CONSTRUCTION TECHNIQUES AND METHODS TO DESIGN NEUTRAL CARBON SCHOOL BUILDINGS IN ITALY

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

To my parents

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ABSTRACT

With respect to the past the schools today must satisfy the new needs mainly related to the society changes and the development of innovative teaching and pedagogical methods and at the same time, in the context of the Paris Agreement and the 2030 climate and energy framework, be designed as neutral carbon buildings with low primary energy needs.

In Italy the last law deals with the environmental system of school buildings dates to 1975. The only integration proposed by the Ministry of Education, University and Research (MIUR), dated 2013 outlines only a series of uniquely qualitative guidelines, without any reference to any building's typological features. Furthermore, this national law of 1975th did not refer to any energy requirements because the first regulation about the buildings' energy performance was approved in Italy in 1976. Moreover, the design support manuals appear outdated, especially because they are based on the current school regulation of 1975th. In addition, in Italy, the European legislation on energy saving has been implemented with the Ministerial Decree of 26th June 2015 and it points out that starting from the 1st January of 2019 all the public buildings must be nZEB.

Therefore, for the design of a new school building specific and interdisciplinary references are currently absent that considers both the innovations introduced by new didactic and pedagogical methods and the principles of sustainability for environmentally friendly buildings, with almost low energy needs and zero emissions. Now the designer cannot refer to a guide, to updated typological models and to specific indications that can direct him towards proper and coherent design choices both in relation to the internal layout organisation and functional distribution of the school building and to energy and environmental strategies.

The main aim of the research work is to define qualitative and quantitative guidelines that can help the designer during the preliminary phase of the design process to build carbon-neutral kindergartens and elementary schools in Italy.

ZUSAMMENFASSUNG

In Vergleich zur Vergangenheit müssen Schulen heute neuen Bedürfnisse befriedigen, die hauptsächlich mit den gesellschaftlichen Veränderungen und der Entwicklung innovativer Lehr- und pädagogischer Methoden zusammenhängen. Im Rahmen des Pariser Abkommens und des Klima- und Energierahmens 2030 müssen Schulen als Carbon-neutralen und mit geringem Primärenergiebedarf konzipiert werden.

In Italien stammt das letzte Gesetz über das Umweltsystem von Schulgebäuden aus dem Jahr 1975. Die einzige vom Ministerium für Bildung, Universität und Forschung (MIUR) vorgeschlagene Integration vom Jahr 2013 enthält nur eine Reihe einzigartiger qualitativer Richtlinien, ohne Bezug auf jene typologische Merkmale der Gebäuden. Darüber hinaus bezog sich dieses nationale Gesetz von 1975 nicht auf den Energiebedarf, da in Italien die erste Regelung zur Energieeffizienz von Gebäuden erst in 1976 verabschiedet wurde. Außerdem erscheinen die Handbücher zur Entwurfsunterstützung veraltet, insbesondere weil sie auf Schulverordnung von 1075 basieren. In Italien wurde die europäische Gesetzgebung zur Energieeinsparung mit dem Ministerialdekret vom 26. Juni 2015 umgesetzt, und es wird darauf hingewiesen, dass erst ab dem 1. Januar 2019 alle öffentlichen Gebäude nZEB sein müssen.

Daher fehlen für die Gestaltung eines neuen Schulgebäudes derzeit spezifische und interdisziplinäre Referenzen, diese sollten die durch neue didaktische und pädagogische Methoden eingeführten Innovationen als auch die Prinzipien der Nachhaltigkeit für umweltfreundliche Gebäude mit nahezu geringem Energiebedarf und null Emissionen berücksichtigen.

Designer können sich gerade nicht mehr auf einen Leitfaden, auf aktualisierte typologische Modelle und auf spezifische Hinweise beziehen, die ihnen zu richtigen und kohärenten Entwurfsentscheidungen führen können, dieses gilt auch für die interne Layoutorganisation und die funktionale Verteilung des Schulgebäudes als auch für Energie- und Umweltstrategien.

Das Hauptziel der Forschungsarbeit ist die Definition qualitativer und quantitativer Richtlinien, die dem Designer in der Vorphase des Entwurfsprozesses helfen können, klimaneutrale Kindergärten und Grundschulen in Italien zu bauen

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CHAPTER 1. Introduction, aim of the research and methodology

1.1 INTRODUCTION

The last Italian law that enters into the merits of specific aspects related to the size and distribution and internal functional organization of a school building dates back to 1975 [1]. The only integration proposed by the Ministry of Education, University and Research (MIUR), dated 2013, outlines a series of uniquely qualitative guidelines, without any reference to dimensional and morphological aspects that should characterize the internal environments. The Ministerial Decree n. 29 of 1975 defines the urban context where the school building should be located, outlines the various functional units, the relative minimum services that must necessarily be present within a school and defines the main characteristics and the surface according to the number of students who use them. The MIUR guidelines supplement the previous text mainly by introducing new functional areas and new names for spaces (agorà, additional spaces for the Civic Center, formal learning areas, ateliers etc.) and underlines that the flexibility of the environments within a school is fundamental because they must adapt to the different needs of the teaching activity (Deepening in *Chapter 2 - Literature review*).

It is essential to remember that the Ministerial Decree of 1975 lays the foundations for the concept of modern school that develops during the 1900s, but only partially reflects the change of which the major pedagogists of the time become precursors. During the 20 century, several schools of thought followed one another, outlining the concept of modern school with radical and considerable changes and rethinking of teaching and pedagogical methods. The first pedagogists Maria Montessori and her child-friendly school, Piaget with cognitive stages, Papert and his cognitive information and finally Malaguzzi with the centrality of the child and inclusive space have revolutionized the cardinal points of the scholastic world. The main changes concerned the teaching method, the communication between teacher and child and their relationship in the school environment, how to educate children also through free and manual activities, life inside the school building and the method of learning (Deepening in *Chapter 2*). And it can be said that the profound change in teaching and pedagogical methods has not yet modified the typological models of the school buildings assumed as the basis for the design of new buildings or the recovery of the existing school heritage. Besides the last typological models of the "school" building in literature refer exclusively to the modifications necessarily occurred after the enactment of the law of 1975th.

Furthermore, at present the Italian scholastic heritage is characterized by a limited energy efficiency mainly motivated by the fact that 75% of the schools in Italy were designed and built before 1976, the year in which the first Law on energy was issued [2] (Ordinary Law of Parliament n.373 of 04/30/1976) concerning the regulation of energy consumption of buildings at national level. The problems that characterize the existing scholastic heritage are mainly linked to the overheating of the premises during the summer season, as there is hardly a cooling system, especially for schools built before the 90s, in the presence of ineffective heating and/or cooling systems that do not allow to maintain the internal temperature set point, and to the choice of inadequate technological solutions for the external envelope that show insufficient thermophysical performance and dynamic thermal characteristics according to the current regulatory standards and above all do not comply with the requirements of the Minimum Environmental Criteria (CAM). Furthermore, we are witnessing the lack of an appropriate ventilation that guarantees the correct exchange of air, with consequent poor quality of the indoor air not suitable for the presence of children, insufficient natural lighting in the spaces destined for the classrooms and for the collective activities where the main visual tasks are performed, and finally to the excessive energy requirement due essentially to the complete lack of use of renewable sources. Strictly linked to this general framework of the conditions in which the existing Italian scholastic heritage is based, it is important to underline that the inadequate environmental quality inside school buildings certainly involves a lowering of children's scholastic performance and considerable repercussions on their health (Deepening *Chapter 2*).

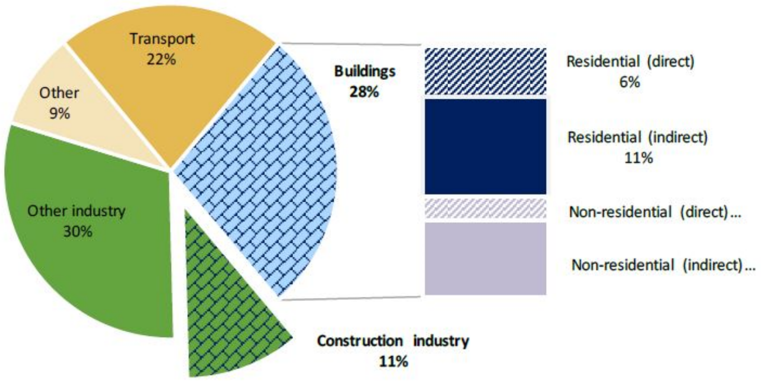

Figure 1.1 CO$_2$ emissions by sector 2015 - Global status report 2017. Reference: www.iea.org/statistics

Buildings are responsible for 36% of global energy consumption and 39% of CO$_2$ emissions into the atmosphere, including the production of building materials for the construction of the building itself (Figure 1.1).

With reference to the national school sector, in 2012th energy consumption was estimated at around 1 million toe/year, of which 77% was the request for thermal energy while the remaining 23% was electricity [3]. In 2016 the situation did not appear to have improved as only 0.3% of school buildings were in energy class A [4]. For example, as for the cities of Rome and Milan, according to a study conducted for the European COMMONCENSE project in 2009th, the consumption of thermal energy for school premises was estimated at intervals equal respectively to 24-32 kWh / m^2a and 73- 85 kWh / m^2 [5]. From the analysis carried out by ENEA (National Agency for Energy Efficiency), again in 2009 and concerning the need for thermal energy, it emerged that the greatest consumption was recorded for kindergarten with an average value ranging between 80 and 100 kWh/m^2 [6].

At the moment, in this framework relating to the existing Italian scholastic heritage, there are the binding laws on energy saving at international level developed starting from the European Directives 2002/91/CE, 2010/31/UE [7][8]. These regulations outline the groundwork for a common calculation methodology among member states to establish the energy performance of new and existing buildings, taking into account all those elements that contribute to defining energy efficiency. The 2020 climate and energy package[1] and then the 2030 climate and energy framework[2] establish real goals to reach for member states: the reduction of greenhouse gases equal to 40% compared to the levels of the Kyoto Protocol definitively entered into force in 2005, the increase in the share of energy produced by renewable sources up to 32% and the energy efficiency improvement of buildings by 32.5%. No less relevant from the point of view of atmospheric greenhouse gas emissions is the Paris Agreement 2050 long-term strategy[3]. This agreement promotes a drastic reduction in greenhouse gas emissions for member states in order to obtain a carbon-free economy by 2050.

In Italy the European legislation on energy saving has been implemented with the Ministerial Decree of June 26th 2015 [9] which defines for the first time at national level the minimum requirements for the construction of a Nearly Zero Energy Building (nZEB) (Deepening in *Chapter 2*).

In Germany, on the other hand, the European Directive and the following have been implemented mainly by taking into consideration the cancellation of CO_2 emissions expected from now to 2050 for both existing and new buildings. Berlin wants to achieve, at best, a reduction in CO_2 emissions of 87% compared to 1990 levels[4]in order to achieve the decarbonisation of the entire real estate assets (Figure 1.2) with consequent reduction of the non-renewable primary energy[5] consumption of 80% [10].

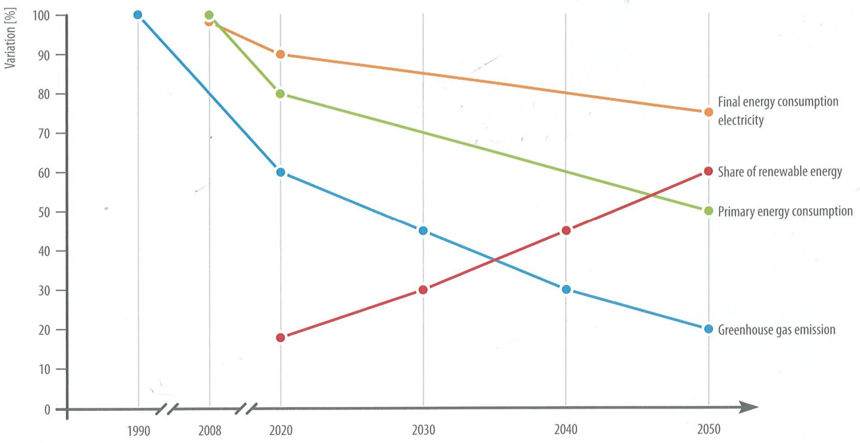

Figure 1.2 Objectives of the energy concept in Germany. Reference: EnergyPLUS page 23

In Germany the legislation develops according to a broader perspective that does not stop at the single building but extends to the neighbourhood, based on the creation of entire energy-efficient urban areas with low environmental impact, which produce more energy than they need. In this case the schools are part of the German reference standard for non-residential buildings (Deutsche Institut für Normung DIN V18599: 2011).

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[1] https://ec.europa.eu/clima/policies/strategies/2020_en

[2] https://ec.europa.eu/clima/policies/strategies/2030_en

[3] https://ec.europa.eu/clima/policies/strategies/2050_en

[4] https://www.berlin.de/senuvk/klimaschutz/politik/en/ziele.shtml

[5] Primary energy means: "*energy from renewable and non-renewable sources that has not undergone any conversion or transformation process*" - Article 2 "Definitions" European Directive 2010/31/EU

From an energy saving point of view, both international and national regulations have evolved to cope with the high energy consumption of the construction sector and there are still protocols that underlie the design of sustainable and energy-efficient schools (CasaClima , LEED[6], ITACA[7], BREAM[8]); however, as reported above on what happened in relation to the evolution of teaching and pedagogical methods, currently in the literature there are no typological models for schools that have assumed the demands of energy sustainability.

1.2 AIM AND MOTIVATION OF THE RESEARCH

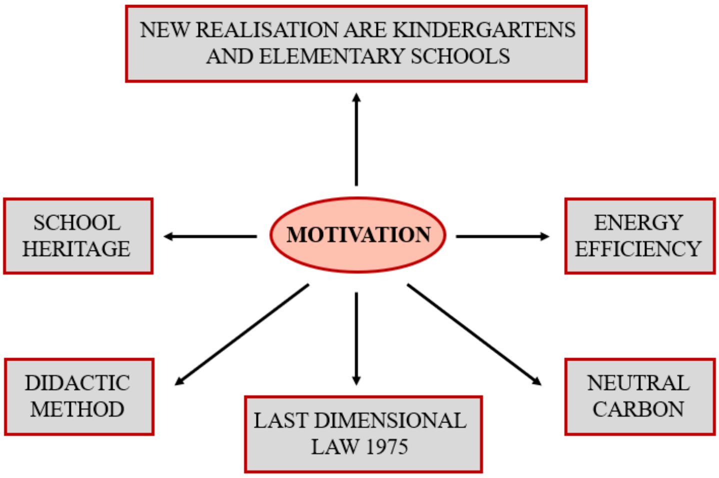

Figure 1.3 Scheme of the main motivations

On these premises, doctoral research is developed which has the final objective of defining qualitative and quantitative guidelines for the design of new construction school buildings following the current criteria of education and Carbon Neutral in Italy, considering the school of childhood and primary school located in the different climatic zones present on the Italian territory. The choice of this grade of schools is correlated to the fact that currently in Italy, according to what reported by the municipal administrations, the school buildings of new construction are mostly those of small size and related to schools of lower grade, while for buildings intended for higher education restructuring is mainly involved. However, the schools are configured as complex and specialized buildings which, anyway, lack adequate up-to-date legislation both according to the needs of the new teaching and pedagogical methods and which refers simultaneously to the current energy legislation (Figure 1.3).

The design support manuals appear outdated, especially in light of the fact they are based on the school regulations still in force in 1975 and the state of the art of research takes into account only specific aspects and not the different themes underlying the project as a whole and in an integrated way. As a result, the regulations and manuals show inappropriate typological models for school buildings. The designer who is currently in charge of the design of a school building does not currently have the possibility of relying on references that take into account the two fundamental aspects that have changed profoundly since 1975: the evolution of educational and pedagogical methods, which have necessarily modified the teaching method,

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[6] Leadership in Energy & Environmental Design

[7] ITACA are the initials of the Institute for Innovation and Procurement Transparency and Contract Compatibility and together with iiSBE Italia and ITC-CNR manages the ITACA Protocol at national level

[8] Building Research Establishment Environmental Assessment Method

the needs and the ways in which children, increasingly belonging to different cultures and ethnic groups, live the schools and the instances of sustainability to be inevitably considered in the construction so that the buildings are zero emissions. With reference to this, the creation of energy-efficient schools with a view to zero emissions becomes a considerable opportunity for renewing the existing educational heritage, characterized by limited energy efficiency as already mentioned, and requires an important rethinking of the principles that outline its design.

In conclusion, the innumerable changes that have characterized the most innovative school buildings in recent decades, with reference to shape, functional distribution but also in relation to the technological and system solutions adopted, cannot be identified in any legislation at national level nor in the manuals technique.

The drafting of qualitative and quantitative guidelines that embrace the demands deriving on the one hand from educational and pedagogical changes, on the other from the energetic sustainability of the construction thus becomes essential to configure a solid cultural reference for those preparing for a school building project, especially during the preliminary phase of the design process.

In this way it will be possible from the first phases of the project to be able to define solutions that are distributively adequate to the current requirement framework, with a low environmental impact and energy efficient without necessarily resorting to the use of expensive systems in subsequent phases of the design process. In fact it often becomes necessary to introduce articulated plant solutions only during the last stages of the design so that the designed schools comply with the minimum requirements for the Neutral Carbon Buildings foreseen by the international legislation and with the requests of the Ministerial Decree 26th June 2015 for nZEB buildings in Italy.

The research aims to outline and define for school buildings the specific aspects related to typological factors such as the orientation of the building, its morphology, the orientation and distribution of its functional bands, the definition and dimensioning of the environmental units, organization of façades and sizing of openings, structural systems, technological solutions for the external envelope and internal partitions, environmental, energy, active and/or passive strategies and plant systems in order to create up-to-date schools, suitable for the functions that are carried out, sustainable, energy-efficient and with zero emissions for Italy.

In short, the first step in the research is to define new typological models for kindergarten (3 models) and primary school (4 models) derived from the analysis of a large number of contemporary, avant-garde case studies from a functional/distribution point of view, characterized by high energy efficiency and built with a view to sustainability. Subsequently we will deal with understanding, through energy simulations in step-by-step dynamic mode using the Energy Plus software, using Design Builder as a graphical interface, how and how much the aspects related to the typological factors listed above affect the energy needs of the new school models outlined. At the same time the study of energy performance also becomes a validation for the school building type defined through the study of existing representative buildings, considered highly efficient but also a kind of check of the new defined school building type with respect to energy performance and environmental one in according to current regulations. Moreover, these energy simulations could suggest some modifications to the defined building typological factors in order to verify their influence and to individuate the most advisable configurations to be help to the designers to build schools with low primary energy demand and low the emissions of greenhouse gases in the atmosphere. Finally outline qualitative and quantitative guidelines for the construction of zero-emission schools. In particular, primary energy demand is intended as a request for energy for heating, cooling, domestic hot water, auxiliary systems, artificial lighting and devices, while the calculation of emissions refers both to the construction of the building and to consumption during the operating phase considering a useful life of 50 years. For a school building the greatest consumption of energy is mainly due to heating and cooling essentially linked to the high ventilation rates for the air exchange required by the Italian legislation for buildings with this intended use, which necessarily and significantly influence the energy balance. The study is carried out for the 3 new typological models for the nursery school considering 5 cities representative of the Italian climate each belonging to a different climatic zone (Milan, Florence, Rome, Naples, Palermo). It is necessary to underline that the results presented in the doctoral research are obviously closely linked to the new building type defined during the first phase and to its functional distribution and not less to the simulation set up of the Design Builder software.

1.3 METHODOLOGY

The methodology with which the doctoral thesis is developed is briefly presented in the diagram in Figure 1.4.

As the diagram illustrates, the methodology begins with the study of the state of the art and literature on the subject (*Chapter 2*). The main objective in this phase is to understand how school buildings have changed over time in relation to the new needs of teaching methods and new educational and pedagogical methods with reference to the main lines of thought of the educators of the last century. Furthermore, it is important to understand, through the analysis of literature and the most illustrative school buildings, how the characteristics and typological factors of schools have changed both in relation to the concept of modern school and in reference to the most current principles of sustainability and energy efficiency. This phase also includes the study of the main dimensional regulations on energy and the existing protocols for the construction of sustainable school buildings, so as to be able to identify all the minimum standards required for this type of building in Italy.

Figure 1.4: Scheme of the methodology of the present research

The second phase of the methodology concerns the definition of new school building type for kindergarten and primary school [11] (*Chapter 3*). It is necessary in relation to the development of new teaching and pedagogical methods and all the needed systems, strategies and technologies to build sustainable and environmental-friendly schools.

In literature there are many definitions of the "Building type". For instance, a building type could be defined as: "*a structured set of historically established knowledge and a stabilised and recognised configuration of building products*"[9]. Or Saverio Muratori defined it as a "*sintesi a priori*"[10]. It means: "*set of elements linked one with each other already in the mind of those who must work and build. The type is the concept that the designer has of a work he is preparing to create*"[11]. Moreover, Klaus Koenig defined it as "*a spatial articulation scheme that has been created in relation to a set of practical and ideological needs (...). The architectural type, in turn, is not a formal and structuring indication, but is a particular indication of the function performed by the complex in question*"[12]. The building type is related to 7 different features of the design and the building process[13]: the relationship between the design theme and the functional contents, the cataloguing of the formal relationships between elements, especially the planimetric ones, the structural solutions that repeat and change but always relating to the same concept, the relationship between the building and the city, the aspects of representation, the inevitability and the ideality.

A building type was defined through a series of different factors, divided in different classes, such as: the use of the space, the land use for building aim, related to morphology and geometric configuration of the building, internal layout functional organisation (individuation of functional bands and units), and finally factors related to construction systems, techniques and materials.

Starting critically from what has already been defined, changes and modifications can be made, assuming the building type as a dynamic system that could be implemented and could be considered as a reference for each project.[14] Consequently it is possible, within the definition of a new building type, to suggest different configurations of the main building typological features (mainly functional/formal characteristics and technological/technical solutions) that could affect the building energy and environmental performance and could improve it.

Consequently, the definition of a building type is still today a useful and necessary tool for the preliminary stage of the design process. It is a normal procedure that comes first the practical design of an initial idea.

So, the new school building type was defined through different steps. First, through the analysis of the literature on the subject it was possible to identify representative school buildings both for the functional internal distribution and their excellent energy performance. These buildings have received prizes or awards for the application of the principles of sustainability and energy efficiency in the project or belong to a high certification class for the relevant protocols or for the national certification system. The school buildings in question were built between 2003 and 2015 and were studied starting from the analysis of the climatic data

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[9] Translation from "Edilizia. Progetto, costruzione, produzione" Franco Nuti, Polistampa, 2010

[10] "Trattato di Architettura" Renato de Fusco, Altralinea Edizioni, prima edizione, Laterza, 2001

[11] Translation from "La valutazione del rendimento nel progetto della residenza: Per un'architettura di qualità fra innovazione e tradizione" Marco De Martin, Gangemi editore spa, 2009

[12] "Analisi del linguaggio architettonico" Koenig, Giovanni Klaus, Libreria Editrice fiorentina, Firenze, 1964

[13] Translation from "Comporre l'architettura" Franco Purini, Edizioni laterza, VIII edizione, Bari 2006

[14] Translation from Esther Giani, Corso di Caratteri tipologici e distributivi degli edifici, Iuav, 2010-2011

of the construction site and then through the detailed analysis of the environmental system, the technological system and the building system facility. "*By environmental system we mean the logical structure that interconnects according to specific rules, the requirements, the elementary activities, the complex activities*"[15], while "*By technological system we mean the structured and hierarchical set of elements that constitute any architectural structure. The technological system therefore represents the physical reality of what has been built, the material concretization of the realization design process*"[16].

In this phase it is possible to determine the typological factors that characterize the school building type that are at the basis of the 7 new typological models for the construction of neutral carbon school buildings in Italy: the external layout, the optimal orientation of the building, its geometry, the size of the building, the functional areas, the internal distribution, the functional units, the sizing and distribution of the openings in the facades, the structure, the technological solutions used, the characteristics of the systems, the active and/or passive strategies and of energy and environmental type used in the perspective of sustainability.

The third phase (*Chapter 4*) of the method is to verify and to validate the new school building type (derived from literature) with respect to the current energy standard in Italy and in the context of the Paris Agreement. This validation can be carried out by comparing the results obtained through energy simulations (Design Builder software) with the national energy regulations or with the data collected in the literature during the second phase of the research. The main objective in this phase is to verify the energy performance of the new defined building type and to identify the typological factors that have the greatest impact on the energy performance of the models analysed. Moreover, to individuate some advisable modifications of building distinguishing features with respect to the defined building type in order to design zero-carbon schools. Besides this phase includes the calculation of CO_2 emissions in the atmosphere (eLCA software and ecosoft2 software) according to the different configurations suggested for the school building type. Later, we will proceed with the study of the benefits deriving from the use of photovoltaic technology as an active strategy for the reduction of greenhouse gas emissions in order to give some suggestions to help the designers to obtain the construction of a school building that produces more energy than it needs. The study on energy performance was performed in 5 cities in Italy (Milan, Florence, Rome, Naples, Palermo).

Finally (*Chapter 5*) qualitative and quantitative guidelines for the design of a zero-emission school building for lower education orders in Italy are defined. These school guidelines, connecting the new building type for schools with an estimation of their energy and environmental performance, will lead to the definition of qualitative references but at the same time they will suggest some evaluations and some possible changes related to the building typological factors that could improve the building energy and environmental performance. In the state of art, considering other building type as well, there is not a guideline organised in this way.

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[15] Translation from "Edilizia. Progetto, costruzione, produzione" Franco Nuti, Polistampa, 2010

[16] Translation from "Edilizia. Progetto, costruzione, produzione" Franco Nuti, Polistampa, 2010

It is clear that the quantitative indications and evaluations in these school guidelines could be used as rough reference for feasibility projects. It is because of for a real building design which differs in part from the building type the overall energy/environmental performance will certainly have significant variations. Otherwise, the qualitative and quantitative guidelines outlined constitute a helping guide for the designer during the preliminary phase of the design process in order to make proper and informed choices.

Moreover, obviously, it is important to stress that there are many factors that influence and impact the decision-making process during the early design procedure that clearly must be considered as well, such as: the initial investment cost, the construction time, the constructability, the materials availability and also the construction tradition.

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CHAPTER 2. Background and literature review

2.1 LITERATURE REVIEW

2.1.1 Main changes over time for schools: the concept of modern school

In 1839 Friederich Fröbel (1782 - 1852) founded the "first kindergarten" in Blankenburg, Germany. His vision completely changes the way we see pre-schooling for children under 6 years old. His school consisted of two distinct spaces: one internal and one external. In fact, the German educator was firmly convinced that contact with nature was the basis of every child's education and that play, even when practiced in open spaces, was fundamental for preparation for adult life: "*I found, I will call it a garden childhood. The children will be the plants: I want to be the gardener*"[1] (Friederich Fröbel) [1]. Later, Maria Montessori (1870 - 1952), founded the foundations of the concept of modern school. The educator states that freedom, group activities and practical activities related both to personal care and to the natural environment are the basis of children's school learning. His children's home built in Rome in 1907 was a completely open building and the child was free to move and to carry out collective activities together with his school friends [2]. The fundamental principles of the Montessori method enhance the centrality of the child, underline that the school environment must be welcoming and customized to make it feel not only free to move, but also at ease, and also invites to educate children in contact with nature [3]. In line with the Montessori method on practical activities and learning through contact with nature, which is being developed in Italy, the ideas of Francis O'Neill (1850 - 1975), principal of an English elementary school in Lancashire, who sets his primary school according to "learning by doing" and according to a series of internal and external spaces that follow one another, and where the child is completely free to move at will during school hours, were born [4]. The same Seymor Papert in 1928 states that the child can learn through the construction of material objects defined as cognitive artefacts. But it is only in the following years that pedagogy is closely linked to the architectural form. For example, the educationalist Jean Piaget (1896 - 1980) states that cognitive ability and the capability to adapt to the physical environment are correlated. According to this philosopher, school learning takes place mainly through the assimilation of information and exchanges that take place directly with the surrounding environment[2]. Even the pedagogist Louis Malaguzzi (1920 - 1994) argues that the school environment is the third educator in that the architectural space itself must be proportionate to the child and welcoming and must encourage learning without representing a barrier [5]. In Emilia-Romagna he built the Reggio Children in 2000 (Figure 2.1 - Figure 2.2) which today represents one of the

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[1] https://www.ecopedagogia.it/Friedrich%20Froebel

[2] https://www.stateofmind.it/2016/05/sviluppo-cognitivo-piaget/

most advanced childcare laboratories in Europe where the child is considered an active citizen and experimenter open to the world [6].

Figure 2.1 Reggio Children collective area – Reference: https://zpz-partners.squarespace.com/scuola-loris-malaguzzi

Figure 2.2 Reggio Children play area - Reference: https://zpz-partners.squarespace.com/scuola-loris-malaguzzi

Malaguzzi introduces the concept of ateliers, laboratories and especially of the piazza with the agora, where the family can actively participate in the school life of their children. This is exactly how the old theory that presupposed the clear separation between school and family is overcome. The functional units introduced by Malaguzzi are one of the bases of the concept of modern school and are also taken from the guidelines for school buildings of the MIUR of 2015. Finally, at the end of the 90s Gianfranco Zavalloni (1957 - 2012)[3] with its "*Pedagogy of the snail*" (Figure 2.3) seems to sum up its predecessors. In fact, with its pedagogical principles, he emphasizes that for the education of children direct experience of both nature and social space is required in order to be able to face problems and at the same time the child must be autonomous, at ease within school environment. Learning is mainly based on play, manual work and study, moving away from the traditional teaching method based exclusively on classroom lectures. Fundamental to his idea of a school building are the collective areas that enclose 5 functional zones (canteen, gym, theater, laboratories, spaces for the collection of teaching materials) and the garden and the botanical garden that become an integral part of the teaching activity.

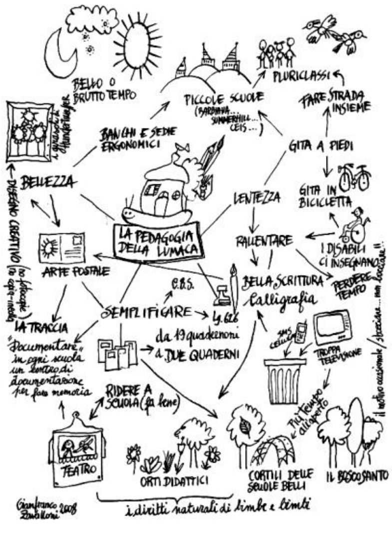

Figure 2.3 Scheme of "Pedagogy of the snail" – Reference: http://www.tuttaunaltrascuola.it/scuola-creativa-ricordando-zavalloni/pedagogia-della-lumaca/

The changes in teaching and pedagogical methods and in the school learning method thus inevitably influence also the architectural space, which in turn becomes a cultural reference point for the child, transforming the school building that must necessarily meet the new demands of educational and teaching activity. In fact, the form and the functional distribution of the school building evolve and adapt at the same time to the pedagogy trying to satisfy its main needs [4].

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[3] http://www.tuttaunaltrascuola.it/scuola-creativa-ricordando-zavalloni/

In Italy the first school buildings date back to the 1800s and are made through the reconversion of intended use and the functional redevelopment of existing buildings, typically barracks and hospitals [7]. Only with the introduction of compulsory education (the Orlando Act of 1904 provides for compulsory education up to the age of 12) do schools become an independent building type with specific architectural features (Casa della Scuola 1911, Ministry of Education). The school building is essentially a building with a symmetrical layout with an internal open space that divides the area for the females and for the males [8].

In the 1930s, with the emergence of the fascist regime, schools became buildings exclusively representative of political power and of the new ideal of devotion to the Italian State [7], characterized by monumental and rigorous structures that must astonish at the sight and from austere interior environments. With the Gentile Reformation (1923) the four school orders present today are established (the 3-year nursery school for children from 3 to 5 years of age, the elementary school lasting 5 years, the lower secondary school for a period of time equal to 3 years and the high school, which provides a duration of 3 years for the classical high school and 4 years for the scientific high school) and compulsory education was brought to 14 years. The educational program in this historical period pays particular attention to physical education and collective activities. The school is characterized by a precise internal hierarchical organization that is reflected both in the architectural body and in the teaching methods based mainly on classroom lectures where the only purpose is to transmit knowledge to the students. During the Fascist regime the school had to teach essentially rigor and discipline. But in recent years, the rationalist Giuseppe Terragni (1904 - 1943) with the construction of the Sant 'Elia kindergarten in Como (1936 - 1937) [9] becomes one of the precursors of the conception of a modern school building from an architectural point of view. This building is considered as the example to follow for the construction of the fascist schools, but it encompasses innumerable architectural aspects that fully reflect the thought of the educators of the '900 [10]. The building is on one single floor above ground and the body of the building develops around a central courtyard designed for collective activities in close contact with nature (Figure 2.4). The classrooms are directly connected with the external space that becomes a real area for teaching and socializing. Finally, we perceive the importance given to the natural light that penetrates inside the rooms (in this case classrooms), in complete contrast with the facade scheme of the nineteenth-century monumental schools (Figure 2.5 - Figure 2.6).

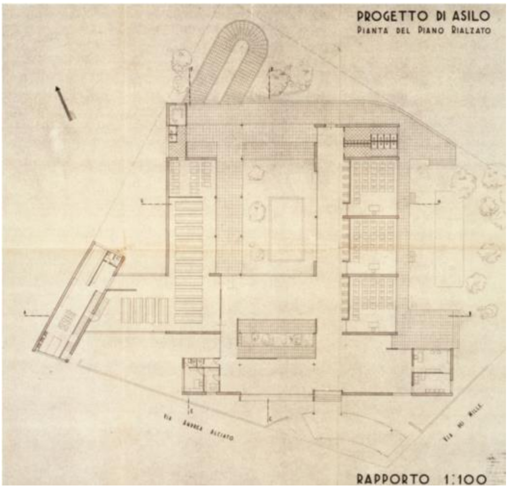

Figure 2.4 Internal Layout of Sant'Elia kindergarten – Reference: www.archivioterragni.itprojects-comoasilo-sant-elia

Figure 2.5 Glass facade of classrooms – Reference: http://www.maarc.it/opera/asilo-infantile-antonio-santelia

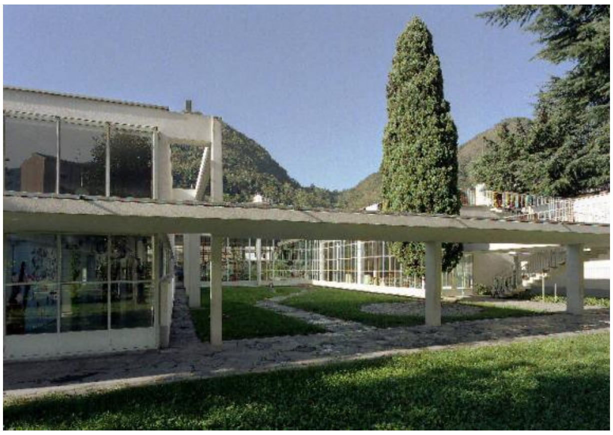

Figure 2.6 Green courtyard – Reference: http://www.maarc.it/opera/asilo-infantile-antonio-santelia

The same line of thought regarding the exploitation of the external space for recreational and didactic activities can be found in the following years in the nursery school of Livio Vacchini (1933 - 2007) [9] where there are large windows that connect the classes directly with the outside garden (Figure 2.7 – Figure 2.8). The external metal shelter represents the element of mediation between the more private and reserved space for individual work and the external space for collective activities and socialization. The boundary between interior space and external space is not so clearly identified and outlined. Even in this case, natural light seems to be a fundamental element for the construction of a school for children, in fact the classes are also illuminated by a series of skylights (Figure 2.9).

Figure 2.7 Window of a classroom for connection with the garden in Ai Saleggi kindergarten – Reference: http://www.studiovacchini.ch/opere/10

Figure 2.8 Window of a classroom for connection with the garden in Ai Saleggi kindergarten – Reference: http://www.studiovacchini.ch/opere/10

Figure 2.9 Skylight of a classroom – Reference: http://www.studiovacchini.ch/opere/10

Another precursor of the concept of modern school that reflects part of the philosophy of the pedagogists of the time is Mario Ridolfi (1904 - 1984) with the nursery school in Poggibonsi Siena (1954) and the Olivetti kindergarten in Ivrea (1954 - 1964). Both structures are organized according to the same planimetric scheme, essential and child-friendly, as all the architectural elements are sized according to the height of the children themselves. The environments are developed through the aggregation of pavilions within a common green area and are connected by a continuous shelter, which also in this case represents an element of mediation between the internal and external environment as well as being a real and its own fixed solar shading for the underlying classes [11][12].

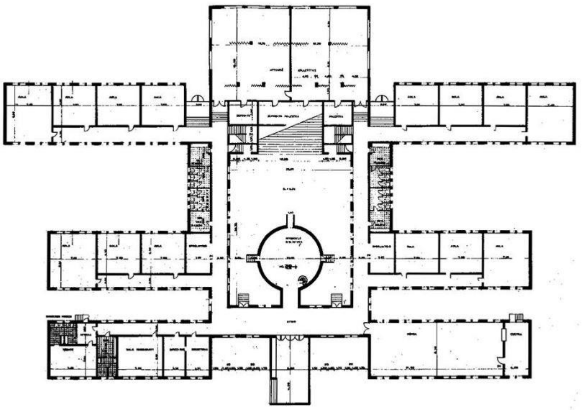

Figure 2.10 Internal layout – Reference: https://www.proloco-fagnanoolona.org/2000/scuola-elementare-salvatore-orru/

Finally, the designer Aldo Rossi (1931 - 1997) with the primary school Salvatore Orrù (1972 - 1976) in Fagnano Olona which fully represents the concept of the city school by Herman Herzberger (6 July 1932) deserves to be named for his vision of a modern school. In fact, according to this architect, the school can be divided into a series of environments where collective, individual activities and activities for small groups can be carried out. The first ones take place mainly in large interior spaces or in green outdoor areas that resemble the squares of a city while the latter take place essentially in classrooms or in dedicated areas of modest surface, which recall the private environment of the houses [13]. The corridors instead represent real roads linking the various spaces. The Salvatore Orrù primary school (Figure 2.10) is designed to be a real small town that develops around a central square where the library is located to serve the whole neighbourhood. The main court of the school is organized in steps and it is here that the main collective activities and events are concentrated.

During the 1960s, instead, the theme of prefabrication takes over for the construction of school buildings, as it allows schools to be built in a short time and at low cost [14]. Examples are the works of Luigi Pellegrini (1925-2001) and Gino Valle (1923 - 2003). The first designs and builds various schools throughout Italy and believes that compactness is essential to reduce costs. He therefore manages to adapt the prefabrication to the needs of a school building and to create organic and flexible forms that adapt to the needs of teaching [15]. The second proposes an elementary school prototype (Venice, 1977) characterized by compactness and repetitiveness with a modular structure with a rectangular mesh [16].

Herman Herzberger thinks of the school as a building consisting of standardized environments that can be repeated in series and connected to each other [13]. The classes that currently remain the center of the teaching activity have the same layout and the same dimensions and are simply placed side by side. An example is the Montessori school in Delft built in 1960 [17] and later in more recent times the La Romanina primary school (2008) designed by the same Herzberger so that it is even possible to repeat the single base unit, configured with all the minimum functional units, which can therefore be independent or connected in series with other identical units [13] [18] (Figure 2.11 - Figure 2.12).

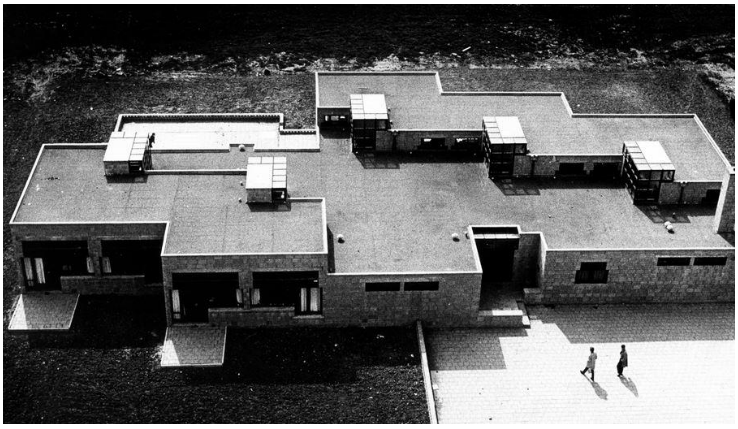

Figure 2.11 Montessori School in Delft

Figure 2.12 The Romanina school in Rome

Since the 1980s, for the following decade, research and experimentation concerning school buildings have lost interest, thereby losing their value both from a social point of view and in reference to architectural quality. The buildings of that period are essentially monumental buildings, usually built in the suburbs, which are absolutely not distinguished within the urban fabric and certainly cannot be considered representative of the company [17] and be an example and push for the construction of new schools and the redevelopment of neighbourhoods.

With reference to this brief historical framework concerning the evolution of school buildings, it is important to underline that during the '900 it is possible to recognize different planimetric schemes for the school building that today can no longer be considered appropriate mainly on a dimensional level.
In literature, with reference to typological models, we find mainly 2 different distribution models and 5 planimetric configurations that declare them differently [8][16][7][19][20]:

- Aisle type (distribution model): typical of the first half of the 20th century, it is considered the simplest and the most widespread, characterized by a horizontal distribution space which is the connecting element between the functional strip used for the classrooms and the common. The plant can simply be rectangular in shape or follow the shape of an L. classrooms are usually distributed along a straight path and are conceived as independent functional units. This distribution scheme enhances the classroom space devoted to teaching by putting the areas devoted to collective activities into second place.
- Type with functional units (distribution model): typical of post-war reconstruction, it is characterized by basic nuclei (functional units) which are combined together in various ways and which combine complementary functions.
- Block type: it develops from the corridor type, in fact also in this case the horizontal connections are linear and perform the function of connection between the classrooms. These face directly onto the main road while the horizontal connection faces the back. Services are usually located at the ends of the building. This type evolves later into the unified block configuration where more blocks are placed side by side and the plan is more articulated and the more widespread planimetric scheme is the C-shaped one with the long side that houses the classrooms and the horizontal

connection system while the short sides services and ancillary rooms. Finally, we have the block type with an internal void that becomes the center of collective activities and sometimes develops according to the gallery layout.

- Plate type: it develops according to both the two distribution models and is characterized by a main building to which the different environments are connected (gym, swimming pool, laboratories, theater). Usually it is articulated on one or two levels and has a lower height development than the block type. Given the wide planimetric extension of this type, the lighting problem is solved through a series of skylights placed on the roof. In many cases the problem of lighting is solved by inserting a central courtyard where the spaces dedicated to children usually overlook. The connection between inside and outside can take place through mediation elements such as solar greenhouses, porches, shelters.
- Open plan: typical of the '60s, it shows considerable flexibility, it is in fact characterized by the presence of large internal areas of different sizes which, through the use of movable walls, can be subdivided according to the needs of teaching and the different school activities. The connections are eliminated to save internal space.
- Extensive type: the distribution model is that of the functional unit with a series of large spaces that develop and expand towards the outside. The basic nuclei are repeated. This type develops through different planimetric configurations, such as, the cross distribution and the comb distribution which foresee a central building, usually linear, connected through the external space to the other independent buildings that occupy the various functions (canteen, gym, auditorium, laboratories). Another example is the pavilion distribution scheme which is based on the repetition of the basic functional units and leaves the possibility to expand the school even later. This typology opens completely towards the outside especially through lessons in outdoor classrooms.
- Street type: they are very complex and articulated buildings where hierarchies are completely eliminated with the main spaces and accesses. The building is open to the outside and communicates with the surrounding environment. The school is conceived as if it were a city in which the classrooms represent the buildings and the horizontal connections the streets.

From the analysis of the state of the art, in relation to the form of the class, there is instead a universally recognized subdivision based on the number of students and on the didactic activity they carry out [1] [21]:

- “*Whole class teaching*”: all the students carry out the same didactic activity, therefore all those activities that involve frontal lessons;
- “*Individual work*”: space for the work of the individual student where he learns through goals that he has set for himself and which were not requested by the teacher;
- "*Paired work*": space in which work is done in pairs so that the students can collaborate with each other;
- “*Group work*”: spaces for collective activities where group work is carried out and socialization and collaboration among students are encouraged and promoted.

Over time we have gone from a class characterized by a rigid form that did not fit the teaching methods (shapebox) and above all had no connection whatsoever with the external space, to an open plan class where it is possible to identify spaces that host different functions , characterized by a different distribution of the furnishings or obtainable through the use of mobile walls. In the perspective of a class that adapts to the needs of the teaching activity and of the interaction between a functional unit and the other for the intercycle activities, but above all of the multi-functionality of the environments obtained through a change of the mobile furniture according to the occurrences, Natascha Meuser in her school building design manual identifies three different class configurations [1]:

- "*Classroom plus*": classrooms of about 70 square meters for 25 students; between one class and another there is a common space for collective activities divided through glass walls in order to maintain a continuous visual contact between one environment and another. This makes it possible to meet the needs of intercultural activities by having a common collective space;
- "*Learing cluster*": the classrooms (5 m^2 per student) in this case are combined and connected with the environments dedicated to teachers (1.5 m^2 per teacher). There is no longer a hierarchical distinction between the environments for the students and those for the teachers;
- "*Learning landscape*": it is a typical configuration of secondary schools; classrooms are real open spaces and students are free to choose between different areas for individual work or group work. There is no longer a clear distinction between one area and another, but the function is expressed through the use of various equipment and furnishings.

Simultaneously with the shape of the class the distribution of the desks that represent the fundamental element especially for primary school has changed over time. Different configurations are found [16]: scheme with counters in a row or divided by couple, horseshoe/amphitheatre scheme that allows for greater interaction among the children, the circular scheme where there is no longer the teacher/student hierarchy and the scheme with benches in groups with modular tables that encourage collaboration and socialization among the boys. This last configuration developed initially in Northern Europe (Figure 2.13).

Figure 2.13 Scheme of school desk of Kirkkojarvi in Denmark

2.1.2 Schools and sustainability

As we have seen in the brief historical excursus, in the last century the design of a school building changes essentially with reference to the philosophy of thought of the first pedagogists who outline the basis of the concept of modern school. Currently, however, during the design of a school building, the choice of its shape in plan or of its internal functional distribution cannot depend exclusively on the change of didactic and pedagogical methods, but must inevitably take into account the energy aspect and be defined in the optical of sustainability.

In the 1987 Brundtland report on sustainable development we understand that: "*development that meets the needs of the present without compromising the ability of future generations to satisfy their own*" and consequently sustainable architecture or sustainable construction is defined as: "*an architecture which is based on the principle of sustainable development from a global design perspective that considers every phase of the building's life cycle and its construction works, from its birth to its demolition, considering environmental, economic and social aspects* " [22]. While for bioclimatic architecture we mean: “*that type of architecture that optimizes the energy relations with the surrounding natural environment through its architectural design. The word bioclimatic wants to relate man, "bios", as a user of architecture in front of the external environment, the "climate", architecture being a result of interactions between both* " [22]. Bioclimatic architecture seeks to maximize the use of renewable resources while minimizing and limiting energy consumption and pollutant emissions. The bioclimatic approach essentially involves the historical-critical reading of the context, the geo-morphological survey, the design in relation to the relationship with the local climate and an accurate and in-depth investigation of environmental problems [23].

In the world of school buildings there are several examples in the past that can be considered for some aspects precursors of a sustainable and bioclimatic architecture. First of all is the Open Air School (1927 - 1930) created in Amsterdam and conceived in its original project by Jan Duiker (1890 - 1935) and Bernard Bijvoet (1889 - 1979) [9]. The school is oriented in the construction site so as to be able to take advantage of the prevailing winds for passive cooling of the building during the summer season, it also has large windows that, in addition to allowing continuous visual contact of children with the surrounding environment, allow exploitation natural light that penetrates unhindered inside the rooms (Figure 2.14).

Figure 2.14 Open air school Amsterdam – Reference: https://en.wikipedia.org/wiki/File:Openluchtschool_-_Open-air_School_(8157211576).jpg

However, the most relevant example is certainly the nursery school in Crosara di Marostica (1975) created by Sergio Los (May 24, 1934) which can be considered as the first bioclimatic school building built in Italy (Figure 2.15). The building, due to the hilly conformation of the construction site, is partially buried. Accessory and service areas are organized on the north-facing functional strip. On the south orientation a solar greenhouse is inserted (Figure 2.16) which allows children to be able to play in a space characterized by intermediate thermo-hygrometric conditions between inside and outside. In a central position there is an atrium where the main educational activities are concentrated. The technological solution adopted for the roof is the green roof which allows the dispersion to be reduced during the winter and during the summer to reduce the surface temperature of the roof (Figure 2.17).

