE, STEP E and outdoor temperatures.

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-26%	-3%
JUNE	14%	20%
JULY	10%	79%
AUG	41%	37%
SEP	28%	0%
OCT	0%	0%

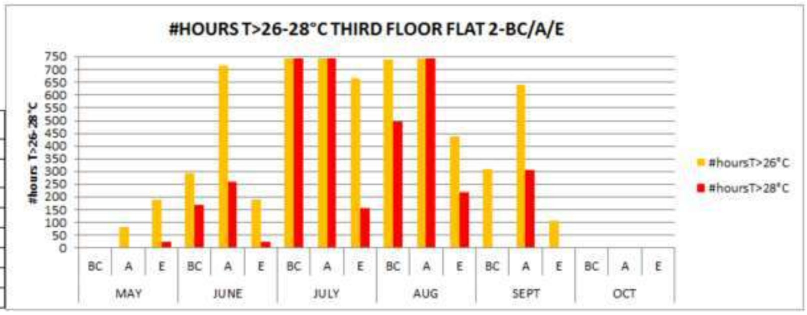


Figure 4.101: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP E and BASE CASE (FLOOR 3-FLAT 2).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 36% #hoursRH>70%;
- JUNE: Decrease of 60% #hoursRH>70%;
- JULY: Decrease of 5% #hoursRH>70%;
- AUGUST: Decrease of 9% #hoursRH>70%;
- SEPTEMBER: Decrease of 40% #hoursRH>70%;
- OCTOBER: Decrease of 30% #hoursRH>70%.

This flat presents high levels of Relative Humidity especially in May, June, September and October. The smart ventilation control helps to decrease these levels.

FLOOR 3-FLAT 2-MEAN RH VALUES (%)		
	BASE CASE	**STEP E**
MAY	66.29	59.81
JUNE	67.07	60.76
JULY	57.96	57.35
AUGUST	54.50	52.84
SEPTEMBER	66.93	62.04
OCTOBER	72.96	64.60

Table 4.40: BUILDING A-Mean values of Relative Humidity during the worst months in Summer and during the shoulder season (FLOOR 3-FLAT 2). Comparison between BASE CASE and STEP E.

$R_{RH,60-70}$ (%) STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	22%	36%
JUNE	31%	58%
JULY	27%	5%
AUG	19%	9%
SEP	21%	37%
OCT	9%	27%

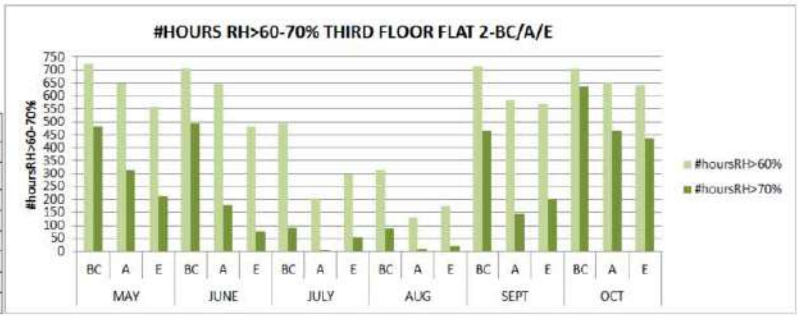


Figure 4.102: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in BASE CASE, STEP A and STEP E (FLOOR 3-FLAT 2).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September and in June.

The strategy, by either decreasing or increasing temperatures depending on the month, improves indoor comfort levels in all Summer months.

$R_{PPD,6-10-15}$ (%) STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-26%	1%	-6%
JUNE	-11%	-17%	-16%
JULY	-1%	-8%	-24%
AUG	-24%	-43%	-40%
SEP	9%	-28%	-30%
OCT	-20%	-5%	-3%

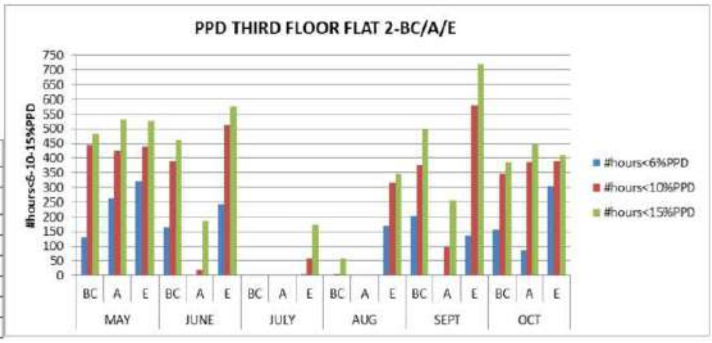


Figure 4.103: BUILDING A-Comparison between the PPD index values in BASE CASE, STEP A and STEP E (FLOOR 3-FLAT 2).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: Small increase of the mean temperature value (less than 1°C);
- JUNE: Decrease of #hours>28°C (23%); the mean temperature value decreases compared to BASE CASE (≈1.20°C);
- JULY: Decrease of #hours>28°C (≈70%); the mean temperature value decreases of 2.8°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (40%); the mean temperature value decreases of almost 2.8°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (40%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1 °C).

The fig. 4.106 shows the hourly trend of temperatures during Summer months. There is a decrease of indoor temperatures in the central month and in the first part of September. Conversely in May, in the second half of September and in October temperatures increase.

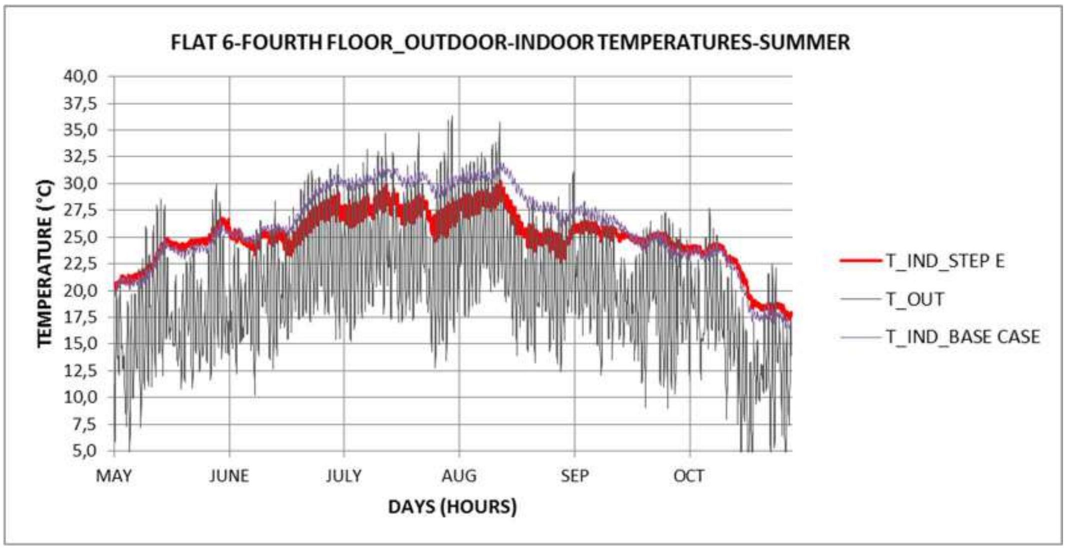


Figure 4.104: BUILDING A-Hourly trend of temperatures in Summer (FLOOR 4-FLAT 86). Comparison between BASE CASE, STEP E and outdoor temperatures.

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	26.85	28.24	25.62	30.33	31.95	27.51	29.52	30.28	26.76
MAX T (°C)	31.02	32.18	29.27	31.85	33.14	29.85	32.10	32.33	30.28
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	23.07	24.18	23.47	25.80	27.48	25.18	20.84	22.55	21.45
MAX T (°C)	26.36	27.42	26.79	28.15	29.65	26.62	24.59	25.75	24.64
MIN T (°C)	19.45	20.13	19.80	22.69	24.54	23.46	16.45	18.31	17.31

Table 4.41: BUILDING A-Temperature values during the worst months in Summer and during the shoulder season (STEP E/FLOOR 4-FLAT 6).

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-6%	0%
JUNE	19%	23%
JULY	7%	68%
AUG	40%	39%
SEP	37%	1%
OCT	0%	0%

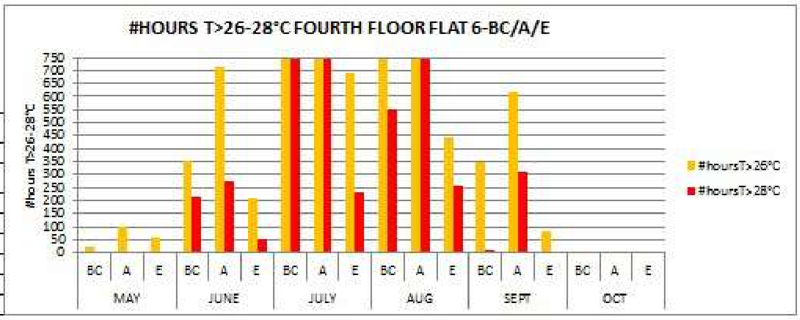


Figure 4.105: BUILDING A-Comparison between the number of hours exceeding 26-28°C in STEP E and BASE CASE (FLOOR 4-FLAT 6).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 13% #hoursRH>70%;
- JUNE: Decrease of 24% #hoursRH>70%;
- JULY: Decrease of 1% #hoursRH>70%;
- AUGUST: Decrease of 4% #hoursRH>70%;
- SEPTEMBER: Decrease of 6% #hoursRH>70%; there is a small increase of hours above 60%RH which derives from the reduction of hours above 70%, but the table below, however, shows a reduction of the mean RH value;
- OCTOBER: Decrease of 9% #hoursRH>70%.

FLOOR 4-FLAT 6-MEAN RH VALUES (%)		
	BASE CASE	**STEP E**
MAY	56.51	53.43
JUNE	59.53	57.50
JULY	55.43	53.84
AUGUST	51.55	49.92
SEPTEMBER	59.82	58.42
OCTOBER	65.02	60.48

Table 4.42: BUILDING A-Mean values of Relative Humidity during the worst months in Summer and during the shoulder season (FLOOR 1-FLAT 8). Comparison between BASE CASE and STEP E.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	12%	7%
JUNE	10%	12%
JULY	16%	1%
AUG	10%	4%
SEP	-2%	6%
OCT	5%	9%

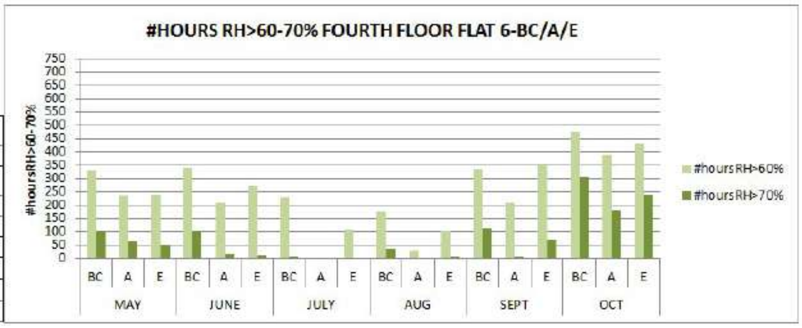


Figure 4.106: BUILDING A-Comparison between the number of hours exceeding 60-70% of RH in STEP E and BASE CASE (FLOOR 4-FLAT 6).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September, when almost all the month presents PPD<15%. The strategy helps to decrease indoor temperatures In July and in August, and Relative Humidity, improving indoor comfort levels compared to BASE CASE.

In June comfort levels get close to the BASE CASE starting conditions, highlighting an even small improvement. In May the hours with PPD<6% increase of 25% compared to BASE CASE as well as October shows a relevant improvement (24% of #hours with PPD<6%).

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-25%	3%	-5%
JUNE	-13%	-11%	-11%
JULY	0%	-6%	-16%
AUG	-23%	-40%	-38%
SEP	-8%	-32%	-23%
OCT	-24%	-10%	-2%

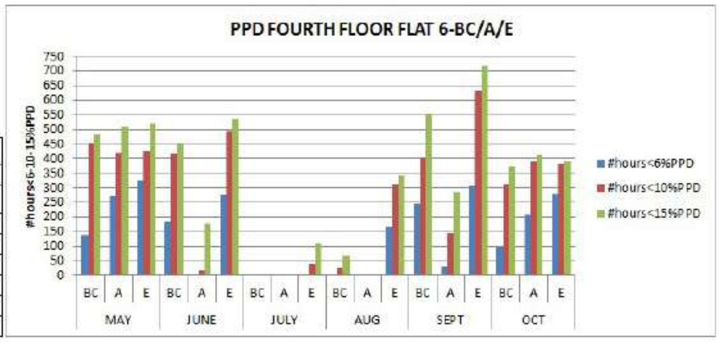


Figure 4.107: BUILDING A-Comparison between the PPD index values in BASE CASE, STEP A and STEP E (FLOOR 4-FLAT 6).

SYNTHESIS

According to the previous discussion, the smart ventilation control led to improvements of indoor comfort conditions during all Summer months. The results of the whole building analysis have been confirmed by the detailed study of each flat answer in terms of indoor comfort (temperatures, RH, PPD index). More in detail:

- MAY:
  Increase of the mean temperature value (1°C);
  Decrease of #hoursRH>70% (≈10%, the decrease is higher when RH values are above 60% for all the month-FLOOR 3-FLAT 2);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- JUNE:
  Decrease of the mean temperature value (1°C);
  Decrease of #hoursRH>70% (20%÷30%, the decrease is higher when RH values are above 60% for all the month-FLOOR 3-FLAT 2);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- JULY:
  Decrease of the mean temperature value (1.7°C÷2.8°C, the higher the reduction the higher is the initial mean temperature value-FLOOR 4-FLAT 6);
  Decrease of #hoursRH>70% (5%, the decrease is higher when RH values overcomes 60%RH for almost all the month-FLOOR 2-FLAT 6);

Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);

- AUGUST:
  Decrease of the mean temperature value (1.8°C÷2.8°C, the higher the reduction the higher is the initial mean temperature value-FLOOR 4-FLAT 6);
  Decrease of #hoursRH>70% (5%÷10%, the decrease is higher when RH values overcomes 60%RH for almost all the month-FLOOR 2-FLAT 6);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- SEPTEMBER:
  The temperatures on average are equal to BASE CASE values;
  Decrease of #hoursRH>70% (6%÷15%, the decrease is higher when RH values overcomes 60%RH for almost all the month-FLOOR 3-FLAT 2);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- OCTOBER:
  Increase of the mean temperature value (1°C);
  Decrease of #hoursRH>70% (9%÷14%, the decrease is higher when RH values overcomes 60%RH for almost all the month-FLOOR 3-FLAT 2).
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);

The strategy was able to go back to the starting point comfort conditions (BASE CASE) and to improve them. The next step will analyse the possibility to extend this strategy to all the other case studies, given that, from the previous analyses, they present similar characteristics to the building analysed in this chapter (BUILDING A-IOLO).

4.2 SYNTHESIS OF THE REFURBISHMENT METHOD

After the analyses from the technological and environmental point of view, along with the energy analysis of the BASE CASE of all the buildings chosen as sample cases, a series of strategies have been applied until to arrive to the solution considered the most suitable (STEP E, which as explained in the previous paragraph, is applied on the "recovered" envelope, as result of STEP A).

Having said that we can summarize the procedure to be applied on the other buildings:

BASE CASE:

- Energy analysis of the current state of the buildings: evaluation of the energy performance both in Winter and in Summer, paying particular attention the mean values of temperatures and Relative Humidity, by considering the building in its entirety;
- Choice of the sample flats to be monitored in the application of the strategies and evaluation of their thermal comfort levels;

STEP A: Application of an insulation layer on the façade and on the slab surrounding the heated volume, along with the substitution of the windows:

- Energy analysis of the "renovated" buildings: evaluation of the energy performance both in Winter and in Summer, paying particular attention to the mean values of temperatures and Relative Humidity, by considering the building in its entirety and comparison with BASE CASE;
- Evaluation of the thermal comfort levels in the sample flats and comparison with BASE CASE;

STEP E - Application of a mechanical ventilation system (supply system-single flux) with the smart control of ACH according to the different months in the Summer period:

- Energy analysis of the "renovated" buildings: evaluation of the energy performance in Summer[18], paying particular attention to the mean values of temperatures and Relative Humidity, by considering the building in its entirety;
- Evaluation of the thermal comfort levels in the sample flats and comparison with BASE CASE and STEP A.

The next chapter will analyse the results of the application of STEP A and STEP E on the other building complexes, in order to validate this method, according to the fact that these buildings present characteristics in common from the architectural, energy and climate point of view.

[18] The mechanical ventilation system does not work during the Winter Season; the Energy performance in Winter is therefore equal to that found in STEP A.

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5. APPLICATION OF THE REFURBISHMENT METHOD TO THE SAMPLE CASES

This chapter takes into account the results after the application of the recovery method to the other buildings. Accordingly, the steps are:

- STEP A: Envelope Recovery;
- STEP E: Application of the smart ventilation system according to the smart control studied in chapter 4 on the “recovered” envelope (STEP A).

The results will be analysed by presenting the new Energy Class of the buildings found through the semi-stationary conditions and the comparison between Indoor temperatures, RH levels and thermal comfort conditions found from the dynamic simulations between BASE CASE, STEP A and STEP E.

This chapter takes into account the results after the application of the recovery method to the other buildings. Accordingly, the steps are:

- STEP A: Envelope Recovery;
- STEP E: Application of the smart ventilation system according to the smart control studied in chapter 4 on the “recovered” envelope (STEP A).

The results will be analysed by presenting the new Energy Class of the buildings found through the semi-stationary conditions and the comparison between Indoor temperatures, RH levels and thermal comfort conditions found from the dynamic simulations between BASE CASE, STEP A and STEP E.

5.1 COMPLEX A: Prato-Iolo

BUILDING B

The first step (STEP A) was the application of an insulation layer on the facades, on the attic and arcade/cellar slabs and the substitution of the windows.

The U-values are the same used in BUILDING A.

	Before the recovery	After the recovery	Standards
External walls	U-value: 0.698 W/m^2K	U-value: 0.25 W/m^2K	U-value: 0.29 W/m^2K
Stairs walls	U-value: 0.798 W/m^2K	U-value: 0.26 W/m^2K	U-value: 0.29 W/m^2K
Windows	U_w-value: 2.83 W/m^2K	U_w value: 1.70 W/m^2K	U_w value: 1.80 W/m^2K
Arcade/Cellar slab	U-value: 0.83 W/m^2K	U-value: 0.28 W/m^2K	U-value: 0.29 W/m^2K
Attic slab	U-value: 0.92 W/m^2K	U-value: 0.28 W/m^2K	U-value: 0.29 W/m^2K

Table 5.1: U-values of the building elements before and after the intervention.

1. **Semi-stationary conditions**

We will apply the same verifications conducted in Chapter 3.

The Global Energy Performance index ($\boldsymbol{EP_{gl,nren}}$) is:

$EP_{gl,nren}$= 59.49kWh/m^{2}y

$EP_{gl,nren,rif}$(2019,2021)= 53.61kWh/m^{2}y

The NEW building Energy Class is **B**, in fact:

$1.00^* EP_{gl,nren,rif}(2019,2021) < \mathbf{EP_{gl,nren}} \leq 1.20^* EP_{gl,nren,rif}(2019,2021)$

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K
H'_T = 0.36 W/m^{2}K→ $H'_T < H'_{Tlim}$ **VERIFIED**
In BASE CASE this verification was not satisfied, because of the high values of Transmittance of the building elements.

b. Envelope Energy Performance in Winter through the calculation of ***$EP_{H,nd}$***

$EP_{H,nd}$ = 17.52kWh/m^{2}y
$EP_{H,nd,lim}$(2019,2021)= 14.3kWh/m^{2}y
The result is:
1*$EP_{H,nd,lim}$(2019,2021) < $EP_{H,nd}$ ≤ 1.7*$EP_{H,nd,lim}$(2019,2021)
MEDIUM QUALITY OF THE ENVELOPE
In BASE CASE the quality of the envelope was LOW. It means that the envelope recovery led to a decrease of heat losses through the envelope, improving its energy performance.

c. Envelope Energy Performance in Summer through the evaluation of (***$A_{sol,est}$***) and (***Y_{IE}***)

$A_{sol,est}/S$= 0.062
Y_{IE}=0.02W/m^{2}K
The thresholds are:
$(A_{sol,est}/S)_{lim}$= 0.03
$(Y_{IE})_{lim}$= 0.14W/m^{2}K
The result is:
$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ and $Y_{IE} < (Y_{IE})_{lim}$ → **MEDIUM QUALITY OF THE ENVELOPE**
In BASE CASE the quality of the envelope was LOW. The addition of the insulation layer increased the thermal mass of the building elements, improving then the thermal inertia.