Figure 2.15 Model of Paolo Crosara school – Reference: http://synergiaprogetti.com/it/istituzioni-educative/item/49-scuola-materna-crosara-di-marostica

Figure 2.16 Solar greenhouse in Paolo Crosara school in south orientation

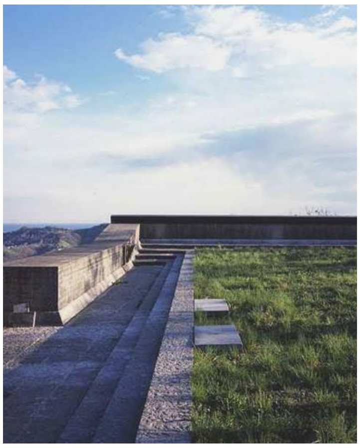

Figure 2.17 Green roof in Paolo Crosara school

The air conditioning system is realized through an air system completed with a passive solar system (water solar collectors system integrated with a thermal water storage). The double-volume solar greenhouse and the ventilation chamber under the floor slab allow air to circulate inside the rooms: the air is heated inside the greenhouse through radiation, penetrates into the rooms through vents of ventilation located at the top and is recovered to then pass inside the interspace of the partition wall between the atrium and service spaces and be introduced into the ventilation chamber present under the floor slab. Here the heat that remains is transferred to a layer of gravel that acts as a thermal accumulation and the cycle at this point can start again [23] (Figure 2.18).

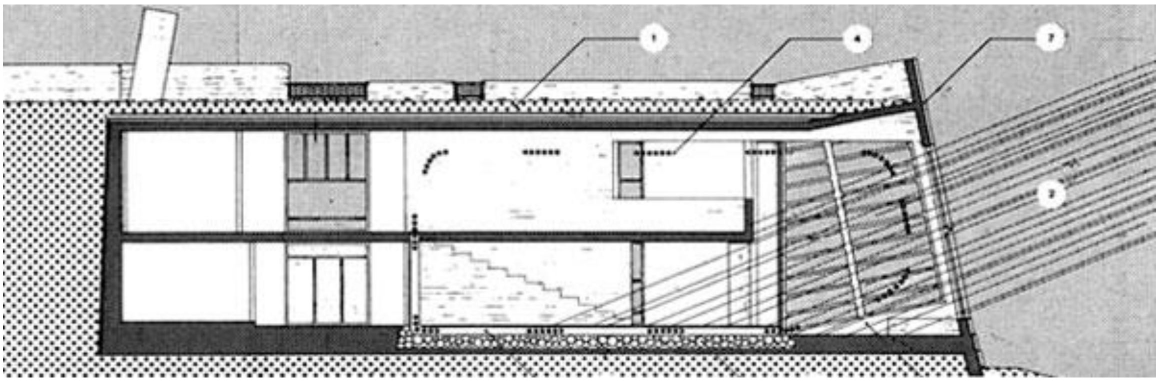

Figure 2.18 Air circulation in Paolo Crosara school

Finally, in the early 1990s, Norman Foster designed and built the Liceo Albert Camus (1993) in Frejus. The peculiarity of this high school is the central atrium with a gallery on the upper floor (Figure 2.19) which, besides representing a connection and socialization space for the students, allows the exchange of air inside the structure for natural ventilation through the exploitation of a solar chimney placed in the roof that activates air circulation in the room. The school does not need mechanical ventilation to guarantee the internal thermo-hygrometric well-being conditions. The other interesting aspect of this school is the study and use of solar shading: the structure of the central atrium is protected by a system of horizontal metal sunshades (Figure 2.20) in order to avoid the overheating of this environment while the south-facing glazed façade is shaded by a cantilever consisting of horizontal sunbreaks in perforated metal (Figure 2.21).

Figure 2.19 Central atrium in Albert Camus school – Reference: https://www.fosterandpartners.com/projects/lycee-albert-camus/#gallery

Figure 2.20 Horizontal view on top of the atrium

Figure 2.21 Horizontal external overhang for south orientation

In contrast to the examples given above, it is further necessary to emphasize that almost all of the national scholastic heritage built in the twenty years 1970-1980 nowadays is in a situation of degradation, not only from the point of view of energy performance, but also from an architectural and structural point of view, mainly due to the general lack of interest created around these buildings during the end of the last century. Nowadays school should be a representative building with strong architectural value and its own identity [24] and should be considered as an example of sustainable and energy-efficient building so that it can be configured as a flywheel to redevelop and regenerate even the neighbourhoods where they are located.

The proposal of the archistar Renzo Piano with his "*the school that I would do*"[4] responds to a provocative article denouncing the condition of the school buildings existing in Italy published in March 2014 (Il Sole 24 Ore 16 March 2014) by Franco Lorenzoni "*Dear architects, redo our schools*"[5]. The school according to Renzo Piano must follow the Montessori philosophy, be a meeting and gathering point. His school has an organization according to three levels: the ground floor which represents the connection between the school and the city, the first floor dedicated to educational activities and the roof used as a garden to play and for collective activities in close contact with nature. The ground floor should be raised above ground level and accommodate the functional areas for collective activities, the gym, the auditorium and the laboratories. These must be able to be used by the inhabitants of the neighbourhood in extra-curricular time and become fulcrum of the city. The ground floor, completely transparent and open to the surrounding environment, is also illuminated through an internal courtyard where there is a large tree that represents the natural environment and is essential for children to understand "*the mutability of life and the need for*

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[4] https://www.ilsole24ore.com/art/cultura/2015-10-11/ecco-scuola-che-farei-081632.shtml?uuid=AC4VuIEB&refresh_ce=1

[5] http://www.inu.it/wp-content/uploads/Sole_edilizia_scolastica_16_marzo_2014.pdf

renewal"[6]. The roof garden as well as representing the place to play and carry out collective activities becomes an extension of the classroom where didactic activities are carried out in close contact with nature (for example the didactic gardens). As a link to the three levels of the building, the architect inserts the library or "*tower of books*", a place of culture opens to all. And finally, a fundamental thing is that the school must be a true example of eco-sustainable building in order to be a real teaching and educational message for students.

In literature some authors anticipate and/or resume the solutions proposed by Renzo Piano for the realization of a sustainable school. According to Anxhela Lika [24] it is necessary to focus and follow certain principles in order to build a sustainable school: functionality in the realization of the areas based on the actual number of students present and flexibility so as to be able to organize the spaces according to the needs of teaching, thermal well-being hygrometric inside the environments to safeguard the health of the children through the direct control of the climatic conditions, exploitation of the natural lighting seen as a priority for a school building and finally the acoustic comfort for the learning areas so as not to have no noise coming from the outside that can distract children during class hours.

For other authors, the term sustainability for a school building is essentially linked to the use of sustainable materials [24]. In fact, they underline the importance of using natural materials for the construction of buildings to reduce the environmental impact and the emissions of greenhouse gases into the atmosphere. Very often designers prefer wood that is not treated with paint or toxic substances, the natural material par excellence, not only for the load-bearing structures, but also the technological solution for the external cladding and the roof, the fixtures and the interior finishes.

Bin Su [25][26] instead states that the sustainability of a school is essentially linked to the intrinsic architectural characteristics of the building that inevitably influence the energy performance and consequently the annual request for primary energy. According to this author the factors that mostly affect energy consumption are the orientation of the building as it is connected to the amount of incident solar radiation, its geometry and shape in plan and finally the choice of the technological solution for the external envelope. For example, an increase in the aspect ratio (dispersing surface/volume) results in an increase in annual energy consumption as a direct consequence. With reference to this, the solution with compact shape is the best as it minimizes this ratio, allows less heat dispersion towards the outside during the winter season and also involves a saving in terms of the green and permeable surface occupied as the space occupied on the ground of the building is smaller [27]. Also, the ratio between the surface of the roof and the volume of the building leads to an increase in energy requirements, since the greater this ratio, the greater the dispersing surface of the roof as well as the ratio between the surface of the external envelope and the volume.

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[6] https://www.ilsole24ore.com/art/cultura/2015-10-11/ecco-scuola-che-farei-081632.shtml?uuid=AC4VuIEB&refresh_ce=1

Boeri et al. [27] instead put the accent on the choice of the construction site and on the control of the construction process of the structure to limit the environmental impact of the building and build a sustainable school that respects the environment, green areas and natural resources . It is therefore necessary to place the relationship between the building and the surrounding environment and climatic conditions at the center of the design. The school should change in relation to the variation of the external climatic conditions always preserving the conditions of internal comfort. In fact, the envelope is no longer seen only as an element of separation between the internal and external environment, but as a flexible system capable of adapting to the changing climatic conditions. Mainly it has to satisfy two fundamental functions: to minimize the dispersions during the winter season and to regulate the entry of the solar contributions during the summer season [20].

Finally, other authors link the sustainability of a school building not only to the construction of the building itself but also to its management during the use phase. For example, the choice of the construction site during the preliminary design phase is also carried out in relation to the transport system to reach the school building itself, as transport is the second source of CO_2 emissions in the atmosphere. It is essential that designers take care of defining a transport plan and the means to be used by teachers and students to reach the school [28].

2.1.3 Regulatory framework

The legislation of 1975 [29] underlines the importance of choosing the construction site, both for the kindergarten and primary school. This is closely linked, for schools of lower order, to the journey that the children, still not autonomous, must travel to reach the school building. It is preferable to place the school in a residential neighbourhood so that it can be reached in most cases on foot or by public transport. In addition, the school must be located in a context where there are no urban facilities and/or infrastructures that could cause damage to children's health or otherwise create discomfort for the performance of school activities.

As far as sizing is concerned, this legislation sets limits on the number of classes so that the building can really be considered a school: for kindergarten it provides for a minimum of 3 sections to a maximum of 9, while for primary school establishes a minimum of 5 classes up to a maximum of 25. It also suggests that the kindergarten develops on a single floor above ground to allow direct contact with the outside while the elementary school can be organized also on more than one floor (the classes of the first cycle must however be organized on the ground floor).

As far as kindergartens are concerned, the legislation defines the section as the main pedagogical unit and the internal layout must allow the carrying out of the following activities: desk-organized activities, free activities for motor and play purposes and finally practical activities. The area for free activities can be used by one or more sections while the space for practical activities should be integrated within each section because it still has an educational component.

For the elementary school, the pedagogical unit is the class that represents the center of the didactic and educational activity. Within the class, the furnishings and equipment are required to be mobile so that they can adapt to the various activities and teaching methods in continuous evolution; moreover, it is advisable that there can be the possibility of connecting two different classes in order to perform inter-cycle activities also through the use of mobile walls. In addition to the environments essentially aimed at educational activities, the legislation defines a series of accessory spaces both for didactics (for example the gym, which becomes mandatory for schools with a number of classes greater than 10 but which does not necessarily have to be located inside building) both for the administration (for example archives, teachers' room, changing rooms for staff etc.), then size the canteen and the sanitary facilities.

For the sizing it imposes minimum limits based on the number of students (establishing the maximum number) and on the surface area per pupil to be assigned to each environmental unit both for primary school and for nursery school, also proposing basic functional schemes. Currently the maximum number of students[7] is equal to a minimum of 18 and a maximum of 26 (for any surplus students there is a maximum of 29 students) except for the presence of disabled for kindergarten while for elementary school it is a minimum of 15 and a maximum of 26 students is foreseen (for any surplus students there is a maximum of 27 students), except for the presence of disabled students. For classes that accommodate a pupil with a disability the maximum number is instead 20. Furthermore, the minimum and maximum number of students can be reduced by 10% according to the provisions of the Decree of the President of the Republic n. 81 of 20th March 2009 [30].

The 2013 guidelines of the MIUR [31] are a supplementary document to the current legislation of 1975 and introduce different quality requirements to improve the usability of school buildings and adapt the internal layout to the current needs of educational and teaching method.

The learning spaces must adapt to the required activity and be characterized by "transparent walls" that allow the sharing of activities beyond the environmental classroom unit. The flexibility and multi-purpose environments that can be reconfigured according to the needs of teaching are the basis of these guidelines. The classroom is always the space dedicated to the frontal teaching activity where the role of the teacher remains more explicit but the spaces for group activities become central within the school building. The main novelty introduced by the MIUR are the laboratories or, as they are defined within the guidelines, the ateliers or spaces of doing: "*an environment in which the student can move independently by activating processes of observation, exploration and production of facts*"[8].

The other novelty at the environmental unit level is the informal and relaxing space where students can interact and socialize with each other in order to relax and detach themselves from the formal learning activity and have access to resources not strictly related to the didactic activity. At the level of the internal distribution of the school building, two areas dedicated essentially to collective activities are introduced: the atrium and the agora. The first represents the meeting place between the school and the city and at the

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[7] https://miur.gov.it/formazione-classi

[8] Norme tecniche quadro, contenenti gli indici minimi e massimi di funzionalità urbanistica, edilizia, anche con riferimento alle tecnologie in materia di efficienza e risparmio energetico e produzione da fonti rinnovabili, e didattica indispensabili a garantire indirizzi progettuali di riferimento adeguati e omogenei sul territorio nazionale. MIUR, 2013

same time it is the space in which parents can be welcomed to make them come into contact with the activities of the school. The second is defined in the guidelines as "*the functional and symbolic heart of the school*" and is the center of the horizontal and vertical connections that unite the places where public activities (parties and meetings) take place, hosted mainly inside the square.

It is thanks to these guidelines that the concept of class developed during the early 1900s is exceeded. In fact, not all teaching activities are carried out within the class but this represents a "*home base*" that is outlined as "*a parent company from which everything starts and to which we return, characterized by great flexibility and variability of use*"[9] and is no longer a center of school life. Finally, inside the school building there will be a series of independent spaces that can be used by people in the neighborhood during extra-school hours (auditorium, library, music room and recording) or by students during the summer period of suspension of educational activities.

The European Directive 2010/31/EU to outline guidelines common to all member states defines first of all the nearly zero energy building (*Nearly net energy building*) as: “*a building with very high energy performance, determined in accordance with the Annex I. The very low or almost zero energy requirement should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced locally or nearby*"[10]. Furthermore, the definition of the energy performance of a building is explicit: "*the amount of energy, calculated or measured, necessary to satisfy the energy needs connected to a normal use of the building, including in particular the energy used for heating, cooling, the ventilation, the production of hot water and lighting*"[11] and the level of performance based on costs: "*level of energy performance that involves the lowest cost during the estimated economic life cycle and which is located within the scale of performance levels in which the cost-benefit analysis calculated in the economic cycle is positive*"[12].

Each member state to calculate the optimal performance level based on costs and to be able to carry out a building verification in relation to minimum limits must define a reference building [31] illustrative which represents the minimum performance level. This must be compared to the level of performance of the new building for which, through innovative technological solutions, optimized building-plant system and use of renewables, the annual primary energy consumption is minimized. Finally, in

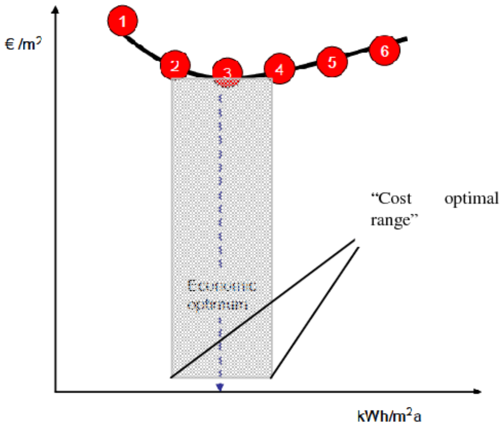

Figure 2.22 Definition of cost optimal level of energy performance

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[9] Norme tecniche quadro, contenenti gli indici minimi e massimi di funzionalità urbanistica, edilizia, anche con riferimento alle tecnologie in materia di efficienza e risparmio energetico e produzione da fonti rinnovabili, e didattica indispensabili a garantire indirizzi progettuali di riferimento adeguati e omogenei sul territorio nazionale. MIUR, 2013

[10] Article 2 "Definitions" European Directive 2010/31/EU

[11] Article 2 "Definitions" European Directive 2010/31/EU

[12] Article 2 "Definitions" European Directive 2010/31/EU

relation to this, to calculate the global cost according to the economic life cycle of the building [32]. It is possible to represent the optimal energy performance level through a graph considering the annual primary energy consumption per unit of useful area in abscissa and the overall costs related to the single measures adopted in the ordinate [32] (Figure 2.22).

The creation of an nZEB building is certainly based on an integrated approach to design in order to make architectural design interact with energy design right from the preliminary phase of the design process, which therefore can no longer be traced back to a linear diagram [32]. The ultimate goal of this integrated approach must surely be the reduction of the energy requirement for heating and cooling by improving the performance of the external envelope by using energy-efficient technological solutions [33] and the use of active and passive systems integrated with renewables [34] [35].

Initially in the report of the Federation of European Heating Ventilation and Air Conditioning Association (REVHA) low-energy buildings are outlined using two different definitions [36]:

- NZEB: “*Net zero energy building with energy use of 0 kWh/m^{2}a primary energy*”;
- NNZEB: “*National cost optimal energy use of > 0 kWh/m^{2}a primary energy*”.

After the enactment of the European Directive, different definitions of nZEB building followed one another before arriving at a common definition [37] [34]:

- Net zero site energy: “*A site ZEB produces at least as much as it uses in a year when accounted for at site*”;
- Net Zero Source Energy: “*A source ZEB produces at least as much energy as it uses in a year, when accounted for at the same source. Source refers to primary energy used to generate and deliver the energy to site. To calculate building’s total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers*”;
- Net Zero Energy Costs: “*In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over year*”;
- Net Zero Energy Emissions: “*A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources*”.

As some authors point out [37] [38] the definition of nZEB building can instead be strictly defined also with respect to where the energy produced by the building is produced (Figure 2.23). In fact, a building can use renewable resources within the confines of the construction site (on site):

- On-site supply option 1: “*Use renewable energy sources available within building’s footprint*”;
- On-site supply option 2: “*Use renewable energy sources available at the site*”.

Or use an energy production system outside the confines of the construction site (off site):

- Off-site option 1: “*Use renewable energy sources available off site to generate energy on site*”;
- Off-site option 2: “*Purchase off-site renewable energy sources*”.

A zero-energy building can also be defined based on its connection to the public distribution network (Figure 2.24):

- *Autonomous ZEB* Off-grid: “*It is not connected to any utility grid and hence needs to use some electricity storage system for periods peak loads (self-sufficient or stand-alone)*” [38];
- *Net ZEB* On-grid: “*When the energy production on site is greater than the building loads, the excess is done to the grid*” [39].

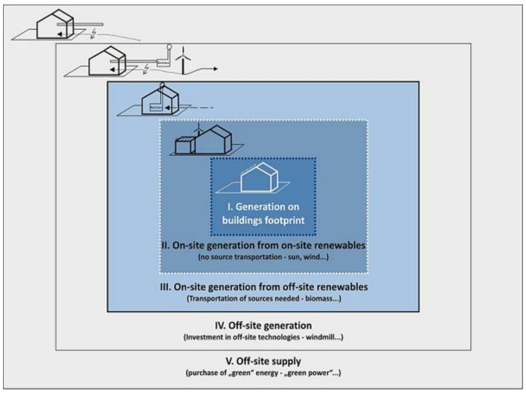

Figure 2.23 Definition of NZEB building with respect to energy supply options [38]

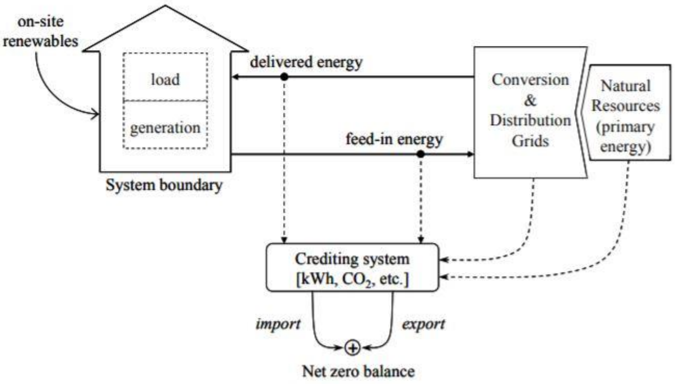

Figure 2.24 Definition of NZEB building with respect to the grid [40]

Lund et al. [41] classify buildings with zero energy / emissions based on the renewable energy generation system:

- PV ZEB: “*Building with a relatively small electricity demand and a photovoltaic installation*”;
- Wind ZEB: “*Building with a relatively small electricity demand and a small on-site wind turbine*”*;*
- PV-SolarThermal-HeatPump ZEB: “*Building with a relatively small heat and electricity demand and a photovoltaic installation in combination with a solar thermal collector, a heat pump and heat storage*”;
- Wind-SolarThermal-HeatPump ZEB: “*Building with a relatively small heat and electricity demand and a wind turbine in combination with a solar thermal collector, a heat pump and heat storage*”.

Finally, a low-energy building can also be outlined by its energy balance (obviously accompanied by boundary conditions) which represents the definition of the lowest common denominator behind all the previous definitions found in the literature on the subject.

The budget of a NZEB building in a period of one year can be based on the energy exported and imported from the network (import/export balance) and this is the one that provides the most information on the energy performance of the building or between the needs of the building and the energy produced on site (*load/generation balance*) [41]. A third option instead is to carry out a budget that is not annual but monthly. The European Directive of 2010 proposes the following balance equation:

Equation 2.1 $|weightedsupply| - |weighteddemand| \geq 0$

Through this equation it is possible to state that the balance between the incoming energy and the output energy of a nZEB building, connected to the public distribution network, is equal to zero or positive [42], considering a precise interval of time (usually a year) and defining the boundaries of the system.

Sartori et al. [40] specify the previous equation in the following form for the import/export balance approach:

Equation 2.2

$$\sum_i e_i \times w_{e,i} - \sum_i d_i \times w_{d,i} = E - D \geq 0$$

where: e is the exported energy [for instance kWh/m^2 or kWh/m^{2}a], d is the delivered energy [for instance kWh/m^2 or kWh/m^{2}a] while w[13] is the weighting factor and i is the energy carrier; E is the weighted exported energy while D is the weighted delivered energy. While for the load/generation balance approach we obtain:

Equation 2.3

$$\sum_i g_i \times w_{e,i} - \sum_i l_i \times w_{d,i} = G - L \geq 0$$

where: g stands for generation [for instance kW], l stands for load [for instance kW] while w is the weighting factor and i is the energy carrier; G is the weighted generation while L is the weighted loaded.

European standards on energy and emissions [43] [44] are summarized in the recent European Directive n. 844 of 30th May 2018 [45] which aims mainly to favour the evolution of a sustainable energy system in order to really achieve the reduction of emissions and the decarbonisation of buildings and combat climate change and the consequent increase in temperature. Furthermore, the legislation encourages the improvement of the energy performance of existing and new buildings and introduces an indicator of the predisposition of buildings to intelligence (Smart Readiness Indicator - SRI) and the related calculation methodology.

In the ENEA technical report of October 2018 [46] the Smart Readiness Indicator is described as a value that measures the capacity of the building to adapt to the users' comfort needs, monitors their correct functioning, facilitates maintenance and finally assesses the ability to adapt to the energy infrastructure to district level to which the building is connected.

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[13] The weighting factor: “*converts the physical units into other metrics, for example accounting for the energy used (or emissions released) to extract, generate, and deliver the energy.*” [138]

At European level the member states have already implemented the requests of the various European directives that have occurred over the last 10 years. For example, in France, for the calculation of the energy performance of a building, we moved from a purely energetic approach with the RT2012 Thermal Regulation to an approach that takes into account the environment and the emissions produced by the building for the construction phase. of exercise. The RT2018 promotes the construction of "Bâtiment a énergie positive" (BEPOS) and a greater exploitation of renewable resources for energy production [35]. In Greece in 2017 no report is available with the indications for the implementation of European standards, while in Spain and Portugal, indices are defined to be respected with specific limits [35]. For Portugal the nZEB building is defined as a building that chooses the solution of its external envelope through the optimal cost and where the energy requirement is covered for a significant part by renewable energies produced on site or in a nearby area [35]. Almost all the member states have the more or less complete definition of nZEB building on their national legislation while only the Netherlands, Denmark, Luxembourg and Ireland have outlined clear and precise requirements and indexes also through the use of renewable energies for obtaining nZEB buildings both for the redevelopment and for the new realizations [47].

At national level, the latest legislation on the subject is the D.M. n. 162 of 26th June 2015 [48] which defines through a series of requirements to respect the nZEB building and establishes the obligation for newly built public buildings, including therefore schools, to be nZEB from 1st January 2019. The main obligations established by the legislation [49], in addition to those relating to the minimum transmittance of opaque and glass casing components, to thermo-hygrometric checks to avoid the formation of superficial molds and interstitial condensation and those relating to the plant, are the following:

1. the verification of the thermal performance indices useful for heating $EP_{H,nd}$ [kWh/m^2] and for cooling $EP_{C,nd}$ [kWh/m^2] and the overall energy performance index of the total building [kWh/m^2] (considering both the non-renewable and renewable portion) $EP_{gl,tot}$ [kWh/m^2] which must be lower than a limit value calculated with the reference building;
2. the verification of the average global heat transfer coefficient H'_T [W/m^{2}K] which has as its maximum limit a value depending on the shape ratio of the building and the climatic zone;
3. verification of the equivalent summer solar area $A_{sol,est}$ of the building for each glazed component dependent on the reduction factor for shading, from the transmittance of the total solar energy of the window calculated in the month of July with the active solar shielding, from the frame area and of the glass component and finally from the correction factor for the incident irradiation and which has as a maximum limit a value established through the category of the analysed building;
4. the verification of the surface mass M_s [kg/m^2] of the vertical opaque walls and of the periodic thermal transmittance Y_{IE} [W/m^{2}K] for the vertical and horizontal / inclined opaque walls excluding some areas specified in the standard;
5. the verification of the obligation relating to the integration and use of renewable sources as specified in Annex 3 of Legislative Decree n. 28 of 3 March 2011 [49], according to which 50% (60% for public buildings) of the primary energy needs of the building for the heating, cooling and

the production of domestic hot water must come from renewable sources. Furthermore, a minimum amount of electrical renewable energy is established to be installed on its own building dependent on a regulatory coefficient and on the floor area of the building at ground level;

6. the verification of the average seasonal efficiency of the summer and winter hot water production air conditioning system.

For the calculation of the parameters related to a nZEB building for the national legislation it is necessary to refer to the Italian National Agency of Unification (UNI)/Technical specification (TS) 11300 1-6 which explain in detail the different calculation methods. In Italy, as recorded in the ENEA report of 2019[14], several school buildings have been built following the nZEB standard in the last three years: the Italo Calvino primary school in Novate Milanese (MI) of 2017 which is in energy class A4 with a global performance index of building amounting to 19.88 kWh/m^{2}a and 85% coverage from renewable sources, the nursery school in the S. Andrea district in Fermo (FM) built in 2017 again in energy class A4 with coverage of energy needs from sources renewable energy equal to 61% and finally the kindergarten Sandro Pertini in Bisceglie (BAT) which has a global performance index of 90 kWh/m^{2}a with coverage from renewable sources of 69%[15].

In Germany, on the other hand, the first standard for buildings with low energy consumption and consequently low CO_2 emissions comes with the Three literhaus (3 liters of diesel per square meter per year for heating) [32] and subsequently with the Passivhaus (1988, Dr. Wolfgang Feist). The first approach is essentially based on the exploitation of internal and solar inputs to reduce the energy requirement for heating considering Germany's harsh climate. Instead the second is a real evolution and involves the adoption of a series of technological solutions well rooted in the German culture to obtain a building that, considering a climate characterized by harsh winters, is able independently to cover its own needs energy for heating without using traditional systems. In the first definition of a passive building the energy requirement for heating was not to be greater than 15 kWh/m^{2}a while the total primary energy consumption had to be less than 120 kWh/m^{2}a [22]. Over the last 30 years, the German legislation has focused on the definition of *Plus Energy Buildings* and *Neutral Carbon Buildings*. The first terminology was used for the first time in 1990 by the architect Rolf Disch who defined a residential building as Plus Energy House as a house that produces more energy than its inhabitants manage to consume [50]. Subsequently, this definition has evolved since the building must necessarily: use only 100% renewable energy, cancel emissions of greenhouse gases, be on-grid in order to transfer the energy produced to the public network and finally it must be verified that both the primary energy and the annual final energy demand are both less than 0 kWh/m^{2}a . It is also preferable that renewable energy is produced at the construction site of the building (on-site) [39]. In Germany, and beyond, there are school buildings built according to this standard. Examples are the Primary school Hohen Neuendorf built in 2011 (Figure 2.25) and the Elementary school

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[14] "Nearly zero energy observatory (nZEB) in Italy 2016-2018" by Ezilda Costanzo, 2019

[15] https://www.ediliziascolastica.it/progetti/scuola-materna-sandro-pertini-bisceglie/

Franziskus Halle built between 2012 and 2014 (Figure 2.26) both part of the European program The School of the Future.

Figure 2.25 Primary school Hohen Neuendorf – Reference: https://legep.de/projekte/grundschule-niederheide-hohen-neuendorf/?lang=en

Figure 2.26 Primary school Franziskus Halle – Reference: http://projects.archiexpo.it/project-27510.html

The two German schools are essentially characterized by a low energy requirement for heating (about 20 - 30 kWh/m^{2}a according to the German EnEV[16] regulation), passive cooling takes place during the night with natural ventilation of the internal environments and the use of one geothermal heat exchanger. Ventilation is hybrid and mechanical ventilation is activated essentially when the concentration of pollutants inside the classes is high. Both have a photovoltaic system for the production of renewable energy on the roof so as to obtain a zero-emission school and able to comply with the concept of energy plus.

Another example of an energy plus school was built in the northern suburbs of London in Crouch Hill Community Park and is the Ashmount Primary School (Figure 2.27 - Figure 2.28). This school building was the first to have obtained BREEAM[17] certification and, through a cogeneration plant powered by gas microturbines, manages to meet its energy needs for heating and at the same time use excess energy production in buildings adjacent residential areas. The school has a low energy requirement and consequently a production of CO_2 emissions in the atmosphere equal to 35 kg$_{CO2}$/m^{2}a.

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[16] It means: “Energieeinsparverordnung”

[17] Environmental sustainability assessment protocol established in 1988 and developed by the Building Research Establishment (BRE).

Figure 2.27 Primary school Ashmount internal courtyard view

Figure 2.28 Primary school Ashmount main façade – reference: http://projects.archiexpo.it/project-27510.html

An Energy plus building is not a self-sufficient building and its connection with the public network to import and export energy is the basis of its definition. The network becomes a real virtual accumulation for these buildings. The calculation of the energy balance is carried out considering a precise interval of time, generally one year (Figure 2.29) during which it is not said that there is a production of excess energy at any time [50]. But it is also possible to consider the entire life cycle of the building and the energy plus standard is reached when the exported energy produced by renewable resources is greater than the primary energy consumption for the construction, maintenance and demolition of the building [50] (Figure 2.30).

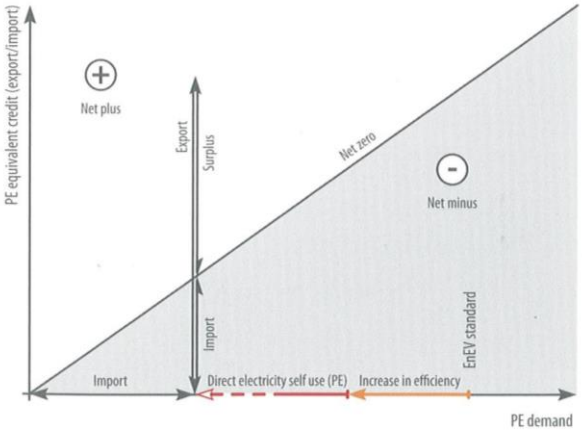

Figure 2.29 Energy Plus annual PE balance - [50] *page 29*

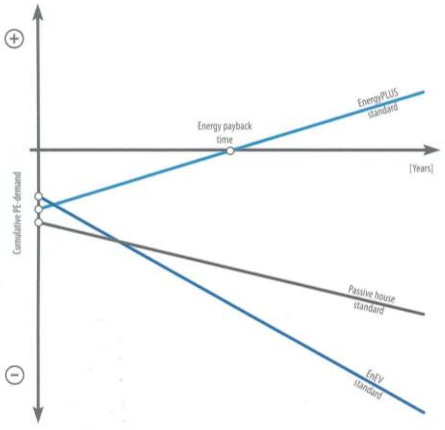

Figure 2.30 Cumulative primary energy demand over the life cycle - [50] *page 30*

German politics is currently oriented towards redevelopment and/or new construction with a view to the energy plus standard but aims at the redevelopment and/or construction of entire neighbourhoods according to this philosophy in order to obtain the decarbonisation of the entire building heritage. In fact, the German legislation defines a *Nearly climate – Carbon-Neutral Building* as: "*It is to build only some energy and that is to be met by renewable resources*"[18]. From a plant engineering point of view the most effective solution seems to be to produce energy in decentralized sites through cogeneration plants, exploit solar energy and

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[18] UBA Texte Klimaneutraler Gebäudebestand 2050

photovoltaic technology at the building and/or neighbourhood level in order to produce 100% renewable energy and build a real smart grid that includes the entire city to import and export energy [50].

In Italy, with regard to zero-emission school buildings, we find, for example, the Aurora Bachelet primary school in Cernusco sul Naviglio designed by ITI STUDIO in 2013 has a CO_2 emission value of 0.98 kg_{CO2}/m^2a with an energy performance index for the winter air conditioning equal to $EP_H = 4.92$ kW/m^2a [51].

2.1.4 Protocols and European Projects

Today for the certification of buildings it is important not to consider only the energy aspect, but it is essential to put the accent also on the environmental aspect of a building especially in reference to the Paris Agreement. In fact, the design of a building with a view to sustainability does not depend exclusively on its energy certification and therefore on its primary energy needs, but it is necessary that it takes into account innumerable aspects that determine its environmental impact [52].

The different types of environmental certification in fact underline the importance of considering sustainability in a global perspective in order to take into account, for example, the lot where the building is built and its relationship with the context [53], from the analysis of the site and consequently from the climatic analysis to be able to use the natural resources on site and not less from the production of the different materials that make up the construction and the emissions of greenhouse gases in the atmosphere during use phase [54]. Consequently, the energy-environmental certification must be an evaluation tool at the base of which is an integrated approach that takes into account all the aspects that come into play in the design and construction process of a building. For this reason, the environmental certification is defined as: "*a process that allows to evaluate a building not only considering consumption and energy efficiency, but also taking into consideration the impact of construction on the environment and on human health*"[19]. It is necessary to take into account both the environmental aspect understood not only as the impact of the construction and the activities but also as an evaluation of the use of the resources available at local and global level both of the short and long term economic aspect and finally of the social aspect essentially linked to the health and well-being of the occupants and their quality of life. Environmental certification differs from energy certification precisely because it considers the greatest possible number of environmental aspects that negatively and necessarily affect the natural ecosystem [55]. The certification protocols are essentially based on this concept and their main objective is to construct a building with a better energy and environmental performance than it would be obtained considering only the legislation on energy [55].

Energy and environmental certification systems are essentially of two types. The qualitative one, which refers to a scoring system that allows to obtain a value of the building's environmental energy performance through a weighted sum of the individual scores assigned to different standards of evaluation that require

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[19] "Technique and technology of building systems. Design and construction. With drawings, functional schemes, construction details and construction site images ", Eugenio Arbizzani, Maggioli Editore, 2015

the achievement of certain performances, or the quantitative one that complies with the LCA (Life cycle assessment) analysis and allows to determine and assess the environmental damage related to the construction and use of the building in question.

The certification systems concerning school buildings at national and international level are the ITACA Protocol[20], the LEED certification[21], the BREEAM certification[22] and the CASACLIMA certification[23].

2.1.4.1 ITACA PROTOCOLS

The ITACA protocol[24] is an internationally recognized system and was created through an interregional working group formed in 2001 which had as its main objective to define a set of shared rules in order to outline minimum requirements for the construction of buildings with green building characteristics [22]. This protocol is based on the SBTool international evaluation model and the basic principles are as follows: "*the identification of the criteria, i.e. the environmental issues that allow the measurement of the various environmental performances of the building under consideration; the definition of benchmark services with which to compare those of the building for the purpose of attributing a score corresponding to the ratio of the benchmark performance; the "weighing" of the criteria that determine its greater or lesser importance; the final score that defines the degree of improvement of the set of performances with respect to the standard level* ”[25].

The ITACA Protocol for schools was approved in September 2012 and consists of 41 evaluation criteria, to which a score is assigned, defined specifically for school buildings and divided into 5 macro areas: site quality, resource consumption, loads environmental, indoor environmental quality and quality of service. It is important to underline that within the quality of the site the main category is the selection of the site which on the total has a weight of 10%.

As can be seen from the following graph (Figure 2.31) for the ITACA Protocol the main macro-area is linked to the consumption of resources and the evaluation criterion that most influences the score is non-renewable primary energy which concerns the reduction of consumption for lighting (35%), primary energy for heating (30%) and finally the production of domestic hot water (35%). It focuses mainly on energy saving and plant operation, while assigning less weight to the materials used in the construction.

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[20] National ITACA protocol 2011. School buildings

[21] LEED 2009 for schools new construction and major renovations

[22] BREEAM New construction technical standards 2018

[23] CASACLIMA school New Buildings Technical Directive July 2015

[24] ITACA is the abbreviation of the Institute for the Innovation and Transparency of Procurement and the Compatibility of Contracts and together with iiSBE Italia and ITC-CNR manages the ITACA Protocol at national level

[25] http://itaca.org/valutazione_sostenibilita.asp

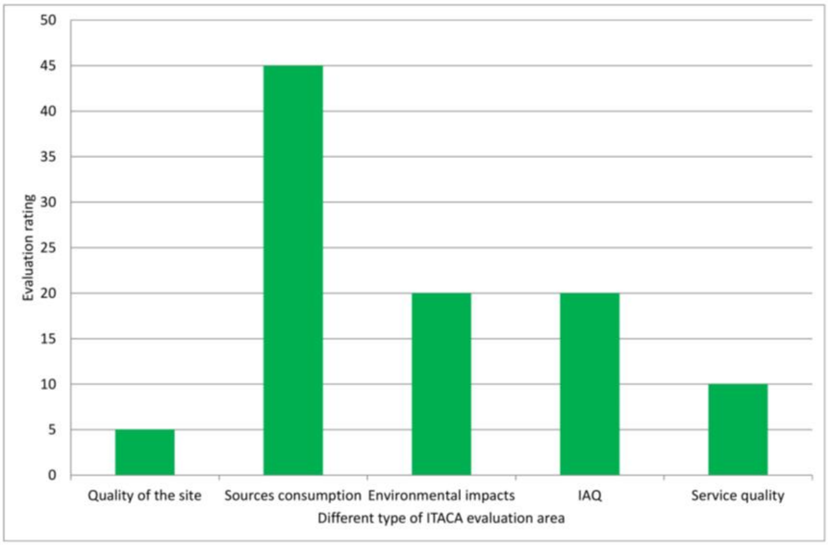

Figure 2.31 Identification of the weight of each macro-area on the total

Compared to the other protocols it has evaluation criteria that concern: the thermal inertia of the casing (B.6) in order to obtain good conditions of internal comfort, electromagnetic pollution (D.6) "*to minimize the level of electric and magnetic fields at industrial frequency (50 Hz) in indoor environments*"[26] and finally Design for all (E.7.1) which concerns the social aspects and specifically the removal of architectural barriers. The main criticality is essentially linked to the qualitative benchmarks that inevitably depend on the subjective judgment of the person in charge of the evaluation and do not have a clear and precise normative reference [53].

In Italy the first schools that received the national certification of the ITACA Protocol for school buildings were designed in 2017 by GP Project Srl and built in Aqui Terme (AI) in 2018: the Monteverde school in Piazza Allende and the Bella school in via Salvatori (Figure 2.32 - Figure 2.33 – Figure 2.34). They are two passive and near-zero energy buildings in A4 Energy class designed in compliance with CAM[27].

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[26] National ITACA protocol 2011. School buildings p. 47 Criterion D.6.1

[27] https://www.youbuildweb.it/2018/05/07/edilizia-scolastica-acqui+terme-itaca-

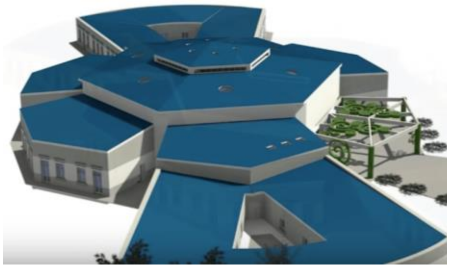

Figure 2.32 3D Model of the Monteverde School – Reference: https://ischool.startupitalia.eu/education/53443-20160415-scuola-acqui-terme

Figure 2.33 External view of the Bella School

Figure 2.34 Internal view of the Bella School Agorà – Reference: https://www.impresedilinews.it/acqui-terme-le-prime-scuole-italiane-certificate-itaca/

2.1.4.2 LEED

The LEED certification is a voluntary certification system developed in 2000 by the United States Green Building Council (USGBC) in the United States. This certification system is composed of 7 main categories[28]: site sustainability (26 points), water management (maximum 10 points), energy and atmosphere (maximum 35 points), materials and resources (maximum 35 points), internal environmental quality (maximum 15 points), innovation in planning (maximum 6 points) and finally regional priority (maximum 4 points) for a total of 100 points reachable. Credits are defined for each category and a score is assigned to each one; after completing the entire checklist, these scores are added together and the greater the value of this sum, the higher the certification level assigned [56]. The LEED for schools first developed in 2007 and was later updated with the "*LEED for schools' new construction and major renovations project checklist*". It is structured like the LEED for New Construction, but concentrates essentially on aspects that significantly affect the internal quality of school environments (acoustic comfort, mold prevention in the rooms, environmental assessments of the project site and sustainable practices by and for students) where students spend most of their day. With reference to this, the LEED Protocol rewards school buildings that consider sustainability and efficiency as an integral part of students' teaching and learning activities in order to make them aware of the sustainable management of the building they are using. The main difference with the other protocols is the assumption of a series of prerequisites for each category that the building must comply with as a sufficient and necessary condition to be able to access the certification since a minimum level of energy efficiency must be respected in reference to both to the construction and to the installed systems. As regards the sustainability of the site, the LEED protocol also assigns a score to the reduction of the heat island effect with reference to both the external surfaces and the roof of the building itself. Furthermore, with respect to the ITACA Protocol, it considers the area of water management as an independent assessment area. In addition to the credit relating to the use of renewable energy produced on site, it refers to green energy (EA Credito 6): "*to promote the development and use of technologies for the production of electricity from renewable sources (with zero emissions) with connection to the national electricity grid (to satisfy at least 35% of the building's electricity needs with energy produced from*

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[28] www.gbcitalia.org

renewable sources (green energy), through a certified supply contract for electricity produced from renewable sources lasting at least two years)"[29]. In Italy the first primary school that received the LEED Platinum certification in September 2007 is the Comprehensive School of Arco di Romarzollo (TN) (Figure 2.35 - Figure 2.36 - Figure 2.37). The certification was achieved with 61 of the 79 available points and the design choices made it possible to create a building with a low environmental impact: for the roofing the technological solution of the green roof was adopted, rainwater is collected and exploited for irrigation and the materials with which the finishes were made (paints, coatings, adhesives, sealants) are low in Volatile Organic Compounds (VOCs). Furthermore, from an energy performance point of view, modelling in dynamic conditions has shown that compared to the reference building, an improvement of 44.2%[30] is achieved.

Figure 2.35 External view of Romarzollo elementary school

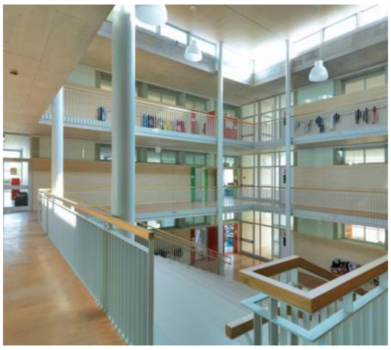

Figure 2.36 Internal view of Romarzollo elementary school atrium

Figure 2.37 Internal view of gym glass façade – Reference: https://www.arketipomagazine.it/plesso-scolastico-di-romarzollo-arco-krej-engineering/

The first LEED school certified is Paolo Crosara in San Bonifacio (VR). This is a demolition/reconstruction as the building was demolished and rebuilt in the same footprint as the previous one in 2011. It obtained the LEED Platinum certification with a score of 85 out of 100 total points with the highest score obtained in energy and atmosphere (33/35). The certification was obtained by adopting plant technologies that allow for example the reuse of rainwater for irrigation and sanitation and through the use of sustainable materials with low environmental impact. Furthermore, a photovoltaic system, solar thermal water for domestic hot water and a floor-mounted radiant heating system have been provided in the building[31]. The National Association of Construction Builders (Ance) has included this school building among the ten best projects for "*The best green buildings in Europe certified LEED* (2013)". A foreign example that deserves to be mentioned is the primary school built in Taichung in Taiwan which received the LEED diamond certification level. The main characteristic is that inside the classes only natural ventilation is used to maintain internal comfort. This choice is closely linked to the analysis of the site and to the direction of the prevailing winds which in this case dictate the rules for internal functional distribution. This solution makes

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[29] LEED 2009 for schools new construction and major renovations

[30] "Romarzollo Primary School - I.C. Arco. ECOSTUSIBLE The Leed Platinum certified plexus "by Maurizio Zambarda in Captions Informs n. 11-12 November-December 2012

[31] http://www.rinnovabili.it/greenbuilding/risparmio-energetico-leed-platinum-555/

it possible to obtain considerable energy savings and a net reduction in emissions of polluting gases in the atmosphere [57]. For the cover the technological solution of the green roof is used in order to reduce the concentration of pollutants in the air and control the surface temperature of the roof [57].

2.1.4.3 CasaClima

The CasaClima certification was developed in Italy in Trentino-Alto Adige in 2002 and is based on the calculation of the building's heat requirements (envelope efficiency and quality of the technological components) and on the overall efficiency of the building-plant system in terms of primary energy and m CO_2 emissions requirements [58]. The main objective of CasaClima certification: "*is to build by reducing the building's heat losses thanks to good thermal insulation. The passive use of solar energy and an efficient plant further optimize energy savings. CasaClima therefore does not define an architectural style or a particular type of construction, but rather the energy category of the building*"[32]. The class for CasaClima certification and the overall sustainability of the building are established through calculation[33]: of the energy efficiency of the building envelope (EIN), of the equivalent primary energy requirement without cooling, of the equivalent primary energy requirement with cooling, of the overall energy efficiency (EEC) and control of thermal bridges. In the CasaClima Nature document there is an explicit reference to school buildings and the calculation of various quantitative indicators relating to the environmental impact of the materials used for the construction, to the water impact, to the air quality, to the exploitation of natural lighting is illustrated , to acoustic comfort and finally to the production of radon gas. The main differences with the other Protocols are first of all that this certification is not a scoring system but involves the calculation of indexes that prescribe a minimum standard of performance, and secondly the request for a mandatory verification during the construction phases of the building and work completed so as to verify that the building has been built consistently with respect to the architectural design and in a workmanlike manner (for example the Blower Door Test is mandatory before students occupy the building) [58].

On the national territory with this certification there are the Capuana Nursery School (Istituto Comprensivo Gandhi) built in Florence in 2014 which received the CasaClima A certification (<30 kWh/m^2a) and the primary school in the municipality of Valsamoggia (BO) with CasaClima Gold certification class (<10 kWh/m^2a) and a global performance index according to the Emilia-Romagna regional legislation equal to 1.175 kWh/m^3a.

2.1.4.4 BREEAM

Finally, the BREEAM certification protocol was born in Great Britain through the BRE (Building Research Establishment) in 1990 and is the first evaluation method born in Europe from which all others were inspired. The main objectives of this certification system are: "*To mitigate the life cycle impacts of buildings on the environment, to enable buildings to be recognized according to their environmental benefits; to provide a credible, environmental label for buildings; to stimulate demand and create value for sustainable*

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[32] "Casa Clima- Klimahaus, Vivi in più" Norbert Lantschner, Rateia Editions, Bolzano 2015 p.23

[33] New Buildings Technical Directive, July 2015, South Tyrol Energy Agency - CasaClima

buildings, building products and supply chains"[34]. Like the ITACA protocol and the LEED certification system, this is also a scoring system: it is structured according to 9 macro-areas which are assigned a weight with respect to the total (management, health and wellbeing, energy, transport, water, materials, waste, land use and ecology, pollution, innovation) subdivided into sub-categories to which a score is assigned. The BREEAM method provides for a classification from Acceptable (with a score between 10 and 25) to Outstanding (with a score above 85). Like the LEED certification system, it is necessary to comply with minimum standards in order to access the certification (*Not Acceptable* <10 points). As can be seen from the graph below (Figure 2.38) the two macro-areas that have the greatest influence on the classification of the building are Health and Wellbeing to guarantee building users an adequate level of comfort within the building environments in relation to the visual, thermal, acoustic and air quality environments and Energy which through a series of requirements favors the construction of buildings with low energy consumption and low CO_2 emissions. Both macroareas compared to the total have a weight of 15%.