2. **Dynamic conditions**

The figure below shows the comparison between the Sensible Energy Demand for heating in BASE CASE and STEP A. The STEP A results, obtained through the dynamic simulations in Trnsys and by an average across all the flats during the heating season, show a decrease of almost the 40% of the total Energy Demand for heating, compared to BASE CASE.

REDUCTION (%)	
	STEP A/BASE CASE
JAN	31%
FEB	32%
MARCH	40%
APR	65%
NOV	42%
DEC	31%
TOTAL	**36%**

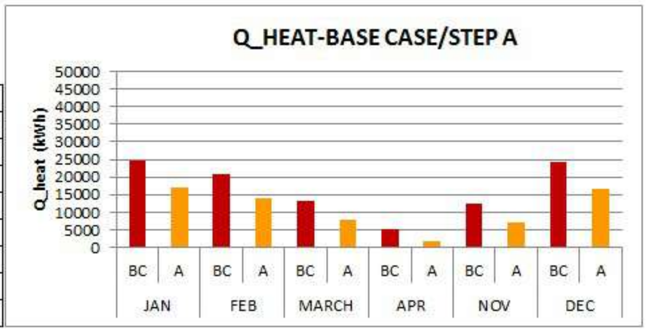

Figure 5.1: Monthly Sensible Energy Demand for heating in BASE CASE and STEP A (BUILDING B).

The next sections show the results in terms of indoor comfort (and the linked parameters). The analysis is conducted through the comparison between BASE CASE, STEP A and STEP E.

WHOLE BUILDING

For what concerns the internal comfort, the addition of an insulation layer on the facades leads to an increase of indoor temperatures, in Summer, of almost 2°C and a consequent decrease of Relative Humidity. The warmest floor is still the fourth floor. The fig. 5.2 shows the average hourly trend of indoor temperatures in the final STEP E compared to BASE CASE and STEP A. In the central months STEP E (red line) lowers the temperatures compared to both STEP A (violet line) and BASE CASE (green line). In May temperatures are higher than in BASE CASE, but lower compared to STEP A. In the first half of September temperatures decrease according to the higher outdoor temperatures, while in the second part the temperatures tend to increase. In July and August the mean temperature values decrease of almost 2.50°C compared to BASE CASE. In October the mean value of temperatures follows the BASE CASE trend with a slight increase (almost 1°C), while in June it decreases of almost 1°C.

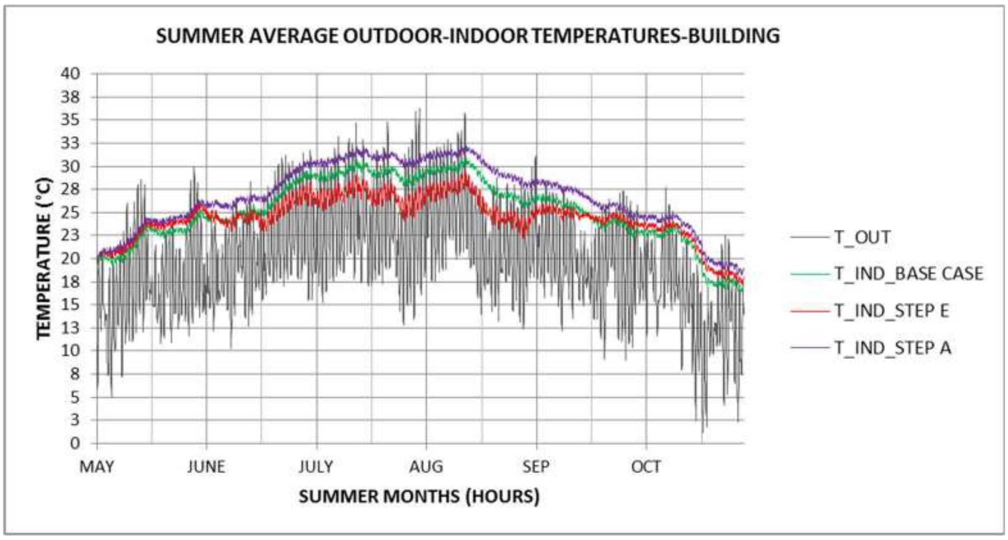

Figure 5.2: Hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between BASE CASE, STEP A, STEP E and outdoor temperatures in BUILDING B.

As it is also shown in the table below, the final Smart Ventilation Control Strategy (STEP E) leads to lower temperatures in the central months (in comparison with STEP A and BASE CASE), while in May and in October it causes an increase.

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.88	27.26	25.03	29.24	30.86	26.87	28.55	30.33	26.22
MAX T (°C)	31.57	32.79	30.11	32.29	33.58	30.71	32.59	33.79	31.11
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	22.18	23.29	22.88	25.02	26.78	24.73	20.32	22.13	21.19
MAX T (°C)	27.05	28.14	27.70	28.49	30.02	27.31	24.01	25.64	24.92
MIN T (°C)	18.58	19.43	19.19	21.55	23.56	22.48	15.36	17.30	16.40

Table 5.2: Temperature values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in BUILDING B.

Taking into account the mean values of Relative Humidity in Summer months, we can note that they decrease compared to BASE CASE in May, June, September and October, while in July and August there is a little increase. Conversely, they increase in comparison with STEP A, but this is the consequence of the increase of indoor temperatures due to the envelope recovery.

BUILDING MEAN RH VALUES (%)			
	BASE CASE	**STEP A**	**STEP E**
MAY	57.92	54.19	54.07
JUNE	60.85	56.08	59.15
JULY	52.90	48.20	55.76
AUGUST	49.23	44.42	51.34
SEPTEMBER	60.71	54.70	59.11
OCTOBER	64.81	58.19	59.71

Table 5.3: RH values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in BUILDING B.

FLATS:

The analysis takes into account the comparison between the results of BASE CASE, STEP A and STEP E for the flats taken as sample cases in chapter 3.

FLOOR 1: FLAT 6

TEMPERATURES:

- MAY: Increase of the mean temperature value (almost 1°C);
- JUNE: Decrease of #hours>28°C (17%); the mean temperature value is close to BASE CASE value;
- JULY: Decrease of #hours>28°C (82%); the mean temperature value decreases of 2°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (40%); the mean temperature value decreases of about 2°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (22%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1°C).

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%
JUNE	13%	17%
JULY	16%	82%
AUG	38%	40%
SEP	22%	0%
OCT	0%	0%

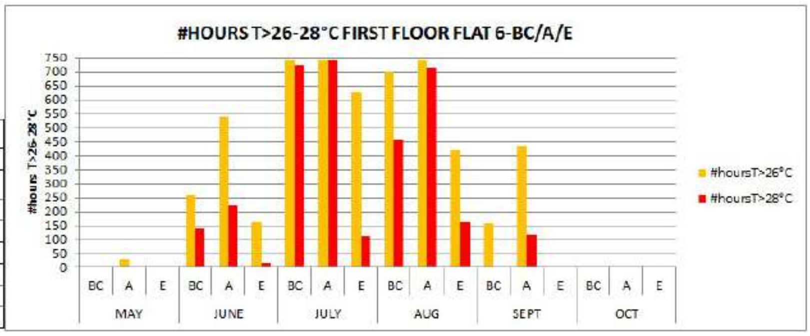

Figure 5.3: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (BUILDING B-FLOOR 1 FLAT 6).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.83	27.27	25.25	29.25	30.97	27.23	28.44	30.33	26.53
MAX T (°C)	30.17	31.42	28.95	30.97	32.44	29.55	31.17	32.59	29.96
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	22.08	23.21	22.90	24.78	26.60	24.77	20.02	21.84	21.13
MAX T (°C)	25.49	26.72	26.47	27.22	28.99	26.28	23.41	24.91	24.18
MIN T (°C)	19.08	19.58	19.42	21.87	23.77	22.93	15.74	17.59	16.85

Table 5.4: Temperature values during the worst months in Summer and during the shoulder season (BUILDING B-FLOOR 1 FLAT 6).

The fig. 5.4 shows the hourly trend of temperatures during Summer months. There is a decrease of indoor temperatures in the central month and in the first part of September. Conversely in May, in the second half of September and in October temperatures increase. These results reflect the behaviour of the whole building obtained by averaging all the flats temperature values.

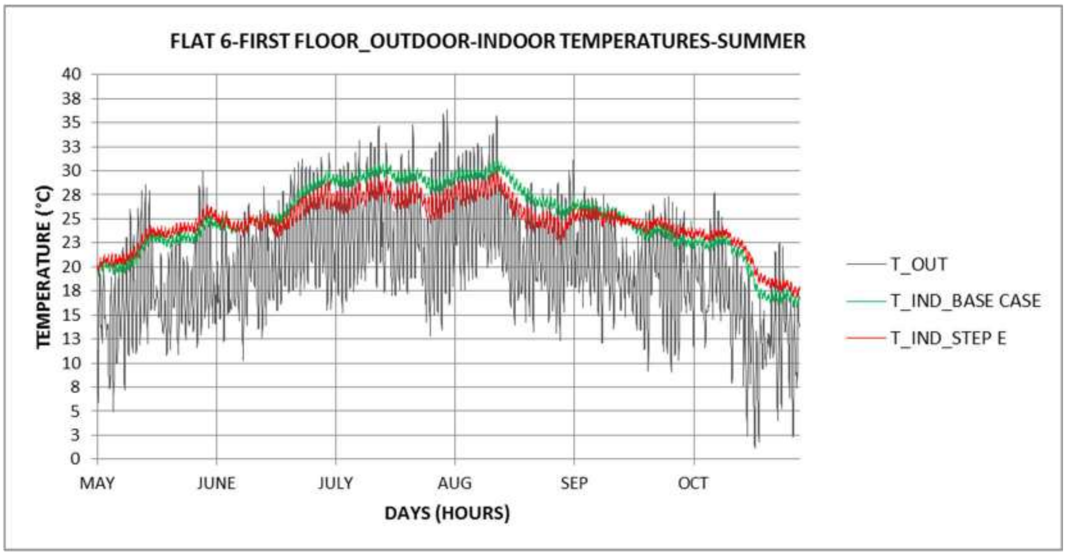

Figure 5.4: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (BUILDING B-FLOOR 1 FLAT 6).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 12% #hoursRH>70%;
- JUNE: Decrease of 18% #hoursRH>70%;
- JULY: Increase of 1% #hoursRH>70%;
- AUGUST: Decrease of 1% #hoursRH>70%;
- SEPTEMBER: Decrease of 11% #hoursRH>70%;
- OCTOBER: Decrease of 20% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	17%	12%
JUNE	14%	18%
JULY	-2%	-1%
AUG	1%	1%
SEP	13%	11%
OCT	13%	20%

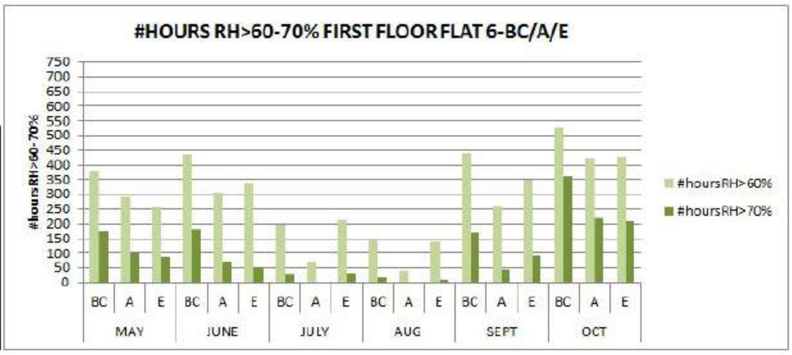

Figure 5.5: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (BUILDING B-FLOOR 1 FLAT 6).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September, when all the month presents PPD<10%. The strategy helps to decrease indoor temperatures in July and in August, and Relative Humidity, improving indoor comfort levels compared to BASE CASE.

In June comfort levels improve compared to BASE CASE, increase of hours with PPD<6%. In May the hours with PPD<10% increase of 20% compared to BASE CASE as well as October shows an improvement of 20% of #hours with PPD<6%.

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-12%	-19%	-5%
JUNE	-7%	-9%	-12%
JULY	-1%	-7%	-22%
AUG	-23%	-34%	-27%
SEP	-30%	-28%	-7%
OCT	-19%	-21%	-10%

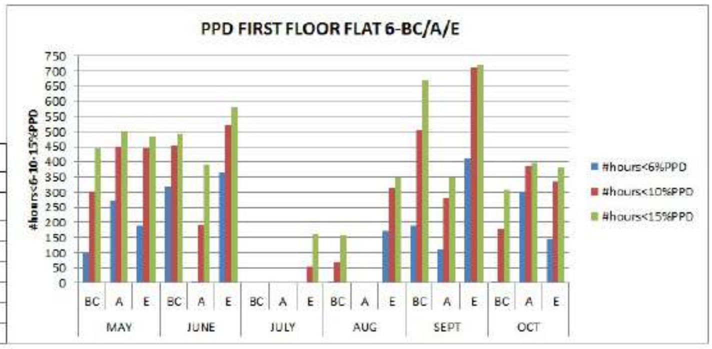

Figure 5.6: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (BUILDING B-FLOOR 1 FLAT 6).

FLOOR 3: FLAT 2

TEMPERATURES:

- MAY: Increase of the mean temperature value; Increase of #hours>26°C (22%);
- JUNE: Decrease of #hours>28°C (20%); Decrease of the mean temperature value (≈1°C);
- JULY: Decrease of #hours>28°C (86%); the mean temperature value decreases of about 2.5°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (41%); the mean temperature value decreases of almost 2.5°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (31%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1°C).

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-22%	-1%
JUNE	15%	20%
JULY	18%	86%
AUG	43%	41%
SEP	31%	0%
OCT	0%	0%

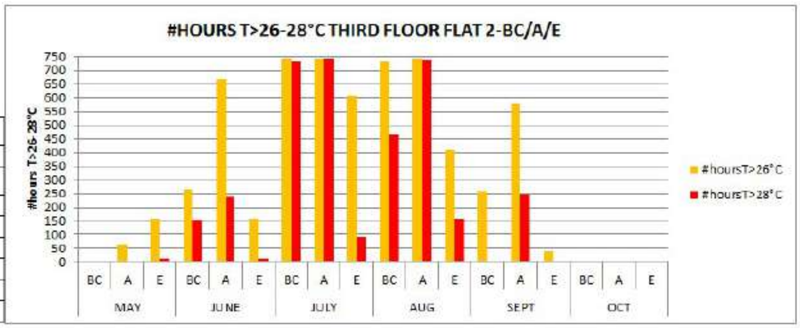

Figure 5.7: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (BUILDING B-FLOOR 3 FLAT 2).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	26.06	27.61	25.12	29.42	31.25	26.88	28.76	30.75	26.29
MAX T (°C)	30.09	31.44	28.49	31.03	32.56	29.21	31.43	32.90	29.83
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	22.31	23.56	23.10	25.25	27.19	25.00	20.66	22.64	21.62
MAX T (°C)	25.55	26.87	26.38	27.43	29.25	26.28	23.99	25.48	24.55
MIN T (°C)	19.29	19.98	19.77	22.55	24.61	23.53	16.56	18.59	17.54

Table 5.5: Temperature values during the worst months in Summer and during the shoulder season (BUILDING B-FLOOR 3 FLAT 2).

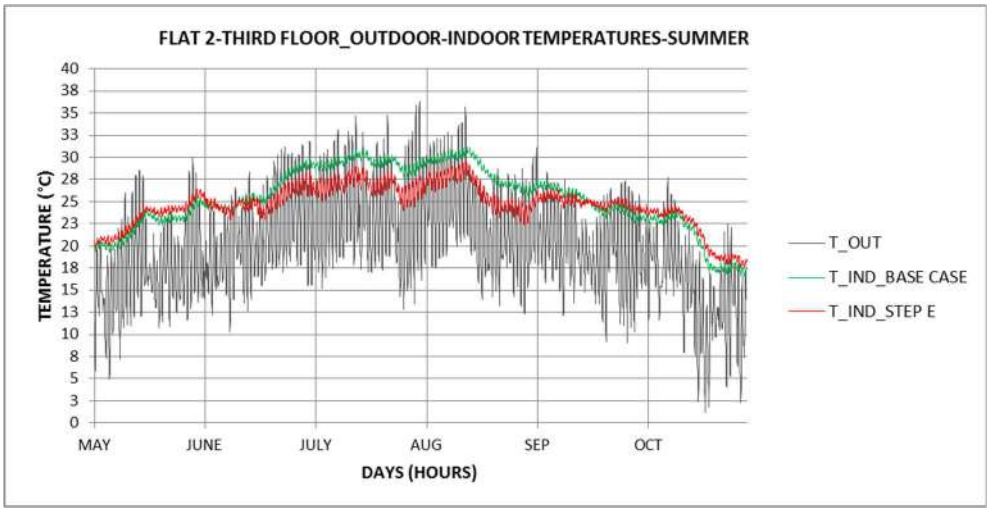

Figure 5.8: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (BUILDING B-FLOOR 3 FLAT 2).

<u>RELATIVE HUMIDITY (RH):</u>

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 13% #hoursRH>70%;
- JUNE: Decrease of 20% #hoursRH>70%;
- JULY: Increase of 1% #hoursRH>70%;
- AUGUST: Decrease of 1% #hoursRH>70%;
- SEPTEMBER: Decrease of 12% #hoursRH>70%;
- OCTOBER: Decrease of 18% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	15%	13%
JUNE	10%	20%
JULY	-1%	-1%
AUG	2%	1%
SEP	10%	12%
OCT	13%	18%

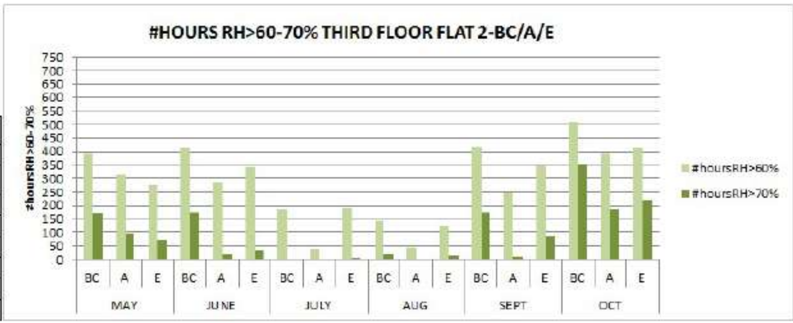

Figure 5.9: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (BUILDING B-FLOOR 3 FLAT 2).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September and in June. In July and in August the hours with PPD<6-10-15% increase, showing that decreasing indoor temperatures, improves internal comfort. The mean temperature value in July is still above 26°C, but the results are improved in comparison with BASE CASE.

In May hours with PPD<6% increase of almost 20%, as well as in October they increase of 5%.

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-18%	4%	-4%
JUNE	-14%	-21%	-16%
JULY	0%	-7%	-22%
AUG	-22%	-44%	-42%
SEP	15%	-28%	-32%
OCT	-5%	-3%	-3%

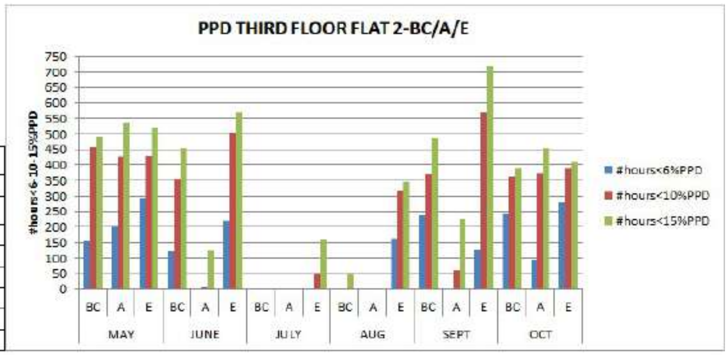

Figure 5.10: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (BUILDING B-FLOOR 3 FLAT 2).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: Small increase of the mean temperature value (less than 1°C);
- JUNE: Decrease of #hours>28°C (21%); the mean temperature value decreases compared to BASE CASE (≈1°C);
- JULY: Decrease of #hours>28°C (≈70%); the mean temperature value decreases of 2.4°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (33%); the mean temperature value decreases of 2.4°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (34%); the mean temperature value is close to the value in BASE CASE;
- OCTOBER: The temperatures are in line with the results obtained in BASE CASE.

$R_{T,26-28}$ (%)		
	STEP E/BASE CASE	
	$R_{T,26}$	$R_{T,28}$
MAY	-2%	0%
JUNE	14%	21%
JULY	13%	72%
AUG	42%	33%
SEP	34%	0%
OCT	0%	0%

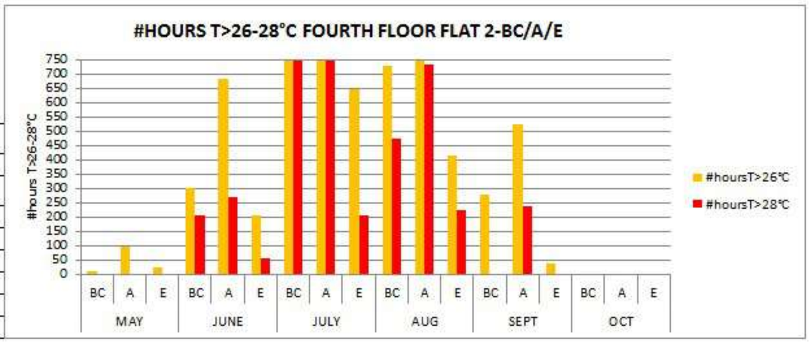

Figure 5.11: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (BUILDING B-FLOOR 4 FLAT 2).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	26.58	28.03	25.65	29.93	31.64	27.53	29.02	30.85	26.73
MAX T (°C)	30.88	32.15	29.55	31.59	32.98	30.10	31.82	33.14	30.49
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	22.74	23.92	23.51	25.27	27.03	25.11	20.32	22.08	21.20
MAX T (°C)	26.23	27.39	27.11	27.68	29.26	26.71	23.89	25.31	24.49
MIN T (°C)	19.22	19.88	19.65	22.18	24.10	23.15	16.06	17.89	16.97

Table 5.6 Temperature values during the worst months in Summer and during the shoulder season (BUILDING B-FLOOR 4 FLAT 2).

The hourly trend of mean temperatures in Summer highlights what explained before: great decrease of temperatures in the central months and slight increase in the shoulder months.

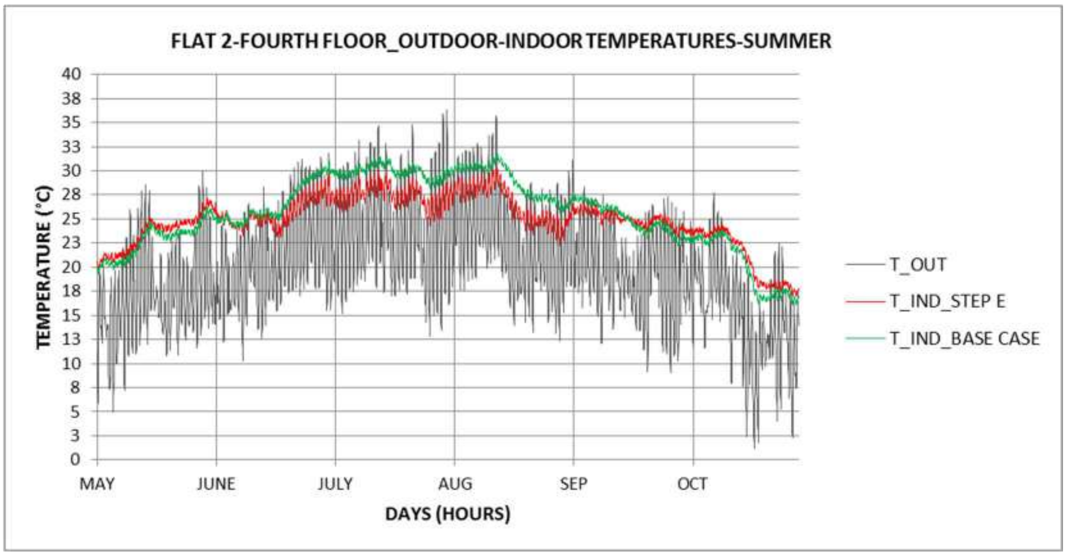

Figure 5.12: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (BUILDING B-FLOOR 4 FLAT 2).

<u>RELATIVE HUMIDITY (RH):</u>

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 9% #hoursRH>70%;
- JUNE: Decrease of 13% #hoursRH>70%;
- JULY: The Relative Humidity is negligible;

- AUGUST: Decrease of Relative Humidity, even it was negligible also in BASE CASE;
- SEPTEMBER: Decrease of 13% #hoursRH>70%;
- OCTOBER: Decrease of 19% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	19%	9%
JUNE	18%	13%
JULY	1%	0%
AUG	3%	2%
SEP	12%	13%
OCT	13%	19%

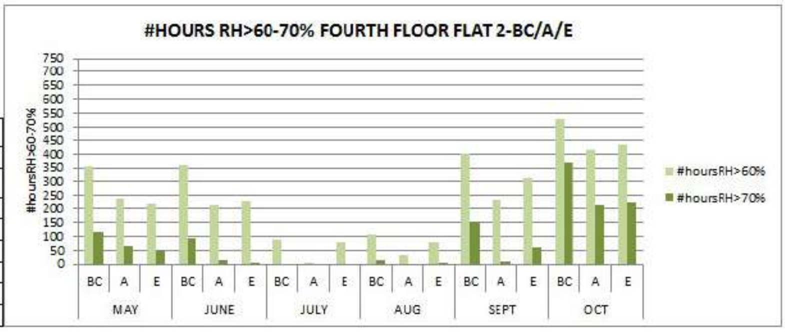

Figure 5.13: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (BUILDING B-FLOOR 4 FLAT 2).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September, when all the month presents PPD<15%. The strategy helps to decrease indoor temperatures in July and in August, and Relative Humidity, improving indoor comfort levels compared to BASE CASE. The effect is more evident in August, because the strategy led to a mean temperature value close to 26°C.

In June comfort levels are improved compared to BASE CASE. In May and in October there is an increase of hours with PPD<6%.

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-9%	5%	0%
JUNE	-13%	-13%	-8%
JULY	0%	-3%	-9%
AUG	-17%	-40%	-37%
SEP	6%	-19%	-28%
OCT	-19%	-8%	-1%

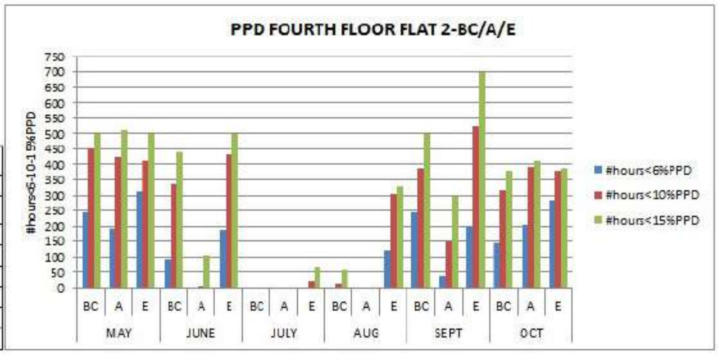

Figure 5.14: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (BUILDING B-FLOOR 4 FLAT 2).

SYNTHESIS

The use of the smart ventilation control applied on the “recovered” envelope in building B, given that STEP A led to an increase of Indoor temperatures of about 2°C in July and August, and about 1.5°C in June, has improved thermal comfort conditions especially during the central months in Summer, by lowering the indoor temperatures. This strategy showed improved results also in September, when the smart control related to the humidity levels lowered both the indoor temperatures (still keeping them within the comfort range) and the Relative Humidity, leading to better comfort conditions. In May and in October STEP E improved the indoor temperatures, improving the comfort levels.

5.2 COMPLEX B: Firenze-Via Canova

The first step (STEP A) was the application of an insulation layer on the facades, on the attic and arcade/cellar slabs and the substitution of the windows. All the COMPLEX B buildings' envelope were recovered with the same insulation layers and windows.

We consider the minimum thickness of insulation, in order to compliant the National Standards (see chapter 4): in this case for the walls this compliance was reached with 6cm of EPS, while for the cellar and arcade slab we used 8cm (as in IOLO):

	Before the recovery	After the recovery	Standards
External walls	U-value: 0.55 W/m^{2}K	U-value: 0.25 W/m^{2}K	U-value: 0.29 W/m^{2}K
Stairs walls	U-value: 0.52 W/m^{2}K	U-value: 0.26 W/m^{2}K	U-value: 0.29 W/m^{2}K
Windows	U_w-value: 2.75 W/m^{2}K	U_w value: 1.70 W/m^{2}K	U_w value: 1.80 W/m^{2}K
Arcade/Cellar slab	U-value: 0.76 W/m^{2}K	U-value: 0.26 W/m^{2}K	U-value: 0.29 W/m^{2}K
Attic slab	U-value: 1.08 W/m^{2}K	U-value: 0.29 W/m^{2}K	U-value: 0.29 W/m^{2}K

Table 5.7: U-values of the building elements before and after the intervention.

Qd1

1. **Semi-stationary conditions**

We will apply the same verifications conducted in Chapter 3.

The Global Energy Performance index (***$EP_{gl,nren}$***) is:

$EP_{gl,nren}$= 58.30kWh/m^{2}y
$EP_{gl,nren,rif}$(2019,2021)= 49.58kWh/m^{2}y

The NEW building Energy Class is **B**, in fact:
1.00* $EP_{gl,nren,rif}$(2019,2021) < $\mathbf{EP_{gl,nren}}$ ≤ 1.20* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K
H'_T= 0.47 W/m^{2}K→ $H'_T < H'_{Tlim}$ **VERIFIED**
In BASE CASE this verification was not satisfied, because of the high values of Transmittance of the building elements.

b. Envelope Energy Performance in Winter through the calculation of ***$EP_{H,nd}$***

$EP_{H,nd}$ = 32.18kWh/m^{2}y
$EP_{H,nd,lim}$(2019,2021)= 13.42kWh/m^{2}y
The result is:
1*$EP_{H,nd,lim}$(2019,2021) < $EP_{H,nd}$ ≤ 1.7*$EP_{H,nd,lim}$(2019,2021)
MEDIUM QUALITY OF THE ENVELOPE
In BASE CASE the quality of the envelope was LOW. It means that the envelope recovery led to a decrease of heat losses through the envelope.

c. Envelope Energy Performance in Summer through the evaluation of (***$A_{sol,est}$***) and (***Y_{IE}***)

$A_{sol,est}/S$= 0.082

Y_{IE}=0.01W/m^{2}K

The thresholds are:

$(A_{sol,est}/S)_{lim}$= 0.03

$(Y_{IE})_{lim}$= 0.14W/m^{2}K

The result is:

$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ and $Y_{IE} < (Y_{IE})_{lim}$ → **MEDIUM QUALITY OF THE ENVELOPE**

In BASE CASE the quality of the envelope was LOW. The addition of the insulation layer increased the thermal mass of the building elements, improving then the thermal inertia.

2. **Dynamic conditions**

The figure below shows the comparison between the Sensible Energy Demand for heating in BASE CASE and STEP A. The STEP A results, obtained through the dynamic simulations in Trnsys and by an average across all the flats during the heating season, show a decrease of almost the 50% of the total Energy Demand for heating, compared to BASE CASE.

REDUCTION (%)	
	STEP A/BASE CASE
JAN	45%
FEB	46%
MARCH	51%
APR	63%
NOV	61%
DEC	45%
TOTAL	**49%**

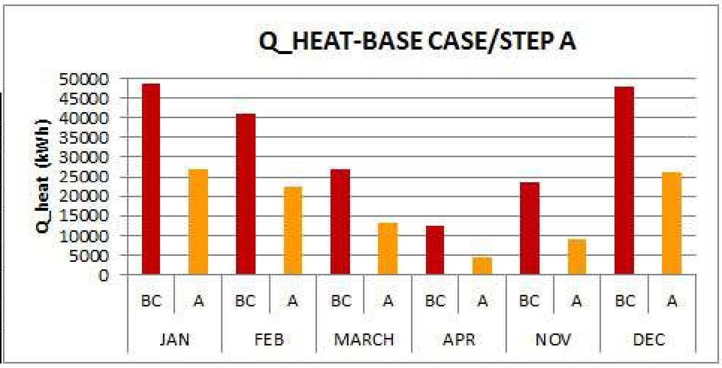

Figure 5.15: Monthly Sensible Energy Demand for heating in BASE CASE and STEP A (Qd1).

The Smart Ventilation Control (STEP E) and therefore the mechanical ventilation system works only in Summer; accordingly, the Energy Demand for heating is the same calculated in STEP A.

WHOLE BUILDING

For what concerns the internal comfort, the addition of an insulation layer on the facades leads to an increase of indoor temperatures, in the Summer central months, of almost 2°C.

The fig. 5.16 shows the average hourly trend of indoor temperatures in the final STEP E compared to BASE CASE and STEP A. In the central months STEP E (red line) lowers temperatures compared to both STEP A (violet line) and BASE CASE (green line). As it is also shown in the table below, the final Smart Ventilation Control Strategy (STEP E) leads to lower temperatures in the central months (in comparison with STEP A and BASE CASE), while in May and in October it causes an increase.

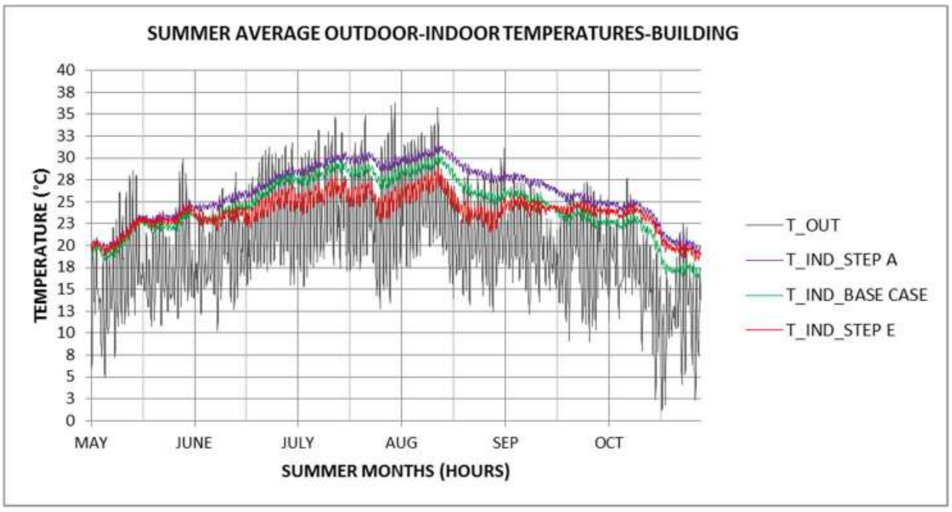

Figure 5.16: Hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between BASE CASE, STEP A, STEP E and outdoor temperatures in Qd1.

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	24.97	26.06	23.94	28.16	29.49	25.66	27.70	29.51	25.32
MAX T (°C)	30.18	30.15	27.76	31.40	31.93	28.77	31.74	32.54	29.48
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	21.44	22.29	21.96	24.51	26.57	24.40	20.26	22.70	21.92
MAX T (°C)	25.72	25.90	25.52	27.65	29.37	26.29	24.16	26.05	25.14
MIN T (°C)	17.46	18.53	18.13	21.02	21.76	21.76	15.20	17.90	17.22

Table 5.8: Temperature values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in Qd1.

Taking into account the mean values of Relative Humidity in Summer months, we can note that they decrease compared to BASE CASE in May, September and October, while in June, July and August there is a little increase. In July and August the mean values of RH are below 60%, while in June the value exceeds 60% of RH (the building in BASE CASE had already the mean value above 60%). Conversely all the values increase in comparison with STEP A, but this is the consequence of the decrease of indoor temperatures due to the envelope recovery.

BUILDING MEAN RH VALUES (%)			
	BASE CASE	STEP A	STEP E
MAY	57.34	54.47	54.53
JUNE	61.66	57.78	62.17
JULY	54.19	50.22	59.11
AUGUST	49.56	44.65	53.40
SEPTEMBER	59.98	53.13	58.63
OCTOBER	61.89	53.52	54.95

Table 5.9: RH values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in Qd1.

FLATS:

The analysis takes into account the comparison between the results of BASE CASE, STEP A and STEP E for the flats taken as sample cases in chapter 3.

FLOOR 1: FLAT 1

TEMPERATURES:

- MAY: In this case there is a slight decrease of the mean temperature value;
- JUNE: Decrease of #hours>28°C (19%); the mean temperature value is decreased of 1.5°C compared to the BASE CASE one;
- JULY: Decrease of #hours>28°C (66%); the mean temperature value decreases of 3°C compared to BASE CASE; The mean temperature value is below 26°C;
- AUGUST: Decrease of #hours>28°C (30%); the mean temperature value decreases of about 2.8°C compared to BASE CASE; The mean temperature value is below 26°C;
- SEPTEMBER: Decrease of #hours>26°C (17%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1.40°C).

$R_{T,26-28}$ (%) STEP E/BASE CASE	$R_{T,26}$	$R_{T,28}$
MAY	-1%	0%
JUNE	12%	19%
JULY	10%	66%
AUG	27%	30%
SEP	17%	0%
OCT	0%	0%

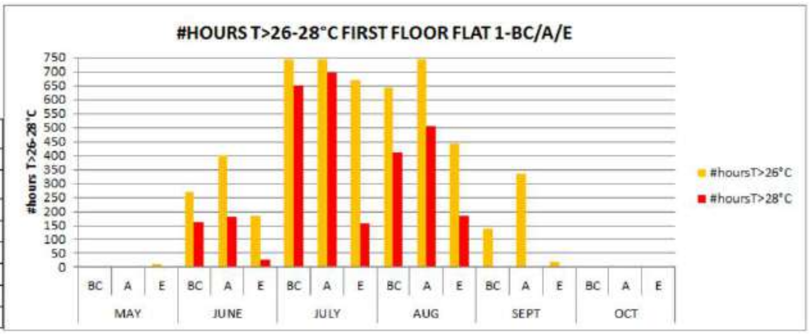

Figure 5.17: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qd1-FLOOR 1 FLAT 1).

	JUNE			**JULY**			**AUGUST**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	25.83	27.43	23.72	28.82	31.02	25.52	28.03	30.02	25.16
MAX T (°C)	29.94	30.50	27.18	30.72	32.70	28.00	31.09	32.30	28.90
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	22.20	23.45	21.64	24.62	25.86	24.11	20.10	22.00	21.37
MAX T (°C)	25.64	26.78	24.53	27.17	27.98	25.75	23.67	24.79	24.27
MIN T (°C)	19.06	19.10	18.48	21.58	23.40	22.60	15.84	18.18	17.47

Table 5.10: Temperature values during the worst months in Summer and during the shoulder season (Qd1-FLOOR 1 FLAT 1).

The fig.5.18 shows the hourly trend of temperatures during Summer months. There is a decrease of indoor temperatures in the central month and in the first part of September. Conversely in May, in the second half of September and in October temperatures increase. These results reflect the behaviour of the whole building obtained by averaging all the flats temperature values.

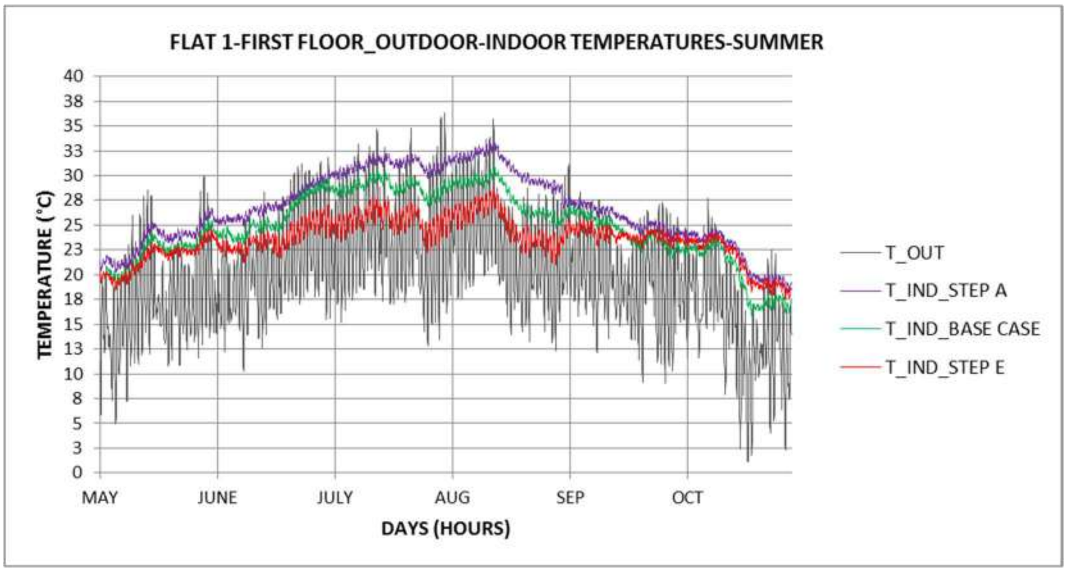

Figure 5.18: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qd1-FLOOR 1 FLAT 1).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: The increase of RH levels is negligible;
- JUNE: Increase of 5% #hoursRH>70%; the
- JULY: Increase of 41% #hoursRH>60%; No significant effects on the #hoursRH>70%;
- AUGUST: Increase of 16% #hoursRH>60%; No significant effects on the #hoursRH>70%;
- SEPTEMBER: The increase of RH levels is negligible;
- OCTOBER: Decrease of 14% #hoursRH>70%.