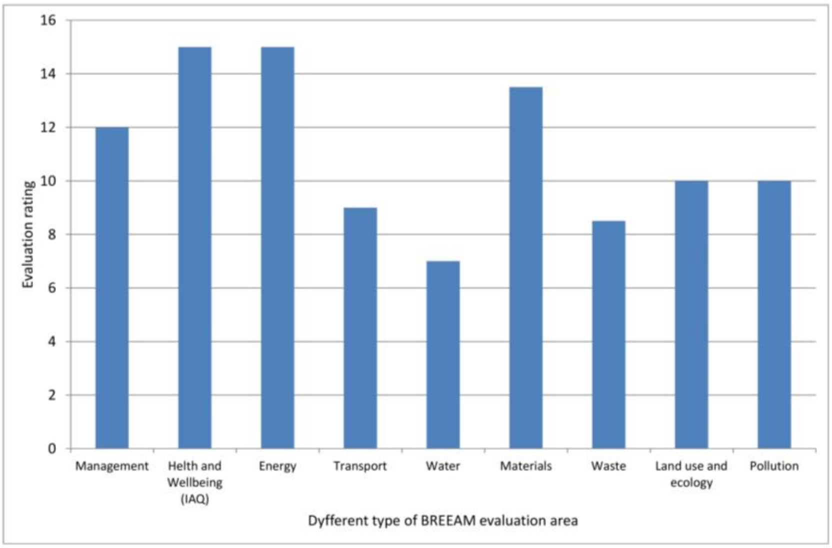

Figure 2.38 Identification of the weight of each macro-area on the total

Compared to the other protocols mentioned above, the BREEAM system provides for sub-categories of evaluation that concern: the shape of the building in plan with respect to the consumption of land, preferring the compact form, the passive design and therefore the application of low or zero-carbon technologies , efficient refrigeration systems, the monitoring of water consumption inside the building, the integrated building process that is part of the Management category and involves the presence of an expert who follows the entire design phase in order to obtain the certification and finally the evaluation of the flood risk.

The school buildings that received BREEAM certification were essentially built in the United Kingdom where the certification was born: the Rogiet primary school in Monmouthshire which obtained the excellent classification in 2006 (78.18%) obtaining a 100% in the Pollution category satisfying all the requirements regarding the use of refrigeration systems, insulation, renewable energy and flood risk with

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[34] “BREEAM UK for New Construction Non-Domestic Buildings, Technical Manual”, Code for sustainable Built Environment, www.breeam.com

related drainage systems. The Bygrove primary school in Poplar always in the excellent category for the certification system, the Arcadia nursery school in Edinburgh with a score of 82.2% which obtained the maximum score in the Materials and Pollution categories as it was mainly made of wood, with low-emission materials for the finishes and in the absence of use of refrigerants in the building. The school is also equipped with a sustainable urban drainage system (SUDS) despite being in an area with low risk of floods. Finally, it is worth mentioning the nZEB primary school Ysgol Ffwrnes at Lianelli which obtained the highest score and the Outstanding classification with a score of 85.9%. All the school buildings mentioned that have obtained the BREEAM certification are characterized by the natural ventilation of the rooms to maintain the internal comfort through the manual or automatic opening of the windows in relation to the internal monitoring of pollutants, in particular CO_2.

2.1.4.5 European projects

In Europe, after the enactment of the energy directives, a series of research projects and initiatives followed, which in any case mainly concerned the redevelopment of school buildings and only partially new constructions. The most significant are listed below and the main characteristics are reported.

- *The school of the future*: it is a project of the European Union (2011-2016) whose main purpose is to design, implement and monitor school buildings in order to make them sustainable. 3 pilot projects are outlined to be analyzed in 4 different states (Italy, Germany, Denmark, Norway): two linear ones, one with a side corridor and the other with a central corridor, and one with a compact shape. The idea is to outline the guidelines for the designer for the energy requalification of existing school buildings essentially concerning the improvement of the envelope, the integration with plants that use renewable energies and the system of use and management and control of the plant during the exercise phase. The methodology is essentially based on the study by monitoring the conditions of the existing building, the site climate analysis, the proposal of a series of improvement interventions and the comparison between ante and post-intervention. In Italy, the Tito Maccio Plauto school in Cesena in Emilia-Romagna was part of this project, where energy reduction was aimed at obtaining a 75% reduction in energy for heating and a reduction in energy requirements of 67 % and improvement of internal comfort conditions according to the requirements of this project [59].
- *ZEMds (Zero Energy Mediterranean Schools)* [60]: it is a three-year research project that is part of the Energy Europe program (IEE) and promotes the energy improvement of public buildings by imposing a series of minimum requirements that must be achieved. The main purpose of the project is to provide guidelines for the designer so that schools can be upgraded energetically by proposing various solutions with the related economic analysis and the main advantages of the proposed energy strategy [61]. Also in this case the most effective improvements concern: the building envelope with the proposal of 3 different variants, one of which also includes the replacement of the fixtures, the controlled mechanical ventilation, the heating system, the electrical system, the integration with renewable energies, building monitoring and control over user behavior. The methodology is similar to the previous one but includes energy simulations

through energy plus of the building under examination for each improvement that is proposed in order to understand how much the various technologies affect the energy performance of the school.

- *Schoolventcool*: research project (2010-2013) which is developed within the ERACOBUILD project which essentially promotes the study of a prefabricated modular façade to be used in school buildings to exploit passive cooling and reduce the primary energy consumption of the building of the 20th century %. In fact, the project underlines the lack of information on overheating caused by solar inputs and consequently an energy and economic analysis is proposed which concerns the study of the facade module for passive cooling, the strategies for natural ventilation, the use of solar shields and different control systems for pollutant concentration to deal with this problem and improve the internal quality of the classrooms. The facade module is studied essentially in two cases: use of sensors that measure the amount of CO_2 in the air and the manual opening of the windows to the sound signal indicating a concentration higher than that of legislation, or the use of a mechanical ventilation system with windows that open automatically and fans that suck the polluted air from the classrooms. The mechanical ventilation can be centralized or decentralized and realized through the vents located below the windowsill and above the architrave. The designer is provided with a series of building configurations based on the number of floors, the type of facade and the relationship between the building and the context where this solution can be used and a series of block diagrams to understand if the solution is adoptable or not in reference to the specific case.
- *Greenest school on earth* [62]: it is a research project developed by the United States Green Building Council (USGBC) in 2007; a green school is defined as "*is school building or facilities that create a healthy environment that is conducive to learning as well as saving energy, resources and money*"[35]. This project aims to reward all those school buildings that not only represent sustainability in building but also incorporate it into the educational program. As for the certification systems, also in this case the schools are analyzed following a checklist composed of 6 criteria: energy efficiency, improvement of the quality of the internal environment, conscious use of water, waste treatment, site protection and respect for reality local. The first school to receive such recognition is the Bali Green School in 2012[36] built in bamboo.
- *Julia 2030*[37]*:* it is an initiative (2009 - 2011) that took place in Finland within a Life program funded by the European Union. The aim was to promote initiatives that lead to a reduction in greenhouse gas emissions in the environment in order to combat climate change and obtain public buildings with zero emissions.

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[35] "The green school project: A means of speeding up sustainable development?", Dong-Xue Zhao et al, in Geoforum 65 (2015) pp. 310 - 313

[36] https://www.greenschool.org/

[37] Joining forces to Boost Climate Work in the Metropolitan Area – Layman's Report

- *Schools for Kyoto*[38] [7]: it is a program (2016-2017) of the Kyoto club[39] and promotes the activation of educational programs aimed at students (mainly middle and high schools) in order to prepare and make students aware and consequently families with respect to issues of energy sustainability and environmental. The areas of interest of this project are: energy analysis and savings in construction, renewable energy sources, sustainable mobility, separate collection, redevelopment of urban areas, organic farming and climate change.
- *Eco generation Project - the climate-friendly school* [7]: it is a three-year project involving 10 schools as pilot projects distributed throughout Italy. First of all, the project begins with the energy audit of the selected buildings in order to identify the problems that could lead to student discomfort and that could negatively influence the energy performance of the buildings in question. After a series of educational activities involving both pupils and the teaching staff on energy efficiency and sustainability, schools were invited to outline a sustainable school handbook where they had to indicate a series of interventions that would allow the improvement of internal comfort conditions and energy performance of the building.
- *Eco_school*: was promoted for the first time in Denmark in 1992 by the FEE[40] foundation which promotes the reduction of the environmental impact of buildings and the dissemination among pupils, families and local authorities of good practices for sustainability in order to educate new ones generations and make them aware of the consumption of school buildings and all the consequences they entail for the natural environment.
- *Teenergy projects (High energy efficiency schools in the mediterranean area)* [63]: it is a research project promoted by the Province of Lucca to deal with the numerous problems existing in school buildings (overheating during the summer season, inefficient heating systems, poor indoor air quality, high energy demand) and to promote initiatives for improvement of existing school buildings by defining a series of common strategies for the Mediterranean area in order to approach European policy in this area. The methodology includes 5 main phases: political backing, diagnosis, strategy, action plan and pilot project and finally communication. During the energy diagnostics and audit phase, this project also includes a questionnaire directed at the students and teachers who use the school building. 12 pilot projects have been realized that mainly include redevelopment but also two new high schools in Viareggio.
- *Innovative Schools*[41]: it is a competition of ideas promoted by the MIUR for the realization of *innovative schools from an architectural, plant engineering, technological, energy efficiency and structural and seismic point of view, characterized by the presence of new learning environments and the opening to the territory.*

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[38] https://www.kyotoclub.org/progetti/scuole-per-kyoto

[39] *They are a group of companies, local authorities, universities and associations working in the renewable energy sector, sustainable building energy efficiency and are committed to reducing greenhouse gas emissions in line with the objectives adopted with the Kyoto Protocol* https://www.kyotoclub.org/chi-siamo/soci/elenco-completo

[40] Foundation for Environmental Education

[41] "Competition of ideas for the creation of innovative schools", MIUR - Ministry of University Education and Research 2016

2.1.5 State of art about schools' research

In this paragraph the main research about school building type found in literature will be presented and explained. It is necessary in order to present an overall overview about the studies that have been already performed and to understand the lack in literature about the definition or the study of typological factors of a new building type for school (kindergarten and elementary school). The studies that will be showed concern with some building typological factors that necessarily influence the school energy and environmental performance. It is important to point out that there are not many studies directly related to schools' main distinguishing features.

2.1.5.1 Ventilation strategies, indoor air quality and students' performance

The poor quality of the air, the inadequate internal temperature, the low natural lighting and finally the noise pollution are the main causes of discomfort within the classes and inevitably lead to a loss of productivity [64] [65] and concentration. Furthermore, environments that are not properly sized in relation to the number of children present imply concrete health risks essentially linked to children's sensitivity to temperature changes [66] and to the high concentration of pollutants due to both the presence of people and the emissions of building materials [67]. It would be preferable to keep a building intended for lower grade schools at lower temperatures than in a building where adults are present as children have a higher metabolic rate in relation to the different motor activities that are performed during school hours [68]. Many studies have been carried out that relate thermal comfort and ventilation rate for air exchange with student performance. For example, Wyon D.P. already in the early 1970s [69] [70] showed through an experiment conducted during two hours of lessons within a class of a primary school that the performance of the boys during a math test decreased by 30% if the temperature went up from 20 °C to 27 °C during the winter season. Furthermore, an experiment conducted in two classes in Denmark during the summer season showed that the performance of children both for the verification of mathematics increased significantly if the temperature dropped from 25 °C to 20 °C [71]. As far as ventilation is concerned, it is necessary to have an adequate air exchange rate in order to keep concentration high, constant learning of children [72] and protect their health from internal pollution sources [73] [74] [75] . A study conducted by Wargocki P. and Wyon D.P. with children aged between 10 and 12 shows that raising the ventilation rate from 3 l/s per person to 8.5 l/s per person increases the speed with which the boys carry out both Italian and mathematics language tasks. This is also connected to the fact that the concentration of pollutants in the environment decreases from 1300 ppm to 900 ppm [67]. More recent research concerns the study of school environments in relation to the perception of the environment itself and to the feeling of discomfort of students through the use of specially designed questionnaires [70] [73] [75] [76] [77]. Sometimes the class questionnaire is combined with a monitoring of the real conditions present in the classes in terms for example of air temperature, relative humidity and concentration of pollutants [78] [79] but also in relation to the ventilation system used in the building if natural or mechanical [80]. Francesca et al. [78] conducted a study in an Italian school built in 2010 and showed that a mechanized system for opening windows in relation to the concentration of pollutants in the environment is the best solution for user satisfaction with regard to the internal quality of the environments. This is because usually the manual opening of the windows is more linked to the cold sensation of the users and not to the concentration of pollutants [79]. In fact, the concentration of pollutants is higher in naturally ventilated classes by manually opening the windows with a reference value of 1420 ppm [80] since the manual opening of the windows is strictly connected to the behaviour of the users. In a study developed by Stazi et al. [81] it is emphasized that the opening or closing of the windows depends both on the routine of the school day (opening the windows during time change and recreation) and on the internal temperature perceived by the students (temperature range between 21°C and 22.5°C). Stabile et. al. [82] showed through an analysis of 16 school buildings built in the central Italian area that natural ventilation alone is not sufficient to maintain an adequate replacement suitable for the intended use of the building but it is necessary to adopt a mechanic ventilation system in order to guarantee the minimum air changes required by current legislation. Other authors [83] in studies conducted in Denmark and England have shown that natural ventilation through the manual opening of the windows with respect to mechanical ventilation involves a greater concentration of pollutants in the classes and this reflects negatively on the students' academic performance. In fact, the boys who find themselves in the classes with air exchange performed through natural ventilation obtain a lower score for the educational tests compared to the boys who are in the classes with mechanical ventilation. Schoer L. and Shaffran J. have shown that student performance is greater than 5.7% if a mechanical ventilation system is used in the class for air exchange [84]. Some authors maintain that for boys of lower-level schools the preferred thermoregulation mode is a conditioning system rather than the opening of windows, the use of sunscreens or the change of clothing [85]. As regards the ventilation systems within the classes, various studies have been carried out to understand which is the best both with reference to natural ventilation and mechanical ventilation [86] [87] [88] [89]. The methods of natural ventilation for the exchange of air within a class are mainly 3: single side-ventilation, cross-ventilation and displacement ventilation [89] and certainly entail savings in terms of energy requirements of the building if the ventilation flow rate entering the class remains constant [88]. A correct design of a natural ventilation displacement occurs when the high concentration of pollutants and the temperature higher than that of the set point are recorded above the occupied area. As far as mechanical ventilation is concerned, it has been shown that the mechanical ventilation system controlled by CO_2 concentration detection sensors leads to a better internal comfort condition and also a saving in terms of energy consumption compared to the traditional ventilation system constant [86] [87].

2.1.5.2 *Window-to-wall ratio and its link with school buildings*

Window-to-wall ratio is certainly a parameter that necessarily affects the energy needs for heating, cooling and lighting of a building. Consequently, its definition during the early stage of the design process is remarkable to minimize primary energy consumption.

Nevertheless it is important to consider that the glazed surface of a façade plays a primary role in the energy balance of a building for the exploitation of solar gains during the winter season [90] and the consequent decrease in the energy demand for heating. Finally, to allow natural daylight to enter into indoor environments [91] and to create direct visual contact with the surrounding environments that promotes a feeling of well-being for the occupants of the building [92].

The first studies about the influence of WWR with respect to the energy performance of buildings date back to the late 1970s [93] [94] and they really concern the search of optimal window to wall ratio value for each orientation. The latest researches mainly concern office buildings [95] [96] [97] [98] [99].

WWR optimization for each orientation is achieved for instance:

- by minimizing energy consumption for heating, cooling and lighting [90]. Goia et al. (2016) define a range of optimal values of WWR through the application of a sensitivity analysis by varying building compactness, building equipment and artificial light efficiency;
- by analysing this parameter with respect to CO_2 reduction in the atmosphere [99]. They establish for a specific type of building and a certain climate a proper value of WWR that leads to a related decrease of CO_2 emissions;
- by considering the same building in many areas with different climate characteristics [95] [100] to understand how the climate can affect the definition of this parameter;
- by comparing it to several other buildings distinguishing some features: façade insulation thickness [94] or properties of glass [101] [102] compared to energy consumption for heating.

  Lee et al. (2013) study the relation between WWR, the visible transmission and solar transmission of glass establishing an optimal range to minimize energy needs for heating, cooling and lighting.

  Finally, Grynning et al. (2013) carry out a parametric analysis for an office building with 3 different methods considering the value of windows thermal transmittance and using glass solar factor.

There are only some studies about the analysis of window-to-wall ratio pertain with schools:

- Jorge S. Carlos [103] investigates the window-to-wall ratio of an elementary school classroom considering 2 different cities in Spain and 3 values of WWR. The study aims at defining the optimum geometry of a classroom with respect to both WWR and orientation, taking into account also the calculation of the daylighting factor strictly linked with both these values.

  He concludes that large windows enhance building energy performance during winter season but inevitably lead to a significant increase in cooling loads in summer, especially in warm climate zone. Moreover, this study demonstrates that the number of windows in the same room and the shape are 2 parameters that remarkably affect the distribution of natural lighting inside the classrooms;
- Zomorodian et al. [104] study the effect of the variation of the WWR within a range 15% - 65% in a classroom with respect to thermal and visual comfort inside the room. To evaluate the occupants' comfort, they consider the thermal transmittance, glass solar heat gain coefficient, visible transmittance, orientation and solar shading.

Neutral carbon school construction cannot ignore the study of window orientation, sizing and distribution in façades not only to minimize primary energy demand but also because the light plays a key role in schools. According to the needs of new didactic methods visual contact with nature and direct connection of classrooms and collective areas with the surrounding environment are fundamental. Consequently, the study of window to wall ratio of a school building is also essential to provide well-being, comfort and good learning to students that spend most of their time in educational building.

2.1.5.3 *Solar shading systems*

The use of shielding systems in buildings necessarily affects the energy balance and energy consumption for heating, cooling and lighting [105] as well. As for lighting, their use could also lead to a significant variation in energy requirements [106], this is obviously also linked to the intended use of the building. Furthermore, solar shading is one of the most important bioclimatic passive strategies for the façade [107]. Their correct design can avoid, during the summer season, problems of overheating through the regulation of the solar contributions inside the rooms [108]. For a building where visual activities are carried out on predetermined stations, comfort strongly influences the productivity of the occupants [108][109], which is therefore essential for a school building.

The sunscreens can be of different types:

- active if they allow to change the ratio between the incident and transmitted solar radiation;
- passive and therefore fixed, mainly used in climates where the incident solar radiation does not change significantly during the year;
- and finally, dynamics when they change their position through an automated control mechanism [110].

Many studies favour active or dynamic shielding systems that can adapt to real external weather conditions [111] but at the same time could lead to glare problems [112].

Before analysing different type of solar shading system and performing energy dynamic simulations, it is essential to point out that:

- solar shading is an element that strongly characterizes the appearance of the building's fronts;
- solar shadings regulate the entry of solar gains into the environments, they necessarily and significantly influence the energy balance;
- the correct design of shadings ensures a condition of hygrothermal and visual well-being for the occupants.

For a school building it is essential to maintain adequate internal conditions to ensure the comfort of students both during school hours and during periods in which extracurricular activities or activities for the neighbourhood community are carried out. Consequently, it is necessary, already during the preliminary design phase, to define adequately all the shielding elements that characterize the building and that influence its energy performance. They contribute to guaranteeing internal comfort, significantly influencing the entry of natural light and solar inputs, conditioning both visual comfort and hygrothermal well-being.

2.1.6 Photovoltaic system

The solar energy is the most widely and freely available in nature among the other renewable resources.

The term renewable resource appeared in the scientific literature in the beginning of 20th century as a resource that can be used to prevent the utilisation of fossil fuel [113]. A distinction is immediately identified between a *renewable energy source* like wood that is not forever available and *inexhaustible* ones like wind, hydro and solar radiation [113].

Nowadays the International Energy Agency (IEA) gives this definition of renewable energy: "*energy derived from natural processes that are replenished at a faster rate than they are consumed*".

In the context of the Paris Agreement, the exploitation of renewable resources is one of the best ways that will ensure the minimisation of gas emissions in the atmosphere and so it will lead to decarbonisation within 2050. Although, the development of systems to produce clean energy is one of the necessary phases in order to face the problems deal with pollutants emissions and climate change in the future [114].

The solar energy that the sun emits is approximately 3.8 x 10^{23} kW at a rate [115] and the Earth receives about 70% of the average amount [116] that can be collected and captured. The remaining 30% is in partly absorbed and partly discarded or reflected.

By the way, the incident solar energy on the ground of the earth is divided in:

- *beam radiation* that impacts the ground with one precise and defined angle of incidence;
- *diffuse radiation* that reaches the ground from different and multiple directions because it is scattered by the atmosphere;
- *component of albedo* that is the solar radiation that is reflected for instance by the ground or the water.

The solar energy is strictly linked to the geographic position, the latitude and the climate characteristics that necessarily affect the amount of energy that the earth receives. Moreover, among the inexhaustible energy (for instance geothermal and wind) the solar energy presents the best potential to produce energy [116].

The development of the solar industry is one of the utmost options to face the energy crisis and to meet the future energy needs [117]. Furthermore, the solar energy alone could satisfy the electric energy needs of the entire planet [118].

In literature some authors define the photovoltaic solar energy as the energy derived from the conversion of solar radiation [119] in order to obtain a common definition. In fact, the photovoltaic (PV) systems capture and exploit the solar radiation[42] in order to produce electricity.

A report of the European Photovoltaic Industry Association (EIPA) illustrates that the use of PV technology had a widespread in recent years passing by 23 GW in 2009 to 207.9 GW in 2016. In Europe, Germany is the country with the highest PV installations: 20% in 2017 with respect the entire world installations [120].

Since the beginning of the 21th century, the PV industry can be considered as the best option in terms of availability to face the energy needs, firstly with the production of clean energy and secondly because of accessible energy to everyone [121].

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[42] It means: "*The electromagnetic energy emitted by the sun as a result of the hydrogen fusion processes that it contains*", Progettare ed installare un impianto fotovoltaico, ENEA 2008

The photovoltaic module consists in the assembly in series or in parallel of the photovoltaic cells of about 100 – 400 cm^2 of surface, in order to constitute a single structure.

The power of this system for the electricity generation is measured in peaks kilowatts (kWp) that means: "*1 kWp of photovoltaic systems corresponds to a set of PV modules, arranged in series, able to generate electrical power of 1 kW if they are subjected to a solar radiation equal to 1000 W/m^2, at a temperature of 25°C and air mass equal to 1.5*"[43].

There are different types of photovoltaic panels related to the type of material of the photovoltaic cell that catches the solar radiation.

They are divided in [119] [122] [123]:

- the first generation of PV panels with crystalline silicon in two different options:
    - monocrystalline silicon (efficiency with a range of 15% - 17%);
    - polycrystalline silicon (efficiency of about 14%).

  Nowadays the silicon material to produce photovoltaic modules is the principal one (80% of PV market);
- the second generation of PV panels with photovoltaic thin film in different type materials (for instance amorphous silicon a cadmium) that are less expensive than the first one because they are obtained with less material;
- the third and last generation of PV panels with organic materials (polymers) that are characterized by a long-term potential.

Some of the main advantages of the photovoltaic technologies are:

- it can be applied in small and large scale and it is environmental-friendly also considering this second option [118];
- inexhaustible availability of sun energy [119] [117] [116] [124];
- low maintenance [125] and operational cost [121] [119];
- low environmental impact with respect to fossil fuel because it has not gas emissions during operational stage [126] [127] but only for construction, maintenance and demolition.

  Some authors [128] point out that the highest global warming potential impact is related to transport of PV panels for demolition (up to 80%) and then to the incineration of the sandwich layer.
- noiseless [119] [126];
- operational life of about 30 years [125].

While the main disadvantages are related to:

- the visual impact that could be very high [126];
- the high initial cost with respect the chosen technology;
- the availability of area for the installation of PV panels [119].

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[43] Translation from "*Progettare ed installare un impianto fotovoltaico*", ENEA 2008 p. 47

Moreover, by now PV system is a technology to generate electrical energy widely affirmed on a social level too [118], especially due to job creation and economic growth [127].
The efficiency of PV panels depends not only on climate characteristics of the zone (temperature and wind) of installation of PV systems but also on the thickness of dust that forms on the surface of the panel [129] [130] [131].

For public buildings in Italy, and so for schools as well, in order to obtain nZEB construction the integration with renewable resources to produce energy is mandatory (Annex 3, Legislative Decree n. 28 of 3 March 2011) [132].
In detailed this standard requires that:

- the systems to produce thermal energy must ensure a minimum production of energy demand by exploiting renewable resources:
    - 50 % of energy needs for service hot water + 50% of the sum of energy needs for heating, cooling and service hot water.
- the electric power produced by systems powered by renewable resources measured in kW has to be equal or greater than:

$$P = \left(\frac{1}{K}\right) * S$$

where: ***P*** means the minimum electric power [kW];
K is a constant equal to 50 starting from 1st January 2017;
S means the geometric area of the ground floor of the building [m^2].

Furthermore, the production of electricity with PV system reduces the CO_2 emissions in the atmosphere of about 0.53 kg_{CO2}/kWh [133] and it is important to stress out that, the conversion factor for the calculation of the total amount of CO_2 emissions of a building during the operational phase for the use of renewables, is obviously equal to 0 kg_{CO2}/kWh as reported in the Italian regulation.
This is closely connected with the goals of the Paris Agreement concern with the neutral carbon economy. Indeed, this is helpful to decrease the environmental impact of the service life of the building with its related consumptions and to face the climate change that will cause the increase in the outside air temperature.

The construction of a neutral carbon school building cannot ignore the design and the integration of a PV system on roof top not only for the requirements of the current Italian standards but the production of the plus electrical energy with the aim of feeding the energy in the national grid as well.
The intention is to create not only neutral carbon school buildings with energy demand nearly to zero, but also plus energy schools in the context of the smart and sustainable cities where most of the required energy is the electrical one.

2.1.7 CO$_2$ emissions

In the context of the Paris Agreement and of the decarbonisation of the entire building stock within 2050 (2050 free-carbon economy), it is fundamental to design and to build neutral carbon school building or even energy positive schools.

It is important to stress out that school buildings represent a considerable part of this existing building stock and the related energy needs is necessarily high with respect to the overall energy consumption.

Most of the considerable studies in literature about CO$_2$ emissions in school buildings deal with the refurbishment of existing schools.

For instance:

- Lizana et al. [134] presents a tool that evaluates the energy performance of existing school buildings in terms of indoor thermal comfort, energy demand, final energy consumption, non-renewable primary energy consumption and CO$_2$ emissions.

  The main aim is the transition of existing schools in low-carbon buildings, considering the detailed evaluation and comparison of the effect on energy performance of different type of improvement and choosing the best ones in order to obtain a reduction of 50% of energy consumption;
- Gamarra et al. [135] conduct a Lyfe Cycle Assessment (LCA) analysis with respect to the aggregated energy, the water consumption, the water scarcity exacerbation problems and the related carbon footprint of 2 existing high school buildings.

  The study illustrates that the most relevant advantages are reached with the improvement of heating and lighting systems due to the reduction of cumulated energy demand (CED) and carbon footprint;
- Zanni et al. [136] identify a tool to analyse existing school building energy performance through simple input information in order to provide support to local government to calculate the energy performance of the building stock. The tool allows to individuate the cheapest refurbishment for the energy improvement with respect to the heating consumption and the CO$_2$ emissions;
- Desideri et al. [137] presents the results of a European project “Educa-RUE” applied in the educational buildings in Perugia.

  The main aim of this initiative is the improvement of the energy performance of public building at local level by introducing specific measures and integrated tools in order to encourage the use of renewable sources for the energy saving especially in school buildings and to promote the ability of the local players to guide and to orient initiatives.

  The improvement in energy performance deals with resources consumption, environmental loads and indoor environmental quality.

2.2 BACKGROUND CONCLUSIONS

In conclusion, compared to the state of the art shown in this chapter, for the design of a new school building specific and interdisciplinary references are currently absent that consider both the innovations introduced in relation to the didactic and pedagogical methods that require polyfunctional and flexible spaces to child size, and the principles of sustainability for building low environmental impact buildings, with almost zero consumption and zero emissions. Now the designer cannot refer to a guide, to updated typological models and to specific indications that can direct him towards coherent design choices both in relation to the organization and functional distribution of the school building and to energy and environmental strategies. The legislation on school sizing in 1975 is dated and inadequate in many respects, especially in reference to the dimensioning of the environments also in relation to the demands of sustainability, as well as the manuals that propose typological models that are inappropriate for current school needs. The MIUR guidelines only refer to purely qualitative aspects without referring to any typological factor and the school that I would do with Renzo Piano seems to outline only qualitative suggestions for the initial concept. The environmental certification protocols relating to school buildings essentially focus on specific aspects that do not include the intrinsic characteristics of the building, such as the shape, orientation, sizing and distribution of bands and functional units or the ratio of opaque parts and transparent parts on the facade. There is no explicit reference in literature to how school buildings should functionally change while also considering the regulatory framework on energy. At the moment the scientific literature concerning the schools is mainly concerned with ventilation for the exchange of air within the classrooms, either in relation to the students' academic performance or to internal comfort, or it deals with the study of more specific and punctual aspects (for example window-to-wall ratio with respect to energy consumption, the calculation of CO_2 emissions, the behaviour of users in relation to the opening of the windows) but always with reference to the single class and not with respect to the entire building. The latter are studies that mainly concern existing school buildings. Even the European projects presented in the state of the art are essentially related to the strategies and technologies to be used in energy requalification.

Literature therefore lacks a complete and structured guideline for the design of lower grade schools that can be of help to the designer during the preliminary phase of the design so as to be able to create zero-emission buildings that can be considered as cultural reference and contribute to urban redevelopment actions.

In our opinion the school should in fact be a representative building with a double role: both didactic in the broadest sense of the term, and cultural. Educational programs should be updated to make children, and consequently families, more aware of energy and environmental issues and their inevitable consequences. Due to its cultural role the school should become an example of sustainable architecture in order to favour the interest in creating buildings with low environmental impact and zero emissions both in public and in private bodies.

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CHAPTER 3. Definition of new school building type

3.1 METHODOLOGY, STANDARDS AND ANALYSIS OF REPRESENTATIVE BUILDINGS

The second phase of this work made it possible to define the new building type for kindergarten and primary school to be adopted in Italy and which should be considered as a reference base for the preliminary design of a sustainable school building to replace those reported in the manuals and built on the basis of the current legislation dating back to 1975. The new building type for schools is outlined assuming for their configuration both the new pedagogical and didactic principles and those relating to the energy and environmental sustainability of the building.

The methodology for defining these models has developed according to the following [1]:

1. *Analysis of new teaching and pedagogical methods.* The analysis of the state of the art related to the philosophy of thought of the 20th century pedagogists concerning the transformation of the school idea, reported in chapter 2, allowed to identify and understand the changes suffered over time by the school buildings for primary education in relation to the evolution of didactic methods and the needs of teaching and to outline the main characteristics of the school building in relation to the concept of modern school;
2. *Analysis of the relevant regulations.* This phase has developed through the analysis of all the regulations relating to school buildings in order to define the minimum standards for the sizing of the building, the functional units and their surface, the minimum requirements to maintain a level of comfort appropriate to users and all those regulatory requirements that a school building must necessarily comply with;
3. *Identification and analysis of representative buildings.* The schools chosen in this phase of the research, to conduct a systematic and detailed analysis through reading sheets (in summary: analysis of the construction site, analysis of the environmental system and of the technological system of the building), are characterized by an internal configuration , which reflects the demands of current teaching and pedagogical methods, and by a high energy performance for which they have been rewarded nationally and/or internationally. Through a critical analysis it was possible to:
    - identify the factors characterizing the contemporary school building type and define the criteria that are at the base of the design of a school building with low environmental impact and with almost no energy consumption;
    - specify the technological solutions and the materials used;

    - outline the most recurrent environmental and energy strategies aimed at reducing primary energy demand;
    - collect a series of data regarding the thermophysical properties of the envelope, the energy requirement, the annual CO_2 emissions and the energy performance index for winter air conditioning, so as to have a comparison of the results obtained with the simulations in dynamic regime with the data referring to real buildings and not only to the regulations in force on the subject so as to validate the models outlined in this phase of the research from an energy performance point of view.
4. *Definition of new typological models for a zero-emission school building for kindergarten and primary school in the geographical area with a Mediterranean climate.* In this phase it was possible to define the new typological models for kindergarten and primary school that reflect the considerable changes that have suffered the school buildings both in relation to the new didactic and pedagogical methods, and in reference to the new energy and environmental strategies for the reduction of consumption. These models can be considered as a valid reference for designers for the construction of a zero-emission school building.

In short, this chapter will present:

- the minimum requirements imposed by the legislation in force in Italy for the construction of a school building with the explanation and a brief description of all the standards to be respected both for the nursery school and for the primary school;
- the analysis of representative buildings (general data, analysis of the environmental system and the technological system, environmental and energy strategies, building-plant system);
- the synthesis of the critical analysis (Appendix A) of representative buildings both for the nursery school and for the primary school with the discussion of the main results;
- the definition of new building type for kindergarten and primary school.

3.1.1 Minimum standards for school buildings

The design of a building cannot neglect the minimum requirements imposed by the current building regulations. The following paragraph sets forth the minimum regulatory standards to be respected for the design and construction of a school building (Table 3.1). In Table 3.1, for both school orders, minimum dimensional requirements are indicated, those related to the overcoming and elimination of architectural barriers and fire prevention, the parameters referring to thermal comfort, visual and acoustic and finally the minimum standards for maintaining appropriate ventilation and consequently adequate indoor air quality. The minimum dimensions of the furnishings are also indicated, which obviously vary according to the age of the students to ensure the correct ergonomic conditions and thus safeguard their physical health.

This is necessary as the new typological models must necessarily be in line with the main regulations in force in Italy, as well as being suitable for children in respect of both the needs of children and families and the needs of teaching.

The construction of a school building cannot do without the safeguarding of the health of the children who use it and this depends directly and necessarily on the choices regarding the building's own typological factors carried out during the preliminary phase of the design (such as orientation and dimensioning of functional units, the size of façade openings in relation to visual comfort, use of natural materials that do not emit harmful substances into the environment). It is essential to guarantee and maintain, in every typological model outlined during this research phase, the optimal conditions of internal comfort that inevitably affect not only well-being but also the students' academic performance.

Table 3.1 Summary with main requirements for school buildings

Dimensional standard		
D.M. n. 29 of 18th December 1975	*Kindergarten*	*Elementary school*
Maximum distance from home	300 m	500 m
Time range for public transport	-	15 min
Minimum number of classrooms	3	5
Maximum number of classrooms	9	15
Maximum number of students	270	625
Minimum number of students	15	75
Maximum number of students for classrooms	26	
Number of car parks	Law n. 765 of 6 August 1967: 1 m^2 for 20 m^3 of the building volume; Law n. 122 of 1989: 1 m^2 for 10 m^3 of the building volume	
Minimum height for classrooms	3 m	
Minimum height for horizontal connections and supplementary activities area	2.40 m	
Area for methodical activities	1.80 m^2/stud	
Area for special activities	0.60 m^2/stud	0.64 m^2/stud
Area for free activities	1 m^2/stud	0.40 m^2/stud
Area for practical activities	1.3 m^2/stud	-
Canteen	0.40 m^2/stud	0.70 m^2/stud
Kitchen	0.50 m^2/stud	
Accessibility of Public Building		
D.M. n. 236 of 14th June 1989	*Kindergarten*	*Elementary school*
Reginal law n. 1 of 3rd January 2005		
D.P.G.R n. 41/R of 29th July 2009		
Wheelchair minimum width	0.90 m	
Wheelchair minimum slope	8%	
Main entrance width	1.50 m	
Main entrance height difference with respect to external flooring	2.50 cm	
Area in front and behind of main entrance	1.50 m	
Internal door minimum width	0.80 m	
Glazed door width	< 1.20 m	
Glazed surface height with respect to floor	> 40 cm	
Weight of glazed door	< 8 kg	
Minimum area for rotation of the wheelchair in toilets	1.35 m x 1.50 m	
Height of handrail in toilets	0.80 m	
Thermal Comfort		
D.P.R. n. 74 of 16th April 2013	*Kindergarten*	*Elementary school*
Set point temperature for winter season	20°C	

Set point temperature for summer season	26°C	
Indoor humidity	40% - 60%	
Acoustic Comfort		
D.P.C.M. n. 297 of 5th December 1997	*Kindergarten*	*Elementary school*
Internal partitions	50 dB	
External envelope	48 dB	
Visual Comfort		
UNI 10340 May 2007	*Kindergarten*	*Elementary school*
UNI 12464-1 July 2011		
Classroom	300 lux	
Free activities	300 lux	
Canteen	300 lux	
Toilets and horizontal connections	100 lux	
Discomfort glare index (DGI) classroom	21	
Average daylighting factor classroom	0.03	0.05
Kitchen	500 lux	
Fire Prevention		
D.M. n. 218 of 29th August 1992	*Kindergarten*	*Elementary school*
Access to the area	Width = 3.50 m; Height = 4.00 m; Radius = 13 m; Slope < 10%	
Fire subdivision (based on height)	Within 12 m = 6000 m^2	
Minimum width of stairs	1.20 m	
Crowding classroom	26 person/each class	
Canteen	0.40 person/m^2	
Safety exits	At least 2 exits	
Safety exits width	At least 1.20 m	
Maximum distance safety exit	60 m	
Ventilation and Air quality		
UNI 10339 June 2005	*Kindergarten*	*Elementary school*
Classroom	4 l/s person	
Canteen	10 l/s person	
Free activities	4 l/s person	
Toilets and horizontal connections	2.5 l/sm^2	

The 1975 legislation specifies that a school building must be designed and constructed according to the following general criteria regarding the environmental conditions of the construction site and its location:

- wide construction site (indication of the minimum area of the construction lot depending on the number of students), characterized by the presence of greenery, far from equipment and infrastructures that could cause damage to children's health or inconvenience to the normal course of educational activities;
- a place located in a residential environment so as to allow easy access to the school on foot or through a short journey by public or private transport; the parking area available on site must be sized based on the volume of the building.

As shown in the previous table, the current legislation in terms of size expresses the surface area of the single main functional area in relation to the number of students and the minimum area to be assigned to each.

Moreover, the legislation underlines that the pedagogical unit for the kindergarten must provide for the possible independent and separate development of the following activities in order to be able to meet the needs of the teaching programs: ordered activities, free activities and practical activities.

Instead in the elementary school the classes must adapt themselves to the possibility of variation of the equipment and of the furnishing and between classes of the same cycle a common space must be present for the collective activities.

In school premises, as in any public building, accessibility must be guaranteed as: "*the possibility, even for people with reduced or impeded motor or sensorial capacity, to reach the building and its individual real estate and environmental units, to enter it easily and take advantage of spaces and equipment in conditions of adequate security and autonomy*"[1]. Consequently, it is necessary to comply with the dimensional requirements imposed by the regulations at national and regional level so as to make them usable by students with reduced mobility.

The values of indoor air temperature (*arithmetic mean of air temperature and average radiant temperature at the center of the considered area*)[2] and relative humidity (percentage ratio between vapor density and saturated vapor density at the same temperature) referring to both the winter and summer seasons indicated in table 1 for maintaining thermal comfort, are closely linked to the type of activity carried out, the age of the children who perform it, clothing (indicated by the value of the thermal resistance of the clothing - clo) and the time spent inside the environment.

To maintain the conditions of thermal comfort within the environment, the internal temperature is linked to the value of the internal regulation temperature, it also calls the room set-point: "*minimum internal temperature set by the heating system regulation system and maximum internal temperature set by the cooling adjustment system for the purposes of calculating energy requirements*"[3].

The acoustic comfort inside a school room is essential to be able to carry out the daily teaching activity without interruptions and above all without any distraction from the students in the classroom. It depends essentially on the location of the construction site, on the type of activity that is carried out within the environment and therefore on the intended use of the building, on the occupancy rate of the functional unit but also on the materials used for the technological solutions of the outer casing and those for the finishes.

The UNI 10840 and the UNI 12464-1 [2] instead define the minimum requirements to guarantee visual comfort in school premises depending on the functional unit considered in terms of glare, using the

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[1] Decree of the Minister of Public Works June 14, 1989, n. 236 "Technical requirements necessary to guarantee accessibility, adaptability and visitability of private buildings and public residential buildings, for the purpose of overcoming and eliminating architectural barriers", article 2: definitions

[2] UNI TS-1 October 2014 "*Energy performnce of buildings – Part 1: evaluation of energy need for space heating and cooling*", 3. Terms and definitions

[3] UNI TS-1 October 2014 "*Energy performnce of buildings – Part 1: evaluation of energy need for space heating and cooling*", 3. Terms and definitions

Discomfort Glare Index (DGI)[4] and the average daylight factor (η_{en})[5]. This allows to make the most of natural light inside the rooms and consequently save on the energy requirement for artificial lighting. These factors are mainly related to the shape of the room, to the relationship between opaque parts and transparent parts on the façade, to external obstructions and to the different reflection coefficients of the materials for interior finishes.

Finally, the UNI 10339 of 1995 defines the ventilation and extraction flow rates in reference to the intended use of the building and for each functional unit according to the number of people present or to the surface in plant in order to guarantee an appropriate quality of the 'internal air: *"characteristic of the treated air that meets the purity requirements. It contains no known contaminants in concentrations such as to cause damage to health and cause malaise for the occupants. The contaminants contained in both the fresh and recirculated air are gases, vapours, microorganisms, smoke and other particulate substances"*[6]. Within a school building it is important to maintain an adequate ventilation rate as the quality of the air affects the attention of students and their academic performance as well as their health.

The following is the definition of the main functional areas used for the systematic analysis of representative buildings (Figure 3.1) and therefore for the definition of new typological models for both the kindergarten and primary school:

● - *methodical activities area (MA)*: area for ordered activities divided into desk activities and special activities.

  For kindergarten, this area also includes hygienic services for children to carry out practical activities, a rest area and an area for group activities, identified through a differentiation of the furnishings within a single open space.

  For the primary school it is instead the home base (the section / classroom is an important place for learning but not self-sufficient, that is why it is called home base as *a more complex organism, a parent company from which we start and return, characterized from a great flexibility and variability of use*[7], where activities are carried out in groups or by individuals and characterized by movable walls to obtain spaces of interclass or open towards the common spaces);

● - *free activities area (FA)*: an area that includes all the spaces intended for group activities and leisure activities, and those designed for the socialization of children;

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[4] "*Glare due to natural light*", Annex B UNI 10840 May 2007 "*Light and lighting school rooms, general criteria for the artificial and natural lighting*" 3. Terms and definitions

[5] "*Ratio expressed in percent between the average illuminance of the environment E_m and the external illumination produced by the celestial vault E_0*", UNI 10840 May 2007 "*Light and lighting school rooms, general criteria for the artificial and natural lighting*" 3. Terms and definitions

[6] UNI 10339 June 2005 "*Air-conditioning systems for thermal comfort in buildings – General, classification and requirements – Offer, order and supply applications*"

[7] Norme tecniche quadro, contenenti gli indici minimi e massimi di funzionalità urbanistica, edilizia, anche con riferimento alle tecnologie in materia di efficienza e risparmio energetico e produzione da fonti rinnovabili, e didattica indispensabili a garantire indirizzi progettuali di riferimento adeguati e omogenei sul territorio nazionale. MIUR, 2013

🟡 - *canteen/kitchen area (C/K)*: area relating to the canteen service for the consumption of meals including the kitchen space for the preparation or the dirtying of dishes and toilets and changing rooms for external personnel;
In the nursery school this functional area is no longer mandatory given the age of the children who can eat the meal even in the classroom or in the collective areas (multi-purpose rooms).
As far as the primary school is concerned, the canteen and the kitchen can be realized in an adjacent building, easily reachable on foot;

🔵 - *care area (CA - Kindergarten)/Teachers area (TA - Primary school)*: area for the teachers' room, the archive and for the assistance to children (in nursery schools also an infirmary and a laundry), including toilet facilities for teachers and depots for cleaning staff;

● - *horizontal and vertical connections*: these are the areas intended for the corridors connecting the various main functional areas and between the environmental units for both school orders. Furthermore, for the primary school they also include the areas intended for the stair blocks that act both as a connection between the different floors and as an escape route in the event of a fire.

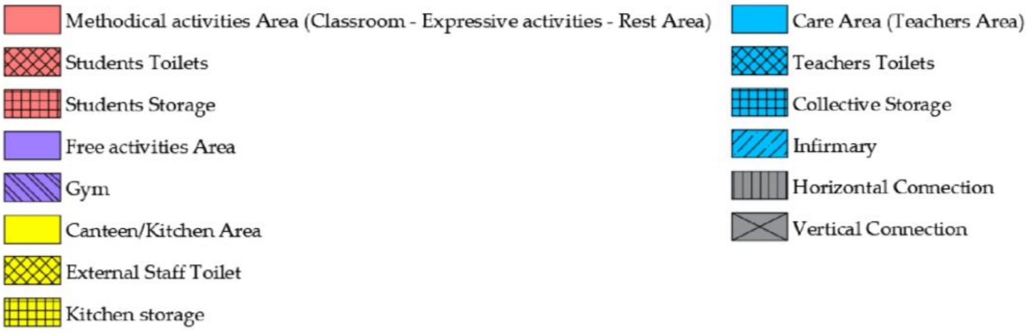

Figure 3.1 Functional area for schools

Obviously in outlining the typological models it is necessary to also consider the guidelines of the MIUR (D.M. 11th April 2013) [3] which follow a performance-type logic and move away from the prescriptive style of the previous legislation. It is important to note that the main novelty introduced by the MIUR of which it is necessary to take into account to define the new typological models is the new classroom concept. In fact, in the determination of the models it is fundamental to conceive the classroom as a space (home base) in which, through lectures, the bases are defined for a broader school path, also open to practical experiences and group work, which is not reduced to the mere and only performance of the lessons taught - student. The clear distinction between the class (pedagogical unit), a place where only frontal lessons are held and the area for supplementary and didactic support activities, now recurrent and widely recognized by the educational programs of each school, is now inadequate and outdated.

The class in modern school is no longer a self-sufficient and independent environmental unit where frontal lessons are held but it is conceived as a more complex organism (*home base: parent company from which we start and return*), which has no precise boundary , but it is directly connected:

- with the outdoor garden through large openings that allow a continuous visual contact with the outside and a direct connection with the garden that becomes space for teaching;
- with adjacent classes using movable walls for the intercycle activities;
- with common areas for group educational activities.

The class of the modern school has a rectangular shape in that this form makes it possible to make the most of the internal environment and its dimensions are linked both to the number of students and to the numerous activities in small groups and to the equipment that requires both visual comfort and the exploitation of natural light. For the minimum size of a class for a modern school, both for kindergarten and primary school, see the geometric definition of the new typological models.

For the kindergarten the class is organized in 4 areas with different intended use:

- the area for ordered activities where benches (movable furniture) are placed that can be positioned singly or in groups according to the educational activities;
- the area for recreational and / or sports activities where there are games and small tools;
- the area for relaxation, for example with soft armchairs and cushions;
- the area for practical activities that coincides with the toilets located within the classroom.

For the elementary school the class is however the place where lessons take place and it is characterized by:

- benches that are now flexible and mobile furnishings that can be organized for single work or for activities for small groups or even grouped in a corner of the class to carry out collective activities;
- bookstores that are no longer exclusively for use by teachers, but each child has his/her own shelf where he can leave school materials as the school without a backpack has developed in recent years;
- an interactive multimedia board (LIM) connected to a computer that can be used as an aid tool for educational activities;
- movable walls that allow the direct connection of two classes for inter-circuit activities.

The other functional units introduced in the guidelines are essentially the ateliers, which replace the laboratories of the 1975 legislation and the agora but are not accompanied by any dimensional or minimum performance requirements.

The ateliers or spaces of doing are defined as: *"an environment in which the student can move independently, activating processes of observation, exploration and production of facts"*[8]. They are environments where the student carries out the specific practical activities, which at the moment are considered equally important in frontal lectures in the classroom and are for example the classrooms of music, drawing and art, multimedia and computer science.