$R_{RH,60-70}$ (%) STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	-3%	-1%
JUNE	-6%	-5%
JULY	-41%	-4%
AUG	-16%	-4%
SEP	1%	-6%
OCT	14%	14%

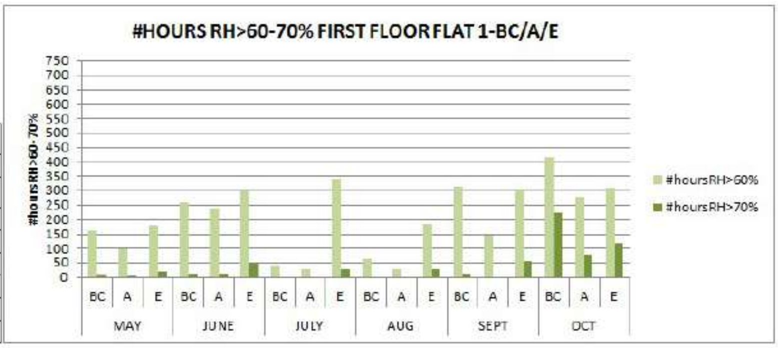

Figure 5.19: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qd1-FLOOR 1 FLAT 1).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September, when almost all the month presents PPD<10%. In June the comfort levels inside the flat increase significantly. The strategy helps to decrease indoor temperatures In July and in August, and Relative Humidity, improving indoor comfort levels compared to BASE CASE. In May the internal conditions are similar to those obtained in BASE CASE. In October a marked improvement in comparison with BASE CASE is highlighted in the figure. Obviously STEP A leads to better comfort conditions, because of the increase of temperatures. Nevertheless STEP E allows to go back to the BASE CASE conditions and, in such a way, without worsening the initial stating point conditions.

$R_{PPD,6\text{-}10\text{-}15}$ (%)			
	STEP E/BASE CASE		
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	2%	-2%	1%
JUNE	11%	-16%	-32%
JULY	-25%	-61%	-84%
AUG	-22%	-40%	-37%
SEP	-47%	-27%	-5%
OCT	-19%	-18%	-10%

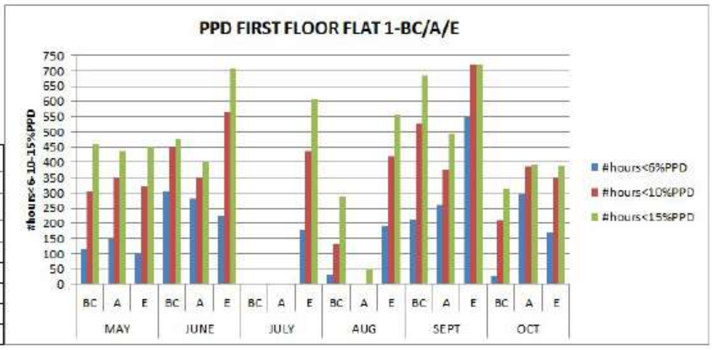

Figure 5.20: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qd1-FLOOR 1 FLAT 1).

FLOOR 4: FLAT 6

TEMPERATURES:

- MAY: Slight increase of the mean temperature value (≈1°C);
- JUNE: Decrease of #hours>26°C (22%); Decrease of the mean temperature value (≈1°C); STEP A led to an increase of temperatures of almost 1.5°C, leading to overcome 26°C. STEP E makes this value decrease below the threshold value to keep the flat within the comfort range;
- JULY: Decrease of #hours>28°C (80%); the mean temperature value decreases of almost 3°C compared to BASE CASE, reaching 26°C;
- AUGUST: Decrease of #hours>28°C (44%); the mean temperature value decreases of almost 3°C compared to BASE CASE, falling below 26°C;
- SEPTEMBER: Decrease of #hours>26°C (27%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1°C).

$R_{T,26\text{-}28}$ (%)		
	STEP E/BASE CASE	
	$R_{T,26}$	$R_{T,28}$
MAY	-12%	0%
JUNE	22%	8%
JULY	45%	80%
AUG	48%	49%
SEP	27%	0%
OCT	0%	0%

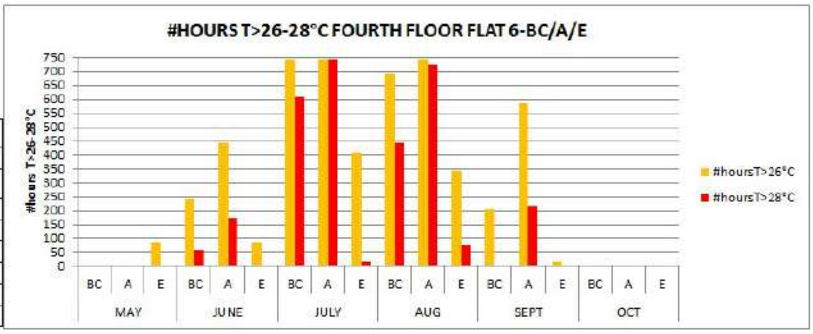

Figure 5.21: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (BUILDING B-FLOOR 4 FLAT 6).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.39	26.70	24.37	28.74	30.23	26.06	28.28	30.20	25.68
MAX T (°C)	28.93	29.84	27.34	30.48	31.65	28.43	31.11	32.45	29.32
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	21.86	22.89	22.53	25.03	27.15	24.81	20.75	23.16	22.32
MAX T (°C)	24.65	25.72	25.33	27.13	29.15	26.15	23.97	25.78	25.07
MIN T (°C)	18.49	19.56	19.19	22.26	24.54	23.27	16.51	19.21	18.37

Table 5.11: Temperature values during the worst months in Summer and during the shoulder season (Qd1-FLOOR 4 FLAT 6).

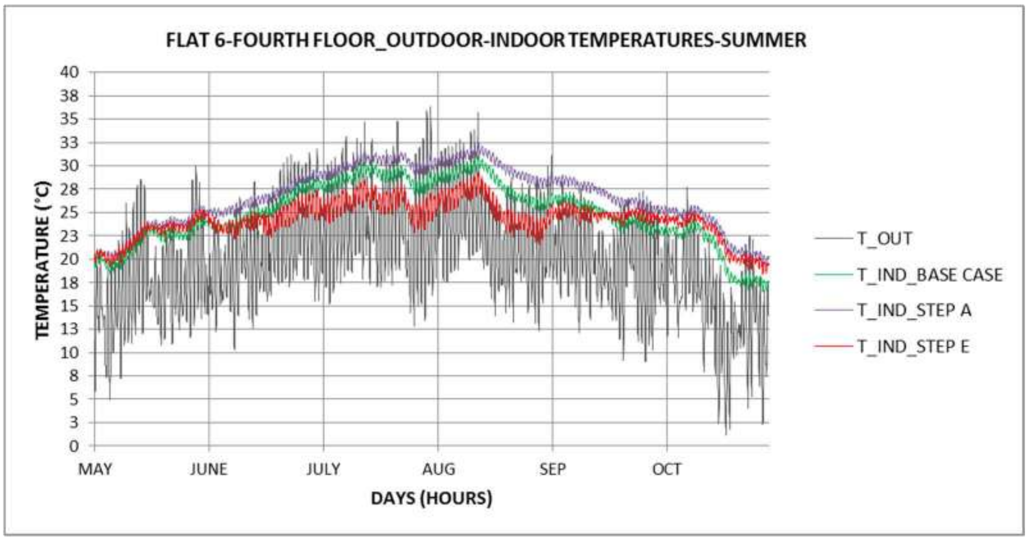

Figure 5.22: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qd1-FLOOR 4 FLAT 6).

<u>RELATIVE HUMIDITY (RH):</u>

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE during the shoulder months. In the other months it increases the humidity because of the increase of ACH, but it does not increase the hours with RH>70%:

- MAY: Decrease of 14% #hoursRH>60%;
- JUNE: The increase of RH is negligible;
- JULY: Increase of 28% #hoursRH>60%;
- AUGUST: Increase of 14% #hoursRH>60%;
- SEPTEMBER: The effects on the Relative Humidity are negligible;
- OCTOBER: Decrease of 15% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	14%	3%
JUNE	-7%	-1%
JULY	-28%	-2%
AUG	-14%	-2%
SEP	2%	-4%
OCT	18%	15%

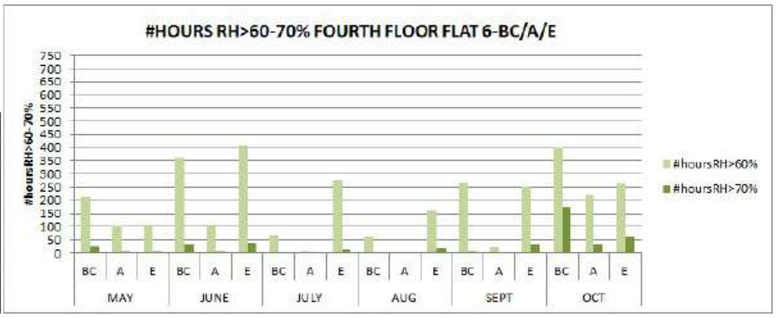

Figure 5.23: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qd1-FLOOR 4 FLAT 6).

COMFORT INDEX (PPD VALUES):

In this flat STEP E led to better comfort conditions in comparison with BASE CASE, in all the Summer months. According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September and in June. In July and in August the hours with PPD<6-10-15% increase, showing that decreasing indoor temperatures improves internal comfort. This flat in July shows the best trend among all the cases analysed so far. The decrease of temperatures up to 26°C, despite the increase of RH (only hours above 60%), improves significantly the indoor comfort. In May there is a slight decrease of dissatisfied percentages (with the consequent increase of the hours at the threshold 6-10-15%), while in October the improvement is more evident.

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-11%	-23%	-8%
JUNE	-15%	-23%	-26%
JULY	-14%	-42%	-66%
AUG	-30%	-39%	-40%
SEP	-33%	-30%	-8%
OCT	-35%	-12%	-6%

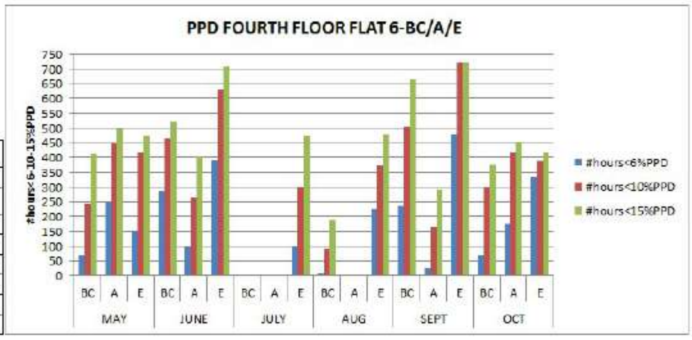

Figure 5.24: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qd1-FLOOR 4 FLAT 6).

FLOOR 6: FLAT 4

TEMPERATURES:

- MAY: Small increase of the mean temperature value, close to the BASE CASE one;
- JUNE: Decrease of #hours>28°C (24%); the mean temperature value decreases compared to BASE CASE (≈1.60°C);
- JULY: Decrease of #hours>28°C (90%); the mean temperature value decreases of almost 3°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (52%); the mean temperature value decreases of almost 3°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (37%); the mean temperature value is slightly lower compared to the BASE CASE one;

- OCTOBER: The temperature increases and the mean value is increased of almost 1.5°C in comparison with BASE CASE.

$R_{T,26-28}$ (%) STEP E/BASE CASE	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%
JUNE	26%	24%
JULY	33%	90%
AUG	46%	52%
SEP	37%	0%
OCT	0%	0%

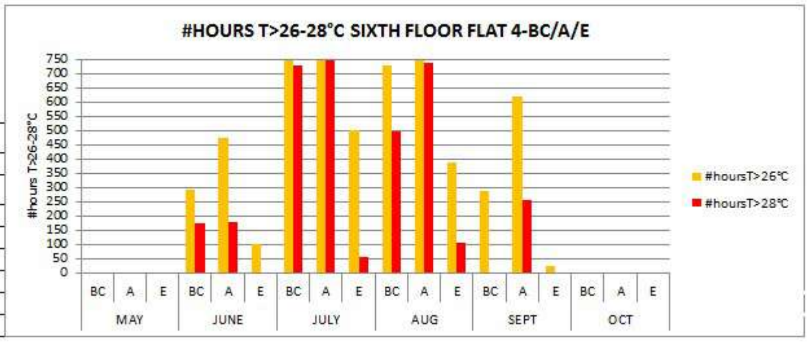

Figure 5.25: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qd1-FLOOR 6 FLAT 4).

	JUNE			JULY			AUGUST		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	26.22	26.86	24.64	29.64	30.52	26.48	28.93	30.47	26.05
MAX T (°C)	30.18	30.15	27.76	31.40	31.93	28.77	31.74	32.52	29.48
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	22.56	22.96	22.62	25.41	27.34	24.98	20.63	23.21	22.39
MAX T (°C)	25.72	25.90	25.52	27.65	29.30	26.29	24.16	25.83	25.10
MIN T (°C)	19.12	19.64	19.36	22.25	24.67	23.59	16.22	19.12	18.32

Table 5.12: Temperature values during the worst months in Summer and during the shoulder season (Qd1-FLOOR 6 FLAT 4).

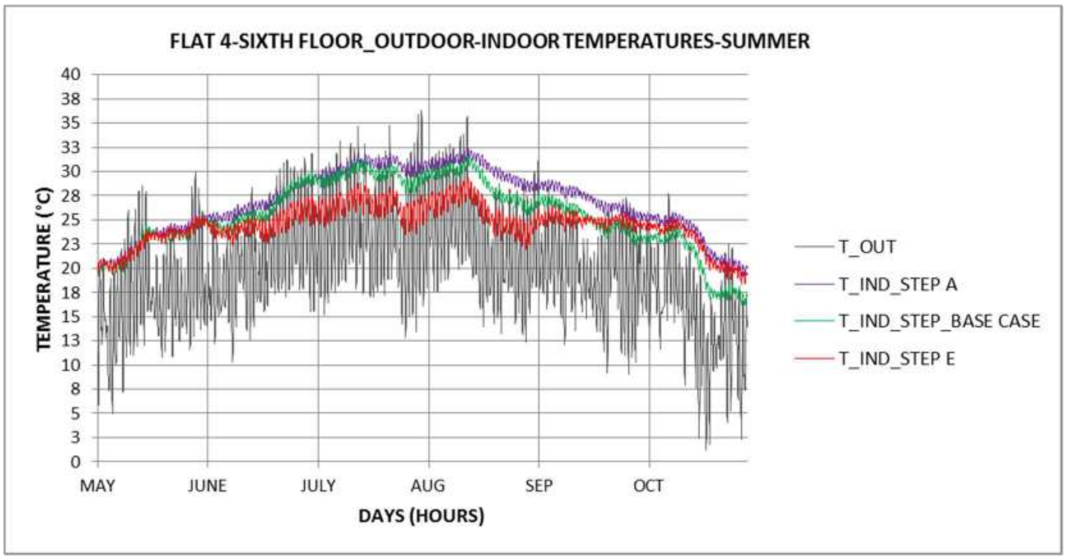

Figure 5.26: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qd1-FLOOR 6 FLAT 4).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in May and in October (the ACH is keeping 0.5/h). The increase of air change rates leads to more outdoor air inside the home and along with the cooling effect, it can introduce humidity. This occurs in the central month of the Summer:

- MAY: Small decrease of #hoursRH>60%; STEP E does not worsen the BASE CASE starting conditions;
- JUNE: Increase of 20% #hoursRH>60%;
- JULY: Increase of hours with RH>60% (29%), but hours above 70%RH do not suffer increases;
- AUGUST: The increase of #hoursRH>60% is around 14%;
- SEPTEMBER: Small increase of Relative Humidity;
- OCTOBER: Decrease of 15% #hoursRH>70%.

$R_{RH,60\text{-}70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	5%	0%
JUNE	-20%	-3%
JULY	-29%	-1%
AUG	-14%	-1%
SEP	-3%	-4%
OCT	20%	15%

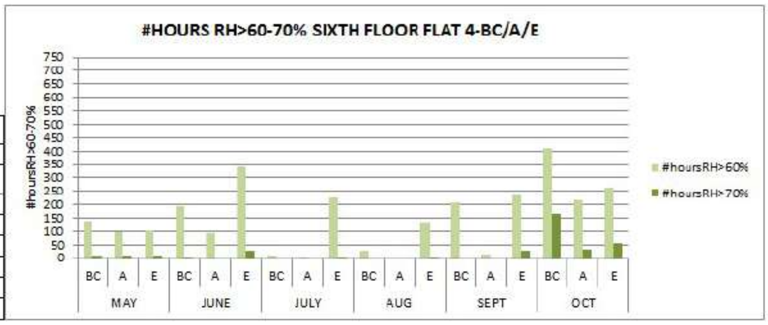

Figure 5.27: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qd1-FLOOR 6 FLAT 4).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September and in June: the first one all the month has hours with PPD<10%, while the second one presents almost all the month hours with PPD<15%. The strategy helps to decrease indoor temperatures In July and in August, and Relative Humidity, improving indoor comfort levels compared to BASE CASE. The effect is more evident in August, because the strategy led to a mean temperature value close to 26°C.

In May the comfort conditions are similar to those found in BASE CASE; in October the figure shows an improvement of 33% of PPD<6%.

$R_{PPD,6\text{-}10\text{-}15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-4%	0%	1%
JUNE	-24%	-24%	-29%
JULY	-7%	-24%	-53%
AUG	-27%	-43%	-47%
SEP	-22%	-43%	-22%
OCT	-33%	-10%	-7%

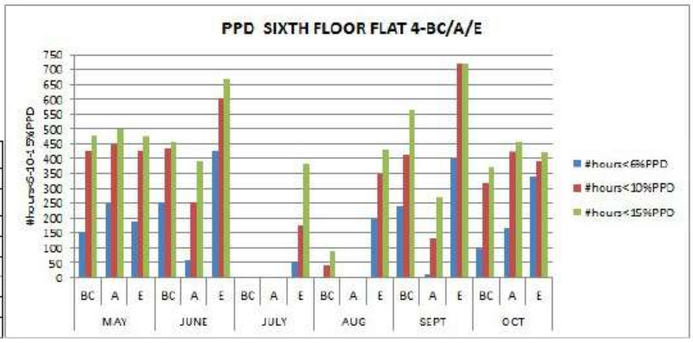

Figure 5.28: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qd1-FLOOR6-FLAT4).

SYNTHESIS

The use of the smart ventilation control applied on the "recovered" envelope in Qd1, given that STEP A led to an increase of Indoor temperatures of more than 2°C in July and August, and about 1.5°C in June, has improved thermal comfort conditions especially during the central months in Summer, by lowering the indoor temperatures. This strategy showed improved results also in September, when the smart control related to the humidity levels lowered the indoor temperatures (still keeping them within the comfort range) and the increase of Relative Humidity is negligible. The internal comfort has been improved by STEP E and the ventilation mechanism, because through the smart control on the ACH, temperature values are checked in order to not fall below the threshold of comfort and it can improve the IAQ, by decreasing the RH levels.

Qa19

1. **Semi-stationary conditions**

We will apply the same verifications conducted in Chapter 3.

The Global Energy Performance index ($\boldsymbol{EP_{gl,nren}}$) is:
$EP_{gl,nren}$= 59.20kWh/m^{2}y
$EP_{gl,nren,rif}$(2019,2021)= 49.76kWh/m^{2}y

The NEW building Energy Class is **B**, in fact:
1.00* $EP_{gl,nren,rif}$(2019,2021) < $\mathbf{EP_{gl,nren}}$ ≤ 1.20* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:

a. Mean global thermal exchange coefficient ($\boldsymbol{H'_T}$)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K
H'_T= 0.47 W/m^{2}K→ $H'_T < H'_{Tlim}$ **VERIFIED**

In BASE CASE this verification was not satisfied, because of the high values of Transmittance of the building elements.