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[8] Norme tecniche quadro, contenenti gli indici minimi e massimi di funzionalità urbanistica, edilizia, anche con riferimento alle tecnologie in materia di efficienza e risparmio energetico e produzione da fonti rinnovabili, e didattica indispensabili a garantire indirizzi progettuali di riferimento adeguati e omogenei sul territorio nazionale. MIUR, 2013

The agora is intended as *"the functional and symbolic heart of the school"* [9], center of the main vertical and horizontal connections, where the main collective activities take place and where the families of the children come into direct contact with the school environment and educational activities.

Obviously, in addition to the minimum requirements at the dimensional level (Table 3.1) and the regulations relating to the comfort inside the school environments (Table 3.1), it is necessary to comply with all the provisions relating to the legislation on energy in relation to the definition of the reference building [4].

3.1.2 Analysis of representative buildings

To have more data available, the study took place in two different ways: the first through the drafting of detailed reading sheets of the representative school buildings of which it was possible to find more material and the second through the compilation of a summary table of the main characteristics of the remaining buildings examined both in terms of internal functional distribution and in relation to the building-plant system.

The reading cards of the representative school buildings are in total 11 (6 for the nursery school and 5 for the primary school), and they are structured according to 5 different sections (Figure 3.2):

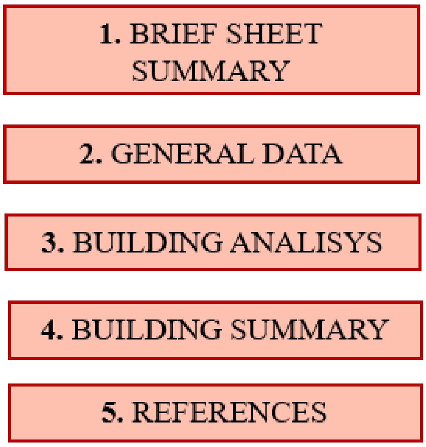

Figure 3.2 Summary sheet layout

- the first section (1. Brief sheet summary) gives a summary of the analysis of the building in its entirety, from the general data of the project to the main environmental and energy strategies used;
- the second one (2. General data) concerns the general data of the building and includes a brief description of the project, a list of the objectives pursued in the design with a view to sustainability and the climatic analysis of the construction site;
- the third section (3. Building analysis) concerns the analysis of the building system subdivided into the environmental system and technological system and reports the systematic study of the building, allowing to identify the peculiarities of the construction site, the shape and orientation of the building, its typological and technological characteristics, the building-plant system and energy strategies;
- finally, the fourth (4. Building summary) and the fifth section (5. References) respectively report a brief report on the orientation of the building, its functional organization, the main dimensional characteristics of the classes and the energy strategies adopted for this functional unit and reference bibliography.

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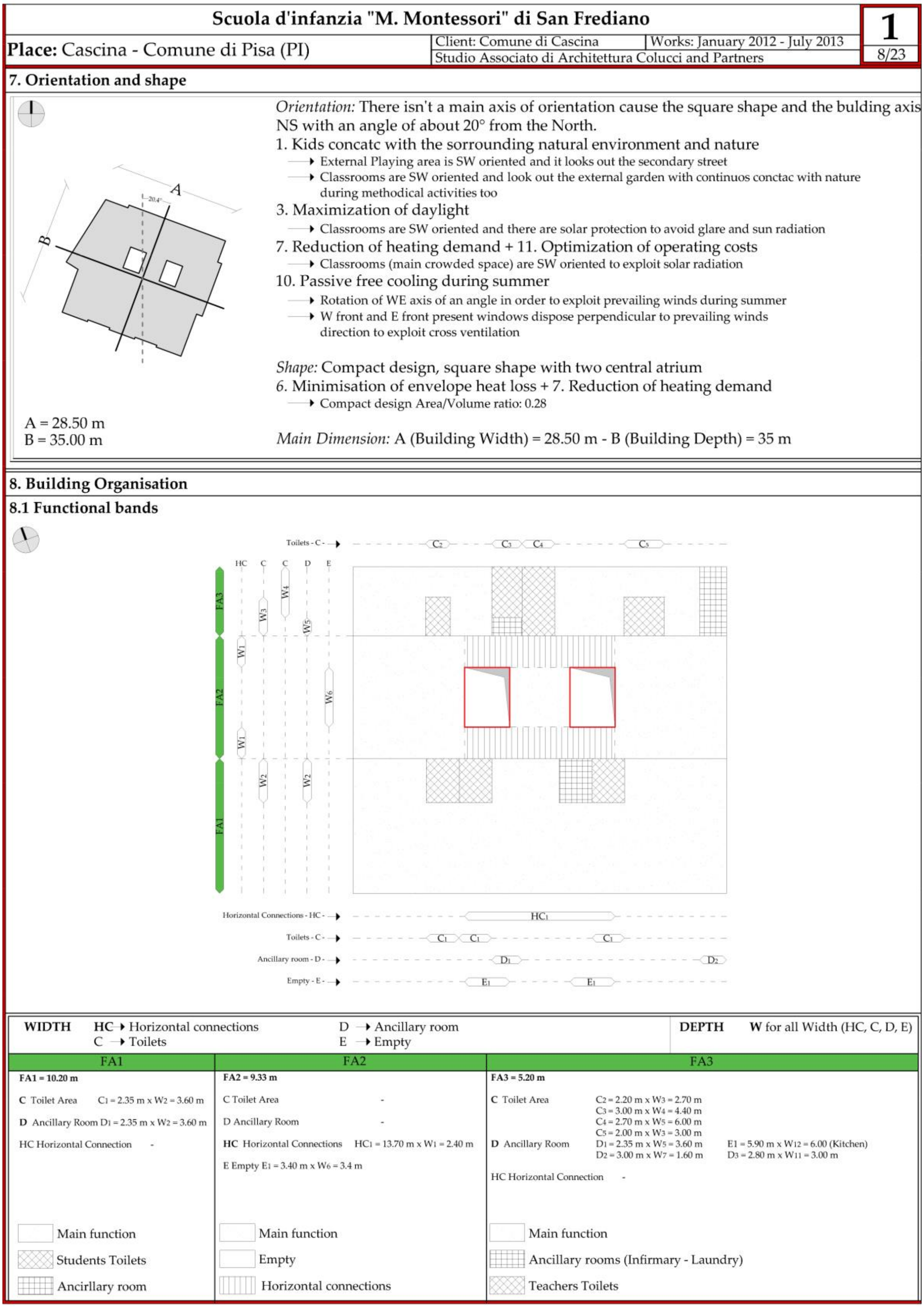
[9] Framework technical standards, containing the minimum and maximum indices of urban planning, building functionality, also with reference to technologies in terms of efficiency and energy saving and production from renewable sources, and teaching indispensable to guarantee adequate and homogeneous planning guidelines on the national territory. MIUR, 2013

The format adopted for the forms is the same (Figure 3.3) and includes the name of the school analysed, the place where it is located, the client and the designer, the year of production, the card number and page number.



Scuola d'infanzia "M. Montessori" di San Frediano

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Place: Cascina - Comune di Pisa (PI)

Client: Comune di Cascina | Works: January 2012 - July 2013

Studio Associato di Architettura Colucci and Partners

8/23

7. Orientation and shape

Orientation: There isn't a main axis of orientation cause the square shape and the bulding axis NS with an angle of about 20° from the North.

1. Kids concatc with the sorrounding natural environment and nature
   - External Playing area is SW oriented and it looks out the secondary street
   - Classrooms are SW oriented and look out the external garden with continuos conctac with nature during methodical activities too
3. Maximization of daylight
   - Classrooms are SW oriented and there are solar protection to avoid glare and sun radiation
7. Reduction of heating demand + 11. Optimization of operating costs
   - Classrooms (main crowded space) are SW oriented to exploit solar radiation
10. Passive free cooling during summer
   - Rotation of WE axis of an angle in order to exploit prevailing winds during summer
   - W front and E front present windows dispose perpendicular to prevailing winds direction to exploit cross ventilation

Shape: Compact design, square shape with two central atrium

6. Minimisation of envelope heat loss + 7. Reduction of heating demand
   - Compact design Area/Volume ratio: 0.28

A = 28.50 m
B = 35.00 m

Main Dimension: A (Building Width) = 28.50 m - B (Building Depth) = 35 m

8. Building Organisation

8.1 Functional bands

WIDTH **HC** → Horizontal connections; C → Toilets; D → Ancillary room; E → Empty

DEPTH **W** for all Width (HC, C, D, E)

FA1	FA2	FA3
FA1 = 10.20 m	**FA2 = 9.33 m**	**FA3 = 5.20 m**
C Toilet Area $C_1 = 2.35$ m x $W_2 = 3.60$ m	C Toilet Area -	**C** Toilet Area $C_2 = 2.20$ m x $W_3 = 2.70$ m $C_3 = 3.00$ m x $W_4 = 4.40$ m $C_4 = 2.70$ m x $W_5 = 6.00$ m $C_5 = 2.00$ m x $W_3 = 3.00$ m
D Ancillary Room $D_1 = 2.35$ m x $W_2 = 3.60$ m	D Ancillary Room -	**D** Ancillary Room $D_1 = 2.35$ m x $W_5 = 3.60$ m $D_2 = 3.00$ m x $W_7 = 1.60$ m $E1 = 5.90$ m x $W_{12} = 6.00$ (Kitchen) $D_3 = 2.80$ m x $W_{11} = 3.00$ m
HC Horizontal Connection -	**HC** Horizontal Connections $HC_1 = 13.70$ m x $W_1 = 2.40$ m	HC Horizontal Connection -
	E Empty $E_1 = 3.40$ m x $W_6 = 3.4$ m	
☐ Main function	☐ Main function	☐ Main function
▨ Students Toilets	☐ Empty	▦ Ancillary rooms (Infirmary - Laundry)
▦ Ancirllary room	▥ Horizontal connections	▨ Teachers Toilets

Figure 3.3 Format for the analysis of representative buildings

The sections relating to the building's reading sheets were in turn divided into several sub-categories shown in the following table (Table 3.2):

Table 3.2 Description of the sheet for building analysis

1. Brief sheet summary	
2. General Data	**2.1** Scenario
	2.2 Building description and Project general data
	2.3 General data (dimensional data, D.M. 18-12-1975, energy data, plant data)
	2.4 Climate Data
3. Building Analysis	
***3.1** Analysis of environmental system*	**3.1.1** External Layout (urbanistic organisation, source of noise pollution, external design)
	3.1.2 Orientation and shape
	3.1.3 Building organisation (functional bands and functional units, main flows)
***3.2** Analysis of technological system*	**3.2.1** Structure
	3.2.2 Envelope composition
	3.2.3 Technological solutions (External envelope, ground floor, roof floor, glass type)
	3.2.4 Internal/External Partitions
	3.2.5 Details specification
	3.2.6 Equipment (Internal/External equipment)
***3.3** Energy concept and systems*	**3.3.1** Heating system
	3.3.2 Cooling system
	3.3.3 Saving water
	3.3.4 Ventilation
	3.3.5 Natural ventilation
	3.3.6 Passive strategies (for instance solar greenhouse)
	3.3.7 Natural Lighting
***3.4** Goals and strategies*	**3.4.1** Energy strategies
	3.4.2 Environmental strategies
	3.4.3 Goals and Strategies
	3.4.4 Key strategies
4. Building summary	
5. References	

In the reading cards the following schools, built between 2003 and 2015 and mainly located in northern and central Italy were analysed:

Kindergartens

- Kindergarten “*M. Montessori*” – Cascina (PI) [5];
- Kindergarten “*Rondine e Pollicino*” – Guastalla (RE) [5] [6];
- Kindergarten “*M. del Grosso*” – Mazzè (TO) [5];
- Kindergarten “*Istituto comprensivo 7 – L.Orsini*” – Imola (BO) [7] [8];
- Kindergarten “*Anna Frank*” – Nichelino (TO) [7] [9];
- Kindergarten “*Sandro Pertini*” – Bisceglie (BT);

Elementary schools

- Elementary school “*Romarzollo*” – Arco (TN) [10];

- Elementary school "*Laion Novale*" – Laion (BZ) [5] ;
- Elementary school "*La scuola nel parco – Margherita Hack*" – Montelupo (FI) [5] ;
- Elementary school "*Istituto comprensivo Ponzano Veneto*" – Ponzano Veneto (TV) [11];
- Elementary school "*Alessandro Volta*" – Chiarano (TV) [12] [13].

The tables (Table A.1 – Table A.2) show a summary of the buildings analysed where they are indicated:

- the main general data;
- the aspects relating to the shape and orientation of the building;
- the typological and technological characteristics;
- the renewable resources used for energy production;
- the building-plant system (generation system, distribution system and ventilation system with related control strategies, domestic hot water);
- the rainwater recovery system.

This overall framework is necessary to compare the information obtained from the systematic analysis of the example buildings and to begin to outline the characteristics of the new typological models for the kindergarten and primary school.

To deepen the study and to have more available data for the definition of the typological and technological characteristics of the new typological models for kindergarten and elementary school (Table A.3 – Table A.4) show a lot of information have been collected and summarized in several tables, information related to other school buildings considered as examples for which however, due to lack of material, it was not possible to draw up detailed reading sheets as those of the buildings listed above.

The available information regarding quantitative data collected in reference to the energy performance of the example school buildings and summarized in Table 3.3 that follows, are essential to be able to carry out, after the energy simulation phase in dynamic regime, a validation of the typological models defined in this research phase. The following Table 3.3 illustrates only some available qualitative and quantitative information for both kindergartens and elementary schools: climate zone, energy needs measured in kWh/m^{2}a, the index for the energy performance measured in kWh/m^{3}a or kWh/m^{2}a, the CO_2 emissions due to the consumption in one year and the material for the insulation layer.

Table 3.3 Summary chart of Kindergartens and Elementary schools' quantitative data

	Some quantitative/qualitative data for kindergartens and elementary schools				
Kindergatens	Climate zone	Energy needs [kWh/m^{2}a]	E_p	CO_2 emissions due to consumption	Insulation material
Ronco Briatino (MI)	E	20			Cellulose fiber
Nichelino (TO)	E	26			
Balenido (BO)	E	28			Wood fiber
Mezzago (MB)	E	45			Cellulose/Wood fiber
Nonantola (MO)	E	54			Cork - kenaf
Pagliare di Sassa (AQ)	E		$E_{p,H}$ = 4 kWh/m^{3}a		
Ponticelli (BO)	E	37			
Guastalla (RE)	E	76 kWh/a – for heating	$E_{p,tot}$ = 0.85 kWh/m^{3}a		

Sequals (PN)	E	38 kWh/a – for heating			Glass wool
Cascina (PI)	D	76 kWh/a – for heating		2 kg_{CO2}/m^3a	Wood fiber
Bolzano (BZ)	E		$E_{p,tot} = 13$ kWh/m^3a	25 kg_{CO2}/m^2a	Rock wool
Merano (BZ)	E	28 kWh/a – for heating		38 kg_{CO2}/m^2a	
Elementary schools	Climate zone	Energy needs [kWh/m^2a]	E_p	CO_2 emissions due to consumption	Insulation material
Cernusco sul Naviglio (MI)	E		$E_{p,H} = 4.92$ kW/m^2a	1 kg_{CO2}/m^2a	Glass wool
Ashmount - UK	-	115		35 kg_{CO2}/m^2a	
Valsamoggia (BO)	E		$E_{p,tot} = 1.175$ kWh/m^3a	8 t_{CO2}/a	
Montelupo (FI)	D	26		43 t_{CO2}/a	
Polcenigo (PN)	E	47 kWh/a – for heating		8 kg_{CO2}/a	
Monguelfo – Tesido (BZ)	E	18 kWh/a – for heating		27 t_{CO2}/a	
Hoen Neuerdorf - Germany	-	34	21% of Renewable energy		
Halle - Germany	-	14	126% of Renewable energy		
Montpelier - France	-	5	89% of Renewable energy		

3.2 SUMMARY OF THE ANALYSIS OF REPRESENTATIVE BUILDINGS

This paragraph summarizes and comments on the main characterizing aspects of the school buildings studied both in tabular form and with reading cards.

The representative buildings analysed are mainly located in Italy but there are also references to significant examples made in Germany, which represents one of the most committed European countries in the reduction of greenhouse gas emissions in the atmosphere [14], Portugal, France, England and Finland.

First of all, the analysis of these buildings shows that the newly built schools, built between 2003 and 2015, pursue a series of common objectives with a view to environmental and energy sustainability: use of materials with low environmental impact, exploitation of natural light, use of solar shading for the control of solar radiation and glare, reduction of dispersion through the envelope, reduction of the demand for primary energy for heating, use of renewable energy, use of passive cooling and optimization of costs management, reduction of CO_2 emissions during construction and operation of the building.

Below, following the outline of the reading sheets of the representative buildings, a summary is given of the parameters for design and technologies mostly used for the school buildings analysed, made with a view to sustainability. The considerations for each category are not divided by school order when they present common characteristics (construction site, energy strategies for the summer season, environmental strategies, plants).

Construction site.

The school buildings analysed are essentially located in green areas located in residential districts characterized by buildings of one or two floors above ground, far from noise sources that could disturb the educational activity and from industrial sites that could cause damage to children's health. Usually the buildings around the school lot do not cause shaded areas on the school and the surrounding garden.

The infrastructure system makes it possible to reach the main entrance of the school through secondary arteries so that there is no excessive traffic during the hours of entrance and exit of the children from school. The stops of the public transport vehicles are almost always at a distance less than 200-300 m and all the schools have a special rubber parking area for public transport that allows the ascent and descent of the students in complete safety (this also happens for the private means of the parents).

The parking area is usually outside the school garden and is reserved for external staff and teachers who can also use a secondary entrance usually located along the North side of the building.

In the Romarzollo primary school there is also a parking area reserved for bicycles with a locker room attached for external personnel in order to promote the use of carbon-free transport vehicles.

External layout.

- *Kindergarten*

The external arrangement of the building is designed as a succession of surfaces with different shapes and finishes dedicated to the most varied activities and experiences (educational gardens, outdoor sensory paths, areas for recreational activities, educational greenhouses, accessible green roofs).

The external flooring is made in most cases in light-colored wood in order to reduce overheating during the summer season, in antishock rubber to safeguard the health of children in order to avoid injuries and through draining floors to maximize the area permeable within the construction lot.

In the Lama Sud school complex of Ravenna, built in 2004, there are 4 areas in the outdoor garden corresponding to 4 different thematic environments [15] (Figure 3.4):

- *"The discovery of nature"* located near the sections and characterized by the use of different colors, scents and tactical experiences linked to the different surface finishes, such as sand and 🟪 rubber;
- *"The natural garden"* characterized by the presence of a green lawn 🟨 and a small wood; 🟩
- *"The suggested play garden"* designed for older children and conceived as a space for recreational activities, in fact there is a labyrinth and small terraces; 🔵
- *"Cultivate and work in the garden"* conceived as a didactic garden where children can carry out educational activities in direct contact with nature. This area is protected on the street side by a barrier of evergreen trees. 🟥

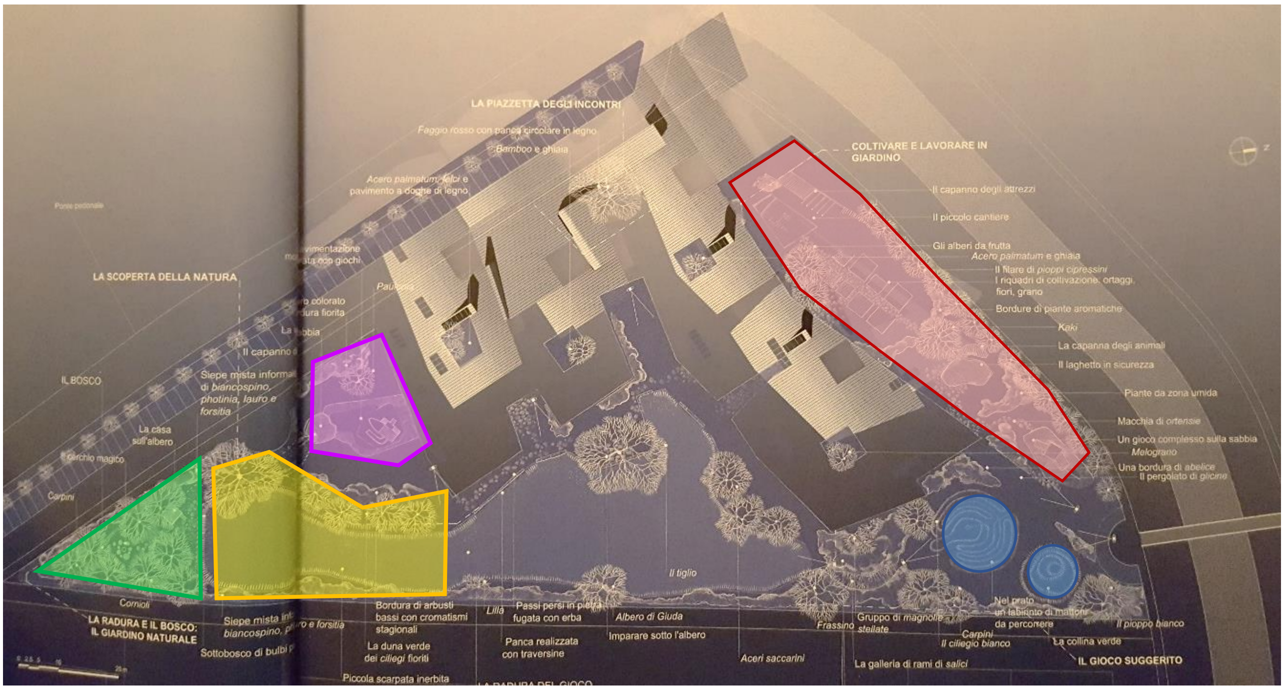

Figure 3.4 External main teaching and playing area of Lama Sud [15]

In the outer garden of the Barbapapà[10] kindergarten the thematic areas are very distinct the one from the other through color and different types of finishes (Figure 3.5): in front of the classrooms there is an external accident-prevention pavement, a play area on the green and one with the sand, finally there are two areas that host educational gardens.

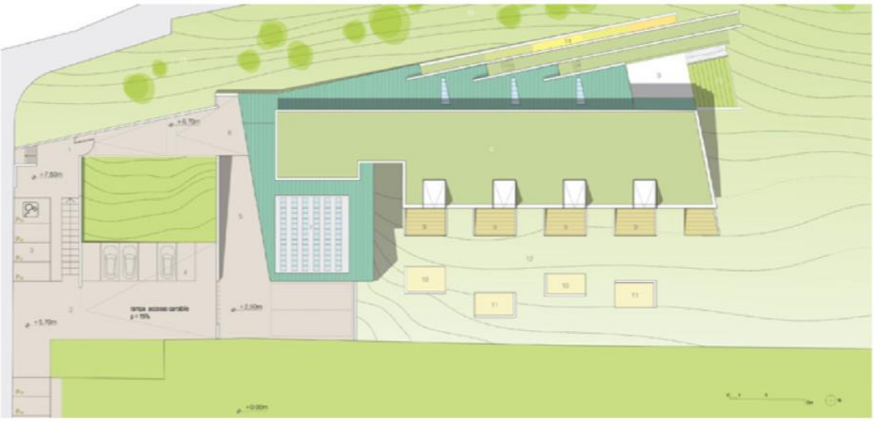

Figure 3.5 External main teaching and playing area of Barbapapà - Reference: https://www.arketipomagazine.it/nido-barbapapa-ccdstudio/

There are also school buildings such as the Montessori school Fuji kindergarten school [16] where nature and the outdoor garden become an integral part of the project and the school building adapts perfectly to the surrounding natural environment. This school is in fact characterized by internal courtyards that develop

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[10] https://www.arketipomagazine.it/nido-barbapapa-ccdstudio/

around existing trees and the external walls are sliding so that they can be completely opened towards the front garden for two thirds of the year (Figure 3.6).

Figure 3.6 View of Montessori school Fuji kindergarten – Reference: http://host.uniroma3.it/docenti/marino/Lab2C_1011/Esempi/Tokio_tezuka/tezuka_home.htm

While the kindergarten in Cacem in Portugal, which received the 2006 Sustainable Architecture award, was built with an urban redevelopment plan in an area near a stream. The ground floor of the building is left completely free (Figure 3.7) with the necessary height to cope with the flooding of the existing stream without creating any problem for the safety of the structure or occupants[11]. In other periods of the year it is used as an outdoor play area.

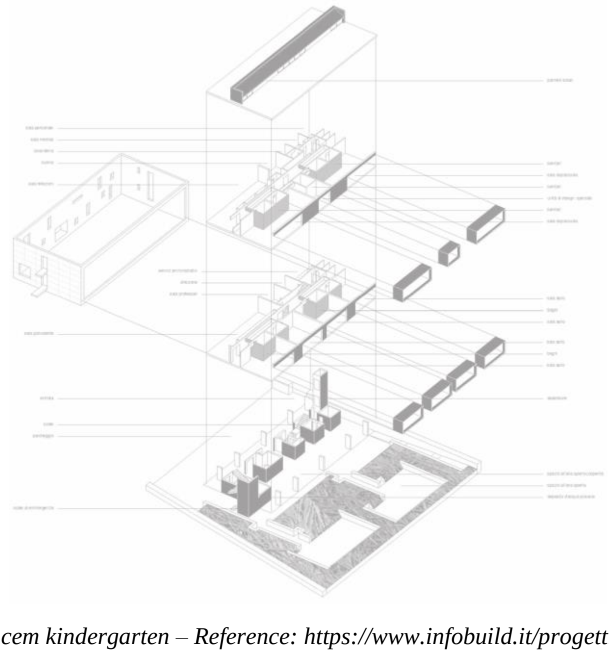

Figure 3.7 Section of the Cacem kindergarten – Reference: https://www.infobuild.it/progetti/asilo-popolare-di-sintra-in-portogallo/#

The design of the outdoor area does not exclusively concern the construction of areas for recreational activities or for educational activities but also that of the green, used as a natural barrier to protect against the possible view of the garden from the streets of the neighbourhood outside the school (Montessori

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[11] https://www.infobuild.it/progetti/asilo-popolare-di-sintra-in-portogallo/

Kindergarten) or as a passive solar shielding system for the building's functional units (Kindergarten Istituto comprensivo 7 - L. Orsini) and as an element to regulate the microclimate of the external areas as it shades the spaces used for educational activities.

In Bisceglie's nursery school the external trees were designed to regulate and control the solar radiation that hits the building during the year[12]:

- in the South pergolas with evergreens have been inserted to screen the class openings;
- to the East and West instead of the olive and almond trees;
- in the inner courtyard, holm oaks and oaks have been planted.

- *Elementary school*

With regard to the primary school, the design of the external area is dealt differently from the kindergarten for the greater age of the students. The outdoor garden becomes a space for conducting collective and sports activities but above all a space for relationships and socialization among the boys.

In many primary schools the practicable cover, designed with the technological solution of the green roof, becomes a real extension of the building that allows to recover the green area lost in the lot for the construction of the school. A clear example is the South Harbor school in Denmark[13] characterized by a green roof, directly connected to the school's outdoor garden on the ground floor via a wooden staircase, which houses areas with sports facilities and areas equipped for recreational activities (Figure 3.8).

Figure 3.8 View of the roof top of South Harbor school in Denmark – Reference: https://www.domusweb.it/it/architettura/2016/05/31/jjw_architects_south_harbour_school.html

Orientation.

In almost all the cases analysed, except for the Ashmount primary school in London, for both school orders the prevailing orientation is mainly dictated by solar radiation and therefore by the exploitation of free solar

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[12] https://www.ediliziascolastica.it/progetti/scuola-materna-sandro-pertini-bisceglie/

[13] https://www.domusweb.it/it/architettura/2016/05/31/jjw_architects_south_harbour_school.html

contributions, rather than the direction of prevailing winds, during the winter season for the main functional units with higher occupancy rate during school hours (classes).

For schools built in areas characterized by a Mediterranean climate, the axis of optimal orientation is therefore the East-West axis with a maximum rotation with respect to the North-South axis included in a range 0°-30°.

For school buildings located in Northern Europe (Kirkkojarvi Elementary school - Denmark and Sausalathi - Finland Elementary school) characterized by a central core and horizontal arms that develop from this central fulcrum with a rotation of these arms with respect to the North-South axis of about 40°.

Geometry.

- *Kindergarten*

The nursery school is designed on a single level above ground due to the age of the children who attend it, between 3 and 5 years (the only exception analyzed is the Terentum kindergarten in Bolzano which is spread over 3 floors above ground). Therefore, there are no vertical connections but only horizontal ones.

The main geometries for the building plan are 2:

- a compact one, that has the two main dimensions that can be compared to each other and does not have a main orientation axis (Figure 3.9).
- a linear one that has a body length which is greater than its depth (Figure 3.10) which has a prevalent orientation along the East-West axis).

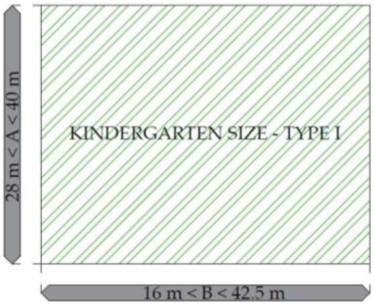

Figure 3.9 Scheme of the compact shape with the indication of the range of main dimensions

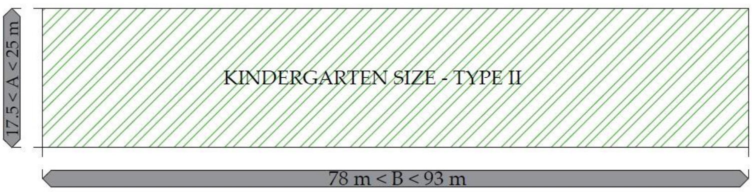

Figure 3.10 Scheme of the compact shape with the indication of the range of main dimensions

The main geometry is interrupted by indentations located mostly in the main facades and internal voids (for example courtyards) to have a lower value of the shape ratio and therefore a better energy performance of the building. This also allows greater exploitation of natural lighting during school hours throughout the building.

- *Elementary school*

The primary school usually develops on 2 or 3 floors above ground according to the number of classes that can vary from a minimum of 5 (1 cycle) to a maximum of 15 (3 cycles).

There are usually 2 rectangular-shaped staircase blocks facing North and facing each other inside the building that also act as escape routes in the event of a fire.

There are 4 recurring geometries in the building plan:

- a compact one with an internal atrium with the main dimensions in plan comparable to each other and without a main orientation axis (Figure 3.11);
- one without an internal atrium (mainly found in northern Italy to minimize dispersions having a low aspect ratio) (Figure 3.12) with the same characteristics of the previous one;
- a linear development that can also be organized on a single plane characterized by a main dimension in plan much greater than the other with a ratio of about 2:1 and a prevalent orientation along the East-West axis (Figure 3.13);
- and finally the last one, recurrent above all in Germany, France and America [17], with a rectangular body, usually oriented to the West, from which perpendicularly branch out 3 other buildings of smaller dimensions, with main orientation along the East-West axis (Figure 3.14).

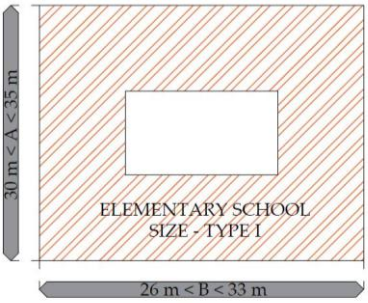

Figure 3.11 Scheme of the compact shape with internal atrium with the indication of the range of main dimensions

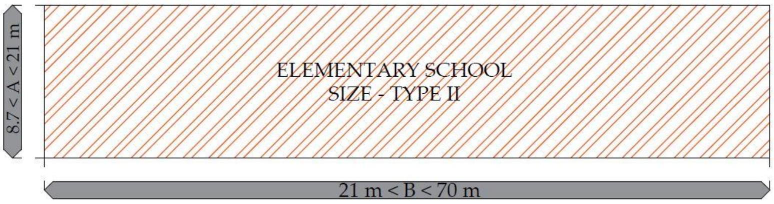

Figure 3.12 Scheme of the compact shape without internal atrium with the indication of the range of main dimensions

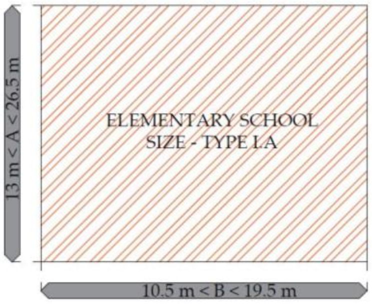

Figure 3.13 Scheme of the linear shape without internal atrium with the indication of the range of main dimensions

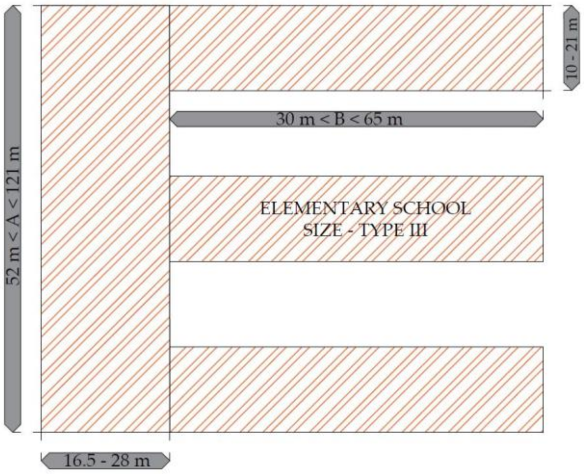

Figure 3.14 Scheme of the last shape with 3 linear buildings with the indication of the range of main dimensions

Building organisation.

- *Kindergarten*

Nursery schools that have a compact form are usually divided into 5 horizontal functional bands where those that host the main functions (3 functional bands) alternate with secondary ones (2 functional bands) where the horizontal connections develop.

For the compact shape (Figure 3.15):

- the main access is usually located in the collective area (agora) while the entrances for teachers and external staff for the canteen are directly connected to the respective functional units on the North side;
- in the southern functional zone, there are essentially classes that have a variable depth in the interval 5.9 m - 14.7 m, closely linked to the size of the openings so as to exploit natural light as much as possible for most of the school timetable;

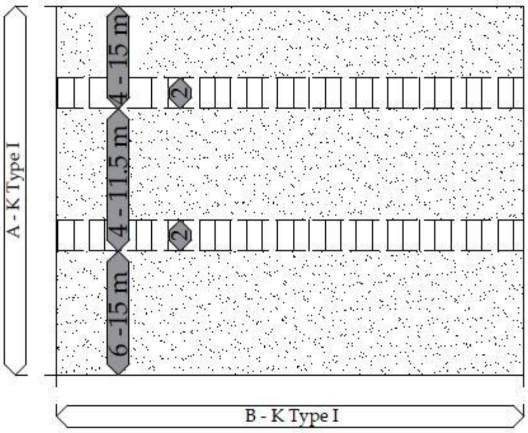

Figure 3.15 Scheme of compact shape with the indication of main functional bands

- to the North the service areas (for example kitchen, storage, archive, plant room) are developed and the teachers' area with a variable depth between 4.3 m and 14.7 m;
- the central functional band, with an average depth of about 4.20 m, houses the canteen facing West and the collective area oriented to the East;
- student toilets are located within the classes given the age of the children.

On the contrary, linear schools have a distribution in plan in 3 functional bands: 2 main functional bands and a functional band for an intermediate horizontal connection.

In this case, as in the previous one (Figure 3.16):

- the accesses to the building are organized as for the typological model with compact form;
- in the South-facing functional zone, which has a variable depth within the range 10 m - 14.7 m, there are the classes but also the collective areas and the canteen;
- to the North, as in the previous case, the environments related to teachers and external personnel are located, and the depth of the functional zone varies between 3.2 m and 11.6 m;
- the central functional band is used as a horizontal connection with an average depth of about 2.90 m;
- the toilets, as in the previous typological model, are located within the classrooms.

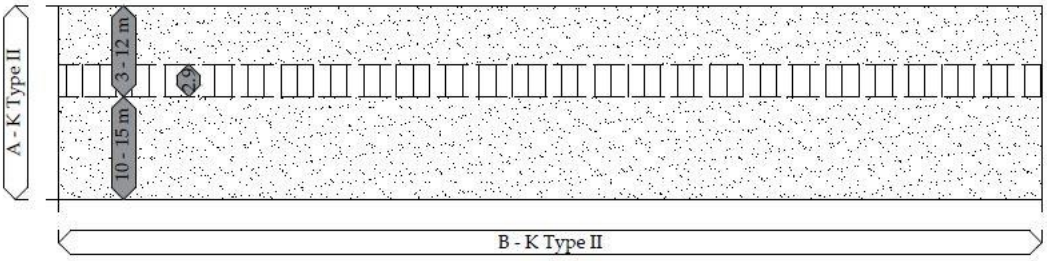

Figure 3.16 Scheme of linear shape with the indication of main functional bands

As can be seen from the functional organization of the sustainable buildings analysed, the South-facing functional strip has in any case a greater depth than the northern one. To the South classes are organized in order to be able to take advantage of the solar contributions during the winter season in the environmental units with the highest occupancy rate during school hours, while to the North there are connections, services and deposits that serve as the buffer spaces and make it possible to limit losses in the winter period as accessory spaces that are used occasionally.

- *Elementary school*

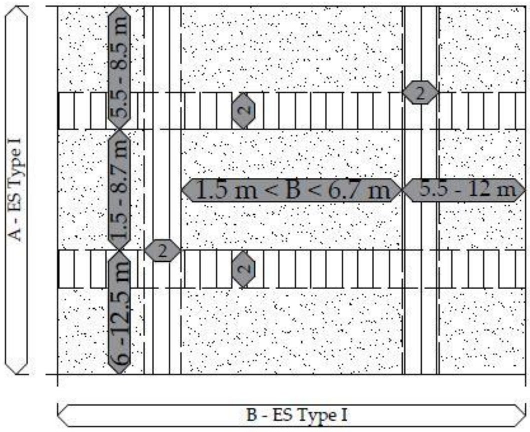

Figure 3.17 Scheme of compact shape for elementary school with the indication of main functional bands

The elementary schools that have a compact shape (both those with an internal atrium and those without an atrium) (Figure 3.17) are generally divided into 5 horizontal functional bands and 5 functional bands vertical:

- the main access to the building is from the external garden at the agora while the secondary accesses are usually located along the North side;
- the functional band facing South, as for kindergartens, hosts classes with a depth ranging between 6.4 m and 12 m for schools with internal atrium and between 4.1 m and 5.3 m for schools without; this last type of school has smaller dimensions than the functional bands compared to the others because usually the classes are designed for an average number of 16 students;
- the North-facing functional strip houses service spaces and areas for teachers with a depth that varies in an interval 5.5 m - 8.4 m for schools with internal atrium and between 2.7 m and 7.7 m for schools without.

In some examples, the North-facing functional band is also used as an area for collective activities (Elementary school Romarzollo);

- in the school with atrium the central area hosts the agora with an average depth of 6.3 m whereas in the atrium-less type the horizontal connections and some relation spaces with an average depth of approximately 2.90 m are concentrated in this functional band;
- the functional bands oriented to the East and West are both characterized by an average depth of about 6 m, and mainly house the laboratories, the toilets (independent of the classes given the age of the students) and in some examples the vertical connections.

The primary school with a linear geometric shape (Figure 3.18), as for the kindergarten, presents an organization on 3 functional bands: 2 main functional bands and one of intermediate connection of average depth of about 3.2 m.

In this case:

- the South-facing functional strip has a depth that varies in an interval 5.3 m - 7 m and also hosts in this case the classes and a part of the agora where the main entrance of the school also faces;
- the North-facing functional strip houses the areas for collective activities, laboratories, toilets (independent of the classes given the age of the students) and vertical connections;
- in this type of model, the functional canteen/kitchen unit, the teachers' area and a part related to the collective area can be developed either on a single floor with a double volume (Elementary school of Polgenico) or on two floors.

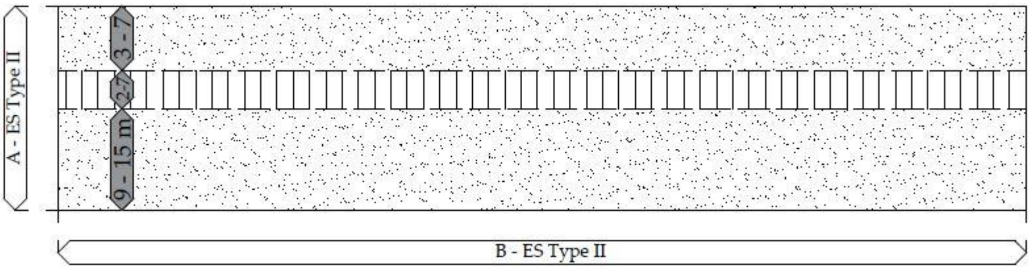

Figure 3.18 Scheme of linear shape for elementary school with indication of main functional bands

Finally, in the last typological model found in literature (Figure 3.19), the building area that houses the environmental units for the methodical activities has a linear development with a distribution in plant with 2 functional bands: a main one for classes with an average depth of about 6.50 m facing South and a connection oriented North of about 2.50 m. The other area of the building houses the remaining main functional areas without following a recurring pattern and is connected to the functional area of the classes through a horizontal connection that runs throughout the building. This model is the one that presents the larger functional bands, in fact it is found mainly in Germany and in France.

Even in the primary school as in the kindergarten school in the southern functional strip there is a greater depth than in the North and classes are organized in order to take advantage of free solar contributions during the winter season and consequently decrease the energy needs.

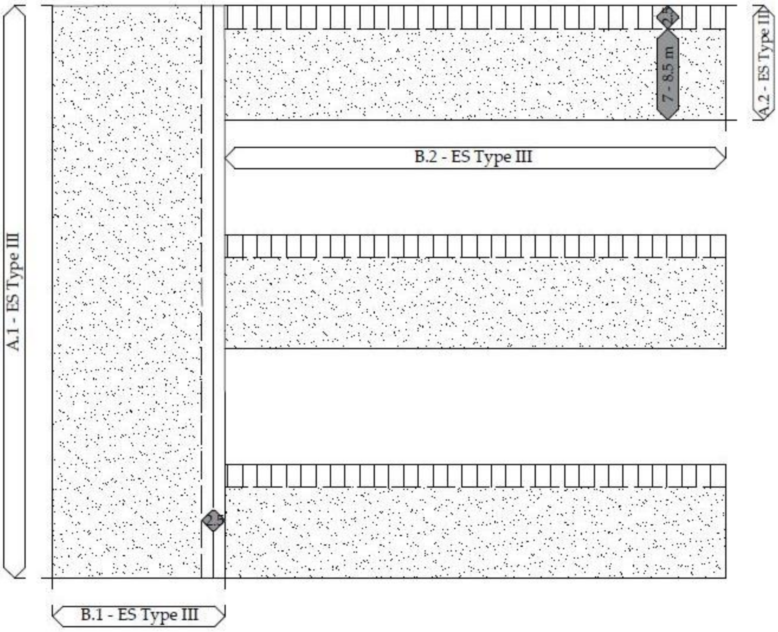

Figure 3.19 Scheme articulate shape for elementary school with the indication of main functional bands

Structure.

- *Kindergarten*

The foundation elements are made of reinforced concrete.

The most common supporting structure is certainly the one that uses wood with the construction technique in cross laminated timber (XLAM) (Kindergarten M. del Grosso) or in platform frame completed with oriented strand board panel (OSB) for the main vertical structure. There are also some examples with a laminated wood structure realized through portals such as in the Rondine and Pollicino di Guastalla kindergarten.

Wood is favored as a natural and sustainable material that allows to reduce the emissions of greenhouse gases into the atmosphere both during production and in operation.

- *Elementary school*

The foundation elements are made of reinforced concrete (Romarzollo Elementary school).

With reference to the primary school, from the analysis of the representative buildings it emerged that the vertical supporting structure is made of both wood (XLAM - OSB) and reinforced concrete. It is interesting to note how the supporting structure of school buildings, as in the complex ones, becomes an integral part of the architectural form: for example the tree-shaped pillars used in the external courts of the primary school of Zugliano (VI) or those of the external shelter of the school building in San Geminiano in Gognento di Modena [18].

No information is available on the structure and on the solution adopted for the interfloor floors.

Envelope composition.

- *Kindergarten*

The most recurrent technology solution for the floor slab is the solution with disposable plastic formworks to create ventilation above the foundation level completed with a functional layer of insulation in EPS resistant to any infiltration of water (Figure 3.20).

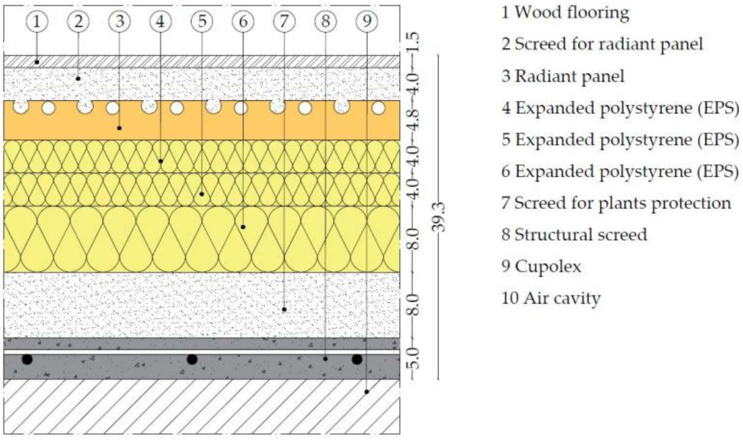

Figure 3.20 As an example scheme of ground floor stratigraphy of kindergarten located in Cascina

The perimeter walls present the following recurrent technological solutions linked also to the type of vertical supporting structure used:

- for the structure with structural panels in XLAM there are 2 different technological solutions for the external casing (advanced screen facade, external insulation) and 2 different natural materials for external insulation (wood fiber and glass wool). The external finish is in exterior plaster for the technological solution that adopts the external coat and in colored plates of various materials for the technological solution with advanced screen façade. The external wall is completed inside with a plasterboard counter-wall and a possible isolation in rock wool or with calcium silicate panels (Figure 3.21 – Figure 3.22);

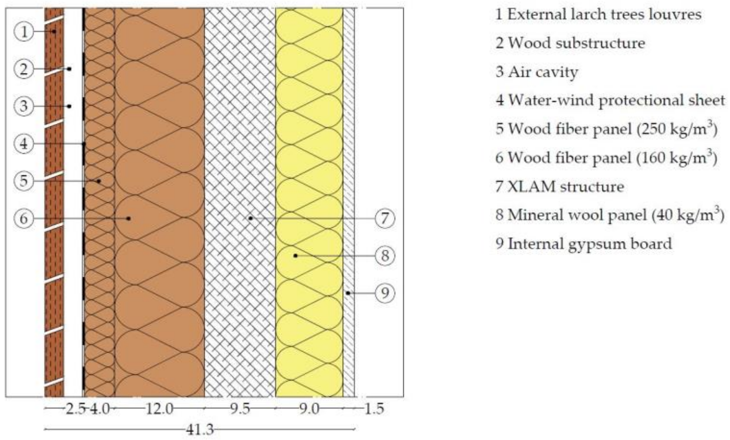

Figure 3.21 Scheme of external envelope layers with XLAM structure with the indication of the main dimensions of kindergarten situated in Cascina (PI)

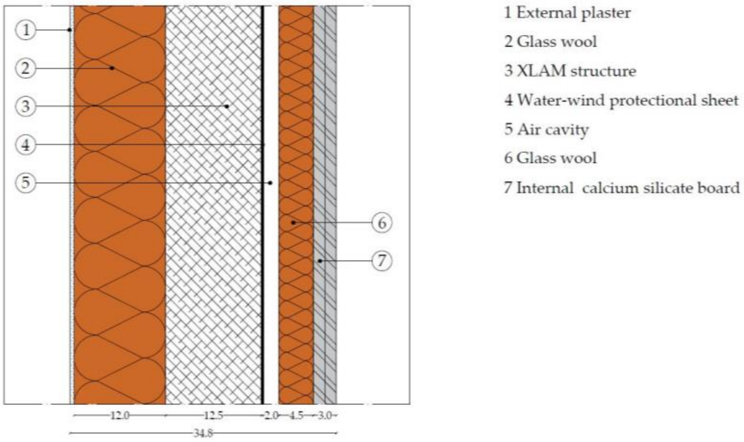

Figure 3.22 Scheme of external envelope layers with XLAM structure with the indication of the main dimensions of kindergarten situated in Sequals (PN)

- for the platform frame structure with single or double OSB panel there is a single technological solution for the external casing (advanced screen facade) and 3 different materials for external insulation (wood fiber, wood cement, rock wool). The external finish is in coloured plates of various materials. As in the previous case, it is completed internally with a plasterboard counter wall with glass wool, XPS or EPS insulation (Figure 3.23 – Figure 3.24);

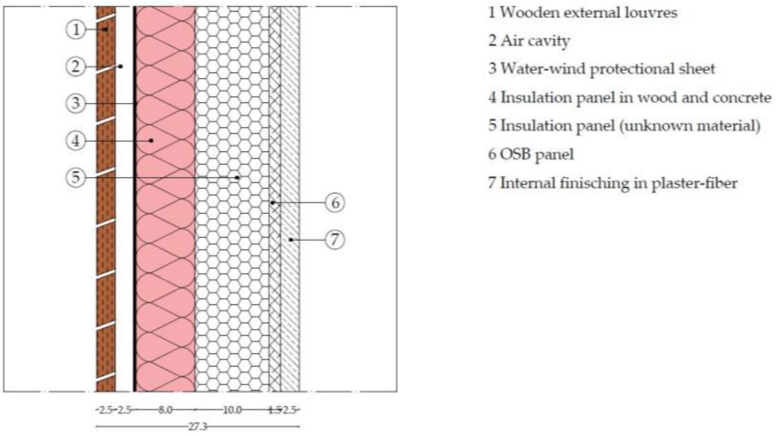

Figure 3.23 Scheme of external envelope layers with platform frame structure with the indication of the main dimensions of kindergarten located in Bolzano

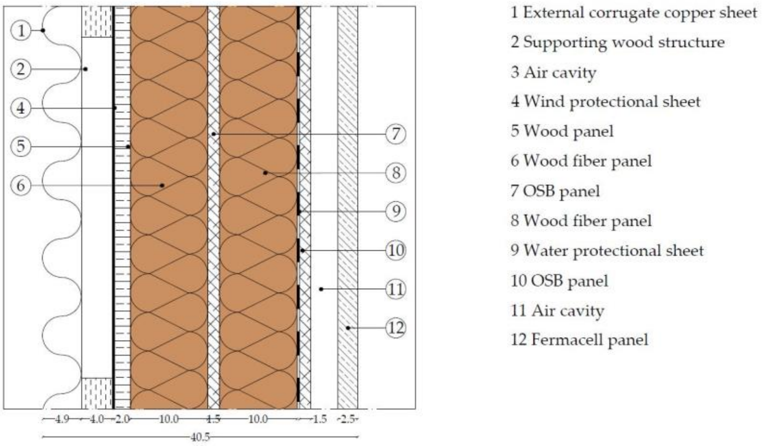

Figure 3.24 Scheme of external envelope layers with platform frame structure with the indication of the main dimensions of kindergarten located in Ponticelli

- for the reinforced concrete structure, the casing is composed of an external brick infill, mainly completed with the technological solution of the outer and insulating EPS coat. The external finish is in exterior plaster. The external wall is completed inside with lime plaster for interior, tiles or gypsum board.

Usually the outer casing is characterized by the presence of a layer of insulation of large size made with natural materials, for example wood fiber as in the zero-emission La Farfalla kindergarten, made in Montevarchi in 2006[14]. This school is one of the first in Italy built with a main bearing structure, insulation of the external casing and internal finishes completely in wood.

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[14] http://www.comune.montevarchi.ar.it/news/il-progetto-dell-asilo-nido-la-farfalla-pubblicato-sul-manuale-dell-utet-progettazione

Figure 3.25 Main section of the building with the indication of PV panels on the roof – Reference: https://www.ediliziascolastica.it/progetti/scuola-materna-sandro-pertini-bisceglie/

The fixtures are mostly thermal break with double-glazed glass and made of aluminum / wood especially in northern Italy (Terento Infant School in Bolzano[15]).

Detailed information on the type of glazing used in the buildings analyzed is not available.

The construction techniques for covering vary depending on the material used for the main structure. Usually for this school order flat or ventilated roofs are built with the inclination chosen according to the tilt necessary for the installation of the photovoltaic system for that latitude in coverage, as in kindergarten Sandro Pertini located in Bisceglie (Figure 3.25).

The most common technological solution is that with a structural panel in XLAM, a vapor barrier, a layer of insulation in wood fiber or EPS, protected by a waterproofing membrane (there is no information available on the most common material used for the waterproofing membrane). To create the ventilation chamber, two rows of wooden slats are usually used, or a warping of wooden slats completed with an OSB panel and then a metal panel as an external finish for the roof.

For flat roofs where solar panels and photovoltaic panels are placed, the external finishing layer is usually gravel, in which the thickness of the layer and the diameter of the gravel are sized according to the wind load.

- *Elementary school*

There is not enough information to establish a recurrent technology regarding the solution used for the floor slab.

For external cladding, brick is mainly used, complemented by the technological solution of the outer coat with thermal insulation made of natural materials such as wood fiber or mineral wool. Especially for school buildings located in the northernmost climatic zones there are high thicknesses of thermal insulation to minimize dispersion during the winter season.

In Italy, for exterior cladding, the use of a material that recalls the tradition of the place, such as stone (Laion Novale Primary School) or brick (San Geminiano Primary School in Gognento, Modena [18] or the school complex in Lallio, Bergamo [19]).

The most frequent technological solution for the coverage of a sustainable primary school is the green roof not only in reference to improving the energy performance of the building but also in relation to the new conception of a school building that provides for teaching to be extended to the level of cover (Figure 3.26).

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[15] https://www.domusweb.it/it/architettura/2010/11/24/un-complesso-scolastico-di-feld72.html

In the case of primary schools, we do not find only flat roofs but also pitched slopes especially in Northern Italy to improve their behaviour compared to snow accumulation.

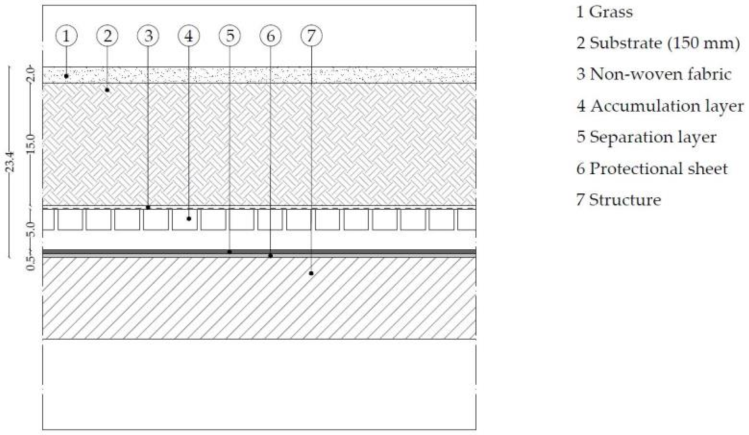

Figure 3.26 Scheme of green roof layers of Montelupo elementary school

Window to wall ratio.

- *Kindergarten*

Classrooms are located in the South-facing kindergarten, so the WWR has an average of around 50% in order to ensure continuous visual contact between children and the surrounding natural environment during school hours.

There are also examples such as the Rondine and Pollicino kindergarten in Guastalla and the Terentum kindergarten in Bolzano which have a WWR of almost 100% and this seems to create a spatial continuity between the classes and the outdoor garden. This is also fundamental for the growth of children who realize the passing of time and the seasons with the change of nature with which they are in direct contact.

A high ratio of opaque parts and transparent parts on the South façade allows during the winter season to be able to take advantage of free solar supplies and reduce the energy requirement for heating.

For the summer season, in order to avoid overheating of the internal environments and consequently an excessive demand for energy for cooling, in the examples we mainly adopt fixed shielding systems (overhangs of the structure and of the roof or external canopies in steel or wood).

With regard to the northern front, the WWR has an average of about 40% as in the so-oriented range there are essentially the premises characterized by the presence of occasional people during school hours.

Finally, for the East West fronts there is an average WWR of 8% and 30% respectively. As far as these orientations are concerned, the dimensions of the openings are usually such as to guarantee the sanitary requisites for the functional units.

Figure 3.27 shows the average in percentage of window-to-wall ratio on the façade for each orientation, again with reference to the available data of the analysed representative buildings, for the nursery school (Figure 3.27).

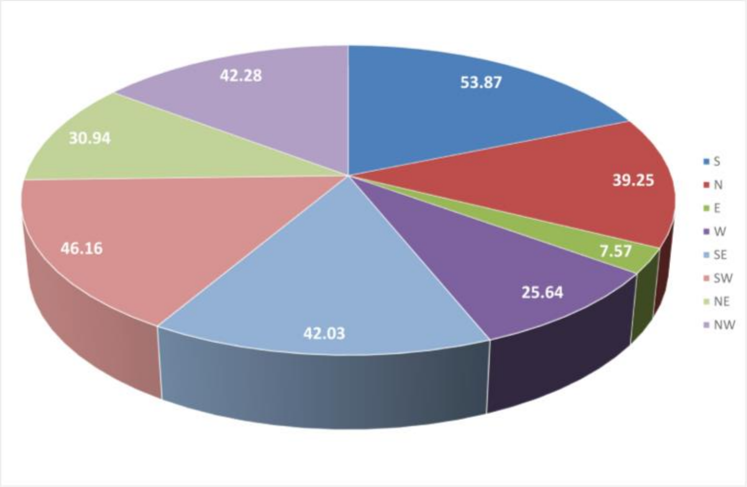

Figure 3.27 Average in percentage of WWR for each orientation for kindergarten

- *Elementary school*

For the primary school it was not possible to perform an arithmetic average with regard to the window-to-wall ratio since the available data were not sufficient, as not all the prospects of the buildings examined were available.

Even in this case, however, as for the kindergarten, the analysis of the photographic documentation of the representative buildings shows that the openings with the largest dimensions are located on the southern front, while for the other orientations the tendency is to have some minimum openings, sized according to the sanitary standards in force to guarantee the adequate conditions of internal comfort, both visual and thermo-hygrometric.

Internal partitions and finishes.

The internal partitions are mostly made of plasterboard with internal mineral wool insulation when high acoustic performance is required (for example between classrooms and horizontal and vertical connections or toilets).

In many school buildings there are movable walls to adapt the rooms to the needs of teaching and carry out collective and intercultural activities with a number of students higher than 26 (1 class).

The interior finishes are essentially in wood as if it is not treated it does not emit substances in the environment that are harmful to the health of the occupants.

An element of considerable importance for schools is color. This is no longer used exclusively as an aesthetic strategy but distinguishes the building as a whole by very often identifying and characterizing the various internal functional areas, especially in kindergartens in such a way as to make the child more easily orientated inside the building.

The most striking examples of the use of color in school buildings are the scholastic building of Didonè and Mide in San Felice sul Panaro (MO) built during the post-earthquake reconstruction of 2016 in Emilia-Romagna and characterized by pillars in facade painted with colors of the rainbow (Figure 3.28), or the primary school in Zugliano (VI) and the primary school of San Michele all'Adige (TN) marked by bright colors in the external facades (Figure 3.29).

Figure 3.28 Main façade of San Felice sul Panaro school – Reference: www.archilovers.com

Figure 3.29 One of main facade of Zugliano school – Reference: www.theplan.it

Energy strategies in order to reduce energy needs in winter season.

- *Kindergarten*

From the analysis of sustainable representative buildings for the nursery school it emerged that various strategies for the reduction of the demand of primary energy during the winter season are recurrent:

- the high insulation of the external casing, especially for high latitudes to reduce dispersion during the winter season, a fundamental strategy for example for the CasaClima protocol to obtain a high certification class (CasaClima Gold);
- the use of large windows for the southern front so as to be able to take advantage of the free solar contributions in the functional units with a higher occupancy rate during school hours and thus be able to reduce energy consumption for heating;
- the realization of masses for the thermal accumulation very often combined with the energy strategy described in the previous point.

  For example, in the Ponticelli kindergarten, reinforced concrete partitions are used, characterized by a high thermal capacity to accumulate heat from solar radiation and through their inertia to release it into the environment at a later time;
- the inclusion in the project of solar greenhouses (passive strategy), which are usually used as an area for recreational activities located in the South adjacent to the classes. The solar greenhouse is a space confined with a shell made up of glass elements; to improve its operation during the winter season it is kept closed so as to maximize the accumulation of energy from the sun and therefore increase the temperature of the indoor environments [20].

In nursery schools of compact form such as the nursery school of Cascina (PI) there is a solar greenhouse in the South for each class, while in the Montelupone (MC)[16] school complex the solar greenhouse develops along the entire side South of the building.

As far as the linear form is concerned, there are no examples of solar greenhouses integrated in buildings, but in the pre-school Ponticelli (the only example in the literature) a double-skin façade was built, connected to the classes, which helps to reduce consumption energy for heating as it allows the external renewal air to be drawn and preheated, entering the rooms through natural ventilation. This natural ventilation for the exchange of air in the environment is activated by probes that measure the internal concentration of pollutants;

- sensible heat recovery for controlled mechanical ventilation with an efficiency of up to 90%.

- *Elementary school*

With reference instead to primary school, in addition to the use of a high insulation of the envelope and large windows facing South, as already mentioned for nursery schools, 2 additional strategies for reducing energy consumption for the season are recurrent during winter:

- the first one is closely linked to the morphology of the construction lot and to any existing elevation levels; very often in fact the functional units with a larger volume, such as the gym in the primary school in Ponzano Veneto (Figure 3.30) for Romarzollo, are built below of the ground zero level, oriented to the North, in order to reduce the dispersions towards the outside, as the soil maintains a constant temperature of about 15 ° C during the year.
- the second one is always linked to the fact that the ground is kept at a temperature more or less constant throughout the year and it is the geothermal preheating of the renewal air before being introduced into the air handling unit.

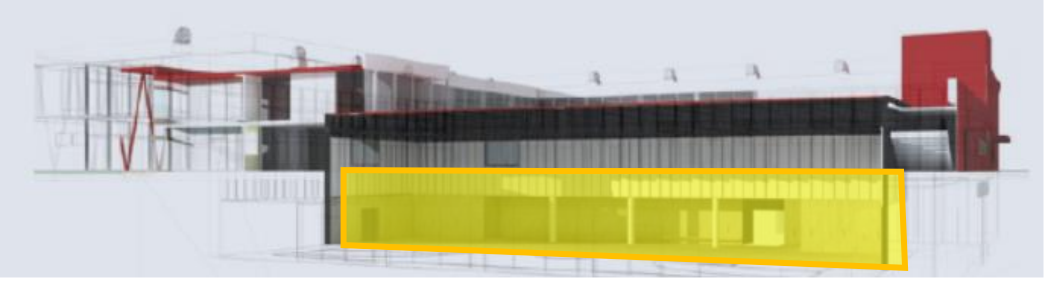

Figure 3.30 Section of Ponzano Veneto elementary school with the indication of functional unit gym [21]

Energy strategies in order to reduce energy needs in summer season.

As for the strategies for reducing the demand for energy for cooling for both school orders, these mainly concern:

- passive cooling of buildings through night cooling during the night hours of the summer season. This strategy uses the flow and the air currents that are created inside the building due to the thermal

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[16] https://www.arketipomagazine.it/polo-scolastico-di-montelupone-mc-pensy/

gradient present between the internal and external environment [22] and/or different pressures acting on the building envelope, this in synergy with the exploitation of inertial masses in the environments.

The night air is used: it has a lower temperature than the internal air of the building to remove heat from the rooms due to natural ventilation using special openings at the base of the building and at the top (chimney effect).

The efficiency of this strategy depends both on the wind speed and on the correct sizing of the openings both from the heat accumulated inside the building during the day and from a correct dimensioning of the inertial masses of the building. In the primary school of Romarzollo the chimney effect for cooling during the night is created through a central atrium inside the building and automatic openings placed at the top;

- passive cooling of buildings by exploiting the chimney effect and solar radiation during the day. If the outside air temperature is higher than that of the indoor environment to guarantee air recirculation through the chimney effect, it is necessary to use solar radiation to increase the air temperature inside the chimney duct and create the upward motion of the indoor air by temperature difference. This case is related to solar chimney.

  In this strategy it is essential to use at the top a surface that has a high capacity to absorb solar radiation such as dark colored surfaces.

  In Sweden in the Tanga school (Figure 3.31) this passive strategy is used combined with the use of fans in the duct to increase the speed of the exhaust air leaving the solar chimney (Figure 3.32). The same strategy is also used in the Ponticelli kindergarten (Figure 3.33) and in the Ronco Briatino school built in 2007 [23];

Figure 3.31 View of Tanga school in Sweden – Reference: http://new-learn.info/packages/euleb/it/p10/index_01.html

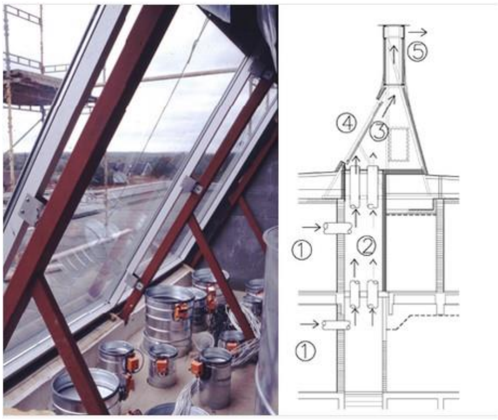

Figure 3.32 Section of solar chimney – Reference: http://new-learn.info/packages/euleb/it/p10/index_01.html

Figure 3.33 View of solar chimney of Ponticelli kindergarten – Reference: host.uniroma3.it

- passive cooling of buildings through the exploitation of cross ventilation during the day.

  In many schools, passive cooling occurs by exploiting cross ventilation by orienting the building within the construction lot according to the direction of the prevailing winds. In this case, the air movement is created by the difference in pressure between the upwind and downwind areas. In fact, the façade of the building oriented perpendicularly to the prevailing wind direction is characterized by a pressure value greater than the opposite one found in depression: the renewal air enters the building from the openings placed in the windward facade and the exhausted air comes out of those in the leeward one;

- geothermal pre-cooling that uses the land as a geothermal exchange well to disperse heat (direct use). The renewal air (heat transfer fluid) taken from the outside is conveyed into underground horizontal ducts (1-2 m). The pre-cooling takes place because the temperature of the outside air is much higher than that of the ground which remains at around 15°C throughout the year;
- the use of external shielding systems. These are mostly realized through fixed overhangs to avoid overheating during the summer season for all South-facing environmental units and thus guarantee an appropriate internal comfort condition for the occupants.
- the design of external water tanks. In the Mezzago kindergarten designed by Arch. Antonio Varisco, built in 2005, to maintain a lower outdoor temperature near the windows of the South-facing classes water basins are used (Figure 3.34) which also serve as rainwater collection tanks and as spaces dedicated to recreational activities [23].

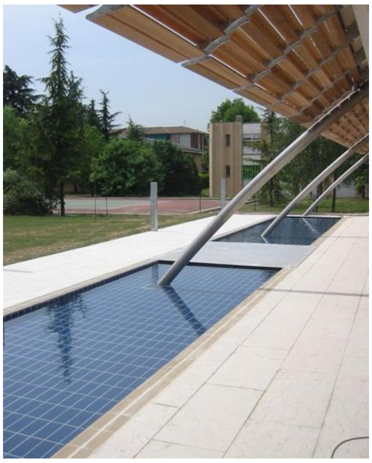

Figure 3.34 External view of Mezzago primary school – Reference: http://www.ordinearchitetti.mi.it/it/mappe/itinerari/edificio/307/32-architettura-e-sostenibilita-tecnologie-costruttive/galleria

Environmental strategies.

The recurrent environmental strategies for both school orders are essentially:

- the use of natural materials, not only for the technological solutions adopted but also for the furnishings and interior finishes for which wood is preferred.

  In most cases, we try to use materials that do not release toxic substances throughout their life cycle so as not to be harmful to the health of the occupants. In many school buildings, sensors are used that activate the opening of the windows or the controlled mechanical ventilation system (VMC) based on the concentration of pollutants in the environment (for instance CO_2, volatile organic compounds - VOC);
- the collection of rainwater so as to be used for the irrigation of the external green area and in the toilets;
- the use of energy from renewable sources in order to reduce emissions of greenhouse gases into the atmosphere.

  First of all the installation of photovoltaic panels on the roof (active solar strategy) for the production of electricity in order to minimize CO_2 emissions in the environment and make the school as independent as possible from the public distribution network, and solar panels for hot water even if the demand is low in school buildings.

  The photovoltaic panels for this type of buildings are mostly placed in the roof and can be integrated as it happens for example in the curved shelter of the Mezzago primary school [23] or in the sloping part of the Nichelino (TO) nursery school [9], or installed on the flat roof and inclined according to latitude.

Furthermore, the use of geothermal heat pumps is especially common for primary schools and in some cases the exploitation of wind energy. In Italy in the nursery school of Cascina (PI) (Figure 3.35) 3 vertical rotation blades have been installed that allow to produce on the basis of wind data between 200 and 250 kWh in a year. In that of Foro Boario (FC) the blades are installed in the central part of the building to deal with part of the building's electricity needs [7].

Figure 3.35 External view of the Cascina wind system – Reference: https://www.arketipomagazine.it/certificazione-casaclima-per-la-scuola-dinfanzia-a-cascina-pisa/

Systems.

As for the facilities for both the kindergarten and primary school, we frequently find:

- the preparation of a heat pump system (air-water or geothermal) to meet the energy needs for heating and cooling and the use of gas condensing boilers to produce service hot water;
- the use of radiant floor panels both for heating and for cooling as they allow to obtain adequate conditions of internal comfort for the occupants and to save energy compared to traditional distribution systems that operate at a higher temperature;
- the adoption of a controlled mechanical ventilation system with sensible heat recovery to contain the demand for primary energy and to obtain good indoor air quality and meet the minimum regulatory requirements for hourly spare parts in most school buildings. Usually this is combined with a system of probes that measure the quantity of pollutants inside the rooms (especially in the classrooms) and activate ventilation when necessary.

3.3 NEW SCHOOL BUILDING TYPE

A building type could be defined as: "*a structured set of historically established knowledge and a stabilised and recognised configuration of building products*"[17]. A building type was defined through a series of

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[17] Translation from "Edilizia. Progetto, costruzione, produzione" Franco Nuti, Polistampa, 2010

different factors, divided in different classes, such as: the use of the space, the land use for building aim, related to morphology and geometric configuration of the building, internal layout functional organisation (individuation of functional bands and units), and finally factors related to construction systems, techniques and materials. The building type defined according to these specific factors thus becomes a final and general model that indicates the level of satisfaction of certain needs and could be followed as a qualitative reference for the design. It is necessary to point out that starting critically from what has already been defined, changes and modifications can be made, assuming the building type as a dynamic system that could be implemented and could be considered as a reference for each project.[18]

Therefore, in this paragraph the new and implemented building type for schools was defined through the definition of both environmental and technological system.

3.3.1 General considerations

The modern school becomes a civic center directly connected with the external environment and the city itself, an example of sustainable and quality architecture and at the same time a place of reference for the community. Especially with regard to primary school, the functional units intended for collective activities, such as the library, the gym and an auditorium, become usable even outside of school by people in the neighbourhood. They are designed and built in such a way as to be completely independent from an architectural point of view, as regards access and the system of exit routes, but also from a plant point of view.

The direct relationship with the neighbourhood is found not only through an efficient infrastructure connection system and proximity to public transport stops but also with the presence of large windows that allow a continuous visual connection between inside and outside. The clear division between the school environment and the city environment is inferior and the school becomes a place open to everyone and used in the daily life of the neighbourhood. This is also found in school activity as the families of the boys become protagonists involved in the didactic activity and establish a direct relationship with the teaching body. The entrance to the school building is transformed into an agora, an essential functional area for a modern school building, where the families of the children are free to enter and be in direct contact with the school environment. In the nursery school this functional area is essential as the parents can stop with the children according to their needs, while in the primary school usually in the agora the works of the boys are exposed.

A considerable change in the modern school refers to the relationship that school buildings have with the surrounding open space that becomes a space for teaching (educational gardens, outdoor sensorial paths, areas for recreational activities, educational greenhouses, accessible green roofs): the classes are directly

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[18] Translation from Esther Giani, Corso di Caratteri tipologici e distributivi degli edifici, Iuav, 2010-2011

connected with the garden which becomes a real extension of the home base where children can learn through both recreational and sports activities and collective educational activities in contact with nature.

As regards the internal functional distribution, each school building must guarantee the integration and interoperability of the various main functional areas.

The flexibility and adaptability of spaces with respect to the needs of teaching are essential in a modern school. Mobile walls and furnishings are used for the home base so as to be able to divide the available area and the equipment relatively to the number of students participating in the teaching or to carry out intercultural and cooperation activities even among students of different ages.

This is also reflected in the modularity of the structure and in the preparation of the system, in fact both must necessarily adapt to the needs of the continuously evolving teaching method.

The multi-functionality of the environments is at the base of the design of a modern school especially for school buildings for lower education.

In the primary school, the canteen becomes an independent and multi-purpose space with mobile furnishings, which can also be used outside of school for performances, exhibitions or temporary installations of children's works.

The main vertical connections change their function, transforming themselves into spaces of relationship, flexible, usable as real amphitheatres for school shows (Figure 3.36 – Figure 3.37 – Figure 3.38).

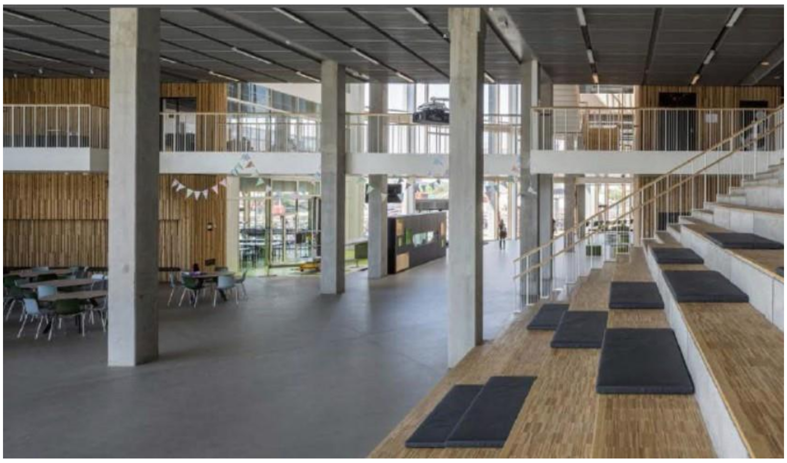

Figure 3.36 Vertical connection in Romanina school [24]

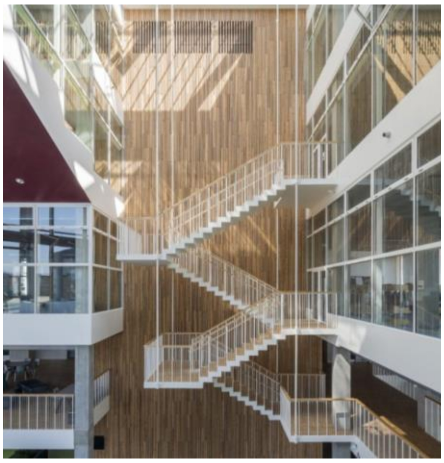

Figure 3.37 Vertical main connection in South Harbor school – Reference: www.domusweb.it

Figure 3.38 Vertical secondary connection in South Harbor school

This also happens for the horizontal connections that host areas for individual or group study, spaces for relaxation or reading, and that are no longer characterized by a minimum depth linked exclusively to regulations for overcoming architectural barriers or for prevention fires.

An important innovation linked to curricular teaching concerns the introduction of the ateliers and the consequent strengthening of laboratory and integrative activities (Law n.107 of 23rd July 2015) which once again underlines the loss of the centrality of the classroom in favour of the areas for practical, special and group activities.

In the perspective of sustainability and also of the requests of the different certification protocols in the didactic programs, lectures and workshops should be included to make the students aware of environmental issues and energy saving. The sustainable school building is seen as a real 3D textbook [25] from which children can learn by observing and actively participating in the management of the building (for example, in some schools' screens are inserted where energy consumption is reported in real time). Even extra-curricular training activities are necessary to involve students in projects aimed at understanding environmental and energy sustainability and climate change in order to make them more aware [26].

3.3.2 Energy and environmental strategies

Energy strategies in order to reduce energy needs in winter season.

In the new building type for kindergarten and primary school, energy strategies that could be adopted to reduce energy needs for heating:

- a low value of the aspect ratio (ratio between the dispersing surface of the building S and its volume V - S/V expressed in m^{-1}) through the creation of voids (internal courtyards) and recesses, made in the geometry of the building;
- the South-facing functional band has a depth greater than that exposed to the North at least in a ratio of 2:1; in the southern band there are the main functional units that have a continuous presence of people while in the North the kitchen and the teachers area that have an occasional presence of people during school hours and all ancillary rooms. This allows for a better energy performance of the building during the winter season;
- the functional units classes have been oriented to the South in order to take advantage of the free solar gains during the winter season in the main functional area related to the methodical activities that has a higher occupation rate during school timetable;
- on the southern front for climatic zones E and D the window-to-wall ratio is greater than that imposed by health and hygiene regulations as this allows to take advantage of free solar contributions and decrease the demand for heating requirements.
- on the northern front, openings are envisaged with the minimum size required by the health and hygiene requirements of the legislation in force for all the climatic zones considered;
- the use of a sensitive heat recovery unit for the controlled mechanical ventilation system with an efficiency at least of 65%.

Energy strategies in order to reduce energy needs in summer season.

To reduce the demand for energy during the summer season the following energy strategies could be adopted for both school orders:

- on the southern front for the climatic zones C and B the size of the openings is kept to the minimum required by the sanitary hygienic regulations to minimize the demand for energy for cooling.
- the use of fixed solar shading systems, made with an overhang equal to 2 m, for all the South-facing functional units in order to avoid overheating of the premises;
- the use of internal and automatic mobile solar screenings, made with light-colored venetian blinds, with control of the external temperature (the blinds close when the external temperature exceeds 24 ° C) in order to avoid overheating of the rooms or with control on glare to avoid problems related to visual discomfort during the course of teaching.

Environmental strategies.

To reduce the environmental impact the following environmental strategies could be used:

- the use of natural materials for the technological solutions of the casing with respect to the CAM requirements in order to reduce the greenhouse gases emitted into the atmosphere during the production of the materials and the construction of the building, but also to minimize the harmful substances in the environment during the operating phase throughout the life cycle to safeguard occupant health;
- the use of renewables. For instance, the preparation in coverage of a photovoltaic system for the production of electric energy both to satisfy the entire needs of the building and to produce energy to be fed into the public grid (Plus energy building) and to reduce CO_2 emissions into the environment.

3.3.3 Architectural definition

Before moving on to the detailed description of the new building type for kindergarten and primary school, it is necessary to underline that the shape and dimensions in plan, the orientation, the distribution and the dimensions of the bands and functional units of the typological models is defined through the arithmetic mean of the parameters obtained through the study of representative buildings carried out through both detailed reading cards and the collection of data available in tabular form.

In detail the parameters considered for the definition of the new building type are: the shape and dimensions of the building in the plan, the total surface, the orientation, the number and depth of the horizontal and vertical functional bands, the number of students, the area per student in reference to the total area and to each individual environmental unit, the number, orientation and size of the classes, the number of teachers and the surface area per teacher for the environmental unit Teachers Area.

No statistical analysis was performed as the number of schools analysed for each individual typological model identified was not enough.

The following table shows the average values of the main parameters considered for the definition of the new typological models. In table 3.8 these values are reported with reference to the different planimetric configurations identified by the analysis of sustainable representative buildings:

Kindergarten

- type I: compact building;
- type II: building with mainly longitudinal development.

Elementary school

- type I: compact building;
- type II: building with mainly longitudinal development.
- type III: building with three horizontal arms that house the methodical area.

In Table 3.4 is illustrated for each type of planimetric configuration: the plan dimensions of the building (C x B), the area (A), the number of students (NS), the surface area per student with respect to the total area (S_{stud}), the number of classes (N) and their size (E x D), the surface area per student for the home base (HB), the kitchen (K) and the canteen (C) and finally the number of teachers (T) and the surface area per teacher in reference to the functional area care area (CA).

Obviously, the surfaces of the models obtained from the analysis of representative sustainable buildings have been compared with those reported in the 1975 legislation in order to comply in any case with the minimum standards required.

Table 3.4 Summary of the arithmetic mean of main parameters

Main Parameters	C [m]	B [m]	A $[m^2]$	N_S	S_{stud} m^2/stud	N	E [m]	D [m]	HB* m^2/stud	K m^2/stud	C m^2/stud	T	CA m^2/tea
Kindergarten													
Type I	32	25	900	72	11.80	3	6.1	8.7	5.50	0.90	1.30	3	28.30
Type II	84	20	1706	122	14.70	5	12	7.9	7.40	1	1.30	5	24.60
Elementary school													
Type I	32.6	29	2130	280	8.50	16	7	6.4	3.3	-	-	8	11.9
Type II	39	20	2735	500	5.30	20	6.8	6.4	2.2	-	-	17	8.70
Type III	41.4	47.3	8611	560	14.4	23	7.5	7.7	4.5	-	-	15	8.80

*For the Elementary school the value is exclusively referred to the methodical activities area

The following graphs show instead the average percentage of each main functional area with reference to the representative buildings analysed both for the nursery school (Figure 3.39) and primary school (Figure 3.40). In both graphs: MAA is the methodical activities area, FAA is the free activities area, CKT is the canteen/kitchen area, CA is the care area and C are the connections.

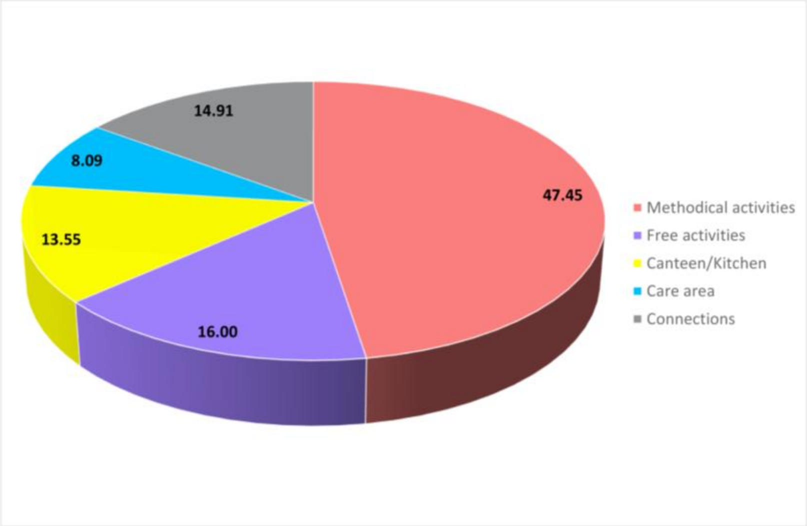

Figure 3.39 Average in percentage of functional area for kindergartens

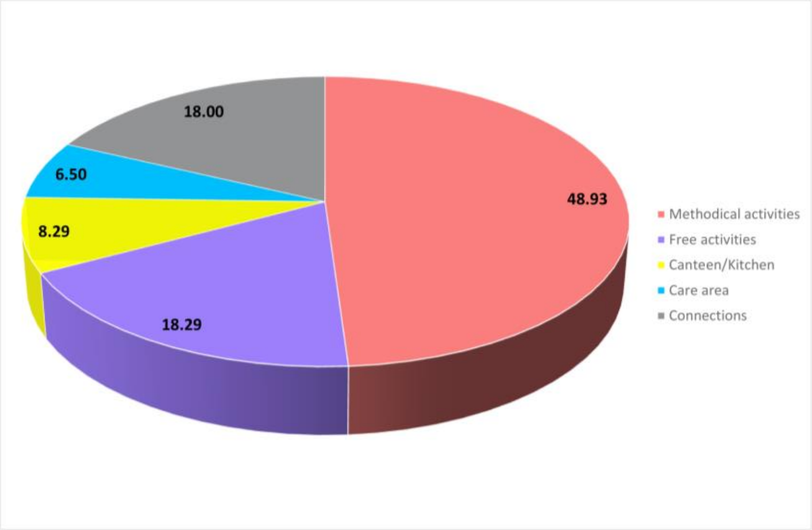

Figure 3.40 Average in percentage of functional area for elementary school

From the analysis of these two graphs constructed on the basis of the average percentage of each functional area with respect to the total area, it is clear that for kindergarten the main functional area Methodical activities (MA) occupies almost 50% of the area in building plan. This is because in the modern school the area relating to the pedagogical units no longer includes only the area for desk activities but also that for collective and recreational activities and that for practical activities (hygienic services within the class).

As far as the primary school is concerned, the most evident datum concerns the area for collective activities (FA) that occupy about 20% of the total area as they have become fundamental and necessary areas for carrying out group teaching activities. The area of the connections (C) occupies about 18% as these in modern school become spaces of relationship and socialization.

Construction site and external layout.

The thesis did not deal in detail with the specific design of the area outside the school and the construction site, but simply outlined qualitative guidelines (*3.3.1 General considerations*) with reference to this, deduced from the study of the state of the art concerning the modern school both in relation to the new didactic and pedagogical methods and in the perspective of sustainability and the critical analysis of representative buildings.

However, some proposal with respect to the surface of the site of construction considering the Italian minimum requirements of a new construction regarding urban design index are defined in the qualitative and quantitative guidelines (Deeping in *Chapter 5*) to build zero-carbon kindergarten in Italy.

Orientation, geometry and building organisation.

- *Kindergarten*

From the analysis of the representative buildings for the nursery school it was possible to identify 3 new typological models for the new school building type for kindergaten:

- of compact shape with internal courtyard with 3 sections (Model I1);
- of linear form with 3 sections (Model I2);
- of linear form with 6 sections (Model I3).

All typological models for kindergarten are developed on a single level above ground and have no vertical connections. This is essentially related to the age of the children who attend it, between 3 and 5 years.
26 students per pedagogical unit are considered for the sizing of typological models for the kindergarten.

Below is the minimum environmental unit with the indication of the dimensions (measured in meters), the furnishings (desks and chairs) according to the intended use of the single area within the class with the indication of the use range and the main routes (Figure 3.41).

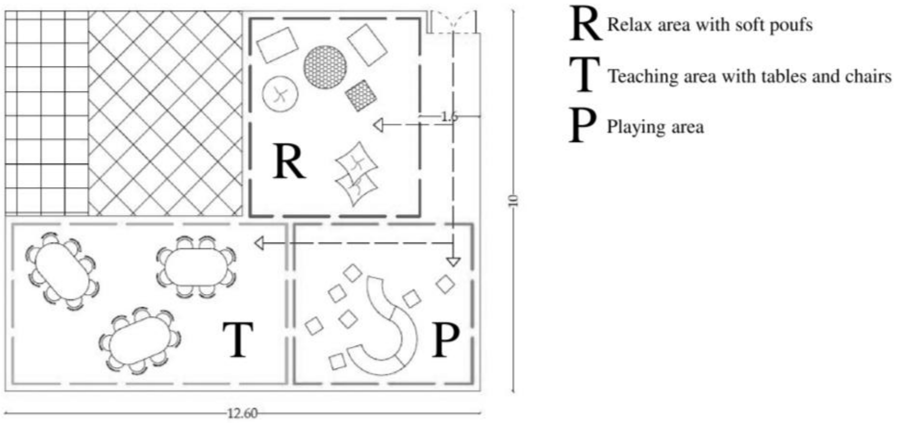

Figure 3.41 Minimum kindergarten classroom functional unit

The compact model I1 with internal courtyard does not have a prevalent geometric orientation but the functional band dedicated to the home base is oriented to the South. The rotation with respect to the North-South axis is between 0 ° and 30 °. It is organized according to 5 horizontal functional bands of different sizes (Figure 3.42) with a ratio of 1.70 between the depth of the South-facing functional strip and the North-facing band. In this form the plan dimensions (depth and length) are comparable to each other.

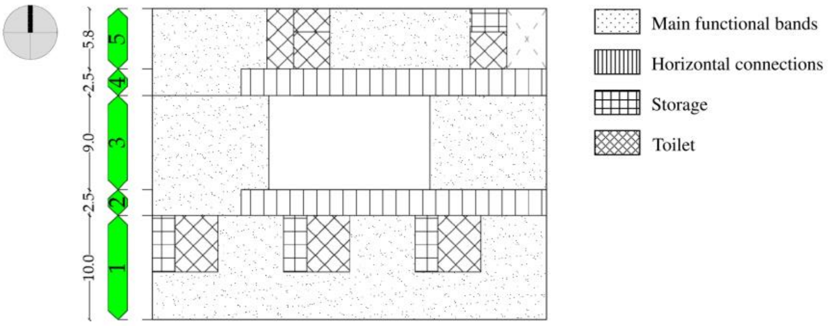

Figure 3.42 Functional bands of Model I1

The typological models I2 and I3 have a prevalent orientation according to the East-West axis in order to allow a greater exploitation of the solar contributions throughout the winter season and therefore improve the energy performance of the building. They are organized according to 3 horizontal functional bands with the horizontal connection placed in the center (Figure 3.43 – 3.44). In these 2 cases instead the dimensions in plan (depth and length) are clearly different with a ratio of about 1:5 for both typological models.

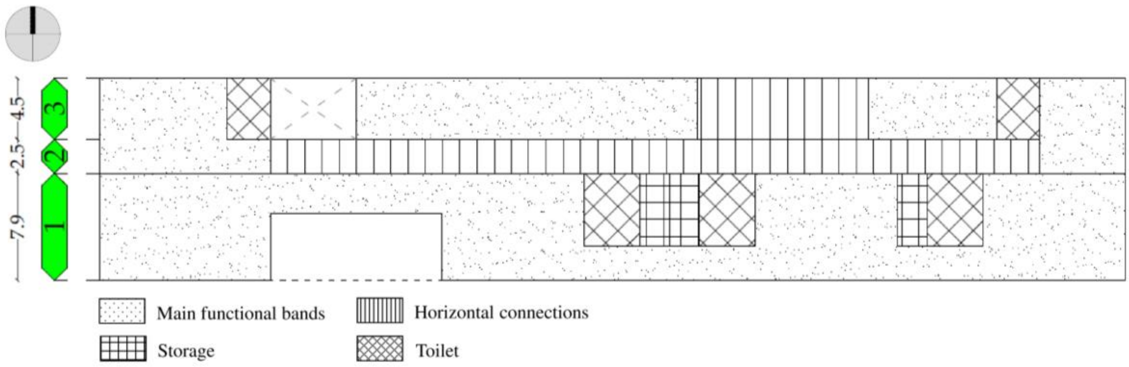

Figure 3.43 Functional bands of Model I2

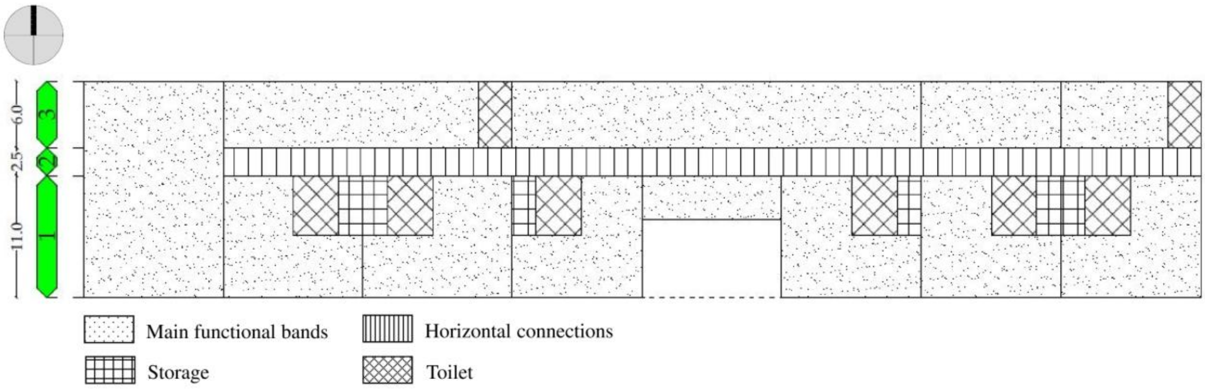

Figure 3.44 Functional bands of Model I3

The main functional areas are outlined in the internal layout of the 3 new typological models for the kindergarten according to the diagrams shown in figure 3.45, figure 3.46 and figure 3.47, where the occupancy percentages of each functional area with respect to the total area of the model are pointed out.

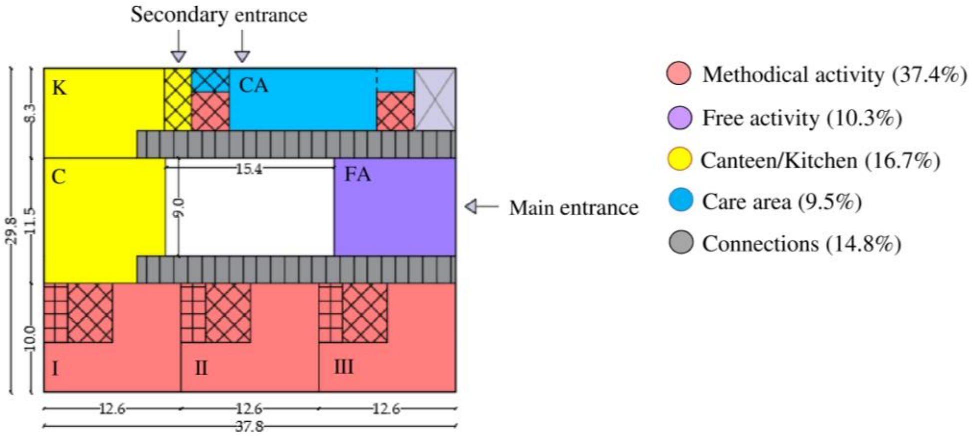

Figure 3.45 Functional units of Model I1 with indication of percentages

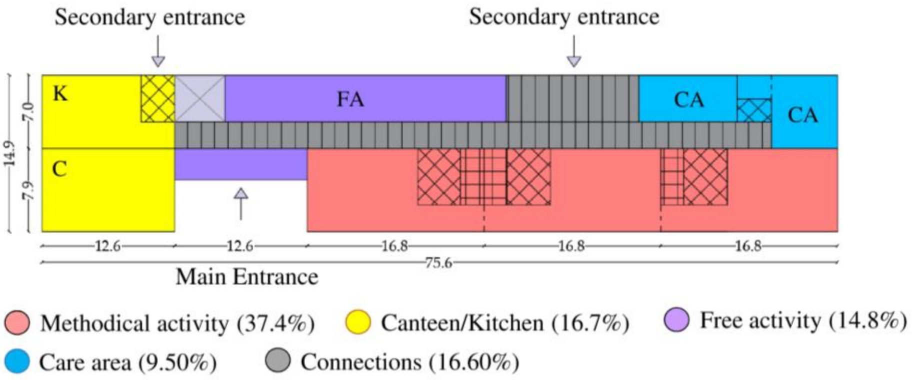

Figure 3.46 Functional units of Model I2 with indication of percentages

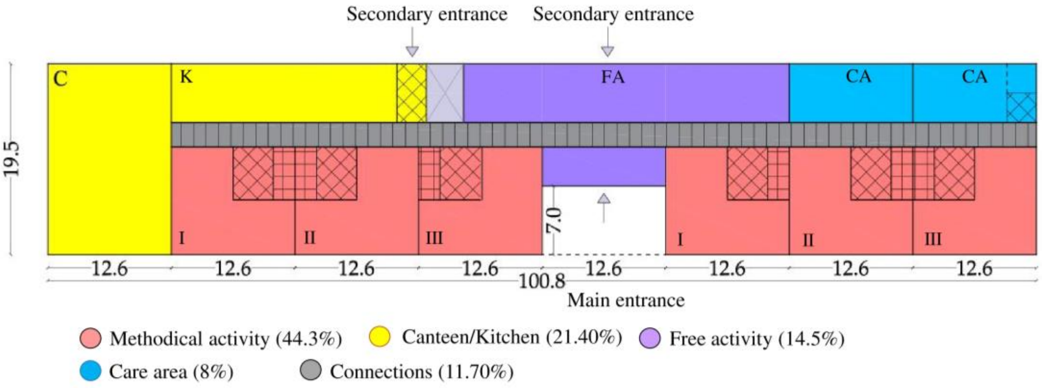

Figure 3.47 Functional units of Model I3 with indication of percentages

As can be seen from the analysis of the data reported in figure 3.45, figure 3.46 and figure 3.47 the average percentages referring to the 3 new typological models of the kindergarten, concerning the different main functional areas, do not differ much (maximum deviation equal to about 5%) from the average deduced from the analysis of representative buildings analysed in the first part of this research phase (Figure 3.39). In the typological models for kindergarten the toilets are located within the classrooms, as they are useful for practical activities and are easily accessible to children.

Inside the section there is also a storage for all the equipment needed to carry out the teaching activity.