Envelope Energy Performance in Winter through the calculation of $\boldsymbol{EP_{H,nd}}$
$EP_{H,nd}$ = 20.23kWh/m^{2}y
$EP_{H,nd,lim}$(2019,2021)= 11.94kWh/m^{2}y
The result is:
1*$EP_{H,nd,lim}$(2019,2021) < $EP_{H,nd}$ ≤ 1.7*$EP_{H,nd,lim}$(2019,2021)
→ **MEDIUM QUALITY OF THE ENVELOPE**

In BASE CASE the quality of the envelope was LOW. It means that the envelope recovery led to a decrease of heat losses through the envelope.

b. Envelope Energy Performance in Summer through the evaluation of ($\boldsymbol{A_{sol,est}}$) and ($\boldsymbol{Y_{IE}}$)

$A_{sol,est}/S$= 0.082
Y_{IE}=0.02W/m^{2}K
The thresholds are:
$(A_{sol,est}/S)_{lim}$= 0.03
$(Y_{IE})_{lim}$= 0.14W/m^{2}K
The result is:
$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ and $Y_{IE} < (Y_{IE})_{lim}$ → **MEDIUM QUALITY OF THE ENVELOPE**

In BASE CASE the quality of the envelope was LOW. The addition of the insulation layer increased the thermal mass of the building elements, improving then the thermal inertia.

2. **Dynamic conditions**

The figure below shows lthe comparison between the Sensible Energy Demand for heating in BASE CASE and STEP A. The STEP A results, obtained through the dynamic simulations in Trnsys and by an average across all the flats during the heating season, show a decrease of almost the 40% of the total Energy Demand for heating, compared to BASE CASE.

REDUCTION (%)	
	STEP A/BASE CASE
JAN	36%
FEB	35%
MARCH	37%
APR	42%
NOV	43%
DEC	36%
TOTAL	**37%**

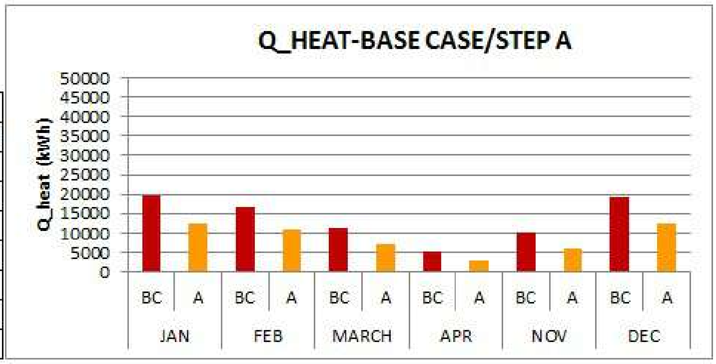

Figure 5.29: Monthly Sensible Energy Demand for heating in BASE CASE and STEP A (Qa19).

WHOLE BUILDING

For what concerns the internal comfort, the addition of an insulation layer on the facades leads to an increase of indoor temperatures, in the Summer central months, of about 1°C, less in comparison with the other buildings, but Qa19 had already temperatures above 26°C; a further increase can worse the internal comfort. The fig. 5.30 shows the average hourly trend of indoor temperatures in the final STEP E compared to BASE CASE and STEP A. In the central months STEP E (red line) lowers temperatures compared to both STEP A (violet line) and BASE CASE (green line). As it is also shown in the table below, the final Smart Ventilation Control Strategy (STEP E) leads to lower temperatures in the central months (in comparison with STEP A and BASE CASE), while in May and in October it causes an increase.

	JUNE			JULY			AUGUST		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	24.59	24.81	23.22	27.91	28.36	25.24	27.36	28.46	24.94
MAX T (°C)	29.82	29.39	27.30	30.90	31.24	28.26	31.13	31.88	28.94
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	21.04	21.28	21.03	24.04	25.51	23.69	19.65	21.64	21.02
MAX T (°C)	25.17	25.10	24.78	27.07	28.67	25.79	23.40	25.17	24.41
MIN T (°C)	16.88	18.26	17.93	20.12	21.76	21.51	14.76	16.25	15.94

Table 5.13: Temperature values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in Qa19.

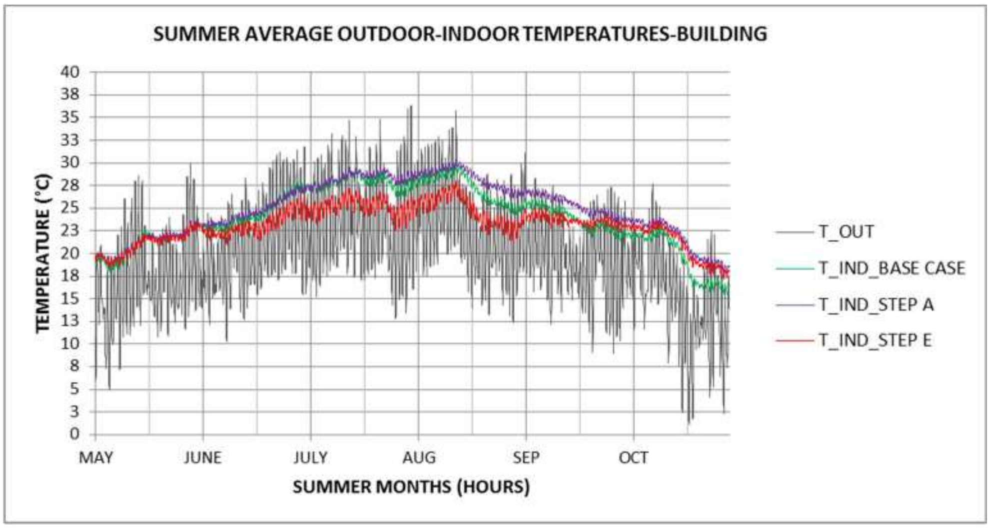

Figure 5.30: Hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between BASE CASE, STEP A, STEP E and outdoor temperatures in Qa19.

Taking into account the mean values of Relative Humidity in Summer months, we can note that they decrease compared to BASE CASE in May, October and in September the value is equal to BASE CASE one; in June, July and August there is a little increase. By the way in August the mean value of RH is below 60%, while in June and July it overcomes of a not relevant rate.

Conversely all the values increase in comparison with STEP A, but this is the consequence of the increase of indoor temperatures due to the envelope recovery.

BUILDING MEAN RH VALUES (%)			
	BASE CASE	**STEP A**	**STEP E**
MAY	56.59	55.78	55.87
JUNE	61.29	60.49	63.15
JULY	53.56	52.19	60.10
AUGUST	49.06	46.03	54.18
SEPTEMBER	59.87	54.85	59.89
OCTOBER	62.06	55.30	56.53

Table 5.14: RH values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in Qa19.

FLATS:

The analysis takes into account the comparison between the results of BASE CASE, STEP A and STEP E for the flats taken as sample cases in chapter 3.

FLOOR 1: FLAT 1

TEMPERATURES:

- MAY: Increase of the mean temperature value;
- JUNE: This flat does not present high temperatures in June. The ventilation system lowers anyway the mean temperature value, after the increase due to the envelope recovery. The system ensures the right number of ACH, while, as we already mentioned, the value of ACH in STEP A derives from a standard value imposed by the Law;

- JULY: Decrease of #hours>26°C (40%); the mean temperature value decreases of 2°C compared to BASE CASE; The mean temperature value is below 26°C;
- AUGUST: Decrease of #hours>26°C (18%); the mean temperature value decreases of about 2°C compared to BASE CASE; The mean temperature value is below 26°C;
- SEPTEMBER: the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1.40°C).

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%
JUNE	2%	0%
JULY	40%	0%
AUG	18%	3%
SEP	0%	0%
OCT	0%	0%

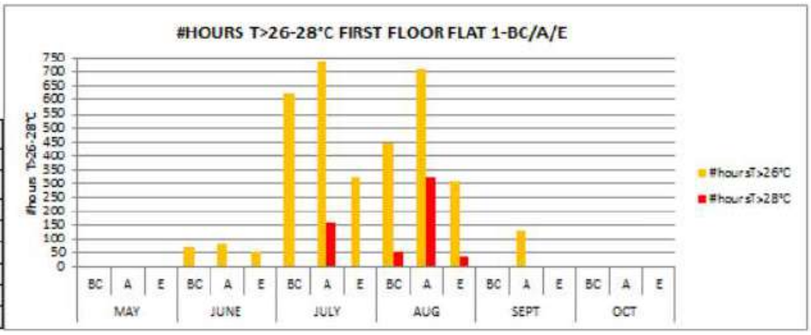

Figure 5.31: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qa19-FLOOR 1 FLAT 1).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	23.52	24.02	22.69	26.63	27.46	24.72	26.24	27.63	24.51
MAX T (°C)	27.00	27.08	25.92	28.18	28.63	26.69	28.82	29.59	27.61
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	20.22	20.76	20.55	23.30	24.92	23.37	19.32	21.24	20.74
MAX T (°C)	22.83	23.06	22.92	25.23	26.79	24.76	22.45	23.74	23.45
MIN T (°C)	17.41	18.42	18.10	20.81	22.64	21.91	15.34	17.54	16.96

Table 5.15: Temperature values during the worst months in Summer and during the shoulder season (Qa19-FLOOR 1 FLAT 1).

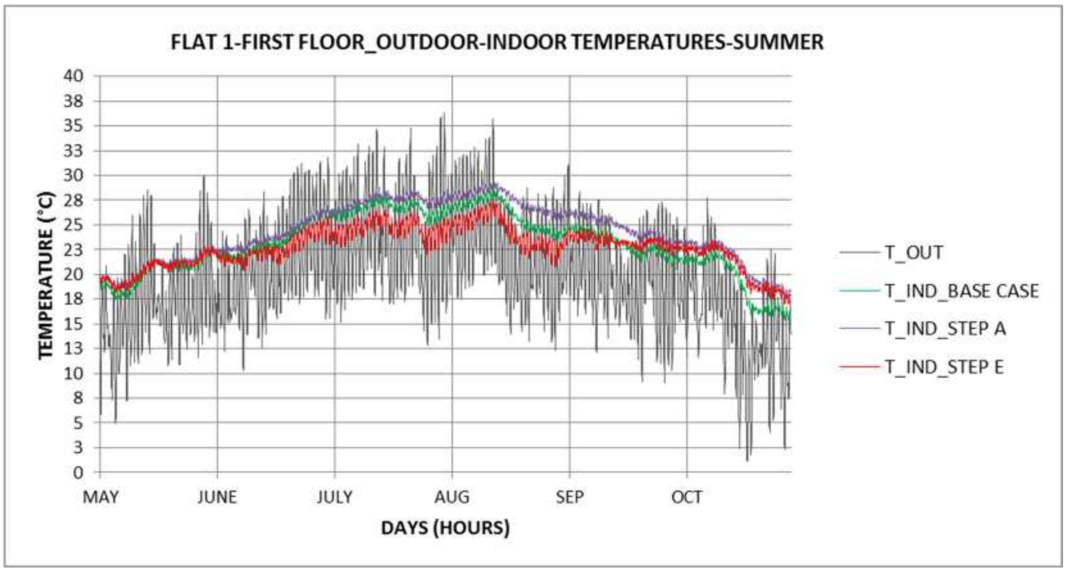

Figure 5.32: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qa19-FLOOR 1 FLAT 1).

The fig. 5.32 shows the hourly trend of temperatures during Summer months. There is a decrease of indoor temperatures in the central months and in the first part of September. Conversely in May, in the second half of September and in October temperatures increase.

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: Decrease of 9% #hoursRH>70%;
- JUNE: Decrease of 14% #hoursRH>70%;
- JULY: No relevant changes in RH levels;
- AUGUST: No relevant changes in RH levels;
- SEPTEMBER: Decrease of 26% #hoursRH>60%;
- OCTOBER: Decrease of 24% #hoursRH>70%.

$R_{RH,60\text{-}70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	33%	9%
JUNE	19%	14%
JULY	-4%	-1%
AUG	-1%	0%
SEP	26%	9%
OCT	20%	24%

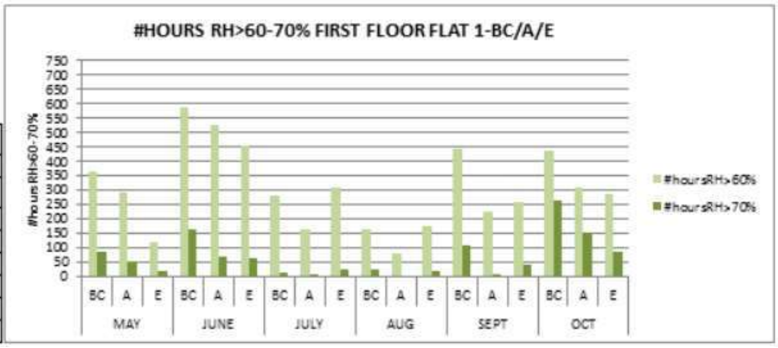

Figure 5.33: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qa19-FLOOR 1 FLAT 1).

COMFORT INDEX (PPD VALUES):

The most relevant increase of internal comfort is shown in September, July and August. In September, given that the indoor temperatures after the application of the ventilation system get close to the BASE CASE values, the improvement of comfort conditions is due to the decrease of Relative Humidity. In July and August the lower temperatures (below 26°C) make the flat more comfortable. In June there is an increase of hours with PPD<6% (the best comfort condition), due to the decrease of Relative Humidity for the introduction of the smart controller. In May the comfort conditions inside the flat seem to not be improved, but in reality the ventilation system led to a significant decrease of RH values and a slight increase of indoor temperatures.

$R_{PPD,6\text{-}10\text{-}15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	0%	-1%	-2%
JUNE	-11%	10%	13%
JULY	-52%	-66%	-53%
AUG	12%	-26%	-33%
SEP	8%	-28%	-14%
OCT	0%	-28%	-34%

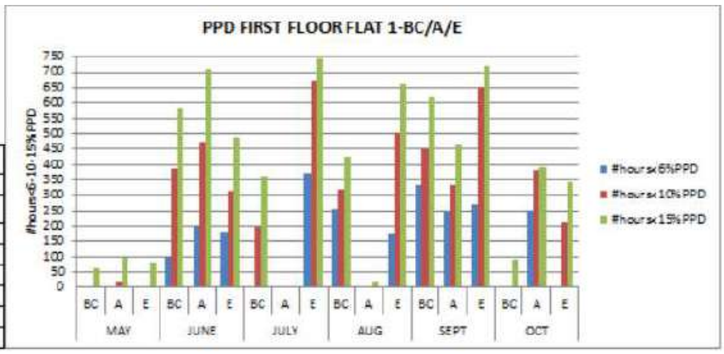

Figure 5.34: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qa19-FLOOR 1 FLAT 1).

FLOOR 2: FLAT 4

TEMPERATURES:

- MAY: Slight increase of the mean temperature value);
- JUNE: Decrease of #hours>26°C (26%); Decrease of the mean temperature value (≈1.5°C);
- JULY: Decrease of #hours>28°C (89%); the mean temperature value decreases of almost 3°C compared to BASE CASE, falling below 26°C;
- AUGUST: Decrease of #hours>28°C (55%); the mean temperature value decreases of almost 3°C compared to BASE CASE, falling below 26°C;
- SEPTEMBER: Decrease of #hours>26°C (22%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1.5°C).

$R_{T,26\text{-}28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-7%	0%
JUNE	26%	11%
JULY	56%	89%
AUG	52%	55%
SEP	22%	0%
OCT	0%	0%

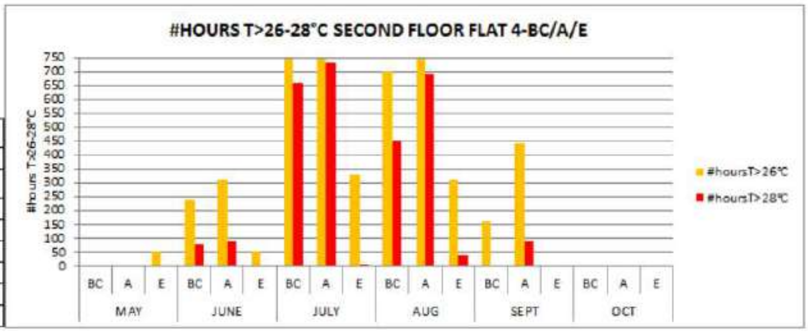

Figure 5.35: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qa19-FLOOR 4 FLAT 2).

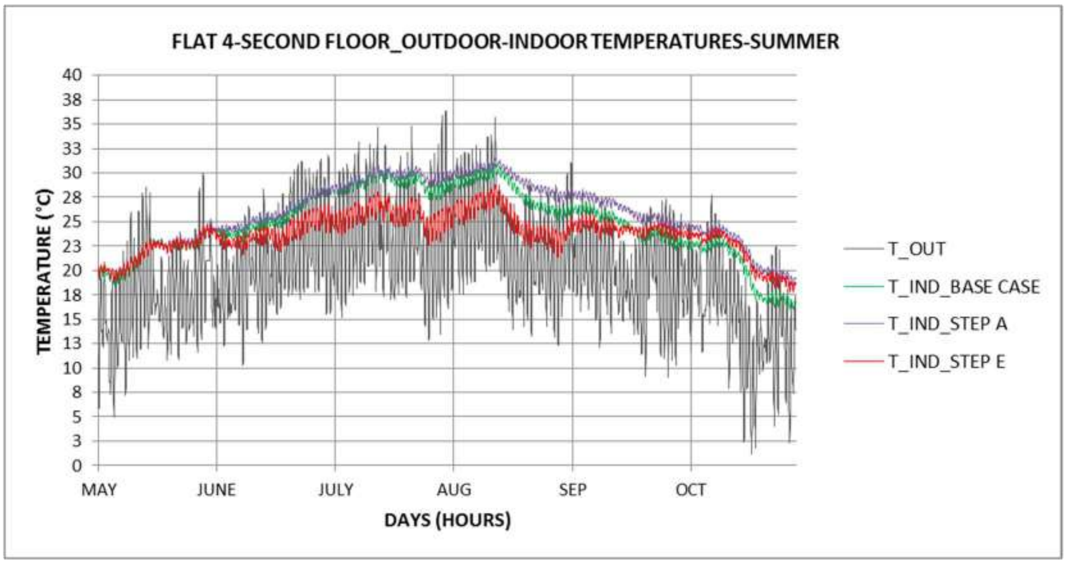

Figure 5.36: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qa19-FLOOR 2 FLAT 4).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.45	26.00	23.91	28.96	29.65	25.74	28.34	29.67	25.37
MAX T (°C)	29.20	29.19	26.98	30.59	31.03	28.00	30.96	31.80	28.83
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	21.77	22.23	21.91	24.85	26.56	24.33	20.24	22.42	21.64
MAX T (°C)	24.68	24.99	24.66	26.94	28.60	25.72	23.40	25.12	24.38
MIN T (°C)	18.45	19.13	18.76	22.06	23.97	22.94	15.91	18.46	17.69

Table 5.16: Temperature values during the worst months in Summer and during the shoulder season (Qa19-FLOOR 4 FLAT 2).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE during the shoulder months. In the other months it increases the humidity because of the increase of ACH, but it does not increase the hours with RH>70%:

- MAY: Decrease of 4% #hoursRH>60%;
- JUNE: Increase of 7% #hoursRH>70%;
- JULY: Increase of 19% #hoursRH>60%;
- AUGUST: Increase of 14% #hoursRH>70%;
- SEPTEMBER: Increase of 7% #hoursRH>70%;
- OCTOBER: Decrease of 12% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	4%	0%
JUNE	-5%	-7%
JULY	-38%	-3%
AUG	-19%	-3%
SEP	-5%	-6%
OCT	15%	12%

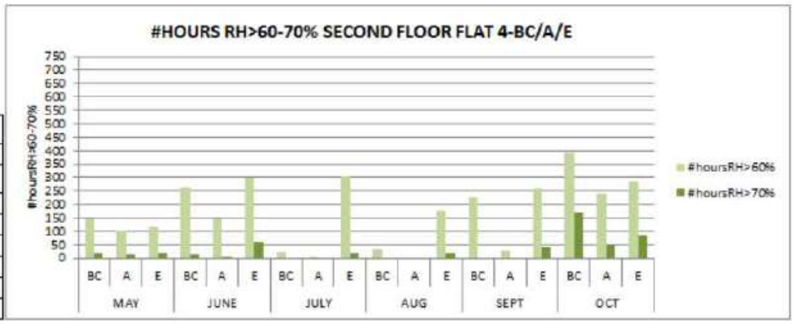

Figure 5.37: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qa19-FLOOR 4 FLAT 2).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in June, July, August and September. In July the decrease of temperatures below 26°C, despite the increase of RH (only hours above 60%), improves significantly the indoor comfort. In May the flat presents similar characteristics to those in BASE CASE, but it is worth to highlight the effects of the ventilation system: reduction of RH and increase of temperatures. In October the ventilation reduces the RH and increases the indoor temperatures, thanks to the smart control on the humidity and temperature.

$R_{PPD,6\text{-}10\text{-}15}$ (%) STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-1%	-1%	-2%
JUNE	6%	-19%	-26%
JULY	-19%	-55%	-77%
AUG	-27%	-45%	-47%
SEP	-53%	-26%	-3%
OCT	-28%	-19%	-7%

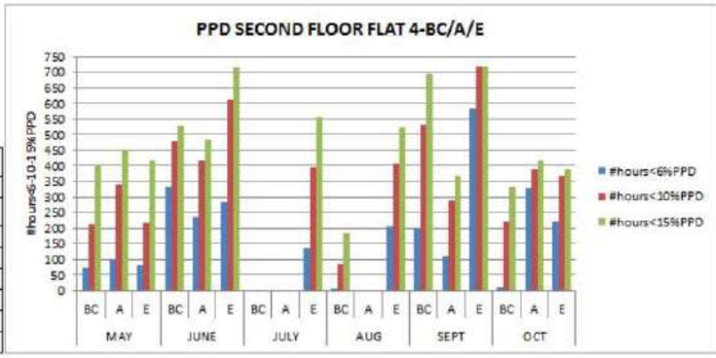

Figure 5.38 Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qa19-FLOOR 4 FLAT 2).

FLOOR 4: FLAT 4

TEMPERATURES:

- MAY: Small increase of the mean temperature value, close to the BASE CASE one;
- JUNE: Decrease of #hours>28°C (16%); the mean temperature value decreases compared to BASE CASE (≈1.60°C);
- JULY: Decrease of #hours>28°C (94%); the mean temperature value decreases of about 3°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (57%); the mean temperature value decreases of about 3°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>26°C (28%); the mean temperature value is slightly lower compared to the BASE CASE one;
- OCTOBER: The temperature increases and the mean value is increased of about 1.5°C in comparison with BASE CASE.

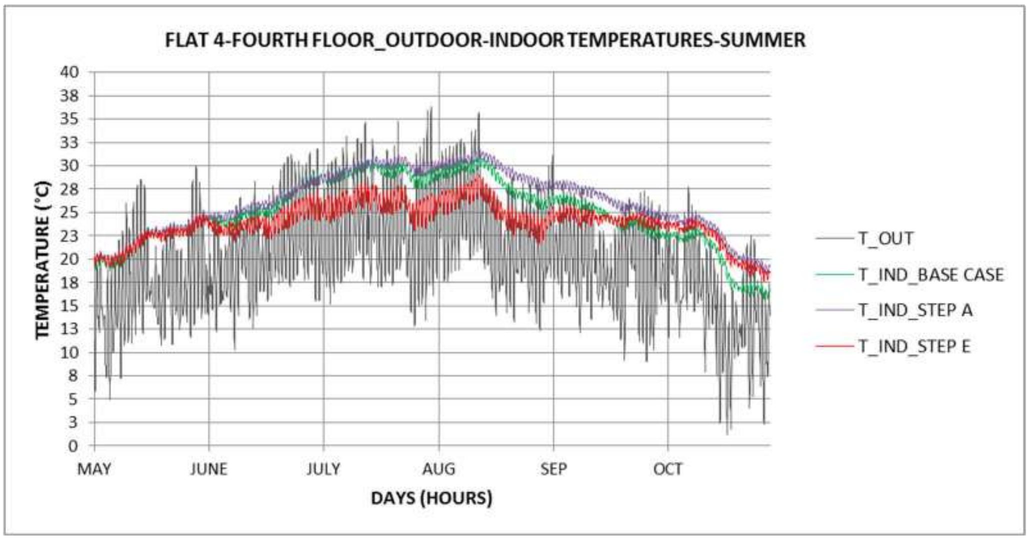

Figure 5.39: hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qa19-FLOOR 4 FLAT 4).

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%
JUNE	25%	16%
JULY	44%	94%
AUG	51%	57%
SEP	28%	0%
OCT	0%	0%

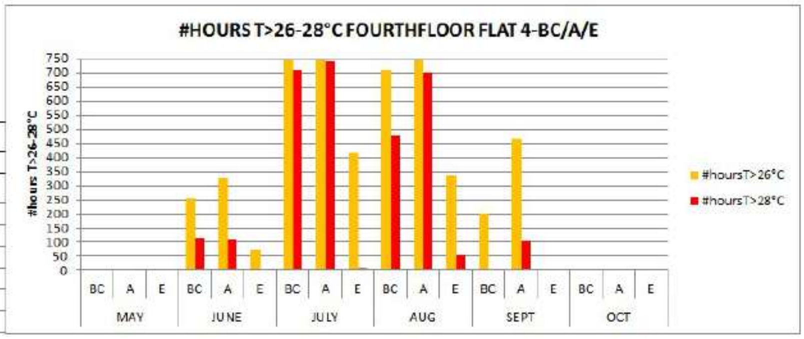

Figure 5.40: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qa19-FLOOR 4 FLAT 4).

The envelope recovery led to an increase of temperatures, albeit to a lesser extent compared to IOLO buildings.

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.71	26.12	24.12	29.27	29.85	26.06	28.55	29.84	25.64
MAX T (°C)	29.59	29.39	27.30	30.90	31.24	28.26	31.09	31.83	28.94
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	21.99	22.33	22.02	24.93	26.66	24.42	20.11	22.43	21.67
MAX T (°C)	25.02	25.10	24.78	27.07	28.65	25.79	23.32	25.13	24.38
MIN T (°C)	18.76	19.30	18.97	21.95	24.01	22.97	15.67	18.35	17.60

Table 5.17: Temperature values during the worst months in Summer and during the shoulder season (Qa19-FLOOR 4 FLAT 4).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in May and in October. In the other months the ventilation leads to increased Relative Humidity levels, but these latter do not overcome 70%:

- MAY: Small decrease of #hoursRH>60%; STEP E does not worsen the BASE CASE starting conditions;
- JUNE: The increase of Relative Humidity compared to BASE CASE is not relevant;
- JULY: Increase of hours with RH>60% (33%), but hours above 70%RH do not suffer increases;
- AUGUST: The increase of #hoursRH>60% is around 18%;
- SEPTEMBER: Small increase of Relative Humidity;
- OCTOBER: Decrease of 13% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	4%	-1%
JUNE	-3%	-5%
JULY	-33%	-2%
AUG	-18%	-2%
SEP	-6%	-5%
OCT	17%	13%

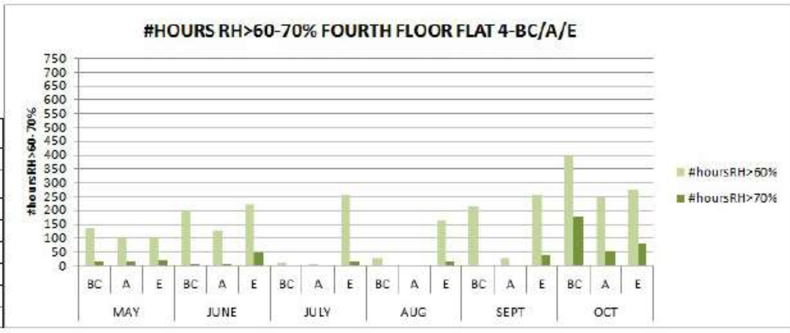

Figure 5.41: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qa19-FLOOR 4 FLAT 4).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in September and in June: the first one presents an increase of hours with PPD<6, as well as the second one. The strategy helps to decrease indoor temperatures In July and in August, improving indoor comfort levels compared to BASE CASE, even though it increases the humidity. The effect is more evident in August, because the smart ventilation control led to a mean temperature value below 26°C.

In May the flat shows a small improvement, demonstrated by the increase of hours with PPD<6%.

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-13%	-24%	-6%
JUNE	-1%	-2%	-1%
JULY	-3%	-11%	-28%
AUG	-31%	-35%	-32%
SEP	-13%	-4%	4%
OCT	-3%	7%	2%

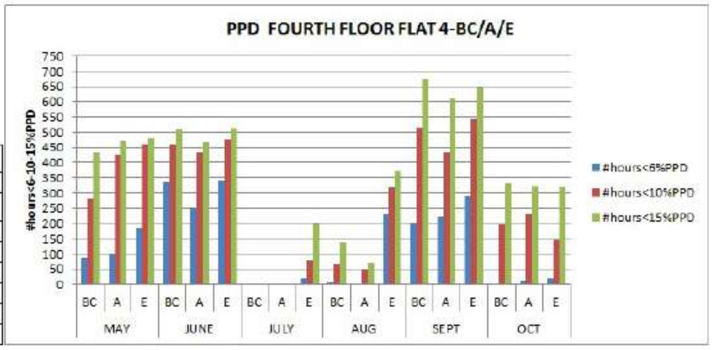

Figure 5.42: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qa19-FLOOR4-FLAT4).

SYNTHESIS

The envelope recovery in Qa19 led to an increase of temperatures in Summer months, as well as the other buildings analysed in this thesis. As we highlighted in the previous sections, this increase can be useful in the shoulder months (May and October) but it leads to worsen the thermal comfort conditions during the Summer central months (especially July and August). In these latter months, despite the increase of temperatures is less significant (about 1°C), compared to the other buildings, it is sufficient to worsen the indoor comfort conditions and the use of the ventilation system allows to decrease temperatures, even overcoming the initial conditions showed in BASE CASE. As in the other samples, in May and in October the increase of temperatures, compared to BASE CASE, has improved the thermal comfort, thanks to the smart ventilation control able to increase or decrease the air change rates according to the outdoor/indoor temperatures. In June and in September the slight increase of temperatures leads to better comfort conditions.

Qb16/Qb40

1. **Semi-stationary conditions**

We will apply the same verifications conducted in Chapter 3.

The Global Energy Performance index (***$EP_{gl,nren}$***) is:
$EP_{gl,nren}$= 55.76kWh/m^{2}y
$EP_{gl,nren,rif}$(2019,2021)= 46.89kWh/m^{2}y

The NEW building Energy Class is **B**, in fact:
1.00* $EP_{gl,nren,rif}$(2019,2021) < $\mathbf{EP_{gl,nren}}$ ≤ 1.20* $EP_{gl,nren,rif}$(2019,2021)

Taking into account the other verifications given by the standards:à

a. Mean global thermal exchange coefficient (***H'_T***)

Since the Climate Zone is D and S/V=0.5, the threshold H'_{Tlim}= 0.58 W/m^{2}K
H'_T= 0.47 W/m^{2}K→ $H'_T < H'_{Tlim}$ **VERIFIED**

In BASE CASE this verification was not satisfied, because of the high values of Transmittance of the building elements.

b. Envelope Energy Performance in Winter through the calculation of ***$EP_{H,nd}$***

$EP_{H,nd}$ = 29.43kWh/m^{2}y
$EP_{H,nd,lim}$(2019,2021)= 12.73kWh/m^{2}y
The result is:
1*$EP_{H,nd,lim}$(2019,2021) < $EP_{H,nd}$ ≤ 1.7*$EP_{H,nd,lim}$(2019,2021)
→ **MEDIUM QUALITY OF THE ENVELOPE**

In BASE CASE the quality of the envelope was LOW. It means that the envelope recovery led to a decrease of heat losses through the envelope.

c. Envelope Energy Performance in Summer through the evaluation of (***$A_{sol,est}$***) and (***Y_{IE}***)

$A_{sol,est}/S$= 0.082
Y_{IE}=0.01W/m^{2}K
The thresholds are:
$(A_{sol,est}/S)_{lim}$= 0.03
$(Y_{IE})_{lim}$= 0.14W/m^{2}K
The result is:
$A_{sol,est}/S > (A_{sol,est}/S)_{lim}$ *and* $Y_{IE} < (Y_{IE})_{lim}$ → **MEDIUM QUALITY OF THE ENVELOPE**

In BASE CASE the quality of the envelope was LOW. The addition of the insulation layer increased the thermal mass of the building elements, improving then the thermal inertia.

2. **Dynamic conditions**

The figure below shows the comparison between the Sensible Energy Demand for heating in BASE CASE and STEP A. The STEP A results, obtained through the dynamic simulations in Trnsys and by an average across all the flats during the heating season, show a decrease of almost the 50% of the total Energy Demand for heating, compared to BASE CASE.

REDUCTION (%)	
	STEP A/BASE CASE
JAN	44%
FEB	44%
MARCH	49%
APR	59%
NOV	56%
DEC	44%
TOTAL	**47%**

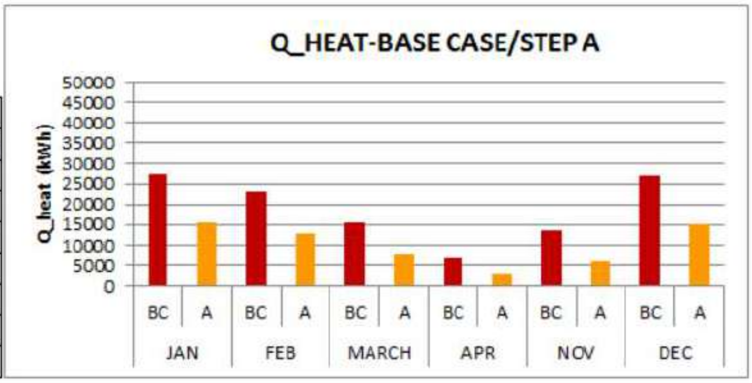

Figure 5.43: Monthly Sensible Energy Demand for heating in BASE CASE and STEP A (Qb16).

WHOLE BUILDING

For what concerns the internal comfort, the addition of an insulation layer on the facades leads to an increase of indoor temperatures, in the Summer central months, of about 1°C, less in comparison with the other buildings.

The fig. 5.44 shows the average hourly trend of indoor temperatures in the final STEP E compared to BASE CASE and STEP A. In the central months STEP E (red line) lowers temperatures compared to both STEP A (violet line) and BASE CASE (green line).

As it is also shown in the table below, the final Smart Ventilation Control Strategy (STEP E) leads to lower temperatures in the central months (in comparison with STEP A and BASE CASE). The mean temperature value in June falls down around 24°C. During the worst months, July and August, the mean temperature values reach values below 26°C.

In May the building shows temperatures close to BASE CASE; in October the smart ventilation control causes an increase of the mean value of temperatures, while in September the temperatures are close to BASE CASE values.

	JUNE			**JULY**			**AUGUST**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	25.03	25.87	23.74	28.33	29.37	25.45	27.78	29.34	25.09
MAX T (°C)	30.51	30.17	27.98	31.36	31.40	28.62	31.53	32.27	29.46
	MAY			**SEPTEMBER**			**OCTOBER**		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	21.36	22.05	21.77	24.41	26.21	24.13	20.03	22.25	21.56
MAX T (°C)	25.71	25.81	25.54	27.57	28.83	26.10	24.02	25.58	25.01
MIN T (°C)	17.19	18.52	18.32	20.39	21.76	21.76	14.93	17.32	16.59

Table 5.18: Temperature values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in Qb16.

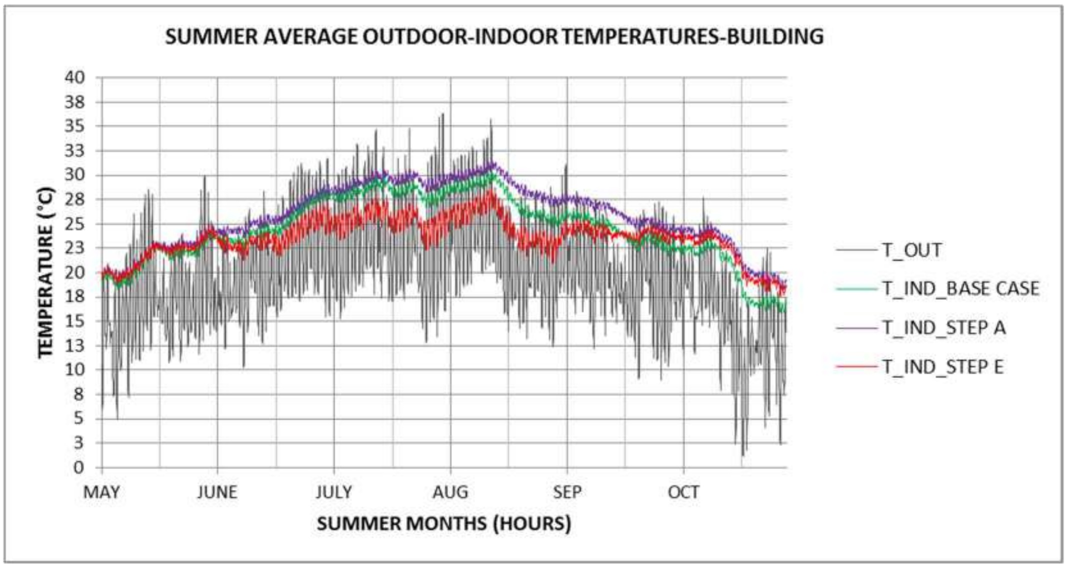

Figure 5.44: Hourly trend of temperatures in Summer (WHOLE BUILDING). Comparison between BASE CASE, STEP A, STEP E and outdoor temperatures in Qb16.

Taking into account the mean values of Relative Humidity in Summer months, we can note that they decrease compared to BASE CASE in May, October and in September the value is almost equal to BASE CASE one; in June, July and August there is a little increase. By the way in August the mean value of RH is below 60%, while in June it overcomes of a not relevant rate. In July the mean RH value is around 60% (threshold for comfort).

Conversely all the values increase in comparison with STEP A, but this is the consequence of the increase of indoor temperatures due to the envelope recovery.

BUILDING MEAN RH VALUES (%)			
	BASE CASE	**STEP A**	**STEP E**
MAY	56.21	53.88	54.69
JUNE	60.28	57.29	63.02
JULY	52.71	49.60	60.04
AUGUST	48.30	44.13	54.43
SEPTEMBER	59.14	53.09	59.40
OCTOBER	61.35	53,71	55.81

Table 5.19: RH values during the worst months in Summer and during the shoulder season (WHOLE BUILDING). Comparison between BASE CASE, STEP A and STEP E in Qb16.

FLATS:

The analysis takes into account the comparison between the results of BASE CASE, STEP A and STEP E for the flats taken as sample cases in chapter 3.

FLOOR 1: FLAT 1

TEMPERATURES:

- MAY: The temperatures suffered a little decrease compared to BASE CASE;
- JUNE: This flat does not present high temperature values in this month. Nevertheless the ventilation system lowers the mean temperature value. In this case the envelope recovery has not improved the indoor temperatures. The thermal inertia contributed to keep the indoor temperatures close to the initial values.
- JULY: Decrease of #hours>28°C (99%); the mean temperature value decreases of almost 4°C compared to BASE CASE; The mean temperature value is below 26°C; also in this case the envelope recovery did not increase the indoor temperatures significantly;
- AUGUST: Decrease of #hours>28°C (58%); the mean temperature value decreases of about 3°C compared to BASE CASE; The mean temperature value is below 26°C; the envelope recovery increased the indoor temperature of about 1°C;
- SEPTEMBER: Decrease of the mean temperature value of about 1.30°C;
- OCTOBER: Small increase of temperatures. The mean value is close to the BASE CASE one.

$R_{T,26-28}$ (%) STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%
JUNE	27%	25%
JULY	53%	99%
AUG	58%	58%
SEP	39%	0%
OCT	0%	0%

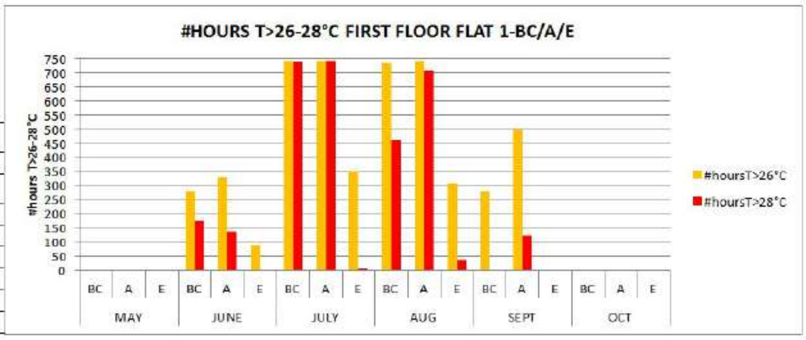

Figure 5.45: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qb16-FLOOR 1 FLAT 1).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	26.25	26.25	24.06	29.51	29.82	25.78	28.76	29.78	25.34
MAX T (°C)	30.36	29.67	27.70	31.10	31.07	28.07	31.34	31.90	28.86
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	22.51	22.39	22.03	25.31	26.77	24,47	20.77	22.83	21.99
MAX T (°C)	25.71	25.23	24.88	27.57	28.83	25,76	24.02	25.58	24.65
MIN T (°C)	18.90	19.22	18.81	22.46	24.35	23,21	16.66	18.99	18.14

Table 5.20: Temperature values during the worst months in Summer and during the shoulder season (Qb16-FLOOR 1 FLAT 1).