The main geometrical characteristics of the new typological models for kindergarten are illustrated in the following Table 3.5 where they are indicated: length (C), depth (B), internal body height of factory (H_{int}), floor area (A) and building volume (V), shape ratio (S/V), number of students (NS), surface area per student compared to the total area of the building (S_{stud}), orientation, number (NC) and class sizes (E width; D depth), depth of functional horizontal bands (Functional bands$_{Horizontal}$) and vertical bands (Functional bands$_{Vertical}$) according to orientation (South/middle/North - East/middle/West), the percentage relative to each functional unit in relation to the total area ($\%_{TOTAL}$), the ratio between the southern functional zone and the northern one (R) and finally the surface area for student compared to the home base (HB).

Table 3.5 Main characteristics of kindergarten typological models

	Building	Students	Classrooms

	C [m]	B [m]	H_{int} [m]	A $[m^2]$	V $[m^3]$	S/V $[m^{-1}]$	NS	S_{stud} m^2/stud	Orientation		NC	E [m]	D [m]
I1	37.80	29.80	4.40	1036	6008	0.53	78	14.44	South		3	12.6	10.0
I2	75.60	14.90	4.40	1064	6172	0.51	78	14.44	South		3	12.6	7.90
I3	100.8	19.50	4.80	1631	10116	0.46	156	12.60	South		6	12.6	11.0
	Functional $bands_{Horizontal}$ [m]			Functional $bands_{Vertical}$ [m]			Functional units [% $_{TOTAL}$] *					R	HB
	South	middle	North	East	middle	West	MA	FA	C/K	CA	C	S/N	m^2/ stud
I1	10	9.00	5.80	-			38.3	10.3	22.4	9.5	14.8	1.7	4.85
I2	7.9	2.50	4.50	-			37.4	14.8	16.7	9.5	16.6	1.8	5.10
I3	11	2.50	6.00	-			44.3	14.5	21.4	8.0	11.7	1.8	5.33

*In model I1 the 4.7% of the total surface is assigned to technical area; for the model I2 the 5%.

It is essential to emphasize that the orientation of the building necessarily influences the distribution of the bands and functional units and their depth regardless of the climate zone to which they belong. In fact, the functional belt in the South has a greater depth than the one in the North according to a ratio of about 2:1 and hosts the main environments that have a higher occupancy rate during school hours. This necessarily entails a lower primary energy demand for winter air conditioning.

- *Elementary school*

The primary school is organized on a maximum of 2 floors above ground and from the analysis of the representative buildings it was possible to outline 4 new typological models:

- of compact form (Model P1);
- predominantly linear development with a single surface above ground (Model P4);
- predominantly linear development with 2 floors above ground (Model P2);
- with 3 horizontal arms (Model P3).

As for the nursery school, even in the case of primary schools, the functional area in the South hosts the classes, while the toilets in the case of primary schools are decentralized compared to the home base.

It is important to underline that the functional unit Teachers Area (TA) also includes some offices for the management and administration of the school building, decentralized with respect to the main site, being today the schools organized for the greater part as Comprehensive Institutes.

26 students per pedagogical unit are considered for the sizing of typological models for primary school. For all the primary school models outlined in this phase of the research a number of classes equal to 10 is considered in order to have the same number of students within the school (equal to 260).

For the typological models for this school order for each 2 curricular classrooms where theoretical lectures are held, a laboratory for activities with specific equipment is considered.

There are 2 stair blocks in the opposite position of the building to meet the requirements of the fire prevention legislation.

Also in the case of primary schools, it was considered appropriate to proceed with the definition of the environmental class unit to define the minimum area relative to the number of students in compliance with the current regulations and then compare it with that determined by the analysis of representative buildings and literature on the subject. The following (Figure 3.48) is the minimum environmental unit with the indication of the dimensions (measured in meters), the benches, the chair and the sessions with the indication of the main paths.

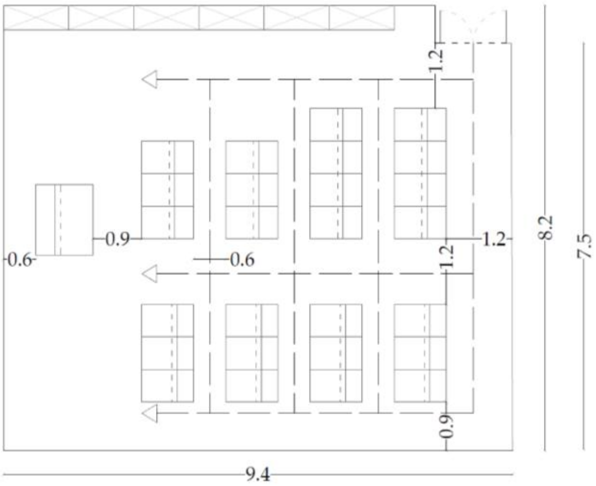

Figure 3.48 Minimum classroom functional unit for elementary school

The compact P1 model does not have a prevalent geometric orientation but the classrooms are oriented to the South. The rotation with respect to the North-South axis is between 0°-30°. As shown in figure 3.49 the internal distribution includes 5 horizontal functional bands and 5 functional vertical bands with the main ones that alternate with the horizontal connections.

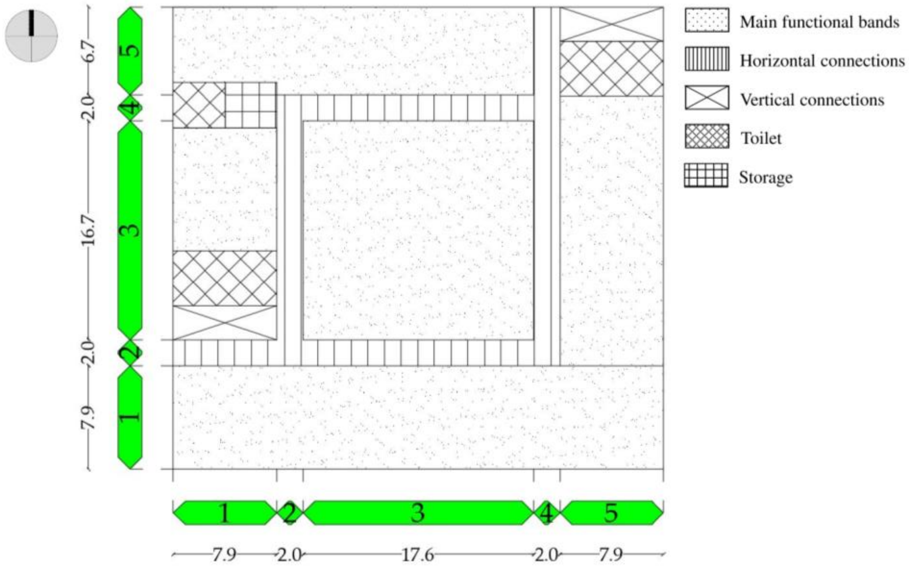

Figure 3.49 Functional bands of Model P1

The model is characterized by the presence of a central atrium (agorà) on the ground floor and a series of connecting balconies on the upper floor that directly overlook the atrium below and these spaces house the collective activities (Figure 3.50).

For this primary school model, services such as the canteen and the kitchen are located in an adjacent building (annex building in the figure 3.50) that can be easily reached by the children on foot, usually via a covered path.

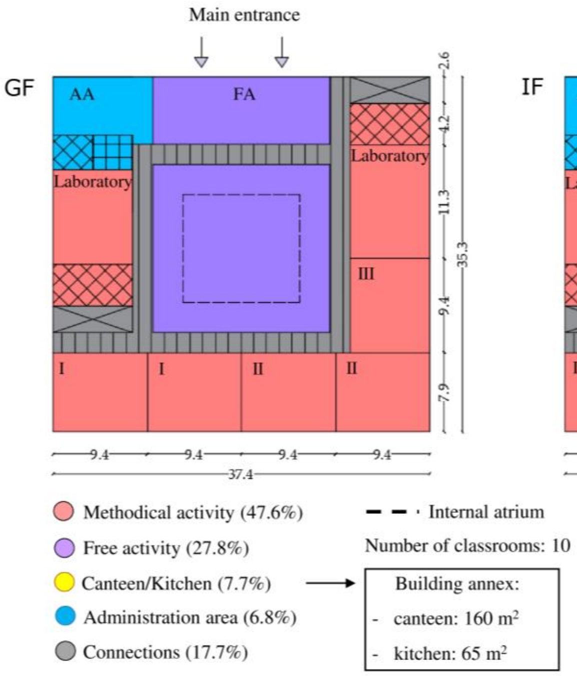

Figure 3.50 Functional units of Model P1

The P4 and P2 models have a prevalent orientation according to the East-West axis and are organized according to 3 horizontal functional bands: the main southern band hosts the classes, at the center there is the main horizontal connection while to the North laboratories, services and vertical connections are developed (Figure 3.51). As in the case of the I2 model of the nursery school, even in this the depth of the functional band in the South is greater than in the North.

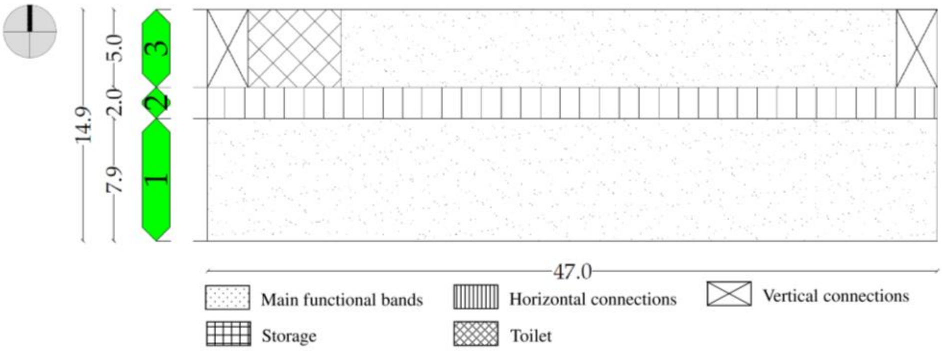

Figure 3.51 Functional bands of the Homebase of Models P2 – P4

The P4 model presents the home base on the ground floor and a central double-height block where the collective areas, the canteen and the teacher area are concentrated, while the P2 block has the functional band dedicated to the methodical area organized on 2 floors and the larger surface area destined for free activities is instead oriented to the West as well as the canteen (Figure 3.52 – figure 3.53).

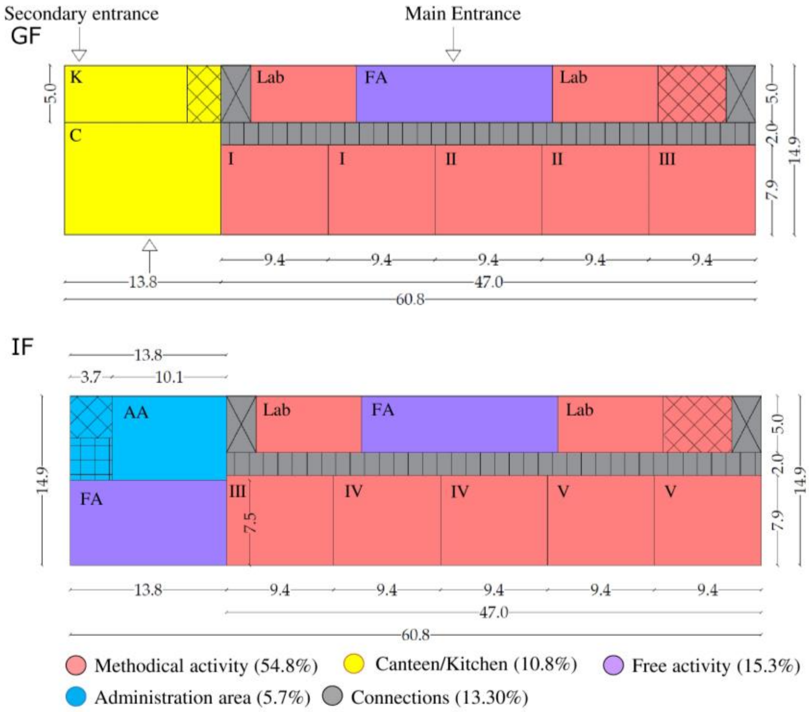

Figure 3.52 Functional units of Model P2

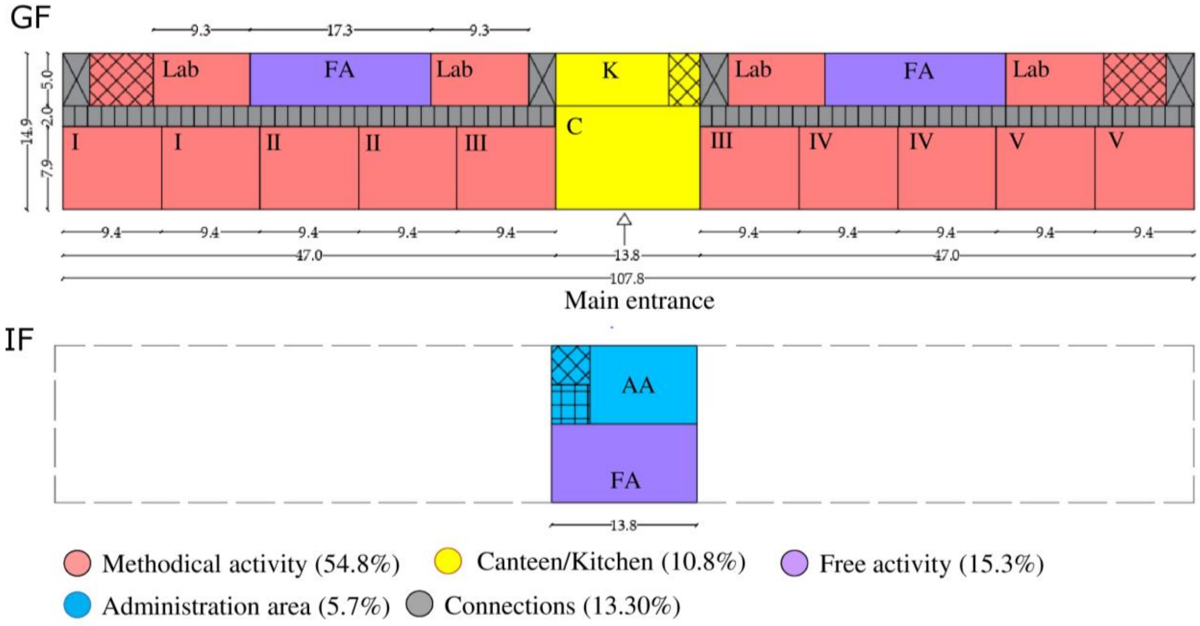

Figure 3.53 Functional units of Model P4

The P3 model is characterized by a particular shape in plan and is developed on a single plane above ground. The main functional area for the methodical activities is spread over three horizontal arms with a distribution of the horizontal functional bands as illustrated in figure 3.54 with the main band of the classrooms facing South and the connections to North. The remaining functional units are concentrated in a block of the building facing East which also houses the two ateliers for special activities in the southern band (Figure 3.53).

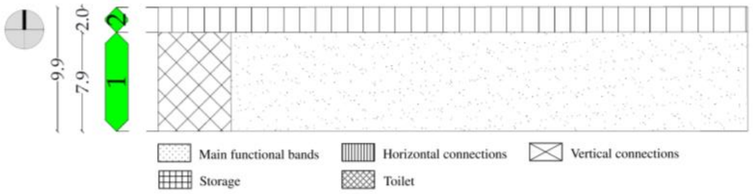

Figure 3.54 Functional bands of the Homebase of Model P3

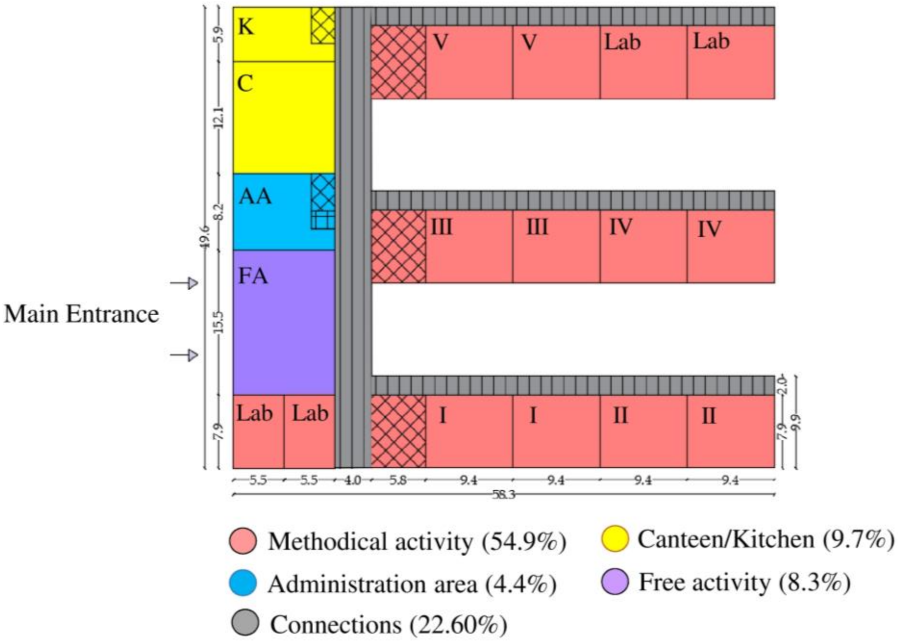

Figure 3.55 Functional units of Model P3

The main geometric characteristics of the new typological models for primary school are shown in the following Table 3.6: length (C), depth (B), internal height of the building (H_{int}), plan surface (A) and building volume (V), the aspect ratio (S/V), the number of students (NS), the surface area per student compared to the available total area of the building (S_{stud}), orientation, the number (NC) and the size of the classes (E width; D depth), the depth of the functional horizontal bands (Functional bands$_{horizontal}$) and vertical (Functional bands$_{vertical}$) according to the orientation (South/middle/North - East/middle/West), the percentage relative to each functional unit in relation to the total area (% $_{TOTAL}$), the ratio between the southern functional zone and the northern one (R) and finally the surface area per student compared to the home base (HB).

Table 3.6 Main characteristics of kindergarten typological models

	Building						Students		Classrooms				
	C [m]	B [m]	N_{floor}	A [m^2]	V [m^3]	S/V [m^{-1}]	NS	S_{stud} m^2/stud	Orientation		NC	E [m]	D [m]
P1	37.4	35.3	2	2516	15246	0.42	260	9.8	South		10	9.3	7.9
P2	60.8	14.9	2	1800	11180	0.45	260	6.9	South		10	9.3	7.9
P3	58.3	49.6	1	2019	12518	0.51	260	7.8	South		10	9.3	7.9
P4	107.8	14.9	1	1800	21060	0.17	260	6.9	South		10	9.3	7.9
	Functional bands$_{Horizontal}$			Functional bands$_{Vertical}$			Functional units [% $_{TOTAL}$]					R	HB
	South	Middle	North	East	Middle	West	MA	FA	C/K	TA	C	S/N	m^2/ stud
P1	7.9	10.7	6.7	9.4	10.7	9.4	47.6	27.8	7.7	6.8	17.7	1.2	4.60 *
P2	7.9	2	5	-			54.8	15.3	10.8	5.7	13.3	1.6	3.80
P3	7.9**	-	2**	-			54.9	8.3	9.7	4.4	22.6	3.9	4.30
P4	7.9	2	5	-			54.8	15.3	10.8	5.7	13.3	1.6	3.80

*The value is referred to the type floor

**The value is referred to the 3 horizontal blocks where the home base is designed

As evident from the typological models configured for kindergarten and primary school, the internal distribution of the main and secondary functional units takes place taking into account the orientation of the building within the lot because this necessarily affects the energy performance of the building. but also, on the thermo-hygrometric well-being of the occupants. This is completely independent of the climate zone where the building is located.

Furthermore, it is important to underline at the end of the geometric and functional definition of the new typological models that the surfaces per student indicated in the D.M. n. 69 of 18th December 1975 are inadequate and insufficient both as regards the home base and the spaces where the integrative activities are carried out both for the nursery school and for the primary school:

- home base for new typological models for nursery school (considering only the ordered activities and special activities) on average around 3.40 m^2/stud > 2.40 m^2/stud prescribed by the legislation of 1975;
- primary school class for the new typological models on average about 3.20 m^2/stud > 1.80 m^2/stud prescribed by the legislation of 1975;
- primary school atelier for new typological models on average about 2 m^2/stud > 0.40 m^2/stud prescribed by the legislation of 1975.

Structure.

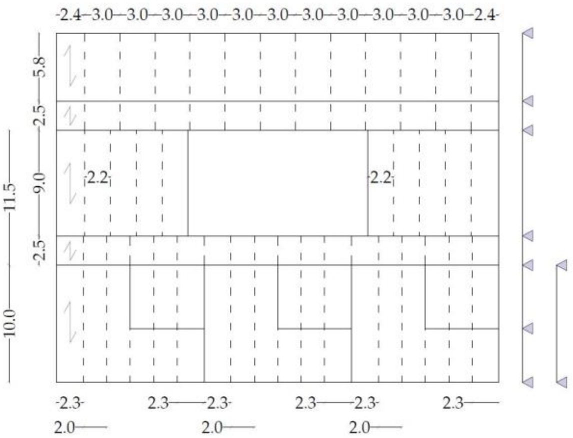

Figure 3.56 Scheme of structural solution in XLAM for Model I1 with dimensions measured in meters

On the basis of what is derived from the analysis of the representative buildings, a reinforced concrete structure for the foundation elements is used for the new typological models for both the kindergarten and primary school.

For the vertical supporting structure, on the other hand, 4 different structural solutions are envisaged to be able to carry out a comparison with the corresponding technological solution for the external envelope:

- wooden structure XLAM with 5-layers structural panel 130 mm thick (Figure 3.56);
- wooden frame platform frame with 1 OSB panel 12.5 mm thick;
- wooden frame platform frame with 2 OSB panels 12.5 mm thick;
- reinforced concrete structure.

Each of these 4 structural solutions makes it possible to cover the lights of the typological models defined with the structural elements available on the market today.

For the horizontal supporting structure, 3 different structural solutions are used depending on the vertical supporting structure:

- wooden floor with XLAM structural panel of 5 layers of 125 mm thickness for the main vertical structure in XLAM;
- slab with platform frame structure with horizontal wooden beams and OSB panel 20 mm thick for the 2 main platform frame structures;
- 32 cm thick brick and concrete floor slab for the reinforced concrete structure.

Envelope composition.

For the supporting element of the vertical perimeter part, different solutions could be adopted depending on the structural type:

- for wooden structures both with XLAM panel and with platform frame with single or double panel in OSB the external infill coincides with the structural elements themselves;
- for the reinforced concrete structure, the external infill is made with a wall in perforated brick blocks with a thickness of 25 cm and 12 cm.

For the floor slab, the solution with disposable plastic molds could be adopted to create ventilation above the foundation, completed with a functional layer of insulation in EPS resistant to any infiltration of water, radiant floor panels for heating and cooling, and finally interior wood flooring (Figure 3.57).

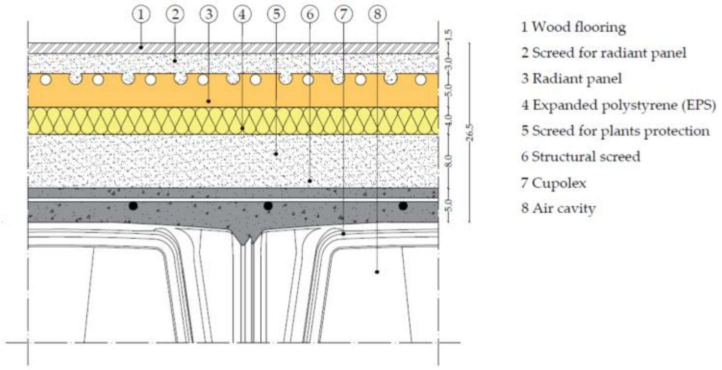

Figure 3.57 Scheme of ground layers with for instance insulation thickness for climate zone D

For the vertical perimeter wall, in order to compare different alternatives in order to consider the recurrent ones in representative buildings, 2 different technological solutions of façade (advanced screen façade, coat) were suggested with 3 different materials for the functional insulation layer (wood fiber, glass wool, EPS) in relation to the 4 different structural types.

For each structural type (column 1) the Table 3.7 shows the technological solutions for the external envelope (column 2), the materials used for insulation (column 3) and finally the external finishing solution (column 4) (Figure 3.58 – 3.59 – 3.60 – 3.61).

Table 3.7 Main layers of different types of technological solutions for external envelope analysis

Structural solution	*External envelope technological solution*	*Insulation material*	*External finishing*
A - Xlam	Advanced screen façade	Wood fiber	Wooden strips
		Glass Wool	
	External insulation	Wood fiber	External plaster
		Glass Wool	
B.1 - Platform frame 1 OSB	Advanced screen façade		
	External insulation		
B.2 - Platform frame 2 OSB	Advanced screen façade	Wood fiber	Wooden strips
		Glass Wool	
	External insulation	Wood fiber	External plaster
		Glass Wool	
C - Reinforced Concrete	Advanced screen façade	Wood fiber	Wooden strips
		EPS	External plaster
	External insulation	Wood fiber	External plaster
		EPS	

The technological solution for the external wall is completed internally with a plasterboard counter-wall with a steel substructure for the wooden structural solutions, while with an interior plaster for the structural solution in reinforced concrete.

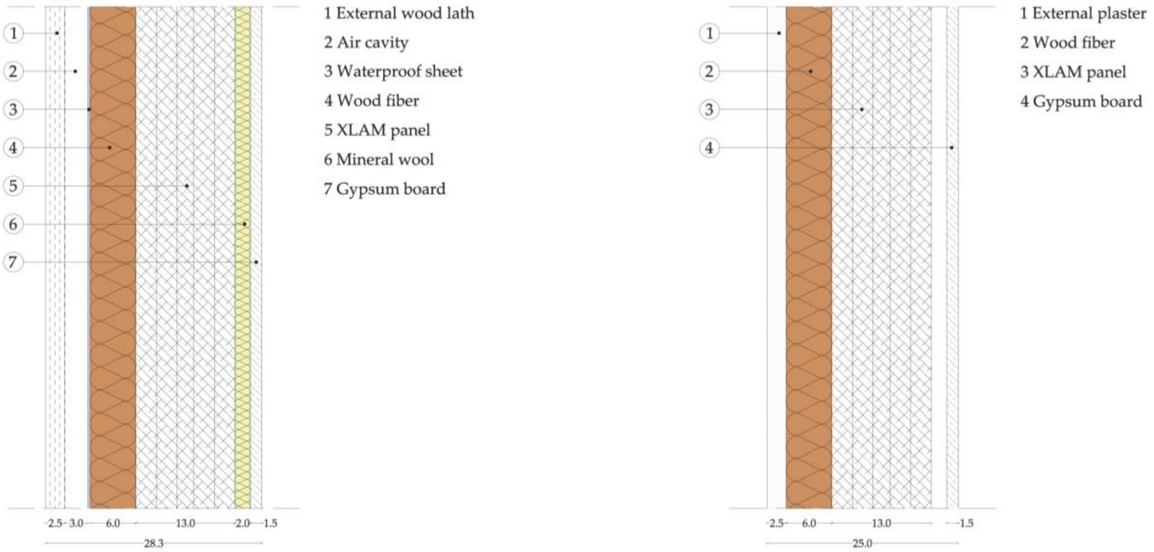

Figure 3.58 Schemes of type A structural solution with both external envelope technological solution considering climate zone D and wood fiber insulation

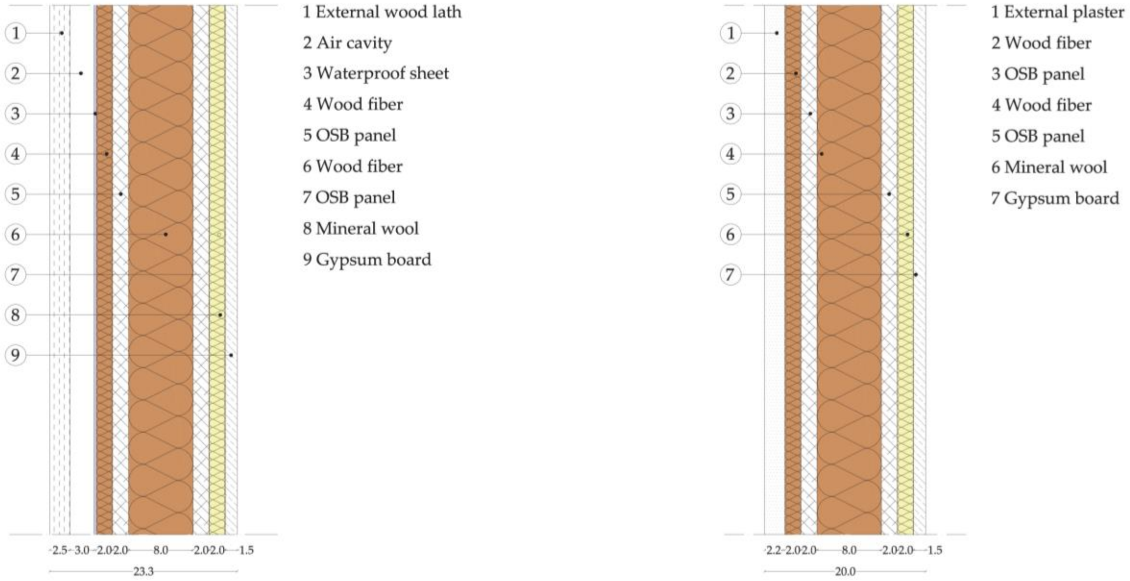

Figure 3.59 Schemes of type B.1 structural solution with both external envelope technological solution considering climate zone D and wood fiber insulation

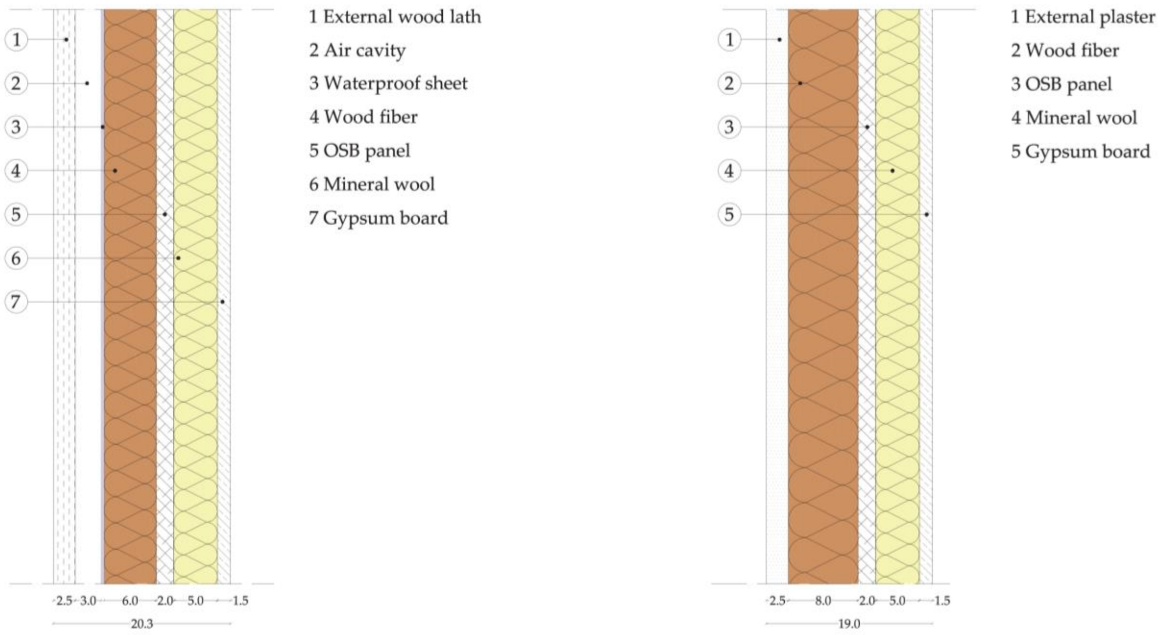

Figure 3.60 Schemes of type B.2 structural solution with both external envelope technological solution considering climate zone D and wood fiber insulation

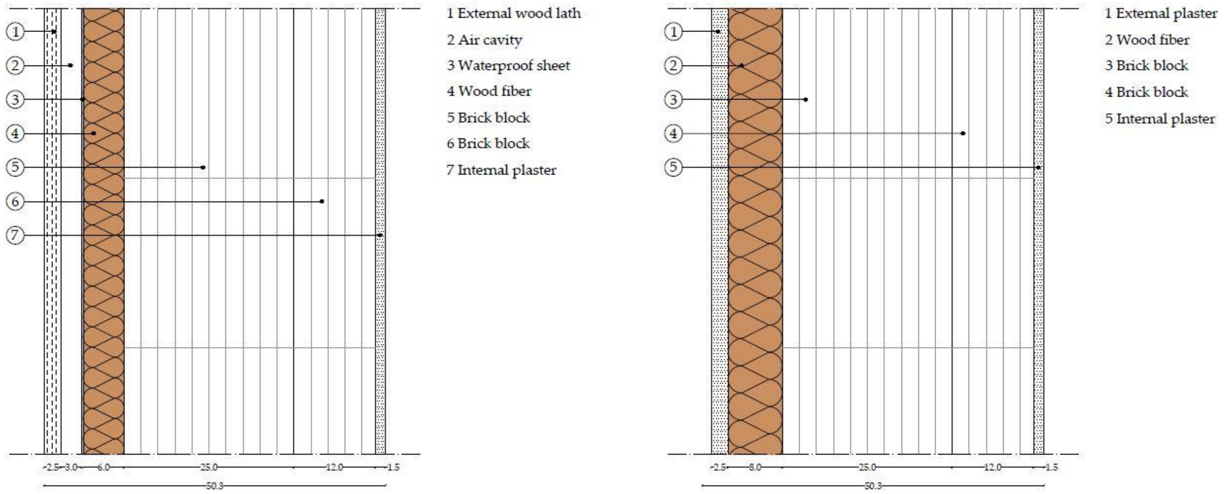

Figure 3.61 Schemes of type C structural solution with both external envelope technological solution considering climate zone D and wood fiber insulation

Following the scheme shown in table 3.11, 16 different combinations (the recurrent ones in literature) are obtained to be studied and compared in terms of energy consumption for heating and cooling on the day of the project (design day), thermodynamic characteristics of the wall, CO_2 emissions for the construction and maximum value and variation of the internal surface temperature for the different orientations.

As far as the openings are concerned, frames should be with aluminium thermal break profiles with transmittance equal to $U_f = 1.7\ W/m^2K$.

In a school building the characteristics of the glazing used must not only satisfy the requirements for the acoustic insulation of the façade and the minimum transmittance values for transparent elements imposed by current legislation but must comply with the minimum performance levels required by UNI 7697 of February 2015 [27].

The glazing of schools of every order and grade must be checked with dynamic and static loads but also with shocks due both to people and to atmospheric phenomena (for example hail). As a result, both slabs used must be safety. In table 2 of the previous regulation it is specified that for *internal and external doors and windows*, *dividing walls and interior glass* in school buildings it is necessary:

- for insulating glass units with a lower side at a height greater than 1 m, both the internal and the external slab must be laminated safety glass 2B2;
- for insulating glass units with lower side at a height less than or equal to 1 m, both the internal and the external slab must be laminated safety glass 1B1.

Table 3.8 below shows the characteristics of the glazings that should be used for the new building type for schools according to the thermal zone: the thermal transmittance of the glass plate (Ug), the solar factor (g) which indicates the ratio between the thermal energy coming from the sun transmitted inside the environment and the thermal energy incident on the external glass plate[19] (or total solar energy transmittance as indicated in UNI/TS 11300-1) and finally light transmission which represents the quantity of light that the glass transmits in the environment (TL).

Table 3.8 Main characteristics of glass with respect climate zone

Climate zone	*Type of glass**	*Ug [W/m^{2}K]*	*Solar factor [%]*	*Light transmittance [%]*
B	66.2 Stratophone 2 x Planibel Clearlite – 20 mm Argon 90% – 44.2 Stratobel 2 x Planibel Clearlite	2.5	69	78
C-D	66.2 Stratophone 2 x Planibel Clearlite – 12 mm Argon 90% - 4 mm ilplu Advanced 1.0 on clearlite pos. 3	1.2	50	74
E	66.2 Stratophone 2 x Planibel Clearlite – 20 mm Argon 90% - 4 mm iplus Advanced 1.0 on clearlite pos. 3	1.1	52	75

*The characteristics of glass have been configured on Glass Configurator AGC

The Stratophone glass sheet is a stratified insulating glass with two interlayers of PVB (polyvinyl butyral) of 0.38 mm, of which at least one of the two is acoustic so as to considerably reduce noise pollution. It allows class 2B2 or 1B1 to be obtained according to requirements (protection against falls and injuries - accident prevention and defenestration) as required by the UNI and to have high protection against ultraviolet rays (over 99% of ultraviolet rays remain outside).

The Stratobel glass sheet belongs to the same previous range of AGC glasses and this is also a layered insulating glass with two PVB interlayers of 0.38 mm each. Also, in this case class 2B2 or 1B1 is obtained according to requirements and there is a high protection against ultraviolet rays.

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[19] https://www.sunbell.it/2018/06/29/fattore-solare-vetro/

Iplus Advanced glass sheet 1.0 on clearlite pos. 3 allows to obtain a high thermal insulation as required by the regulations for climatic zones E and D. The main feature that allows to obtain an excellent energy performance is the layer of metal oxides (neutral coating[20]) made in position 3.

For the roofing, a ventilated solution is used, and 3 different structural solutions should be adopted with reference to the 4 solutions for the vertical supporting structure.
As a result, it is got:

- for the wooden structure in XLAM, a solution with a XLAM floor with a 125 mm thick panel is adopted, a 0.45 mm vapor barrier is completed (protective felt and cover in polypropylene and polyethylene-copolymer films), fiber insulation of wood in variable thickness depending on the climatic zone considered, waterproofing sheath 4 mm thick (plastomeric polymer bitumen) and 5 cm ventilation chamber created with double warping of wooden strips and 0.5 mm thick metal cover with supporting wood panel (Figure 3.62);

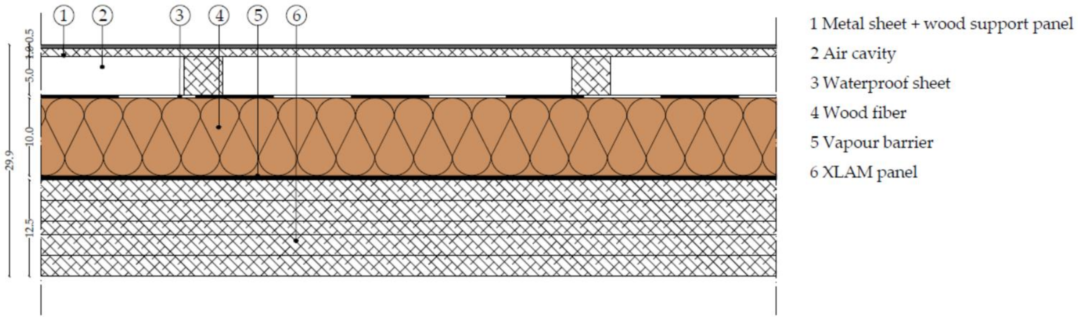

Figure 3.62 Scheme of roof layers for xlam structural solution

- for the platform frame structure both with a single OSB panel and a double one, a solution with a 120 mm thick OSB panel is used, carried by a structure with wooden beams every 60 cm, completed as in the previous case by a 0.45 vapor barrier mm (protective felt and cover in polypropylene and polyethylene-copolymer films), wood fiber insulation in varying thickness depending on the climate zone considered, 4 mm thick waterproofing membrane (plastomeric polymer bitumen) and 5 cm ventilation chamber created with double warping of wooden slats and a 0.5 mm thick metal cover with wood supporting panel (Figure 3.63);

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[20] “*Neutral coatings are coatings that do not affect the color rendering of objects when observed through the glazing*” AGC, yourglass pocket

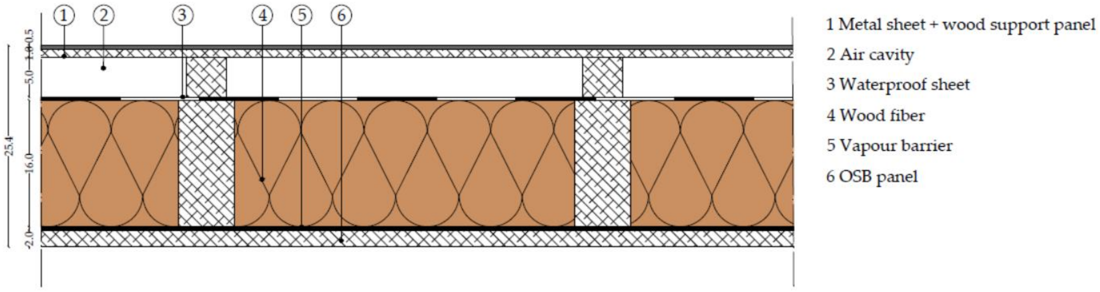

Figure 3.63 Scheme of roof layers for OSB structural solution

- for the reinforced concrete structure, a solution with a 320 mm thick masonry floor is adopted, completed as in the previous case by a 0.45 mm vapor barrier (protective felt and polypropylene cover and polyethylene copolymer films), insulating in wood fiber in varying thickness depending on the climatic zone considered, waterproofing sheath 4 mm thick (plastomeric polymer bitumen) and 5 cm ventilation chamber created with double warping of wooden strips and a 0.5 mm thick metal roof covering (Figure 3.64).

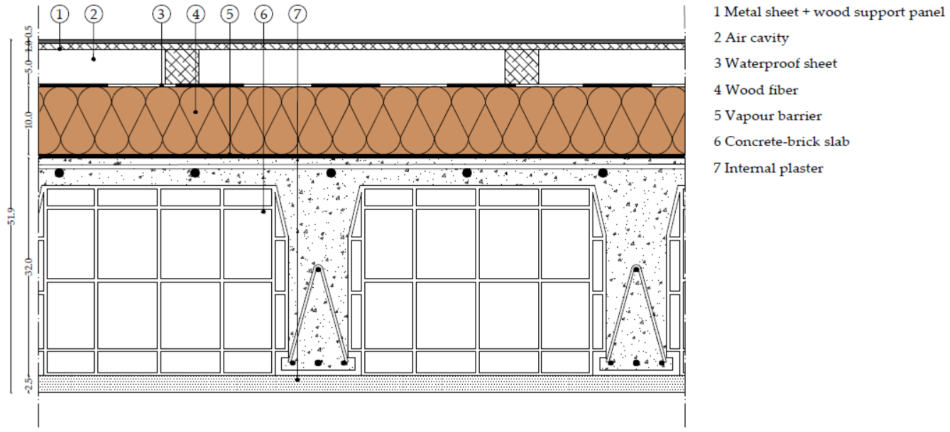

Figure 3.64 Scheme of roof layers for reinforced concrete structural solution

Window to wall ratio.

The size of the façade openings for the new typological models for both the kindergarten and the primary school for each individual environmental unit has been outlined by the minimum sanitary requisites required by the hygiene regulations in force in the national territory in reference to both the rate of air exchange necessary for ventilation and the exploitation of natural light, essential in a school building.

The following are the main prospects of the typological models outlined for the kindergarten (Figure 3.65 – 3.66 – 3.67) and the primary school (Figure 3.68 – 3.69 – 3.70 – 3.71) with the indication of the value of WWR for each front and the main dimensions of building and windows measured in meters.

- *Kindergarten*

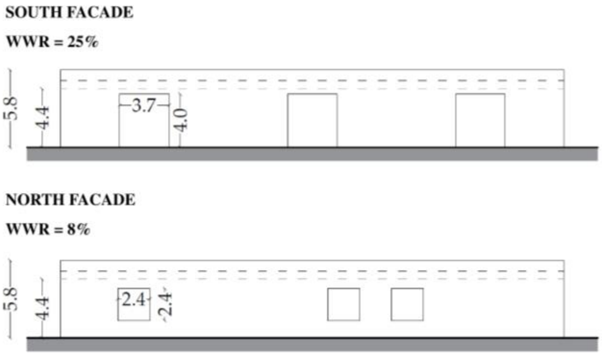

Figure 3.65 View of the main facades for Model I1

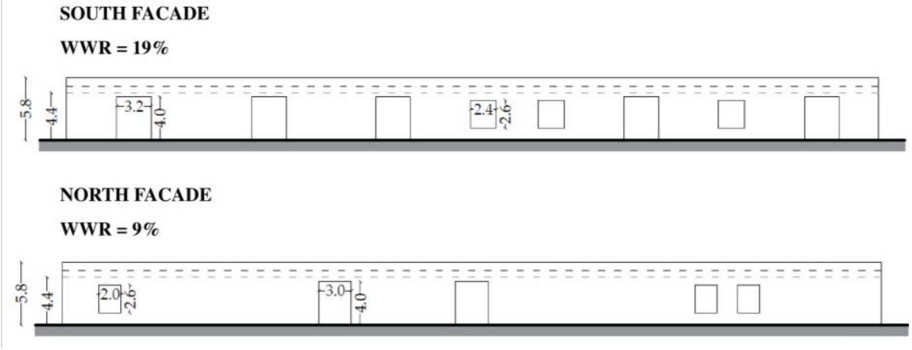

Figure 3.66 View of the main facades for Model I2

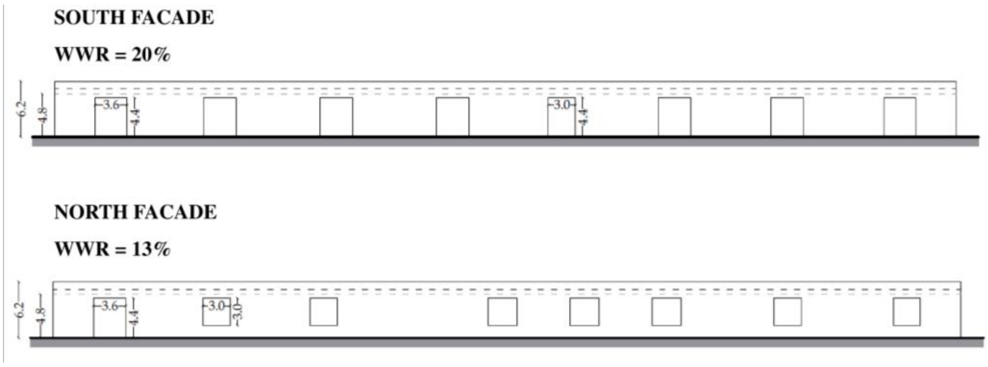

Figure 3.67 View of the main facades for Model I3

- *Elementary school*

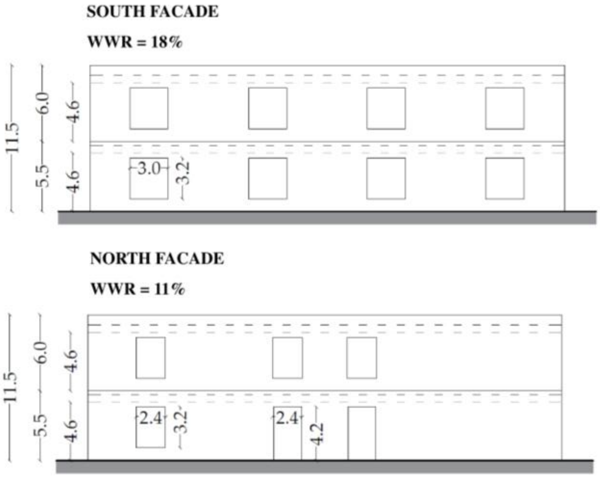

Figure 3.68 View of the main facades for Model P1

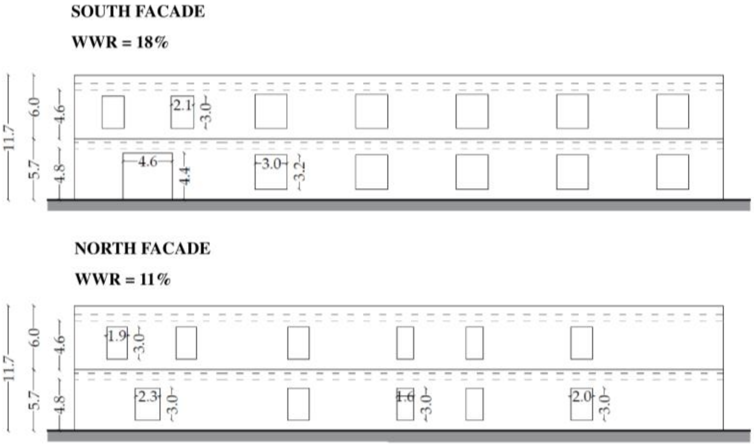

Figure 3.69 View of the main facades for model P2

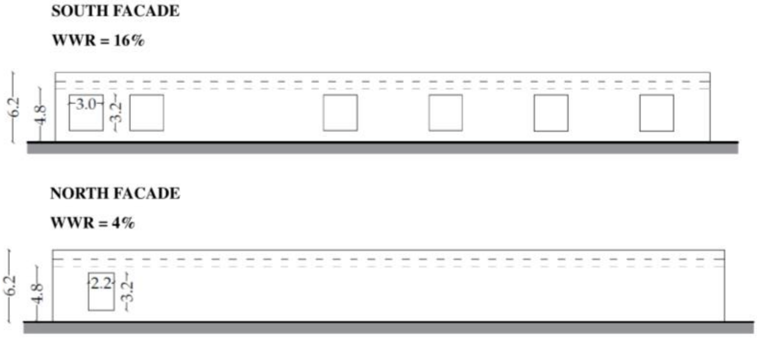

Figure 3.70 View of the main facades for model P3

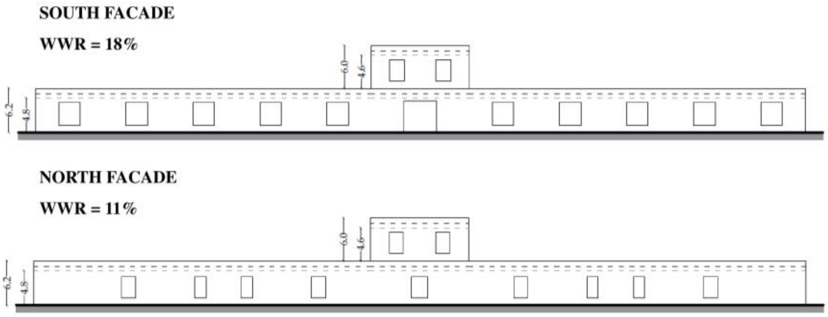

Figure 3.71 View of the main facades for model P4

Internal partitions and finishes.