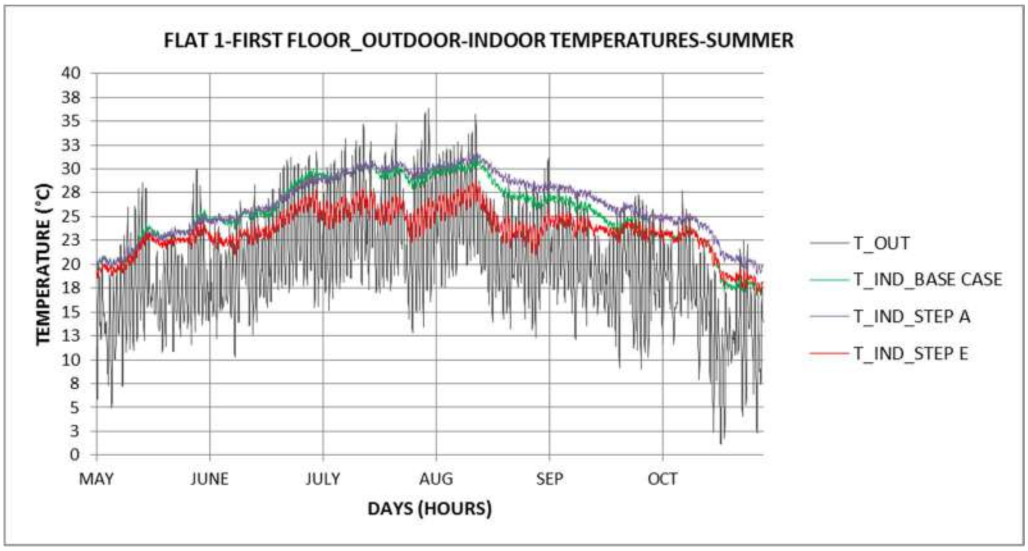

Figure 5.46: hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qb16-FLOOR 1 FLAT 1).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE.

- MAY: No relevant changes in the RH levels;
- JUNE: Increase of 16% #hoursRH>60%;
- JULY: Increase of 39% #hoursRH>60%;
- AUGUST: Increase of 19% #hoursRH>60%;
- SEPTEMBER: Increase of 6% #hoursRH>70%;
- OCTOBER: Decrease of 13% #hoursRH>70%.

$R_{RH,60\text{-}70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	-3%	-1%
JUNE	-16%	-8%
JULY	-39%	-2%
AUG	-19%	-3%
SEP	-8%	-6%
OCT	14%	13%

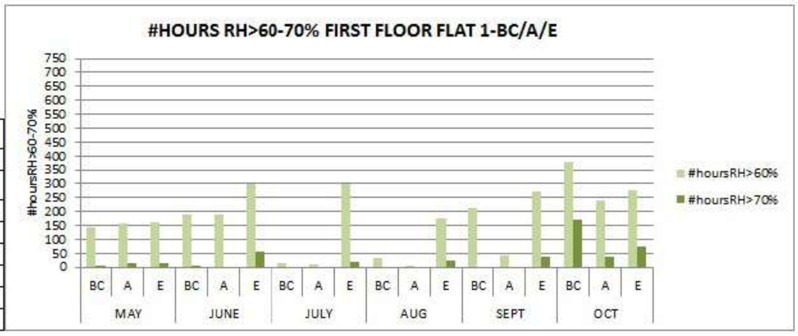

Figure 5.47: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qb16-FLOOR 1 FLAT 1).

COMFORT INDEX (PPD VALUES):

The most relevant increase of internal comfort is shown in September, June, July and August. In September, the decrease of indoor temperatures leads to the improvement of thermal comfort. In July and August the lower temperatures (below 26°C) make the flat more comfortable. In June there is an increase of hours with PPD<6% (the best comfort condition), due to the decrease of Relative Humidity for the introduction of the smart controller. In May the comfort conditions inside the flat is similar to the BASE CASE. In October the thermal comfort conditions are equal to those in BASE CASE, with a significant reduction in the RH levels.

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-10%	22%	4%
JUNE	-4%	-25%	-33%
JULY	-19%	-55%	-80%
AUG	-30%	-52%	-62%
SEP	-51%	-38%	-17%
OCT	-24%	-10%	-2%

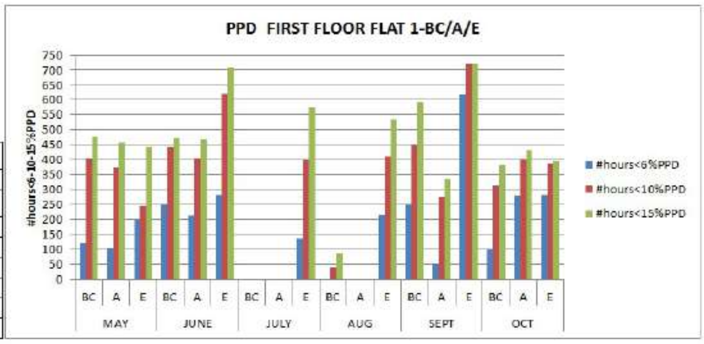

Figure 5.48: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qb16-FLOOR 1 FLAT 1).

FLOOR 3: FLAT 1

TEMPERATURES:

- MAY: Slight increase of the mean temperature value);
- JUNE: Decrease of #hours>26°C (26%); Decrease of the mean temperature value (≈1.5°C);
- JULY: Decrease of #hours>28°C (89%); the mean temperature value decreases of almost 3°C compared to BASE CASE, falling below 26°C;
- AUGUST: Decrease of #hours>28°C (44%); the mean temperature value decreases of almost 3°C compared to BASE CASE, falling below 26°C;
- SEPTEMBER: Decrease of #hours>26°C (22%); the mean temperature value is close to the BASE CASE one;
- OCTOBER: Increase of the mean temperature value (≈1.5°C).

$R_{T,26-28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	0%	0%
JUNE	25%	6%
JULY	76%	75%
AUG	52%	54%
SEP	19%	0%
OCT	0%	0%

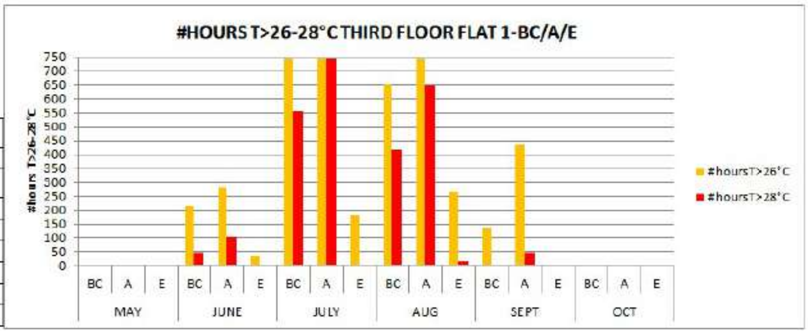

Figure 5.49 Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qb16-FLOOR 3 FLAT 1).

	JUNE			JULY			AUGUST		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	25.07	25.97	23.63	28.41	29.51	25.27	27.95	29.52	24.96
MAX T (°C)	28.90	29.37	26.86	29.98	30.77	27.53	30.64	31.75	28.55
	MAY			SEPTEMBER			OCTOBER		
	BC	STEP A	STEP E	BC	STEP A	STEP E	BC	STEP A	STEP E
MEAN T (°C)	21.37	22.11	21.74	24.75	26.57	24.22	20.57	22.75	21.89
MAX T (°C)	24.24	24.86	24.50	26.84	28.55	25.39	23.72	25.44	24.59
MIN T (°C)	18.39	19.28	18.86	22.25	24.27	22.84	16.48	18.95	18.07

Table 5.21: Temperature values during the worst months in Summer and during the shoulder season (Qb16-FLOOR 3 FLAT 1).

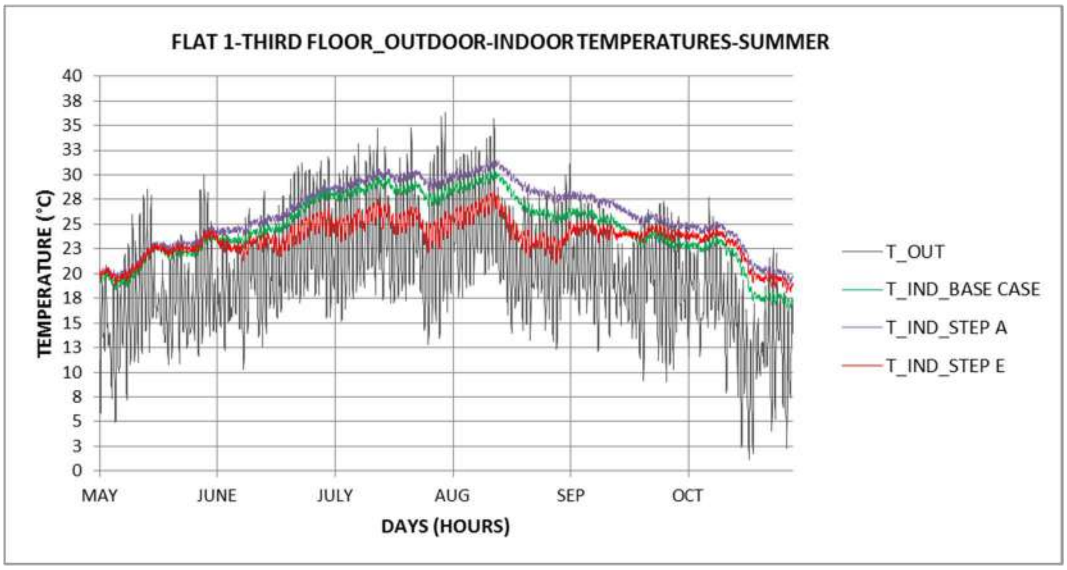

Figure 5.50: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (QB16-FLOOR 3 FLAT 1).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in comparison with BASE CASE during the shoulder months. In the other months, it increases the humidity because of the increase of ACH, but the increase is not significant:

- MAY: Decrease of 7% #hoursRH>60%;
- JUNE: Increase of 8% #hoursRH>70%;
- JULY: Increase of 40% #hoursRH>60%; this percentage is compensated from the decrease of temperatures and the increase of comfort levels;
- AUGUST: Increase of 17% #hoursRH>70%;
- SEPTEMBER: Increase of 5% #hoursRH>70%;
- OCTOBER: Decrease of 15% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	7%	2%
JUNE	-6%	-8%
JULY	-40%	-6%
AUG	-17%	-5%
SEP	1%	-5%
OCT	15%	15%

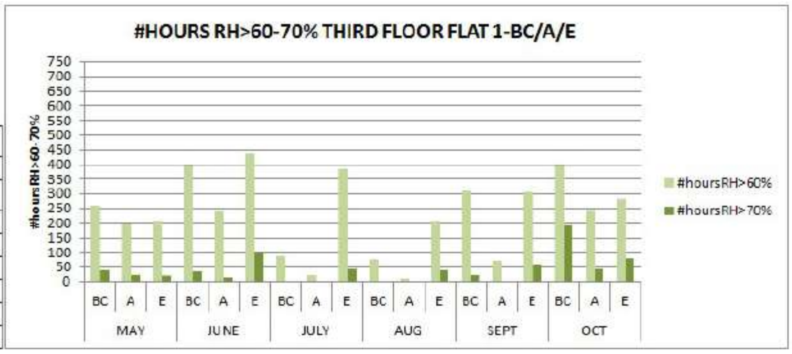

Figure 5.51: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qb16-FLOOR 3 FLAT 1).

COMFORT INDEX (PPD VALUES):

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in July, August and September. In July the decrease of temperatures below 26°C, despite the increase of RH (hours above 60%), improves significantly the indoor comfort. The reduction of indoor temperatures in September without worsening RH levels compared to BASE CASE, makes the flat more comfortable. In May the flat presents similar characteristics to those in BASE CASE, but it is worth to highlight the effects of the ventilation system: reduction of RH and increase of temperatures. In October the ventilation reduces the RH and increases the indoor temperatures, thanks to the smart control on the humidity and temperature.

$R_{PPD,6\text{-}10\text{-}15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	-5%	-4%	-15%
JUNE	15%	-6%	-22%
JULY	-27%	-69%	-94%
AUG	-19%	-42%	-43%
SEP	-63%	-21%	0%
OCT	-32%	-15%	-3%

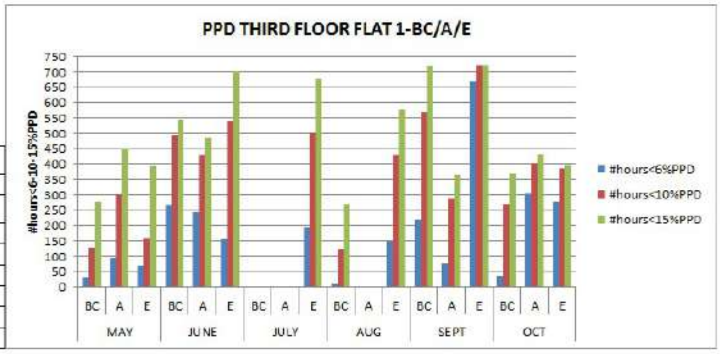

Figure 5.52: Comparison between the PPD index values in BASE CASE, STEP A and STEP E. (Qb16-FLOOR 3 FLAT 1).

FLOOR 6: FLAT 1

TEMPERATURES:

- MAY: Small increase of the mean temperature value, close to the BASE CASE one;
- JUNE: Decrease of #hours>28°C (21%); the mean temperature value decreases compared to BASE CASE (≈1.6°C);
- JULY: Decrease of #hours>28°C (96%); the mean temperature value decreases of about 3°C compared to BASE CASE;
- AUGUST: Decrease of #hours>28°C (54%); the mean temperature value decreases of about 3°C compared to BASE CASE;
- SEPTEMBER: Decrease of #hours>ò26°C (28%); the mean temperature value is slightly lower compared to the BASE CASE one;
- OCTOBER: The temperature increases and the mean value is increased of about 1.6°C in comparison with BASE CASE.

$R_{T,26\text{-}28}$ (%)		
STEP E/BASE CASE		
	$R_{T,26}$	$R_{T,28}$
MAY	-12%	0%
JUNE	24%	21%
JULY	54%	96%
AUG	56%	54%
SEP	28%	0%
OCT	0%	0%

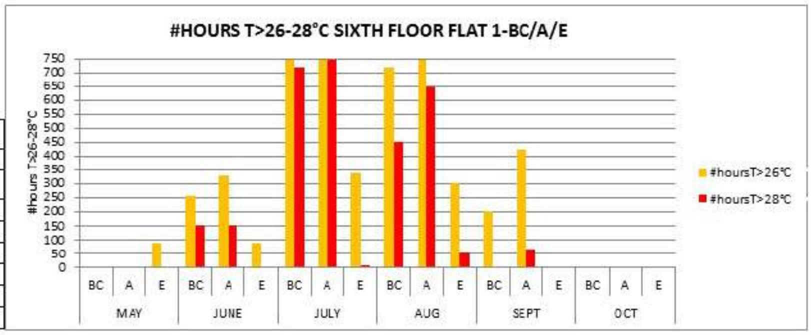

Figure 5.53: Comparison between the number of hours exceeding 26-28°C in STEP E, BASE CASE and STEP A (Qb16-FLOOR 6 FLAT 1).

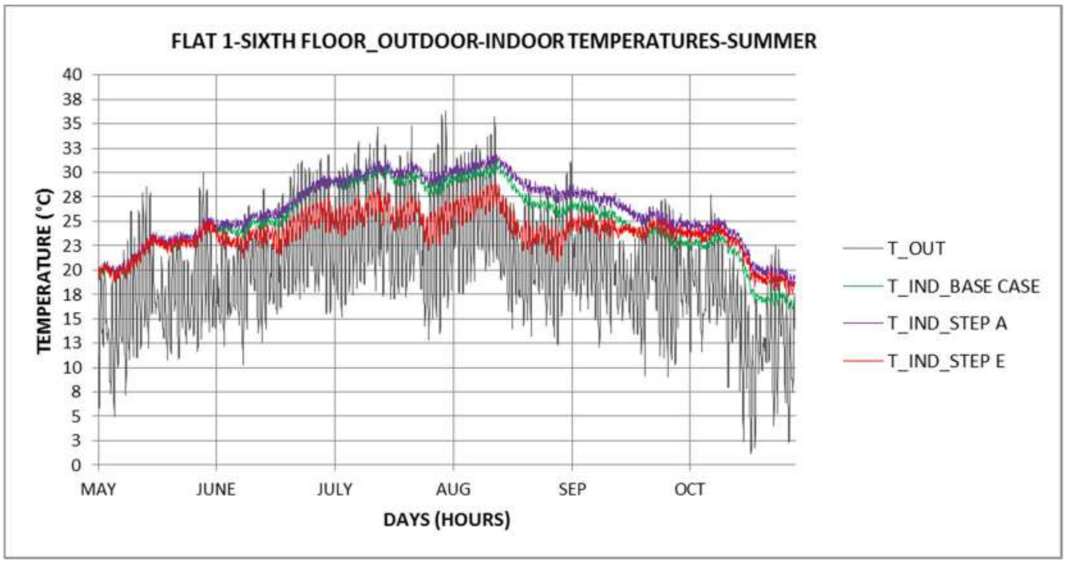

Figure 5.54: Hourly trend of temperatures in Summer. Comparison between BASE CASE, STEP E and outdoor temperatures (Qb16-FLOOR 6 FLAT 1).

The envelope recovery led to an increase of temperatures, albeit to a lesser extent compared to IOLO buildings, due to the better thermal inertia of the envelope.

	JUNE			JULY			AUGUST		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	25.71	26.12	24.12	29.27	29.85	26.06	28.55	29.84	25.64
MAX T (°C)	29.59	29.39	27.30	30.90	31.24	28.26	31.09	31.83	28.94

	MAY			SEPTEMBER			OCTOBER		
	BC	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**	**BC**	**STEP A**	**STEP E**
MEAN T (°C)	21.99	22.33	22.02	24.93	26.66	24.42	20.11	22.43	21.67
MAX T (°C)	25.02	25.10	24.78	27.07	28.65	25.79	23.32	25.13	24.38
MIN T (°C)	18.76	19.30	18.97	21.95	24.01	22.97	15.67	18.35	17.60

Table 5.22: Temperature values during the worst months in Summer and during the shoulder season (Qb16-FLOOR 6 FLAT 1).

RELATIVE HUMIDITY (RH):

The smart ventilation control reduces the Relative Humidity in May and in October. In the other months the ventilation leads to increased Relative Humidity levels, but there is not a significant increase of RH>70%:

- MAY: Small decrease of #hoursRH>70%; The humidity conditions are similar to those in BASE CASE;
- JUNE: The increase of Relative Humidity compared to BASE CASE is not relevant;
- JULY: Increase of hours with RH>60% (30%);
- AUGUST: The increase of #hoursRH>60% is around 13%;
- SEPTEMBER: Small increase of Relative Humidity;
- OCTOBER: Decrease of 14% #hoursRH>70%.

$R_{RH,60-70}$ (%)		
STEP E/BASE CASE		
	$R_{RH,60}$	$R_{RH,70}$
MAY	11%	3%
JUNE	-6%	-5%
JULY	-30%	-3%
AUG	-13%	-4%
SEP	2%	-3%
OCT	13%	14%

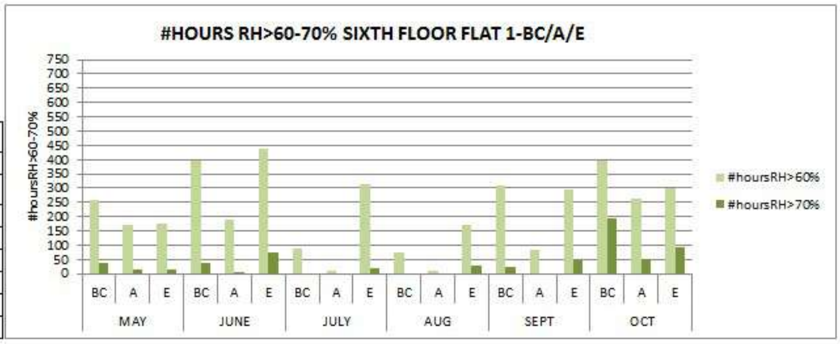

Figure 5.55: Comparison between the number of hours above 60-70% RH in STEP E, BASE CASE and STEPA (Qb16-FLOOR 6 FLAT 1).

<u>COMFORT INDEX (PPD VALUES):</u>

According to the PPD index, verifying the three different percentages of dissatisfied (6-10-15%), the most relevant increase of internal comfort is shown in June, July, August and September. The cause of the significant improvement of comfort (increase of hours with PPD<6-10-15%), in July and August is due to the mean value of temperature below 26°C and the increase of RH does not worsen the indoor conditions.

In May the flat shows a small improvement, demonstrated by the increase of hours with PPD<10%. In October the increase of temperature and the reduction of RH improve the indoor comfort conditions (increase of #hoursPPD<6%). In June the flat presents higher levels of RH compared to BASE CASE, but the decrease of temperatures improves the thermal comfort. In September the increase of RH is not relevant, but the decrease of indoor temperatures makes the flat more comfortable.

$R_{PPD,6-10-15}$ (%)			
STEP E/BASE CASE			
	$R_{PPD,6}$	$R_{PPD,10}$	$R_{PPD,15}$
MAY	0%	-2%	2%
JUNE	17%	-16%	-28%
JULY	-20%	-54%	-76%
AUG	-26%	-45%	-47%
SEP	-46%	-32%	-8%
OCT	-30%	-16%	-6%

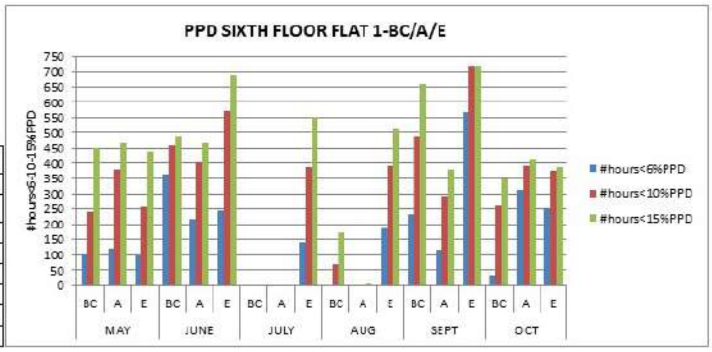

Figure 5.56: Comparison between the PPD index values in BASE CASE, STEP A, STEP E. (Qb16-FLOOR 6-FLAT 1).

<u>**SYNTHESIS**</u>

The envelope recovery in Qb16 led to an increase of temperatures in Summer months, as well as the other buildings analysed in this thesis. As we highlighted in the flats analysis, this increase can be useful in the shoulder months (May and October) but it leads to worsen the thermal comfort conditions during the Summer central months (especially July and August). In this latter months, despite the increase of temperatures is less significant (about 1°C), compared to the other buildings, it is sufficient to worsen the indoor comfort conditions and the use of the ventilation system allows to decrease the temperatures, even overcoming the initial conditions showed in BASE CASE.

5.3 SYNTHESIS OF THE RESULTS

According to the previous discussion, the recovery method studied for BUILDING A led to good results also in the other buildings. The envelope recovery led to better energy efficiency in Winter, but higher temperatures in Summer. The addition of a ventilation system, calibrated according to the different Summer months, led to improvements of indoor comfort conditions during all Summer months. The results of the whole building analysis have been confirmed by the detailed study of each flat answer in terms of indoor comfort (temperatures, RH, PPD index). More in detail:

COMPLEX A: BUILDING B

This building confirms what we found in BUILDING A.

<u>WINTER:</u>

- Decrease of about 40% of the sensible Energy Demand for heating
- The NEW Energy class is B.

<u>SUMMER:</u>

- MAY:
  Increase of the mean temperature value (≈1°C);
  Decrease of #hoursRH>70% (≈10%);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- JUNE:
  Decrease of the mean temperature value (≈1°C);
  Decrease of #hoursRH>70% (10%÷20%);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- JULY:
  Decrease of the mean temperature value (2°C÷2.5°C);
  Negligible effects on the Relative Humidity;
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- AUGUST:
  Decrease of the mean temperature value (2°C÷2.5°C);
  Negligible effects on the Relative Humidity;
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- SEPTEMBER:
  The temperatures on average are equal to BASE CASE values;
  Decrease of #hoursRH>70% (≈10%);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied);
- OCTOBER:
  Increase of the mean temperature value (≈1°C);
  Decrease of #hoursRH>70% (≈10%);

Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied).

COMPLEX B

All the buildings present lower temperatures compared to the buildings in COMPLEX A, but as we analysed in chapter 3, especially in the central months, the indoor comfort conditions are low (temperatures are above 26°C anyway) and on the shoulder months (May and October) temperatures are often too low:

<u>WINTER:</u>

- Decrease of about 40-50% of the sensible Energy Demand for heating;
- The NEW Energy class is B in all the buildings.

<u>SUMMER</u> (making a unique consideration for all the buildings):

- MAY:
  Similar values of temperatures compared to BASE CASE;
  Small decreases of RH or same values compared to BASE CASE;
  Similar comfort conditions compared to BASE CASE.
- JUNE:
  Decrease of the mean temperature value (1÷1.5°C);
  No relevant increases of Relative Humidity levels; the most relevant increase is shown in Qb16;
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied).
- JULY:
  Decrease of the mean temperature value (2÷3°C);
  Increase of #hoursRH>60% (20÷40%);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied).
- AUGUST:
  Decrease of the mean temperature value (2°C÷3°C);
  Negligible effects on the Relative Humidity;
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied).
- SEPTEMBER:
  The temperatures on average are equal to BASE CASE values;
  No relevant increases of Relative Humidity levels;
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied).
- OCTOBER:
  Increase of the mean temperature value (1÷1.8°);
  Decrease of #hoursRH>70% (15÷20%);
  Improvement of indoor comfort conditions (increase of hours with PPD<6-10-15% that means a reduction of percentage of dissatisfied).

Summarizing the steps of the recovery procedure, firstly we applied the minimum insulation layer on the façade and slabs to compliant the transmittance values of the National Standards, as well as for the choice of the new windows (STEP A). We decided to not intervene on the technical implants: neither interventions on the heating system nor adding of a mechanical cooling system. This because, as we already mentioned, the aim of this work was to find a recovery method able to improve both the energy performance and the internal comfort by intervening as less as possible on the buildings and to reduce as much as possible costs for interventions. The results in terms of energy class can be further improved by the substitution of the implants with more efficient ones or by deeper interventions on the envelope. All these strategies imply higher costs and more complicated construction works.

The idea was to verify what was the answer in terms of Energy Performance and Indoor Thermal Comfort of the buildings, by applying the most common technique for the envelope recovery. The results for all the buildings analysed were a reduction in terms of energy demand for heating, but a consequent increase of the indoor temperatures with low levels of indoor comfort. The magnitude of this increase depended on the thermal inertia. In COMPLEX A, with lower thermal inertia the increase was much higher than in the other complex buildings, but both presented higher indoor temperatures after the envelope recovery.

The application of the ventilation system, as a more efficient system in terms of energy demand (it uses only the electricity for the fan functioning) and installation costs (the supply system is the less expensive mechanical ventilation system) in place of an air-conditioning system (energy-hungry and it is one of the causes of the global warming) led to better conditions in terms of thermal comfort in all the buildings taken as sample cases. In May and in October the smart ventilation control (STEP E) led to temperatures and RH levels equal or even better compared to the BASE CASE. Of course STEP A, if on one side increased the indoor temperatures, on the other side it decreased the RH.

The improvement of the ventilation rates has been studied in order to not worsen as much as possible the initial humidity conditions (BASE CASE) or if it happened it was verified the answer in terms of thermal comfort. Indeed, as regards IOLO, the improvement of ACH led always to decreases of the Relative Humidity or to the same levels as in BASE CASE. Conversely in COMPLEX B, the Relative Humidity increased compared to STEP A in the central months of the Summer (June, July and August), but only hours above 60% of RH (the increase of hours above 70%RH was negligible) but the improvement of the thermal comfort was even better than in COMPLEX A; this demonstrates the fact that the temperature is the main factor influencing the thermal comfort sensation of the human being. The RH levels have to be taken under control for the IAQ and they can cause issues on the construction. In the analysed cases these levels can be considered acceptable. The smart ventilation control led to improved thermal comfort conditions in Summer in all the analysed buildings.

From the analyses conducted in chapter 3 where recurring features and common issues in the energy performance among all the sample buildings were evaluated, along with the results obtained from this chapter, it is possible to state that the refurbishment method applied on BUILDING A and validated on the other sample cases can be spread to other buildings presenting similar characteristics and located in comparable climate zones.

6. CONCLUDING REMARKS AND OUTLOOKS

The research analyses the behaviour in terms of energy consumption and thermal comfort of 5 public residential buildings (2 building complexes) made with industrialized techniques located in the Florence area before and after the application of a recovery method for their sustainable refurbishment.

The thesis is structured in 5 main chapters:

CHAPTER 1:

The chapter analyses the field of interest, the aim and the methodology of the work. It explains the current situation of social housing in Italy, with a particular attention given to Florence area. Moreover, it explains the research activity carried out from the building technology group of the University of Florence about the public residential buildings built during the '60s-'80s from the I.A.C.P and made with industrialized techniques. A detailed cataloguing of these buildings was made, through the study and analyses of documentation found in Casa S.p.A Archive. Among these buildings the most representative were chosen for the analysis conducted in this thesis. The chapter shows the motivations of this choice. On one hand, the buildings were chosen for the structural system (great panels structure), that represents the most common construction system used in that period; on the other hand we decided to study 2 different building complexes: one with the common organization of a small district consisting of 2 buildings with a shared courtyard (COMPLEX A-IOLO) and the other one consisting of 4 buildings spread in the neighbourhood located in the Firenze suburb, without therefore a common courtyard (COMPLEX B-FIRENZE).

CHAPTER 2:

The chapter deals with the literature review. The first part analyses the common methodology used in a sustainable refurbishment, in order to understand how to intervene in our case as well. The second part summarizes some examples of public residential buildings refurbishment in Europe and in Italy, with the aim at finding the most common issues and the typical strategies for the recovery of this type of residential buildings. Furthermore an overview of the current research programs in the EU in the social housing recovery field is shown. The latter was useful to understand where and how this research can be located, by addressing the research towards the intervention at the building scale.

CHAPTER 3:

This chapter analyses the buildings chosen for the study. This analysis consists of two sections. The first one is the study of the Environmental and Technological System where the main characteristics of the buildings from the architectural point of view are investigated aiming at finding recurring features and constraints. The second part consists of the Energy Analysis of the constructions, both to understand their energy performance in Winter and the thermal comfort conditions in Summer (BASE CASE). The buildings behaviour was simulated through the use of the dynamic software Trnsys, in order to know in detail, hour by hour, the energy consumption of each thermal zone (each flat), as well as the fundamental parameters necessary to evaluate the indoor comfort conditions (Temperatures, Relative Humidity, Absolute Humidity). The worst flat per floor for each building (taking into account both high temperature values and high RH levels) was chosen as sample case to be monitored in the application of the recovery strategies. Both sections were useful to highlight if the buildings could be considered comparable from the architectural point of view, and which issues they could present. This analysis led to the choice of a common recovery strategy, starting from the common issues highlighted: great Energy Demand for Heating in Winter and high indoor temperatures in Summer and the consequent thermal discomfort.

CHAPTER 4:

This is the main chapter of the thesis were the recovery method is defined. “BUILDING A” in the COMPLEX A is taken as sample case for the definition of the recovery criteria. According to the results obtained in the previous chapter, this section analyses different steps for the renovation, starting from the envelope recovery (insulation layer and windows substitution-STEP A) for solving heat losses in Winter, until arriving to the application of a mechanical ventilation system used as “cooling-system” (STEP E), instead of a simple IAQ controller. These steps were performed by evaluating the answer of the buildings in terms of thermal comfort of the flats chosen in the previous chapter. The chapter shows different systems of mechanical ventilation systems and gives motivation of preferring this kind of ventilation rather than the natural one. At the end the recovery method for BUILDING A is defined, consisting of, firstly, an envelope recovery and finally helped by the addition of a mechanical ventilation system. The latter is applied by studying a specific smart control on the number of air change rates, according to the different months and internal comfort conditions. The results show the improvement of thermal comfort conditions and energy performance.

CHAPTER 5:

This chapter presents the results obtained from the application of the recovery method on all the other buildings. The results are still presented by the analyses of the answer in terms of energy performance of the buildings and thermal comfort of the sample flats. The results show an improvement in both the two aspects, even though the two building complexes present slight differences in terms of indoor temperatures and relative humidity levels. This demonstrates that the results in terms of improved comfort conditions and energy performance obtained in BUILDING A, can be spread also to buildings that present similar characteristics.

As we already mentioned, the work started from a research conducted in the field of public residential buildings in Florence realized with industrialized/prefabricated techniques, that led to the possibility to study in detail a series of buildings and then to choose which of them to analyse in this thesis.

The study of the literature on the sustainable renovation of social housing led to understand the recurring issues in this type of buildings, which can be social and technological at the same time. The social aspect is taken into account in a renovation at the neighbourhood scale: the districts are often organized in more than one building, linked to each other by common areas or courtyards, presenting degradation and unused spaces. The technological aspect is analysed when we intervene at the building scale, because these constructions often present structural and material degradation as well as energy performance weaknesses. We decided to intervene at the building scale, because from the analysis of the current state, the buildings demonstrated high levels of discomfort especially during the central months in Summer and high energy consumption in Winter. The choice of the strategies derived from the fact that we are dealing with public residential buildings: this means low cost interventions and intervening without worsening the users’ life by keeping them inside the buildings even during the recovery works. Moreover the study of the technological system highlighted that, because of the structure made with great panels in reinforced concrete, the possibilities of modifying the construction were limited. The external walls do not allow the realization of great openings. Furthermore there are constraints in the modification of the internal distribution of the flats in the buildings located in Prato (COMPLEX A): the load-bearing transversal walls mark the division between the rooms and therefore openings in these elements could worsen the structural behaviour of the whole building. The COMPLEX B buildings do not present the same issues: the structure is organized in boxes where only the external walls are load-bearing and the rooms are divided though simple internal partitions. Nevertheless, the aim of the work was to find a common strategy able to be applied on all the analysed buildings, so that this kind of intervention was not taken into account. From the analysis of the state of the art, the most common strategy in a recovery intervention is the recovery of the envelope by the application of an insulation layer on the façade and slabs, the substitution of the windows and the technical implants. Accordingly the first step of the recovery procedure was the application of the insulation on the façade/slabs along with the substitution of the external windows with more efficient ones. The choice of the insulation layer thickness or the windows transmittance depended on the compliance with the Standards (minimum values). The substitution of the implants was not considered, trying to evaluate the answer of the buildings only by the intervention on the envelope (still in the field of low-cost interventions). The strategies have been applied, firstly, only on one building (BUILDING A-COMPLEX A), in order to find the “best fitting” and then, given that all the buildings should behave the same, they have been applied on the other buildings as well (validation of the method). The results in BUILDING A showed a decrease of about 40% of the energy demand for heating, but a great increase of temperatures in Summer, due to the fact that the thermal inertia of the envelope was not sufficient both to stop the heat going inside the envelope, and to allow the gathered heat to go out from the structure. The further strategy was then the application of a ventilation system, by exploiting the “ventilative cooling” through the exploitation of the outdoor cooler air (especially during the night). A mechanical ventilation system was chosen, rather than exploiting natural ventilation techniques. The causes of this choice were:

- natural driving forces are not always sufficient to guarantee the right number of air change rates, useful for cooling the spaces and they depend on temperatures differences, on wind strengths and precise openings on the façade capable to create the necessary air movements inside the flat;
- a mechanical ventilation system, used only during Summer months, ensures the right number of air change rates and at the same time it can keep a good indoor air quality, by removing the contaminants.

The mechanical ventilation system chosen was a simple stream supply system (MSV). This system works by pressurizing the home. Indeed, fresh outdoor air is introduced into the house with a fan, forcing indoor air out through openings realized in the building envelope. The system functioning can be helped by the windows’ opening either from the users or mechanically. Several simulations with different number of air change rates (ACH) were performed until to find the correct number to set up on the ventilation system. The ventilation system works by improving the ACH up to the values considered necessary for improving thermal comfort conditions. In the central months of Summer (July and August) ACH=2/h (when $T\_out<T\_ind$), led to a decrease of indoor temperatures up to 2.8°C, without worsening Relative Humidity levels, compared to BASE CASE results. In May the choice of setting ACH=0.5/h led to improved comfort conditions because of the increase of indoor temperatures (≈1°C) and the decrease of Relative Humidity levels, still in comparison with BASE CASE

results. In June, September and October a control on humidity levels was performed, by varying the ACH in accordance with humidity ratio values (for October) and still considering the outdoor/indoor temperatures as control factors, but through over-venting or under-venting, in relation to both outdoor/indoor humidity and outdoor/indoor temperatures. The results were a reduction of indoor temperatures in June (≈1°C) and a decrease of RH levels, as well as in September when temperatures resulted equal to the BASE CASE ones. In October temperatures increased (≈1°C), along with a decrease of Relative Humidity. The thermal comfort conditions improved in comparison with STEP A. This system needs the installation of temperature and humidity sensors. In the table the smart ventilation control settings are shown, as a reminder.

MONTH	**ACH (h^{-1})**
MAY	**0.5**
JUNE	**T_IND>26°C** **2:** when T_OUT<T_IND **1:** when T_OUT>T_IND **T_IND<26°C** **1:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND
JULY	**2:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND
AUGUST	**2:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND
SEPTEMBER	**T_IND>26°C** **1:** when T_OUT<T_IND **0.5:** when T_OUT>T_IND **T_IND<26°C** **0.5:** always
OCTOBER	**1:** when HR_IND>12kg/kg and T_OUT>20°C **0.5:** when HR_IND<12kg/kg and T_OUT<20°C

Table 6.1: monthly schedule of the ACH to be set up on MSV.

The application of the recovery method on the other buildings together with a reduction of the energy demand for heating in Winter (40÷50%) led to improved comfort conditions in July and August, even if the complexes located in Firenze had lower indoor temperatures, due to a better quality of the envelope in Summer and consequent lower increases of indoor temperatures after the envelope recovery, but in such a way, the increase of air change rates led to even more improved comfort levels (mean temperature values below 26°C). In May the reached comfort conditions were comparable to those in BASE CASE, as well as in September. In June and in October, the decrease of temperatures in the first month and the increase of temperatures together with a decrease of RH levels in the second one, led to improved comfort conditions compared to BASE CASE. The aim of not worsening or improving the indoor comfort conditions inside the flats were then reached. The central engine of the system can be located in the corridor (the position of the corridor is always placed in the central part of the flat) in a gypsum plasterboard false ceiling, from which one duct is linked to outside and the other one (or more than one depending on the dimension of the flat) reaches the rooms to be "cooled". The humidity/outdoor humidity sensors, besides to affect the functioning of the mechanical ventilation system can be linked to other mechanisms to allow the mechanical windows' opening or to suggest opening the windows to the users (the humans behaviour can be then addressed towards a more efficient ventilation functioning)

After these considerations, it is possible to state that the recovery method can be applied on buildings with similar characteristics to the sample cases and located in a comparable climate zone (similar to the Mediterranean Climate conditions). Furthermore, after the analysis of the recent European Research Programs, there is a common trend to find a general approach to the sustainable refurbishment of this class of residential buildings, by giving a sort of guidelines and results from some reference buildings, to be followed. The research can be located in this scenario as a further step in the definition of interventions criteria to be applied on buildings realised with the same technological systems, located in climates where besides cold Winter (and high energy demand for heating) warm Summers can lead to overheating inside the constructions.

OUTLOOKS

The choice of the application of an insulation layer, or the substitution of the windows are only basis strategies in a recovery intervention. The energy class of the building can be further improved. Accordingly, the research can be further developed through:

- The evaluation of the possibility to install new energy efficient technical implants or the intervention more in depth on the envelope through the introduction of innovative technologies. All these strategies have to be analysed paying particular attention to the cost-effectiveness of the interventions, keeping in mind the field of interest is the renovation of Social Housing.
- The exploitation of Natural Ventilation which can be combined with the mechanical ventilation. In order to do that it is necessary to establish the real number of air change rates due to the windows' opening. It would be necessary to use a multi-zone indoor air quality and ventilation analysis program able to calculate: airflows, pressures and room-to-room airflows and pressure differences in building systems driven by wind pressures acting on the exterior of the building, and buoyancy effects induced by outdoor-indoor temperature differences.
- Moreover, the choice of the application of a MSV system (Mechanical Supply Ventilation System) derived from the fact that, on the market, it is the less expensive mechanical ventilation system suitable for the objective of this work (obviously after natural ventilation systems, which on the other side depend on a series of uncheckable factors). As we mentioned before, the functioning of this system could be improved by automation controls in windows opening or by the direct opening from the users (this could improve the air recirculation). A further step of this work could be to consider these automatic systems or "smart" users within this recovery method, in order to somehow exploit natural ventilation systems, aspect which is connectable to the previous point.