The internal partitions between the different functional units are made of plasterboard with a steel substructure.

The interior finishes provided are made of wood to ensure adequate environmental quality in terms of emissions of harmful substances into the environment so as to safeguard children's health.

Systems.

Different configurations of system could be used for a school:

- first configuration:
    - heating system:
        - generation system: gas condensing boiler with efficiency equal to 90%.
        - end of distribution system: radiators for each functional unit.
    - cooling system:
        - generation system: heat pump with energy efficiency system (EER) equal to 2.5[21].
        - end of distribution system: fan coil units for each functional unit.
    - ventilation system: air handling unit with sensible heat recovery at least equal to 50%.
- second configuration
    - heating system:
        - generation system: heat pump with coefficient of performance (COP) equal to 3.2[22] up to 3.6.
        - end of distribution system: ground floor radiant panel for each functional unit.
    - cooling system:
        - generation system: heat pump with energy efficiency system (EER) equal to 2.5[23] up to 3.2.
        - end of distribution system: ground floor radiant panel for each functional unit.

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[21] Value defined for the reference building by DM 26th June 2015

[22] Value defined for the reference building by DM 26th June 2015

[23] Value defined for the reference building by DM 26th June 2015

- ventilation system: air handling unit with sensible heat recovery at least equal to 50%.

Thermal zone and design data.

In order to define completely the typological models with respect to the current legislation and to individuate and to delineate all the characteristics needed to the energy simulation the design data presented in this paragraph must be pointed out. All these data are strictly linked to every single thermal zone individuated for each typological model for kindergarten (model I1, model I2, model I3).

The definition of the different thermal zones inside the building and the relative characteristics are fundamental because they influence the energy performance of the building itself.

In this case for the defined 3 models of kindergarten was considered:

- each functional unit corresponds to one thermal zone in order to define in detailed all the thermal features;
- only the thermal zone of the functional units of toilets and storages are grouped and considered as a single thermal zone because they have the same internal thermal conditions.

  It is useful in order to reduce the number of thermal zones of the model to obtain faster simulation as well.

  For the thermal zones related to the classrooms, because of different orientation, they are kept separated;
- the openings of each thermal zone are included in the typological models of kindergarten in according to the minimum WWR defined for each model as reported in previous figure from 2.65 to 2.71.

For each thermal zone in according to the current legislation it is necessary to define:

- the occupancy and so the density of people for each functional unit [person/m^2] according to UNI 10339 (Appendix A) [28]:
  - Class 0.4 person/m^2 with a maximum number of student equal to 26;
  - Canteen 0.6 person/m^2;
  - Free activities 0.4 person/m^2;
  - Teachers area 0.3 person/m^2;

  These values are essential in order to define the air change rate required for each thermal zone considered because the ventilation rate influence significantly the energy balance of each thermal zone. They are fundamental to guarantee the proper internal comfort for the occupants;
- the setpoint temperature according to DM n. 162 of 26 June 2015 [4]:
  - for heating system, it is set equal to 20°C;
  - for cooling system, it is set equal to 26°C.

  The setpoint temperature is defined, by the Italian current legislation, the same for each climate zones considered (E, D, C, B) and for every thermal zone inside the analysed building. This value is necessary to pre-design heating and cooling system during the winter design day and summer design day to evaluate the peak power and choose the advisable system for the building to maintain thermal comfort for the occupants;

- the minimum air change rate refers to table 3 of UNI 10339 [28] in l/s per person or l/s per m^2:
    - Class 4 l/s person;
    - Canteen 10 l/s person;
    - Free activities 4 l/s person;
    - Toilets 2.5 l/sm^2;
    - Connections 2.5 l/sm^2;

The definition of these values is indispensable during the preliminary phase in order to pre-design the air handling unit for the mechanical controlled ventilation to guarantee the wellbeing of occupants and to avoid pollutants' concentration harmful for children's health. It is important to stress out that the ventilation contribution to the energy balance is one the most important for the schools building, as demonstrated after with the performed global sensitivity analysis (*Chapter 3 – 3.4 Global sensitivity analysis*);

- the level of illuminance [lux] in accordance with UNI 10340 and UNI EN 12646-1 [2] in order to ensure the appropriate visual comfort with natural lighting:
    - Class 300 lux;
    - Canteen 300 lux;
    - Free activities 300 lux;
    - Toilets 100 lux;
    - Connections 100 lux;

  The level of illuminance influences the capacity of a person to perceive details at a given distance and the time to perform a visual task.

  The maximum index of glare (DGI) allowed is equal to 21 in order to teaching tasks inside classrooms with the proper visual comfort due to the exploitation of natural light during school opening time.

  The average daylighting factor is the ratio between the daylighting factor [%] measured on a horizontal surface with internal light due to the sky and the external one on the same surface without any obstructions. There are different values for the different type of school:
    - Kindergarten 3%;
    - Elementary school 5%;
- the internal loads in line with table 17 of UNI/TS 11300-1 [29] that are listed in detail here:
    - Class Computer 5 W/m^2;
    - Canteen Additional equipment 1 W/m^2 (Appendix E);
    - Kitchen Food preparation 4.5 W/m^2;
    - Teachers area Computer 3.5 W/m^2;
    - Toilets Additional equipment 0.5 W/m^2.

> The internal loads are related to the equipment used inside the different functional units and they affect the value of final energy needs for heating and consequently the energy balance of the thermal zone and so they are essential to calculate the power peak of the heating system avoiding over-size of the system.

Summing up the new building type for kindergarten and elementary school was defined with respect to both the environmental and technological system.

At this point from an energy point of view it is important to perform some energy dynamic simulations in order to validate these new building type in according to the current Italian energy regulation.

Moreover, the other aim is to propose some different alternative solutions concern with the building typological factors (in particular factors related to formal characteristics and technical/technological ones).

In fact, in a definition of a building type, it is possible to give a variability of the main building distinguishing features in order to obtain a better energy or environmental performance.

So, the energy simulations were performed in order to suggest some changes related to the main typological factors that significantly affect the energy and environmental performance and consequently that could improve them.

At the beginning of the energy simulations the typological models are considered with the same characteristics of the reference building in according to what reported in the D.M. n. 162 of 26 June 2015 for the reference building [4], then they could change and could be implemented with respect to the results of their energy performance.

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CHAPTER 4. Study on energy performance of new school building type

The third phase of the research deals with the energy simulation in dynamic condition with hourly time step of defined new building type for kindergarten in order to determine and to verify its environmental and energy performance with respect to CO_2 emissions and energy needs and to identify the main typological distinguishing features that mainly affect the energy and environmental performance.

Moreover, as I point out before, the energy simulations were performed in order to suggest some advisable changes related to these main typological factors (that could be defined also as a range within the building type) that significantly affect the energy and environmental performance and that could be implemented in order to obtain low primary energy demand and low environmental impact.

There is not in literature any example of building type defined also through the evaluation of the energy and environmental performance. This undoubtedly let to outline it better and to give the chance to improve its performance with some changes of some building distinguishing features that has to be delineated during the preliminary phase of the design process.

The energy simulations were carried out through Energy Plus software using Design Builder [2] as the graphical interface, considering 5 different representative cities belonging to 5 different climate zone in Italy [1]. The different climate zones are considered because in the definition of the new building type also the climate conditions are obviously one of the main factors.

Firstly, this chapter presents:

- the definition of the 5 representative cities for the Mediterranean climate:
    - Milan;
    - Florence;
    - Rome;
    - Naples;
    - Palermo;
- the design builder software brief description and set up with respect to:
    - climate and site (*climate template*);
    - geometry and internal layout (*layout template*);
    - activities in the building (*activities template*);
    - construction characteristics (*construction template*);
    - windows and lighting (*openings template and lighting template*);
    - heating, ventilation and air conditioning (*HVAC template*);

- the evaluation of the energy and environmental performance of the new building type for schools (for each typological models) that at the beginning of the energy simulations was set up, from an energy point of view, as required for the reference building of current energy national law.

Furthermore, in order to suggest some modifications for the configurations of the main building distinguishing features with the aim at obtaining a better energy and environmental performance in the context of new European and national standards to build zero-carbon schools, this chapter illustrates:

- an analysis of different type of structure combined with several kinds of technological solutions for the external envelope and insulation materials with the purpose of the definition of CO_2 emissions, dynamic thermal characteristics and building consumption in operational phase for the design day;
- a parametric study of the thickness of insulation, in order to determine the influence in the energy performance of the models of the increase in thickness of insulation for both façade and roof.

  This analysis allows to assess the medium global thermal transmittance for each kindergarten basic model comply with both ITACA Protocol for schools and D.M. n. 162 of 26 June 2015 for nZEB buildings requirements.
- an on-at-a-time step sensitivity analysis in order to evaluate the influence of each parameters on annual primary energy consumption.
- different parametric analysis. In brief it involves the following main building typological features of both the environmental and technological system:
  - window-to-wall ratio for each orientation;
  - solar shading system for each orientation;
  - used different type of glass for the city of Palermo;

  For completeness, rigorously linked to the previous analyses, at the same time the study of daylighting [3] for classrooms of kindergartens in terms of daylighting and illuminance uniformity with respect to the optimal WWR was performed in order to verify visual comfort [4] [5];
  - different type of configurations (4 configurations) for heating and cooling systems;
  - the possible installation of a photovoltaic system on the roof of the 3 models;
- some results and related discussion referred to the CO_2 emissions calculation of the models of kindergarten in order to outline the difference between one improvement or solution with respect to another one.

The results presented in this chapter are mainly showed in terms of primary energy demand considering the conversion factors for energy sources required by D.M. n. 162 of 26th June 2015 and CO_2 emissions with the conversion factors indicate in the National system for environmental protection and research (ISPRA) report 2017 [6].

The paragraph related to the analysis of each building feature is set as follow:

- the detailed description of the method to conduct the analyses;
- the main results and the related discussion.

It is fundamental to stress out that the results of energy dynamic simulation of the models of kindergarten that will be presented in this chapter are strictly linked to both functional bands and units' distribution, orientation, intended use and occupancy level.

Before proceeding with the analyses, it is necessary to define in detail the 4 different configurations of system that are considered in order to perform energy simulation.

- Configuration 1:
    - heating system:
        - generation system: gas condensing boiler with efficiency equal to 90%.
        - end of distribution system: radiators for each functional unit.
    - cooling system:
        - generation system: heat pump with energy efficiency ratio (EER) equal to 2.5.
        - end of distribution system: fan coil units for each functional unit.
    - ventilation system: air handling unit with sensible heat recovery equal to 50%.

The building electrical energy need is satisfied through the public grid. The primary energy conversion factor[1] is $f_{P,tot} = 2.42$ ($f_{P,nren} = 1.95$; $f_{P,ren} = 0.47$). The conversion factor for gas for the heating system (gas condensing boiler) is equal to $f_{P,tot} = 1.05$.

- Configuration 2:
    - heating system:
        - generation system: heat pump with coefficient of performance (COP) equal to 3.2.
        - end of distribution system: ground floor radiant panel for each functional unit.
    - cooling system:
        - generation system: heat pump with energy efficiency system (EER) equal to 2.5.
        - end of distribution system: ground floor radiant panel for each functional unit.
    - ventilation system: air handling unit with sensible heat recovery equal to 50%.

The building electrical energy need is satisfied through the public grid. The primary energy conversion factor[2] is $f_{P,tot} = 2.42$ ($f_{P,nren} = 1.95$; $f_{P,ren}$ 0.47).

- Configuration 3:
    - heating system:
        - generation system: heat pump with coefficient of performance (COP) equal to 3.6.
        - end of distribution system: ground floor radiant panel for each functional unit.
    - cooling system:
        - generation system: heat pump with energy efficiency system (EER) equal to 3.2.
        - end of distribution system: ground floor radiant panel for each functional unit.
    - ventilation system: air handling unit with sensible heat recovery equal to 50%.

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[1] DM 26th June 2015, Appendix 1, Art. 1.1

[2] DM 26th June 2015, Appendix 1, Art. 1.1

The building electrical energy need is satisfied through the public grid. The primary energy conversion factor[3] is $f_{P,tot} = 2.42$ ($f_{P,nren} = 1.95$; $f_{P,ren}$ 0.47).

- Configuration 4:
  - heating system:
    - generation system: heat pump with coefficient of performance (COP) equal to 3.6.
    - end of distribution system: ground floor radiant panel for each functional unit.
  - cooling system:
    - generation system: heat pump with energy efficiency system (EER) equal to 3.2.
    - end of distribution system: ground floor radiant panel for each functional unit.
  - ventilation system: air handling unit with sensible heat recovery at least equal to 65%.
  - renewables: PV system to produce electrical energy.

In this case there are 2 possible solutions for the PV system: it could be on grid (grid-connected) when it enters into the grid the excess of the electrical energy produced by PV system and it exploit the electrical energy of public grid when PV system could not satisfy the building loads. Or it could be off grid (stand-alone) when the excess of the electrical energy is collected in storage system (such as batteries) that will make it available when there is not the solar radiation.

4.1 CLIMATE ZONES

With respect to Köppen-Geiger classification of climate (Figure 4.1), Italy is characterized by:

- temperate climate (Classification C) for most of the areas of Italian mainland;
- cold-temperate climate (Classification D) for some mountain area;
- and finally, cold climate (Classification E) for Alps in northern Italy.

For the presence and the influence of both Mediterranean Sea and mountains climate changes deeply from a region to another. Because of that the D.P.R. n° 412 of 26th August 1993 [1] divides Italy in 6 climate zones based on the value of Heating Degree Days (HHD)[4] (Figure 4.2).

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[3] DM 26th June 2015, Appendix 1, Art. 1.1

[4] Heating Degree Days means "Per gradi giorno di una località, la somma, estesa a tutti i giorni di un periodo annuale convenzionale di riscaldamento, delle sole differenze positive giornaliere tra la temperatura dell'ambiente, convenzionalmente fissata a 20°C, e la temperatura media esterna giornaliera; l'unità di misura utilizzata è il grado-giorno (GG)" D.P.R. 412/1993 Articolo 1. Definizioni

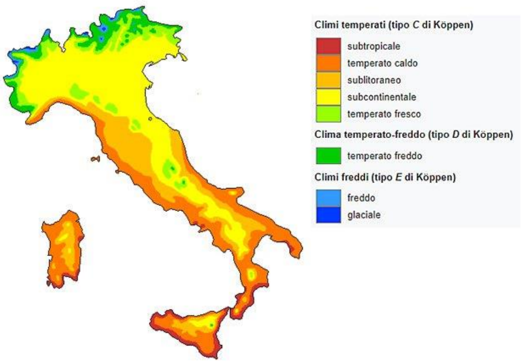


Figure 4.1 Köppen-Geiger classification for Italian climate – reference: https://www.ideegreen.it/zone-climatiche-in-italia-104429.html

Figure 4.2 Climate zone in Italy – reference: https://www.deltau.it/efficienza-energetica-in-edilizia-excursus-normativo-completo/#jp-carousel-1340

They are characterized by different heating periods as Table 4.1shows.

Table 4.1 Heating period for each Italian climate zone

Climate zone	HDD [Kd]	Heating period
A	< 600	1st December – 15th March
B	600-900	1st December – 31th March
C	900-1400	15th November – 31th March
D	1400-2100	1st November – 15th April
E	2100-3000	15th October – 15th April
F	> 3000	No limit

For the study of the energy and environmental performance of the models of kindergarten, 5 different cities belonged to different climate zones are chosen in line with the national law named previously [1], because climate variables obviously and deeply affect the energy performance of the analysed buildings.

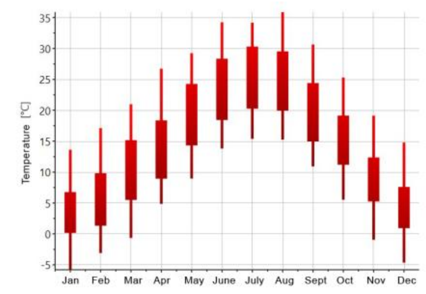
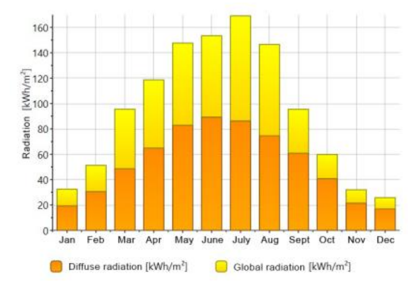
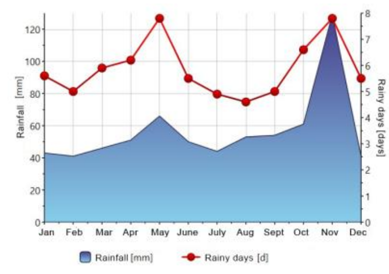
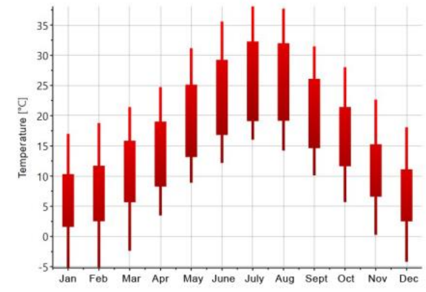
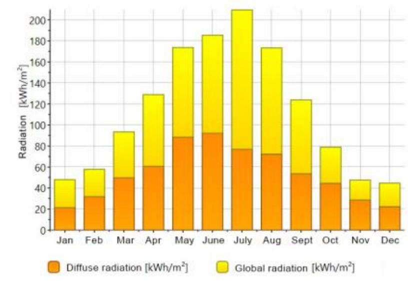
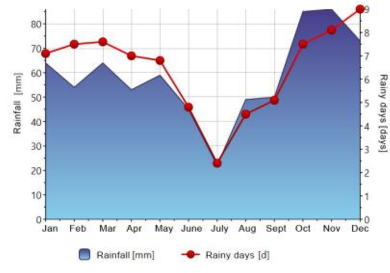
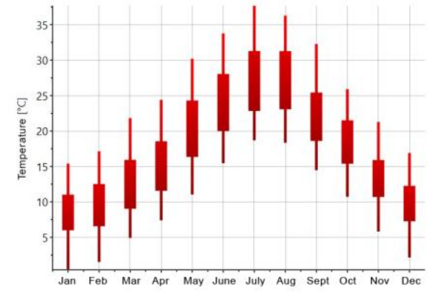
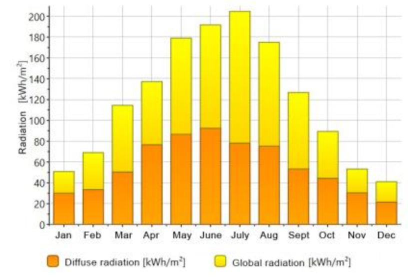
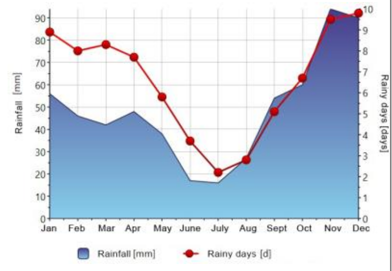
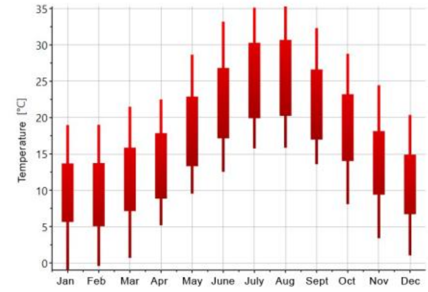
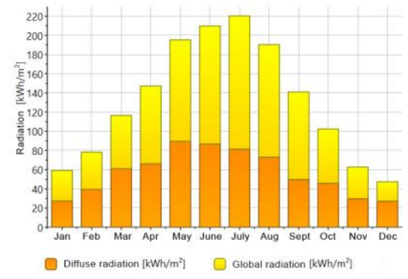
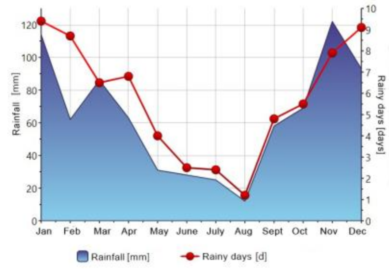
The city considered are the following: Milan, Florence, Rome, Naples and Palermo.

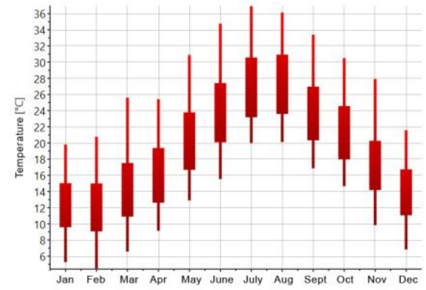
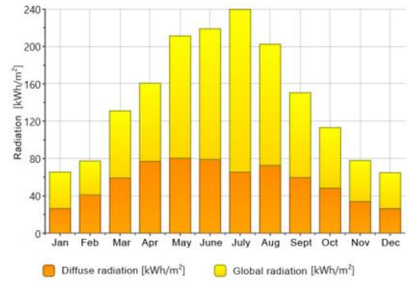
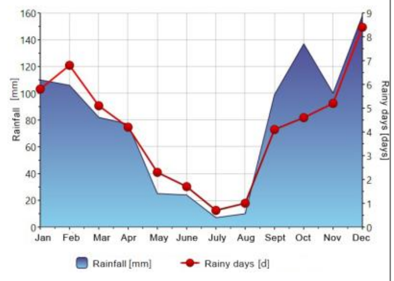
The main characteristics are illustrated in the next Table 4.2: altitude (alt), latitude (lat), longitude (long), heating degree days (HDD), maximum external temperature (T_{max}) and Köppen Geiger climate classification (K-G) with a brief description of main climate characteristics for both the winter and the summer season. For completeness 3 graphs that specify the trend of monthly external temperature [°C], solar radiation [kWh/m^2] and monthly rainfall [mm] with number of days [days] of rainfall (line in red in the graph).

Climate data are obtained with Meteonorm v.7.3.3 demo.

Table 4.2 Chosen cities climate characterisation

City	alt	lat	long	Climate zone	Heating period	T_{max}	HDD	K-G
Milan	122	45.62°	8.73°	E	15th/10 – 15th/04	31°C	2404	Cfb
Brief description	This city has a subcontinental climate with cold winter with possible snowfall and 1-2 months with an average temperature of 0-3°C and warm and hot summer with 2-3 months with an average temperature > 20°C							
Monthly external temperature [°C]			Solar radiation [kWh/m^2]			Monthly rainfall [mm]		

<table>
<tr><td colspan="3"> </td><td colspan="2"> </td><td colspan="4"> </td></tr>
<tr><td colspan="9"></td></tr>
<tr><td>Florence</td><td>50</td><td>41.8°</td><td>12.23°</td><td>D</td><td>15th/11– 15th/04</td><td>36°C</td><td>1415</td><td>Cfb</td></tr>
<tr><td>Brief description</td><td colspan="8">This city has a temperate and sub-coastal climate with moderately cold winter and 2-3 months with an average temperature < 10°C and hot summer with 3-4 months with an average temperature > 20°C</td></tr>
<tr><td colspan="3">Monthly external temperature [°C]</td><td colspan="2">Solar radiation [kWh/m^2]</td><td colspan="4">Monthly rainfall [mm]</td></tr>
<tr><td colspan="3"> </td><td colspan="2"> </td><td colspan="4"> </td></tr>
<tr><td colspan="9"></td></tr>
<tr><td>Rome</td><td>38</td><td>43.8°</td><td>11.2°</td><td>D</td><td>15th/11– 15th/04</td><td>37°C</td><td>1821</td><td>Csa</td></tr>
<tr><td>Brief description</td><td colspan="8">This city has temperate Mediterranean climate with mild and rainy winter with 2-3 months with an average temperature of 5°C and warm and potentially drought summer with an average temperature > 20°C</td></tr>
<tr><td colspan="3">Monthly external temperature [°C]</td><td colspan="2">Solar radiation [kWh/m^2]</td><td colspan="4">Monthly rainfall [mm]</td></tr>
<tr><td colspan="3"> </td><td colspan="2"> </td><td colspan="4"> </td></tr>
<tr><td colspan="9"></td></tr>
<tr><td>Naples</td><td>72</td><td>40.85°</td><td>14.3°</td><td>C</td><td>15th/11– 31th/03</td><td>36°C</td><td>1034</td><td>Csa</td></tr>
<tr><td>Brief description</td><td colspan="8">This city has a Mediterranean climate characterized by mild winter due to the presence of the sea with 3 months of an average temperature < 10°C and hot and humid summer with 4 months with an average temperature > 20°C</td></tr>
<tr><td colspan="3">Monthly external temperature [°C]</td><td colspan="2">Solar radiation [kWh/m^2]</td><td colspan="4">Monthly rainfall [mm]</td></tr>
<tr><td colspan="3"> </td><td colspan="2"> </td><td colspan="4"> </td></tr>
<tr><td colspan="9"></td></tr>
</table>

Palermo	34	38.18°	13.1°	C	1st/12– 31th/03	37°C	751	Csa
Brief description	This city has a temperate Mediterranean climate with hot and arid summer and drought with 5 months with an average temperature > 20°C and mild and not so cold winter due to the presence of the sea with 4 months with an average temperature < 15°C							
Monthly external temperature [°C]			Solar radiation [kWh/m^2]		Monthly rainfall [mm]			
								

4.2 DESIGN BUILDER SETUP

Design builder is a software for the energy simulation in dynamic regime developed by a British company Design Builder Software Ltd in 2005. It is conceived as user-friendly graphical interface for Energy Plus software and it is devised with a European project in order to establish the energy performance of a building through the dynamic energy simulation considering [7]:

- different range of time (from annual simulation to sub-hourly time step one) with the aim of computing the energy consumption;
- the calculation of CO_2 emissions;
- the analysis of daylighting (natural and artificial);
- the indoor air quality (for instance with Fanger index or the distribution of temperature).

For the calculation of the thermal flow in dynamic regime through the external envelope, Design Builder uses simulation algorithms based on the Conduction Transfer Function (CFT) [7].

Energy Plus is the simulation engine of Design Builder and it was developed in 2001 in USA from 2 different software of energy dynamic simulation:

- the DOE-2 elaborated by the Ministry of Energy (DOE);
- the BLAST drawn up by the Ministry of Defence (DOD).

Energy Plus is based on 3 fundamental modules that interact simultaneously [8]:

- the *surface heat balance* that solve the energy balance with respect to each surface of the external envelope. It allows the calculation of the surface internal and external temperature and the heat exchange between them;
- the *air heat balance manager* that solve the energy balance of the building with the simulation of radiative and convective thermal exchanges.
- the *building systems simulation manager* for the simulation of plants. The system is divided in 3 different sub-system:
  - the *air loop* that allows to model the hydraulics network from the air handling unit to the distribution system in the thermal zone;

  - the *plant loop* and the *condenser loop* to model the hydronic network.

Furthermore, it was demonstrated in literature that the combination of the TARP algorithm for internal convection and the DOE-2 for the external one is the better combination in order to obtain proper results in terms of energy consumption of the building.

The settings that follow are adopted in Design Builder in order to perform the energy simulation:

- time steps for hour:
  - at least 6-time steps for the simple HVAC;
  - at least 10-time steps for the detailed HVAC;
- temperature control: air temperature[5];
- algorithm solution: conduction heat transfer;
- algorithm for internal convection: TARP;
- algorithm for external convection: DOE-2.

4.2.1 Design builder templates

Design Builder lets to define the model of the building through a series of templates where all the values used by the software for the energy simulation are set and specified in detailed. In fact, for the selection of the data for the energy simulation, a precise hierarchy is established as shown in the following Figure 4.3.

Figure 4.3 Design Builder data hierarchy

These templates are divided and presented in 2 different parts:

- the first one with the description of the site, the block and the thermal zone. This part will be kept the same for all the analyses performed in this thesis;
- the second one with the definition of the surface and materials. This section includes also the detailed study on the opaque external envelope. Consequently, this part of the templates setting is the one that changes during the development of the thesis.

4.2.1.1 Site, block and thermal zone templates

Site.

This template allows to set and to choose the location where the building is situated (Milan, Florence, Rome, Naples, Palermo). Furthermore, it lets to set the climate hourly data (for annual simulation, heating design day and cooling design day), the geographic coordinates and some geomorphological features of the site.

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[5] It means: "*control the zone mean air temperatures to the heating and cooling setpoint temperatures specified on the Activity tab*" https://designbuilder.co.uk/helpv4.5/#Calculation_Options.htm

In this research the climate data used for the dynamic energy simulation are provided by the Italian Technical Committee (CTI) and they are based on the European standard EN ISO 15927-4 [9]. The climate data are updated to 2015.

Block.

To model the 3 buildings of kindergarten (model I1, model I2, model I3) as defined in previous *Chapter 3 – 3.3 New school building type*, the layout of the ground floor was imported from CAD and each building was composed by one single block (*building block*) in the layout of the software Design Builder (Figure 4.4 – Figure 4.6 – Figure 4.8).

The block represents a three-dimensional space and it is delimited by a series of building elements (external walls, roof and ground floor)[6].

Then the block was divided following the functional units corresponding to one single thermal zone.

Thermal zone.

The individuation of the different thermal zones in a single block allows to define the thermal performance of the building, because it is precisely at the level of thermal zone that all the characteristics that influence the energy performance of the building are delineated. As explained in the definition of the new typological models (*Chapter 3 – 3.3 New school building type*) each functional unit correspond to one thermal zone as shown in the following figures (Figure 4.5 - Figure 4.7 - Figure 4.9).

At thermal zone level is possible to define the *activity template* that lets to introduce these main settings for the energy dynamic simulation detailed and explained in *Chapter 3 – 3.3 New school building type – Thermal zone and design data*. In this case many types of activities were considered and set up in Design Builder with the possible default configurations for a school: the class (*Teaching area*), the collective area (*Dry sports hall*), the kitchen (*Food preparation area*), the teachers' area (*Cell office*) and the canteen (*Eating/Drinking area*). The school is considered open from 7 o'clock in the morning to 18 o'clock in the afternoon and it is considered closed for all the weekends in the whole year and for Italian main holidays (*schedule*).

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[6] https://designbuilder.co.uk/helpv4.5/#Building_Block.htm?Highlight=building block

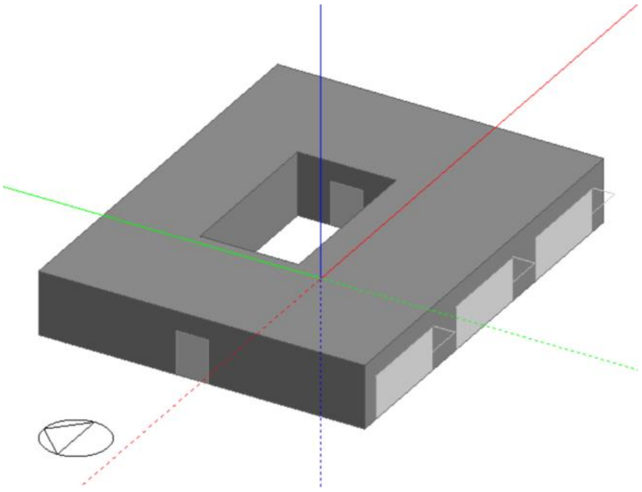

Figure 4.4 Design Builder block for Kindergarten Model I1

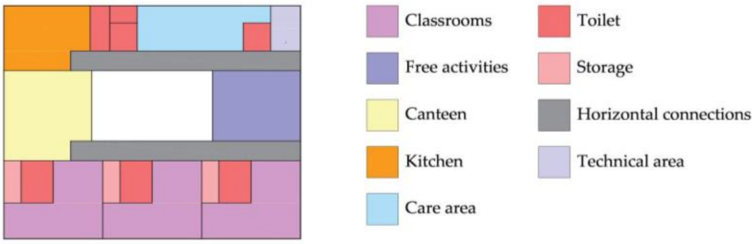

Figure 4.5 Individuation of thermal zones for Kindergarten Model I1

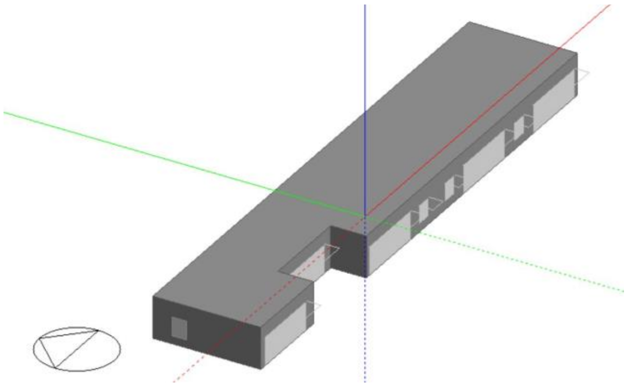

Figure 4.6 Design Builder block for Kindergarten Model I2

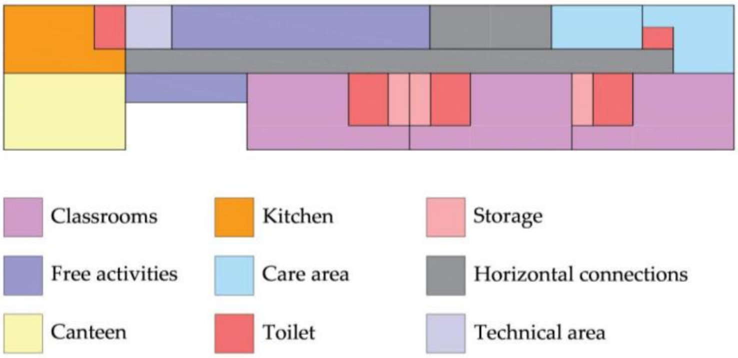

Figure 4.7 Individuation of thermal zones for Kindergarten Model I1

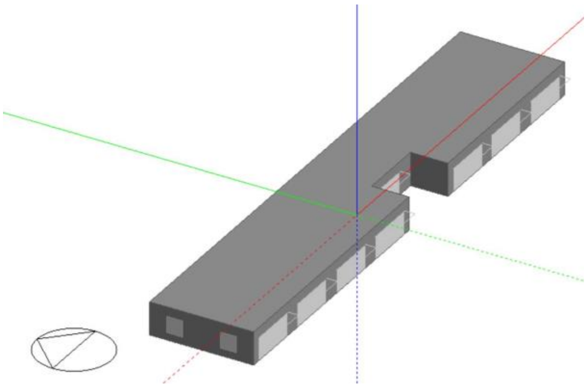

Figure 4.8 Design Builder block for Kindergarten Model I3

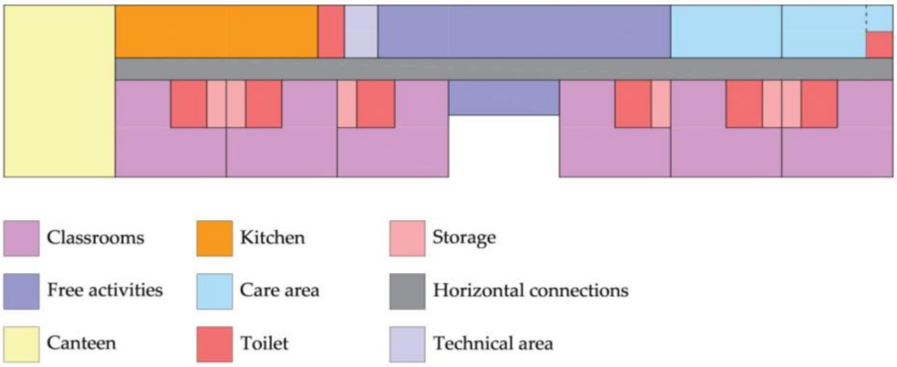

Figure 4.9 Individuation of thermal zones for Kindergarten Model I1

4.2.1.2 Surface and materials and building plants

Study on the opaque external envelope.

To design a neutral carbon school building is fundamental to choose a proper technological solution for the external envelope in terms of both the environmental impact and the energy performance of the building. In this case different technological solutions for the external envelope found in literature and proposed for the definition of the new building type (*Chapter 3*) were compared in order to choose one of them to perform energy simulations regarding the main building typological factors.
It is important to study different technological solutions for the external envelope not only because the delineation of the external envelope is part of the technological system for the definition of a new building type but also because for schools not every types of technological solution for the external envelope or material for the insulation layer is appropriate to be used.

The overall aim is to define some different possible and alternatives solutions, suggesting ranges of performance to be met, for the external envelope to be introduced in qualitative and quantitative guidelines in order to give some indications to the designers about the energy and/or environmental performance of one solution with respect to another. It is necessary because the designers' choice of the most adequate technological solutions for the external envelope it is not related only to the energy demand of the building and to its environmental impact but also to many other factors, such as the initial investment cost, the construction time, the constructability, the flexibility for the location and sizing of windows, materials availability and also construction tradition for the building site.

The thermal building performance is connected to 3 major topics: firstly, the building physics, which is regulated precisely to the building envelope, then to the micro-climate of the environment of the building and finally to the internal hygro-thermal comfort [10].

The choice of an appropriate building envelope is one of the passive strategies [11] [12] that undoubtedly helps to obtain an energy efficient building with final energy request nearly to zero.

Besides, the building envelope controls the energy flow between the inside and the outside of the building [13] due to the difference of the internal air temperature and the external one and consequently the amount of the dispersions during winter season and the total benefit of the indirect gains as well. Obviously, this is strictly linked with the thermal comfort of the occupants that must be maintain especially in a school building.

In literature the main studies about the optimization of the opaque external envelope are related to the following design variables:

- the global thermal transmittance [14] [15];
- the thickness of the insulation [13];
- the insulation types [14];
- the thermal mass and the thermal resistance that deeply affect the human comfort [13];

Lots of the previous studies are related primarily to the building retrofit and they are not concerned with school buildings but with residential ones.

In this paragraph the motivations of the choice of one of the possible technological solution among the most recurrent in literature for schools (deduced with the analysis of representative buildings) for the opaque external envelope and for the roof are presented and discussed. Some studies about the thickness of insulation for different cities are illustrated too.

Method

As previous defined in the paragraph *3.3.3 Architectural definition* (*Chapter 3*) 2 different kinds of technological solution for the façade were adopted (advanced screen façade, external thermal insulation system) with 3 types of material for the insulation (wood fiber, glass wool, EPS) related to 4 typologies of structure (*Chapter 3 – Table 3.11*) in order to obtain 16 different combinations to compare.

Before explaining the results and the method to evaluate one of the possible technological solution to be used for the external opaque envelope for Italian kindergartens, comparing the configurations recurrent in the study of representative buildings, it is important to point out some settings about the study:

- the minimum thermal transmittance for each climate zone required by the Italian law [16] was considered at the beginning, then some study on energy performance was done by varying the thickness of insulation in order to minimise the primary energy demand;

- it was conducted considering all the typological models for kindergarten located in all cities simulated with Design Builder;
- to reduce the technological solution from 16 combinations to 4 combinations related to the 4 different types of structure an analysis on the primary energy demand in a whole year was evaluated with Design Builder.

  The 4 different types of structure considered are XLAM - A (panel of 130 mm of thickness), platform frame with double OSB panel – B.1 (Panel of 20 mm of thickness), platform frame with single OSB panel – B.2 (Panel of 20 mm of thickness) and reinforced concrete with brick as external wall – C.

Once identified, with respect the primary energy demand evaluation, the above mentioned 4 combinations (between the all 16 combinations) related to the 4 different type of structure, they are analysed in detail in order to define the advisable one (within the recurrent in representative buildings), with respect to different features:

- the dynamic thermal characteristics (mass surface [kg/m^2], periodic thermal transmittance in [W/m^{2}K], decrement factor and time shift in hours) calculated following the procedure of the EN ISO 13786 [17];
- the final energy demand for heating and cooling in the winter (the 15th of December) and summer design day (the 15th of July);
- the variation of the attenuation temperature value inside the building for winter season evaluating the energy demand for heating. For this evaluation the value of the internal attenuation temperature was fixed to initially to 5°C, then to 10°C and finally to 15°C;
- the CO_2 emissions with respect to the different technological solutions and the material of the insulation computed with Baubook eco2soft[7];
- the internal and external temperature for the southern and northern oriented surfaces of the external envelope considered without plants estimated with Design Builder as well considering walls in correspondence of the classrooms (southern oriented) and the teacher area (northern oriented). In addition, it is considered in the summer design day (15th of July) in order to consider and evaluate the dynamic thermal properties of the technological solutions as well.
- the predicted mean vote (PMV) calculated without considering systems as found in literature [11] [18] during the 8th of June taking into account with an index for clothes equal to 0.50 clo.

  This is an index to evaluate the thermo-hygrometrical comfort inside of a building determined by Fanger. He elaborated this index to correlate parameters characterising the human sensations, needs and comfort with objective the internal environment:
    - the activity inside the functional unit of the building (M) measured [met];

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[7] https://www.baubook.info/eco2soft/?lng=2

- the thermal resistance of clothes (clo) in [clo];
- the air temperature (T_a) [°C];
- the medium radiant temperature (T_{MR}) [°C];
- the velocity of the air (v_a) measured [m^2/s];
- the humidity of the air with water vapour pressure (P_w) [Pa].

These variables are relating in a function (Equation 4.1 Fanger’s equation of well-being) of this type.

Equation 4.1 $$f(M, clo, v_a, T_{MR}, T_a, P_w) = 0$$

In order to obtain a sensation of comfort the energy variation inside to human body must be equal to 0 W/m^2.

The PMV represents a medium vote falls within the category of the sensation index. It was evaluated with an arbitrary scale of values from “-3” that means a sensation of too much warm thermal condition to “+3” that indicates a sensation of too much cold thermal sensation. The 0 specifies the neutral thermal sensation and so the optimal comfort situation for people inside a functional unit of the building.

The results presented in this paragraph are related to model I1 located in the city of Florence that is chosen as the representative city for the Italian climate. The energy simulations with Design Builder were done for all typological models and for all cities considered.

The results are reported for the model I1 because for this type of analysis with respect to the dynamic thermal characteristics, the envelope CO_2 emissions, the internal and external surface temperature and the PMV the choice of the model is irrelevant. Whereas, for the value of both energy demand for heating due to the variation of the setpoint temperature of heating system and the energy demand for cooling and heating the choice of the model is significant only for the amount of energy needs, but the main results deal with the variation of the technological solution for the external envelope do not change noticeably. This occurs with respect to the city as well, and consequently the better solution for the external envelope chosen with respect to the analysed features is the same for all the cities considered, even if they belonged to different climate zones.

Finally, for the study of the thickness of insulation a parametric analysis was carried out varying the thickness with a minimum value corresponding to the requirements for the minimum thermal transmittance to realize a nZEB building and the maximum that lets to obtain the half value of the same parameter. This is valid for both the roof and the walls of the considered model. The step of the single variation of the thickness of insulation is equal to 2 cm. This analysis was performed for the cities of Florence, Milano and Palermo.

For the study of the external envelope the configuration for the system in this study is the following one:

The tables (Table A.5 – Table A.23) illustrate the different kinds of the most recurrent technological solution for the external envelope and the related roof stratigraphy corresponding to each structural solution considered (A – B.1 – B.2 – C). These are the citated 16 combinations to compare for the study of the opaque external envelope.

In the paragraph that follows a brief description of the stratigraphy layers was shown. For all the technological solutions described the thickness of insulation varies with respect to the climate zone and the air cavity for the solution with advanced screen façade is equal to 30 mm.

A. XLAM structural solution.

Alternative for the external opaque envelope stratigraphy with XLAM structural solution:

- A.1 XLAM structural panel (130 mm) with advanced screen façade with wood laths as finishing as external envelope solution, wood fiber insulation and internal gypsum board with internal acoustic insulation (Table A.5);
- A.2 XLAM structural panel (130 mm) with external insulation and external plaster as finishing as external envelope solution, wood fiber insulation and internal gypsum board (Table A.6);
- A.3 XLAM structural panel (130 mm) with advanced screen façade with wood laths as finishing as external envelope solution, glass wool insulation and internal gypsum board with internal acoustic insulation (Table A.7);
- A.4 XLAM structural panel (130 mm) with external insulation and external plaster as finishing as external envelope solution, glass wool insulation and internal gypsum board (Table A.8);

Roof stratigraphy A with XLAM structural solution.

It is a ventilated roof, composed from internal to external layer by a XLAM structural panel (125 mm), a sheath of vapour barrier (protective felt and cover in polypropylene and polyethylene-copolymer films), wood fiber insulation, waterproofing sheath (plastomeric polymer bitumen), air cavity for ventilation of 5 cm and metal cover (Table A.9).

B.1. Platform frame and double OSB structural solution.

Alternative for the external opaque envelope stratigraphy with platform frame and double OSB structural solution:

- B.1.1 double OSB structural panel (20 mm each one) with advanced screen façade with wood laths as finishing as external envelope solution, and 2 layers of wood fiber insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.10);
- B.1.2 double OSB structural panel (20 mm each one) with external insulation and external plaster as finishing as external envelope solution, and 2 layers of wood fiber insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.11);

- B.1.3 double OSB structural panel (20 mm each one) with advanced screen façade with wood laths as finishing as external envelope solution, and 2 layers of glass wool insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.12);
- B.1.4 double OSB structural panel (20 mm each one) with external insulation and external plaster as finishing as external envelope solution, and 2 layers glass wool insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.13);

Roof stratigraphy B with platform frame structural solution:

It is a ventilated roof, composed from internal to external layer by a OSB structural panel (20 mm), a sheath of vapour barrier (protective felt and cover in polypropylene and polyethylene-copolymer films), wood fiber insulation, waterproofing sheath (plastomeric polymer bitumen), air cavity for ventilation of 5 cm and metal cover (Table A.14).

B.2. Platform frame and single OSB structural solution.

Alternative for the external opaque envelope stratigraphy with platform frame and single OSB structural solution:

- B.2.1 single OSB structural panel (20 mm) with advanced screen façade with wood laths as finishing as external envelope solution, wood fiber insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.15);
- B.2.2 sigle OSB structural panel (20) with external insulation and external plaster as finishing as external envelope solution, and wood fiber insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.16);
- B.2.3 single OSB structural panel (20) with advanced screen façade with wood laths as finishing as external envelope solution, glass wool insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.17);
- B.2.4 single OSB structural panel (20) with external insulation and external plaster as finishing as external envelope solution, glass wool insulation and internal gypsum board with mineral wool internal acoustic insulation (Table A.18);

Roof stratigraphy B with platform frame structural solution:

It is a ventilated roof, composed from internal to external layer by a OSB structural panel (20 mm), a sheath of vapour barrier (protective felt and cover in polypropylene and polyethylene-copolymer films), wood fiber insulation, waterproofing sheath (plastomeric polymer bitumen), air cavity for ventilation of 5 cm and metal cover (Table A.14).

C. Reinforced concrete structural solution.

Alternative for the external opaque envelope stratigraphy with reinforced concrete structural solution:

- C.1 Reinforced concrete structural solution with hollow brick (thickness: one of 25 cm and one of 12 cm) as external vertical infill with advanced screen façade with wood laths as finishing as external envelope solution, wood fiber insulation and internal plaster (Table A.19);
- C.2 Reinforced concrete structural solution with hollow brick (thickness: one of 25 cm and one of 12 cm) as external vertical infill with external insulation and external plaster as finishing as external envelope solution, wood fiber insulation and internal plaster (Table A.20);
- C.3 Reinforced concrete structural solution with hollow brick (thickness: one of 25 cm and one of 12 cm) as external vertical infill with advanced screen façade with wood laths as finishing as external envelope solution, glass wool insulation and internal plaster (Table A.21);
- C.4 Reinforced concrete structural solution with hollow brick (thickness: one of 25 cm and one of 12 cm) as external vertical infill with external insulation and external plaster as finishing as external envelope solution, glass wool insulation and internal plaster (Table A.22);

Roof stratigraphy C with reinforced concrete structural solution

It is a ventilated roof, composed from internal to external layer by a concrete-brick slab with internal plaster as finishing, a sheath of vapour barrier (protective felt and cover in polypropylene and polyethylene-copolymer films), wood fiber insulation, waterproofing sheath (plastomeric polymer bitumen), air cavity for ventilation of 5 cm and metal cover (Table A.23).

Applying all these 16 technological solutions to all typological models and simulating them with Design Builder, the results point out (detailed in Table 4.3) that the 4 best technological solutions referred to the 4 structural solutions (XLAM - A, platform frame with double panel - B.1, platform frame with single panel - B.2, reinforced concrete - C), considering the primary energy demand, are as follows:

- A.2 - XLAM structure + external insulation with plaster for the technological solution for the façade + wood fiber insulation;
- B1.2 - Platform frame with double OSB structure + external insulation with plaster for the technological solution for the façade + wood fiber insulation;
- B2.2 - Platform frame with single OSB structure + external insulation with plaster for the technological solution for the façade + wood fiber insulation;
- C.4 - Reinforced concrete with hollow brick block + external insulation with plaster + wood fiber insulation.

These are the 4 technological solutions (recurrent in the analysis of representative buildings) that are compared to individuate the best one considering all the features described before.

Besides, the following table illustrates (Table 4.3) the amount primary energy demand, referred to the 16 combinations for the technological solutions, considering the Model I1 located in the city of Florence.

Table 4.3 Primary energy demand for model I1 located in the city of Florence

Structural solution - A	A.1	A.2	A.3	A.4

Primary energy demand - A [kWh/m^{2}a]	21	21	21	21
Structural solution - B.1	B.1.1	B.1.2	B.1.3	B.1.4
Primary energy demand - B.1 [kWh/m^{2}a]	22	21	22	22
Structural solution - B.2	B.2.1	B.2.2	B.2.3	B.2.4
Primary energy demand - B.2 [kWh/m^{2}a]	22	22	22	22
Structural solution - C	C.1	C.2	C.3	C.4
Primary energy demand - C [kWh/m^{2}a]	21	21	21	21

As showed in the previous table in terms of primary energy demand during the entire year for each structural solution examined (A - B.1 - B.2 - C), the advisable technological solution for the external envelope is the one that used the external insulation system with external plaster and the insulation functional layer in wood fiber material.

This is valid even if there is a slight difference between the results in terms of primary energy demand related to the 4 different technological solution (for instance A.1 - A.2 - A.3 - A.4) referred to one structural solution (for instance A).

At the same time the results suggest that from an energy point of view these technological solutions proposed are all valid alternatives.

The results to define the advisable technological solution between the recurrent found in the analysis of representative buildings are presented in the following section, divided with respect to the different features considered.

- *Dynamic thermal characteristics and surface internal and external temperature*.

To verify the dynamic thermal properties, defined in the ISO 13786 [17], of the 4 technological solutions for the opaque external envelope explained before the next parameters were looked at:

- the surface mass (M_s) measured in kg/m^2 that depends on density (ρ measured in kg/m^3) and the thickness of each layer that makes up the technological solution of the external wall (in this calculation the layer of internal/external plaster is not considered);
- the periodic thermal transmittance (U_{dyn})[8] measured in W/m^{2}K that evaluates the capacity of a wall of mitigating and shifting in time of the thermal flux that goes through it during a whole day. Moreover, it is based on the value of the air temperature inside of the building;
- the decrement factor (f_d - dimensionless) that is the ratio between the dynamic thermal transmittance and thermal transmittance calculated in stationary regime. It indicates the mitigation of the thermal flux between the external surface of the wall and the internal one;

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[8] It means: "*complex number relating the period heat flow into component to the periodic temperatures on the other side of it under sinusoidal conditions*" UNI 13786:2017 paragraph 3.1.5

- the time shift (φ)[9] measured in hours that specifies the number of hours in which the maximum internal temperature occurs with respect to the maximum peak of the external one. It increases with the value of the density and the specific heat.

The following table (Table 4.4) illustrates the discussed parameters referred to the different technological solutions taken into account:

Table 4.4 Dynamic thermal characteristics of the 4 options for the technological solution of the opaque external envelope

Solution	Ms [kg/m^2]	Udyn[W/m^{2}K]	fd [-]	φ [h]
A.2	171	0.043	0.171	12
B.1.2	87	0.132	0.480	8
B.2.2	105	0.149	0.551	7
C.4	337	0.012	0.045	17

From the previous table it is possible to notice that from this point of view concerns with the dynamic thermal characteristics of the opaque external envelope the solution with the reinforced concrete structure, the external wall in brick block and the wood fiber insulation is the better one especially in terms of time shift and dynamic thermal transmittance. This is mainly due to the high value of the surface mass. The both solutions that used the OSB single or double panel are not recommended in this case on account of the soaring value of the dynamic thermal transmittance and of the decrement factor as well.

This is strictly connected with the variation of internal surface temperature related to the external one for southern and northern oriented façades. Graph in Figure 4.10 and graph in Figure 4.11 represent respectively the variation in the surface internal temperature for the southern façade of one classroom, considering the 4 technological solutions, and the northern one in correspondence of the teachers' area. These temperatures are compared with the value of the external air temperature.

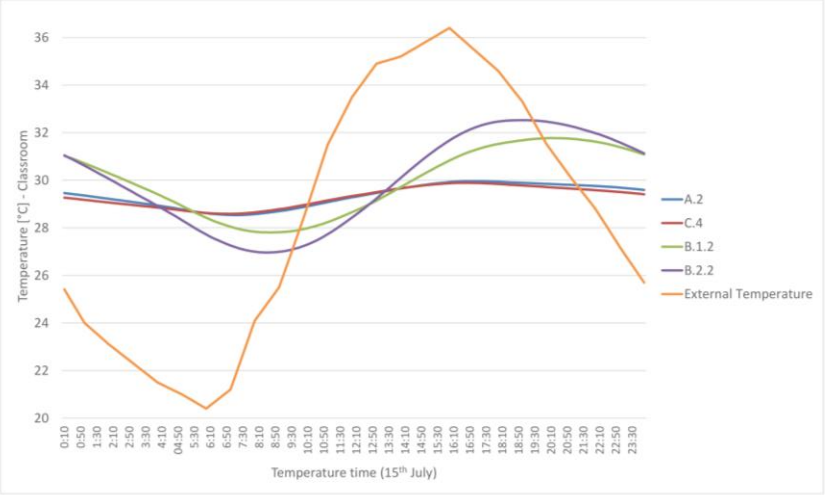

Figure 4.10 Variation of the internal surface temperature for southern façade

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[9] It means: "*period of time between the maximum amplitude of a cause and the maximum amplitude of the effect*" UNI 13786:2017 paragraph 3.1.7

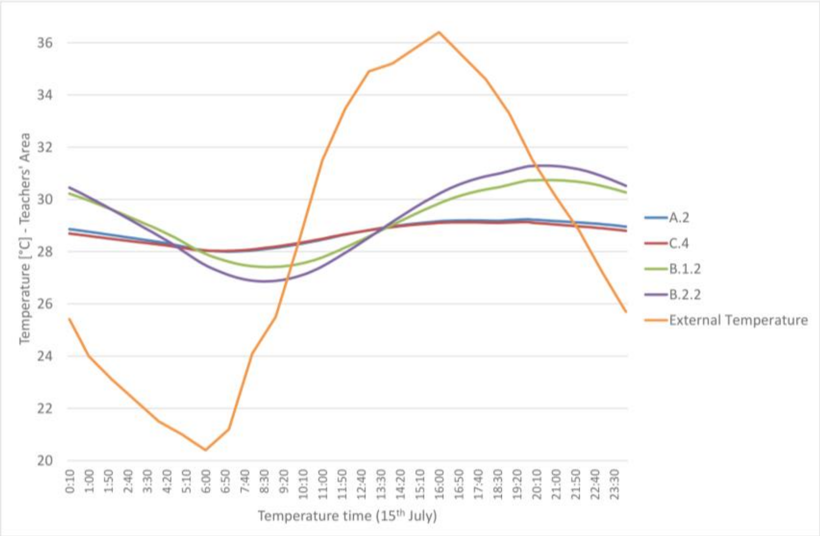

Figure 4.11 Variation of the internal surface temperature for northern façade

The variation of the range of the surface internal temperature is obviously more remarkable for south (> 32°C) orientation than the northern one owing to the solar radiation received. Whereas in both graph it is possible to notice that the higher increase in the surface internal temperature is for the 2 technological solutions with the OSB panels because of low surface mass. With respect to the trend of the external air temperature the best solutions are A.2 and C.4 that present the minimum variation during the day. They approximately levelled off at 28.5°C during the possible opening time of the school.

- *Final energy demand and attenuation temperature for the heating system*.

Firstly, talking about the difference of building heating load for the winter design day with the same condition of the system (configuration 1) and the equivalent thermal transmittance as well, the graph in Figure 4.12 shows the trend of the 4 solutions and it is possible to affirm that there is a minimum difference between them. The heating load climbs noticeably during the initial opening time of the school when the set point temperature indicated in the related template must be achieved. The other peaks in the graph are related to the occupation time of the school and to the value of the attenuation temperature for the heating system. As showed in Figure 4.12 the solutions A.2 and C.4 show lower heating load during the winter design day.

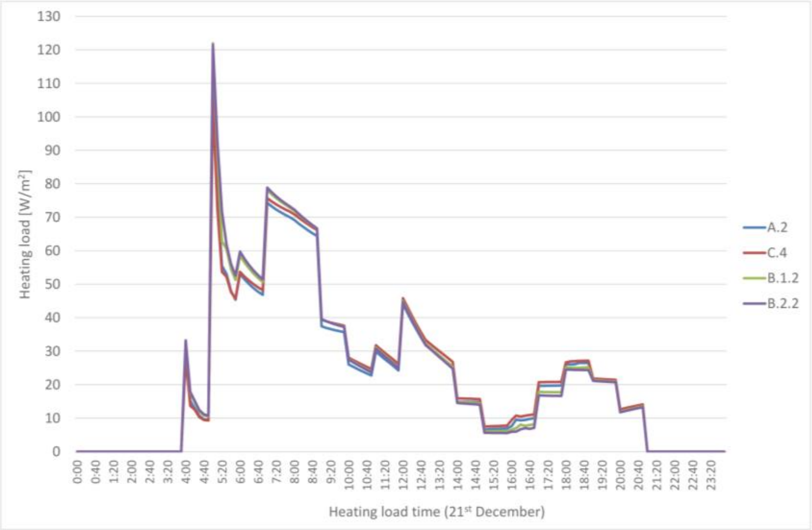

Figure 4.12 Load curve for winter design day

Secondly, Figure 4.13 exhibits the final energy demand for heating with respect to the variation of the value of the attenuation temperature for heating system. Hence as reported in this graph looking at the attenuation temperature obviously there is a constantly growth in the heating demand with the increasing in the value of the attenuation temperature and for this parameter the preferable solution is the one with XLAM structure (A.2). Comparing the best solution (A.2) and the worst one (B.2.2) there is a difference of about 24% in the heating demand.

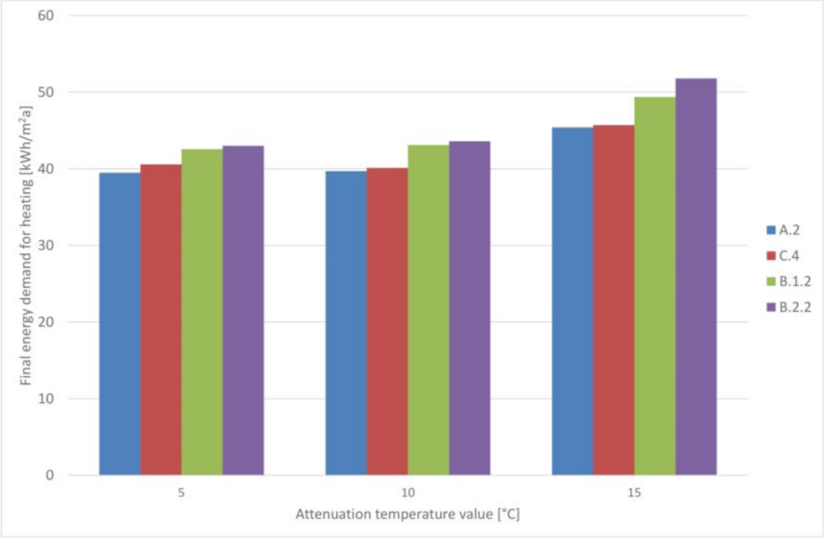

Figure 4.13 Final energy demand for heating with respect to the variation of heating setpoint

Last but not least, Figure 4.14 illustrates the load for cooling for the 4 technological solutions during the summer design day. In this case there is a difference between the solutions A.2 and C.4 and the other 2 solutions with the OSB panels of about 2 W/m^2 considering only one day. This owing to the value of the surface mass that for the last 2 technological choices is clearly lower. Thus, in this case as well the A.2 solution is advisable in order to minimise the cooling load in the summer design day even if the difference with the solution with reinforced concrete is around to 10%.

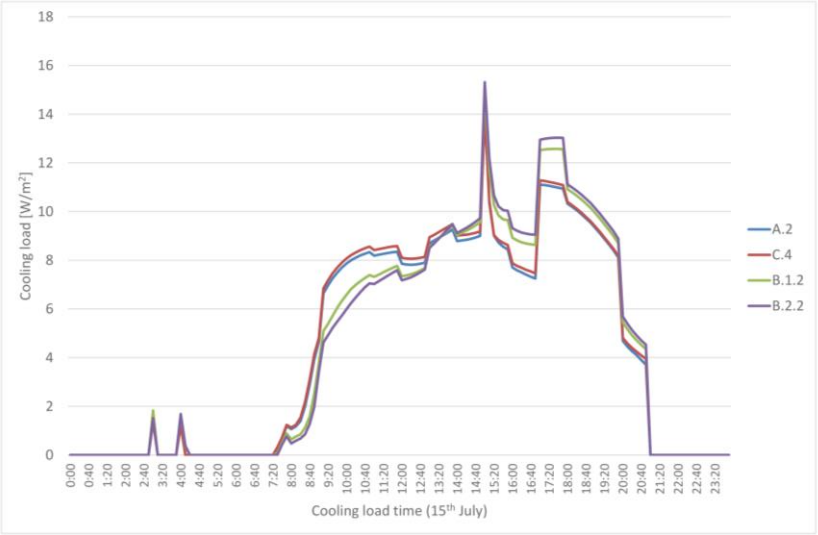

Figure 4.14 Cooling load curve for summer design day

- *CO_2 emissions.*

In this step of the research the CO_2 emissions are calculated only with respect to the technological solution for the opaque external envelope in order to investigate the next parameters:

- the primary energy not renewable (PERNT) measured in MJ/m^2. It is an index that includes the primary energy content to produce the used materials in the stratigraphy of the technological solution;
- the global warming potential (GWP) calculated in $kgCO_2/m^2$ that is a measure of the environmental impact caused by a chemical substance over a period (100 years in this case) and so how much this gas contributes to the increase in the air temperature;
- the acidification potential (AP) measured in $kgSO_2/m^2$. It means the acidification of soil and water primarily caused by the interaction between nitrogen oxide or sulphur dioxide with some components of the external air.

The following Table 4.5 exhibits the parameters described before for the 4 chosen technological solutions:

Table 4.5 Environmental impact of the 4 chosen technological solution for the opaque external envelope

Solution	PERNT [MJ/m^2]	GWP [$kgCO_2/m^2$]	AP [$kgSO_2/m^2$]
A.2	726	-51	0.209
B.1.2	566	-19	0.146
B.2.2	1011	9	0.305
C.4	916	62	0.217

Observing the results showed in the previous table the best solution is the one with XLAM (A.2) owing to the low value of both PERNT and especially GWP with respect to the others considered.

- *Predicted mean vote (PMV).*

The following graph in Figure 4.15 illustrates the results concern with the PMV index for the students that are inside the school building in a summer day (08th June). The range of variation is acceptable for all the considered solutions because it is between a minimum of -0.3 and a maximum of 1.1. The main variation in time of the PMV index related to the sensation of wellbeing happens for the 2 technological solutions with OSB panels. In this case with respect to this parameter the best solution seems the one with reinforced concrete structure (C.4). It is mainly related to the thermal dynamic properties (surface mass and dynamic thermal transmittance) of the layers included in the considered stratigraphy.

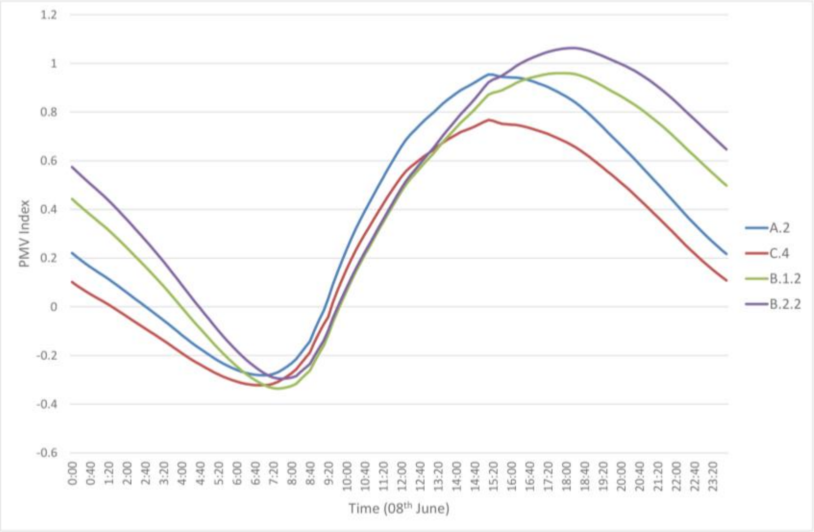

Figure 4.15 PMV index for 08th June

Summing up in consideration of the previous results and observations presented in this paragraph, it seems that the fruitful solution, between the recurrent ones in literature, is the one with XLAM structure, external wood fiber insulation and external plaster (A.2). This technological solution for the opaque external envelope is considered for the energy simulation in dynamic regime for the next results illustrated. Then in the qualitative and quantitative guidelines many possible configurations of the external envelope will be presented.

Brief study on thickness of insulation.

The following graphs concern the variation of the thickness of insulation measured in meters (X axis) for both façade and roof with respect to the final energy demand in kWh/m^{2}a for heating (Figure 4.16) and for cooling (Figure 4.17) for the Model I1 situated in the city of Florence. Instead Figure 4.18 and Figure 4.19 illustrate the results about the same study considering the city of Palermo. This study lets to think about the optimal thickness for the wood fiber insulation in order to reduce CO$_2$ emissions in the atmosphere during the operational phase of the building minimizing the energy demand for heating and for cooling. Moreover, it leads to some considerations about the difference between increasing the thickness of insulation in the façade or in the roof technological solution stratigraphy.

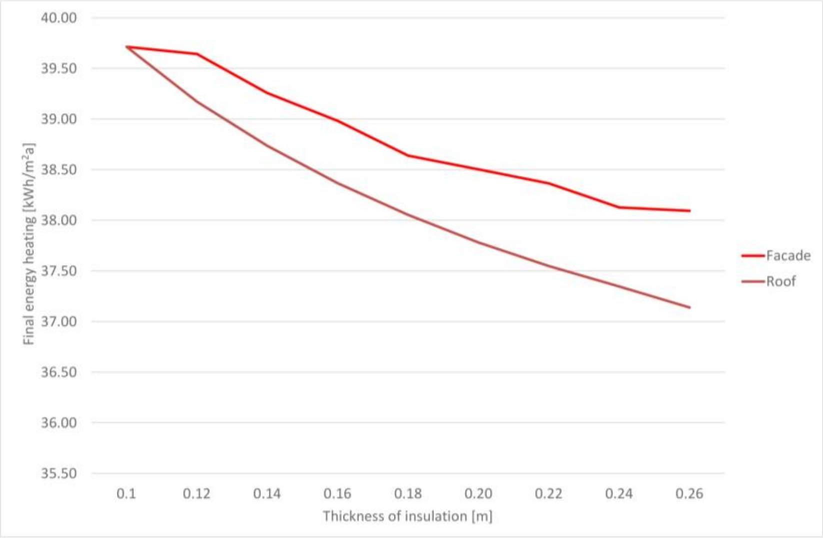

Figure 4.16 Final energy demand for winter season for Florence

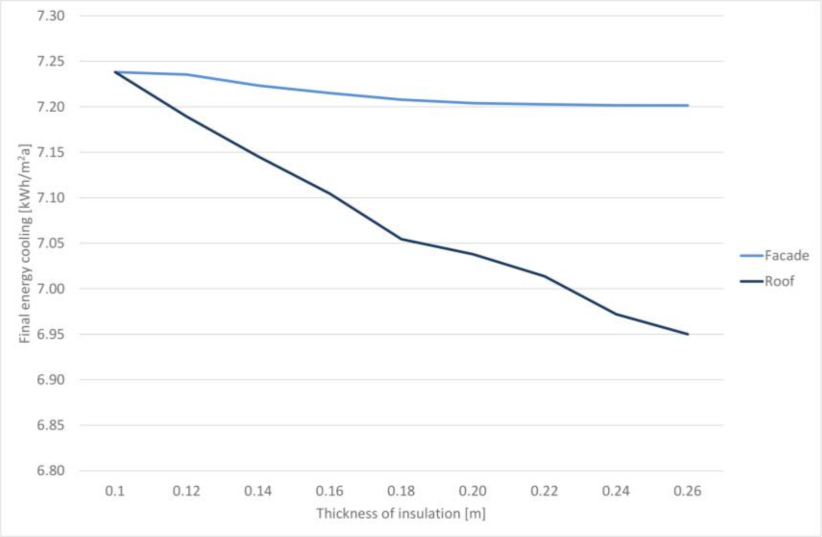

Figure 4.17 Final energy demand for summer season for Florence

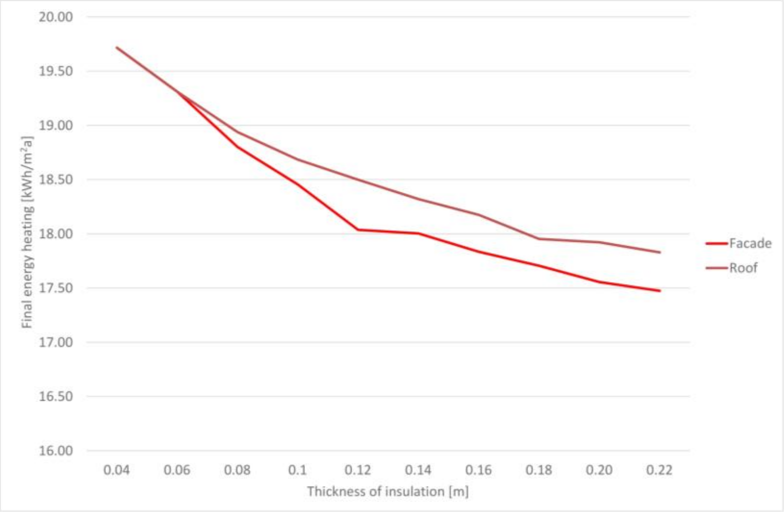

Figure 4.18 Final energy demand for winter season for Palermo

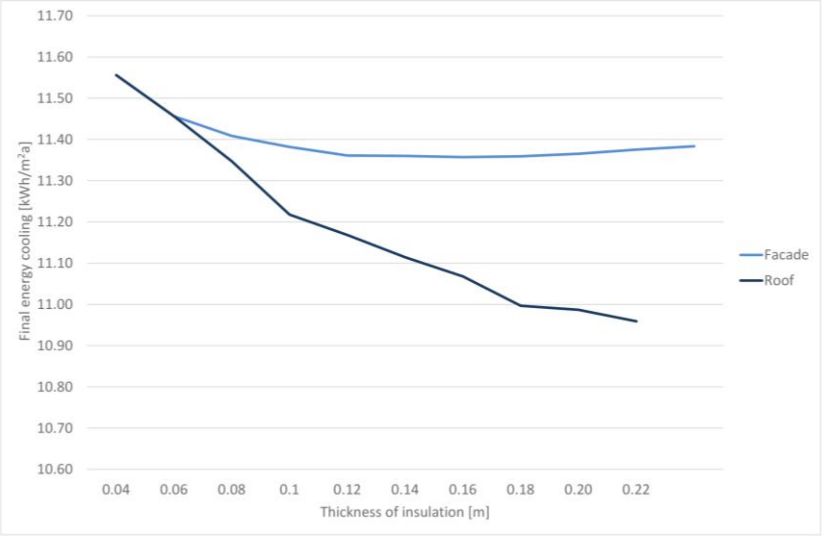

Figure 4.19 Final energy demand for summer season for Palermo

As shown in the previous graphs referred to the city of Florence (Figure 4.16 - Figure 4.17) the increasing in the thickness of insulation of the façade obviously affects most the final energy demand for heating whereas raising the thickness of insulation of the roof has a great impact on final energy for cooling. For the city of Florence an increasing in insulation for the façade from 0.10 m to 0.26 m leads to a decrease in final energy demand for heating of about 5%, while an increasing in the thickness of insulation for roof stratigraphy conducts to a reduction in final energy demand for cooling of about 4%.

From this assumption and for the trend of the graph it is possible to admit that for the city of Florence the following thickness of wood fiber insulation are chosen with respect to the optimisation of the opaque external envelope:

- Wall: thickness for the insulation layer = 0.14 m;
- Roof: thickness for the insulation layer = 0.22 m.

For the façade at 0.14 m the final energy demand for heating has already a reduction of about 2% with respect to the reference building and for the cooling consumption at this point of the graph the trend is almost levelled off. For the roof insulation the reduction for final energy demand for cooling is noticeable at 0.22 m and equal to 3% with respect to the reference building as well. Moreover, they are acceptable values for the most recurrent thickness of insulation for this kind of technological solution among the manufacturers.

Furthermore, these values of the thickness of insulation are strictly liked with both the Italian law requirements [16] about the global average heat transfer coefficient H'_T and the ITACA Protocol for schools [19] regarding the medium thermal transmittance of the elements of the envelope U_m. These 2 values have different limits with respect to the climate zone as defined in Table 10 of the Appendix A of the DM n. 162 of 26 June 2015 [16] considering the surface – volume ratio and in the B.6.2 basis of the ITACA protocols for schools [19].

In the following Table 4.6 the main results related to the city of Florence Model I1 are reported. The table illustrates: the global average heat transfer coefficient limit for climate zone D ($H'_{T,lim}$), the global average heat transfer coefficient limit for the analysed school building (H'_T), the medium thermal transmittance limit of the elements of the envelope ($U_{m,lim}$) and the medium thermal transmittance of the elements of the envelope for the examined school building (U_m).

Table 4.6 Medium thermal transmittance for the elements of the envelope for the city of Florence

City	Climate zone	$H'_{T,lim}$ [W/m^{2}K]	H'_T [W/m^{2}K]	$U_{m,lim}$ [W/m^{2}K]	U_m [W/m^{2}K]
Florence	D	0.58	0.231	0.324	0.231

As shown in the last Table 4.6 the main requirements about the opaque external envelope for the city of Florence are satisfied with the chosen value of the thickness of insulation for both façade and roof.

Despite for the city of Palermo for both the final energy needs for heating and for cooling the rise of the thickness of insulation for the roof has the great influence. As provided in the graph for the city of Palermo an increase in the thickness of insulation for roof from 0.04 m to 0.22 m results in a reduction of the heating demand equal to 10% and for cooling of about 5%.

For the city of Palermo, the next values of the thickness of wood fiber insulation was chosen:

- Wall: thickness for the insulation layer = 0.04 m;
- Roof: thickness for the insulation layer = 0.18 m.

For the insulation of the façade the thickness of insulation is kept equal to the reference building because with respect to the heating/cooling demand does not have a significant influence. In addition, if the final energy demand for cooling is considered, at 0.10 m of the thickness of insulation of façade there is a slight inversion of the trend and the final energy needs for cooling begins to grow.

As a matter of fact the limit of the thickness of insulation for the façade is strictly linked to the reason that an excessive insulation leads to an increase in energy demand for cooling during summer season especially for climate zone characterized by hot summer [20–22].

In the next Table 4.7 the global average heat transfer coefficient limit for climate zone D ($H'_{T,lim}$), the global average heat transfer coefficient limit for the analysed school building (H'_T), the medium thermal transmittance limit of the elements of the envelope ($U_{m,lim}$) and the medium thermal transmittance of the elements of the envelope for the examined school building (U_m) for the city of Palermo are reported.

Table 4.7 Medium thermal transmittance for the elements of the envelope for the city of Palermo

City	Climate zone	$H'_{T,lim}$ [W/m^{2}K]	H'_T [W/m^{2}K]	$U_{m,lim}$ [W/m^{2}K]	U_m [W/m^{2}K]
Palermo	B	0.63	0.343	0.395	0.343

In conclusion for the city of Palermo as well the requirements have been verified with the chosen values of the thickness of wood fiber insulation.

For the other cities analysed in this study the advisable thickness of wood fiber insulation both for the façade ($t_{façade}$) and the roof (t_{roof}), defined in order to decrease the primary energy demand of the considered typological model for kindergarten and consequently a remarkably CO_2 emissions reduction, and furthermore the check of the explained requirement, is presented in the following Table 4.8:

Table 4.8 Medium thermal transmittance for the elements of the envelope for the cities of Milan, Rome and Naples

City	Climate zone	$t_{façade}$ [m]	t_{roof} [m]
Milan	E	0.14	0.24
Rome	D	0.14	0.22
Naples	C	0.10	0.18

Surface and materials.

In this template (*Construction template*) it is possible to set up all the characteristics related to the single surface that delimited the building block with the definition of each single layer that composed the chosen technological solution for ground floor, external envelope and roof floor.

As explained in the previous paragraph (*Study on the opaque external envelope*) concerns with the study about the choice of the external envelope, the technological solution adopted for the energy simulation of typological models is the one (A.2) that has XLAM structural solution with external insulation with external plaster finishing and wood fiber insulation.

So, the following tables illustrate the main characteristics of the materials adopted for the layer of ground floor (Table 4.9), the external envelope (Table 4.10) and the roof floor (Table 4.11). In this phase it is necessary to define only one solution for the external envelope in order to perform some energy and environmental evaluation about the new defined school building type.

The tables show the stratigraphy from external to internal layer with the indication of the material, the thickness of the layer t [m], the thermal conductivity of the material λ [W/mK] and the thermal transmittance U [W/m^{2}K] of the whole technological solution.

The thickness of the insulation layer and the thermal transmittance are indicated in the table for each climate zone (B – Palermo, C – Naples, D – Florence and Rome, E - Milan).

The thermal transmittance is in line with the minimum required for the reference building by DM n. 162 of 26th June 2015 [16].

Table 4.9 Ground plate layer

Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
1	Lightened concrete	0.10	-	
2	Reinforced concrete	0.5	-	
3	Air cavity	0.5	-	
4	Reinforced concrete	0.05	2.3	
5	Lightened concrete	0.08	0.13	
6.B	EPS	0.02	0.03	$U_B = 0.29$
6.C	EPS	0.02	0.03	$U_C = 0.29$
6.D	EPS	0.04	0.03	$U_D = 0.24$
6.E	EPS	0.04	0.03	$U_E = 0.24$
7	Radiant surface in EPS	0.05	0.035	
8	Lightened concrete	0.03	0.13	
9	Internal floor in wood	0.015	0.1	

Table 4.10 External wall layer

Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
1	External plaster	0.025	0.9	
2.B	Wood fiber	0.04	0.038	$U_B = 0.42$
2.C	Wood fiber	0.08	0.038	$U_C = 0.29$

2.D	Wood fiber	0.10	0.038	U_D = 0.25
2.E	Wood fiber	0.10	0.038	U_E = 0.25
3	XLAM	0.13	0.12	
4	Air cavity	0.05	-	
4	Gypsum board	0.015	0.21	

Table 4.11 Roof layer

Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
1	Metal sheet	0.00005	1.07	
2	Air cavity	0.5	-	
3	Waterproof sheet	0.004	0.2	
4.B	Wood fiber	0.06	0.038	U_B = 0.30
4.C	Wood fiber	0.06	0.038	U_C = 0.30
4.D	Wood fiber	0.10	0.038	U_D = 0.23
4.E	Wood fiber	0.12	0.038	U_E = 0.21
5	Vapour barrier	0.0003	0.17	
6	XLAM	0.125	0.21	

Strictly linked with this template for the definition of the construction features there is the *Template Openings* necessary to define the main characteristics of glass (thermal transmittance, solar factor and light transmittance) as reported in table 3.12 (*Chapter 3*) for each climate zone analysed.

Building and plants.

Finally, the last template in Design Builder is dedicated to the definition of the simple HVAC in order to have all the features necessary to perform the energy simulation in dynamic regime. The system configurations are 4 and they are explained in detail at the beginning of this chapter.

4.2.2 Energy simulation for the basic typological models for kindergarten

Design Builder calculates the energy consumption of the 3 models for kindergarten in terms of:

- useful energy (Q_u) calls in the results *system loads* only at building level: it is the available energy utilized for heating, cooling, lighting, auxiliary energy etc. necessary to satisfy the users' needs [23];
- final energy (Q_E) (Equation 4.2 Calculation of the final energy) calls in the results *separate consumption* only at building level and it considers the performance of the systems (η): it is the energy fed to the building continuously or intermittently and it is generally measured by meters (electricity, gas) or volume (wood, coal) .

Equation 4.2
$$\boldsymbol{Q_E = \frac{Q_u}{\eta}}$$

where: $\boldsymbol{Q_E}$ means the final energy [kWh/m^{2}a];

$\boldsymbol{Q_u}$ is the useful energy [kWh/m^{2}a];

$\boldsymbol{\eta}$ is the performance of the system.

In this research the results are reported not only in terms of final energy with respect to each contribution to energy consumption of the building (heating, cooling, equipment, lighting, auxiliary energy and service hot water) but also in terms of primary energy (Q_P).

Primary energy (Equation 4.3 Calculation of the primary energy) is defined as: "*the sum of the primary energy expenditure costs of the final energy used for heating, cooling and electricity. Th expenditure costs include the cost handling from the depository of the fuel resource to the user's building (final energy)*"[10].

Equation 4.3 $$Q_P = Q_E * f_P$$

where: Q_P means the primary energy [kWh/m^{2}a];

Q_E is the final energy [kWh/m^{2}a];

f_P is the conversion factor for primary energy calculation.

In the national regulation (D.M. n. 162 of 26th June 2015) the primary energy is calculated through some conversion factor defined for each energy carrier for the amount of energy produced by renewable sources ($f_{P,ren}$) and for that obtained without renewables ($f_{P,nren}$).

In this thesis the conversion factors have the following values:

- for gas equal to 1.05;
- electricity from national grid without renewables equal to 1.95;
- electricity from national grid with renewables equal to 0.47;
- electricity produced with PV system equal to 1.

4.2.2.1 Final energy demand and Primary energy demand

In this paragraph the main results with the related discussion concerns with the final energy demand and the primary energy demand of the new building type for kindergarten located in the 5 different cities are reported before proceeding with the study of each single building features. The configuration for the system in this study is configuration number 1.

For a school building the main final energy demand is necessarily required by heating and cooling system in order to maintain proper thermal internal conditions.

Considering the 3 models located in the 5 different cities, from the graphs that follows (Figure 4.20 – Figure 4.21) is possible to stress out:

- with respect to the heating demand Milan has the highest request with respect to the other cities analysed, because it belonged to the climate zone with more severe winter.

  In this case the Model I1 has the worst energy performance with an increase in heating demand of about 14 kWh/m^{2}a compared for instance to Model I3;
- for Florence about the heating demand the same situation in Milan occurs and in this city the Model I1 has the worst energy performance with an increase in heating demand of about 11 kWh/m^{2}a;
- while with respect to the cooling demand in Palermo the Model I3 has the highest needs with respect to the other cities.

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[10] "Energy PLUS. Buildings and districts as renewable energy sources" M. Norbert Fisch, Thomas Wilken, Christina Stähr, Published by Dr. M. Norbert Fisch, Leonenberg 2013 ISBN 978-3-00-041246-2

For Palermo the final energy demand for heating for the 3 models is comparable because it is between 12 kWh/m^{2}a and 19 kWh/m^{2}a;

- Rome and Naples present a similar energy performance considering all the 3 models.

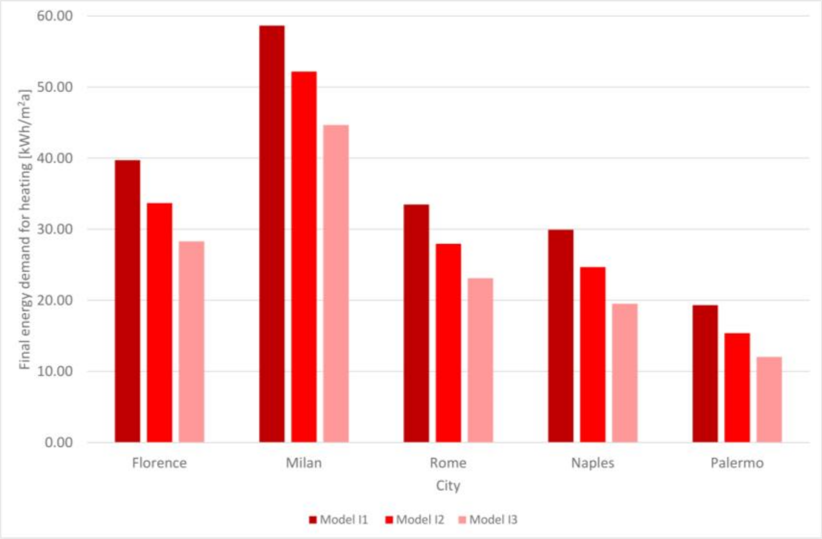


Figure 4.20 Final energy demand for heating

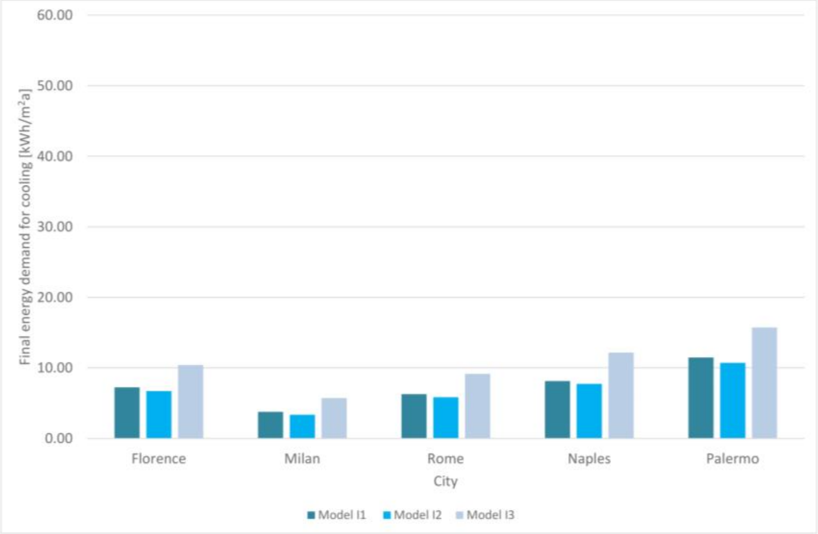


Figure 4.21 Final energy demand for cooling

According to the variation of the shape of the typological models for kindergarten it is possible to point out that for all the cities where the buildings are situated for the final energy demand for heating the energy performance of the Model I1 is the better one, while for final energy demand for cooling the Model I2 has the lower energy needs. This is strictly linked with the distribution and the orientation of the functional units in the internal layout of the models but for presence of the internal courtyard and recesses in the models as well, that inevitably influence the energy performance.

The primary energy demand is calculated considering all the contributions to the energy demand of the basic models for kindergarten (heating, cooling, lighting, equipment, auxiliary energy, service hot water) each one with the related conversion factor.

The 3 graphs that follow illustrate the primary energy demand for the 3 models for kindergarten with respect to the 5 cities considered (Figure 4.22 – Figure 4.23 – Figure 4.24).

From the analysis of the following graphs is possible to observe:

- as stated above the energy demand for heating and cooling is the most relevant for a school building with respect to the other contributions.

  For instance, for Milan the primary energy demand for heating, considering all the 3 models, represents an average of about 51% with respect to the total.

  While for Palermo with respect to the primary energy demand for cooling, considering all the 3 models, constitutes an average of about 30% with respect to the total;
- the primary energy demand for lighting is dependent by the location and by the shape of the building as well but for a school building it is not a significant contribution considering the opening time of the school and the natural lighting that has to be ensured in the functional units. It has a variation in a range between 4% and 7% for all the models in all cities;
- the primary energy demand for equipment does not depend on location and the value is calculated starting from the internal loads defined in the activity template in Design Builder. More or less there is the similar amount of primary energy demand for equipment for all models and for all cities;
- the primary energy demand for service hot water is calculated based on the number of students and so there is only a slight increase in the model I3 for all the cities analysed.
- as expected for all the typological models for kindergarten Palermo needs the lowest primary energy demand with an average of 83 kWh/m^{2}a while Milano requires the highest one equal to an average of 106 kWh/m^{2}a;
- furthermore, from the graphs below is possible to notice that for Milan there is not a noticeably difference between the primary energy demand required by the 3 models (~ 2 kWh/m^{2}a).

  It is possible to admit that for the colder city analysed, the shape of the building (considering these 3 typological models) does not affect significantly the primary energy demand because the primary energy demand for heating is however very high;
- finally, with respect to the primary energy demand the Model I1 is the best one for all the cities while the Model I3 is the worst one for Florence, Rome, Naples and Palermo while for Milan the Model I2 is the one that required the hugest amount of energy to satisfy the users’ needs.

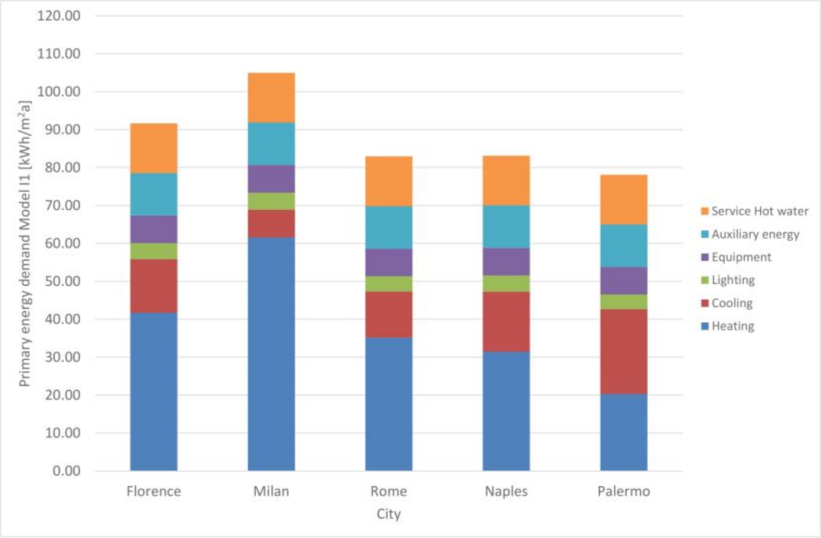


Figure 4.22 Primary energy demand for Model I1

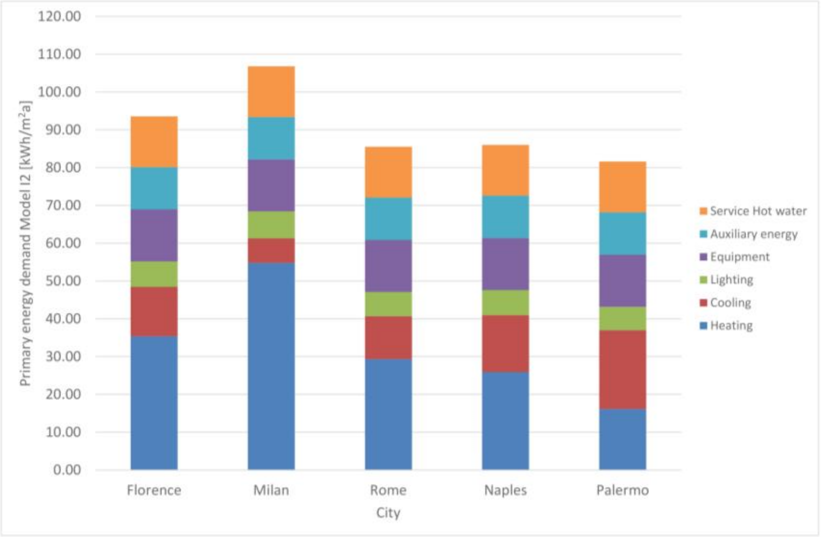


Figure 4.23 Primary energy demand for Model I2

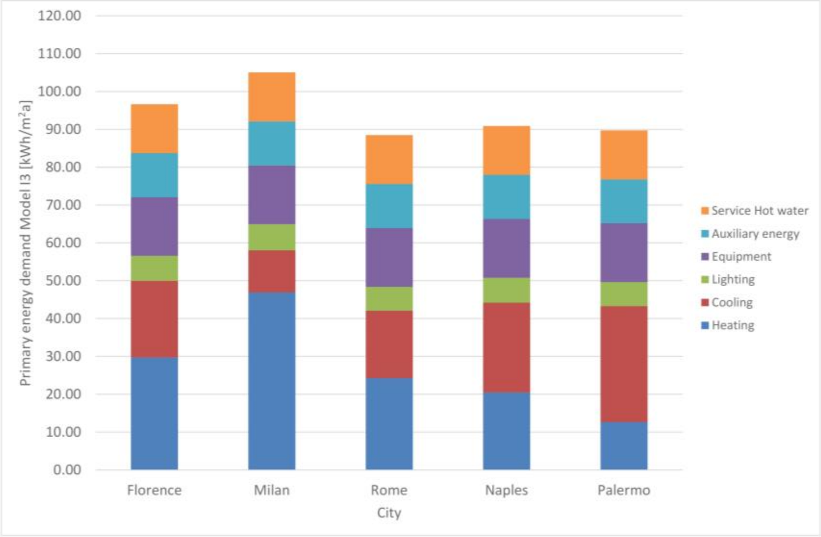


Figure 4.24 Primary energy demand for Model I3

4.3 GLOBAL SENSITIVITY ANALYSIS [24]

4.3.1 Background

In according to the recent European Directives concerning the energy saving of buildings and the related decrease in greenhouse gas emissions into atmosphere it is important to understand how the architectural choices, and in particular those made during the preliminary phase of the design process by the designers, influence the energy performance of building and its environmental impact [25].

In recent literature there are several researches that concern the individuation of all those parameters characterising buildings that mostly affect the primary energy demand and the final energy one for heating and cooling and their implementation in order to build a sustainable building even if they do not concern specifically schools. This assessment is essential for designers during the early stage of the design procedure and the related decision-making process in order to build neutral carbon school buildings. In fact, in this phase, there is the possibility to adopt the measures that have really a greater influence on energy needs reduction and to define the most efficient systems and technologies with respect to the specific building type and the climate zone in which Italy is divided.

For the construction of a nZEB school with zero CO_2 emissions is fundamental to understand since the preliminary design stage what the factors characterising the building that most affect the energy needs for both heating and cooling are.

The main aim of the study presented in this paragraph is to identify which are these factors that most influence in proportion the final energy demand of the new typological models for kindergarten considering the cities of Florence (climate zone D) and Palermo (climate zone B).

These 2 cities were chosen in order to obtain the global sensitivity analysis results in 2 different climate zones, both representatives of Italian climate but Florence characterized by cold winter and the others Palermo by an arid summer and drought.

In the following paragraph are shown:

- the methodology in order to perform the sensitivity analysis and the description of the parameters considered and their range of variation;
- the main results and discussion to identify which one of these factors has the greater influence on the primary energy demand of the new typological models for kindergarten and consequently on the amount of CO_2 emissions in the atmosphere.

4.3.2 Methodology

To evaluate the influence of each parameter on primary energy demand of considered models an on-at-a-time step sensitivity analysis [34] was performed. This is the simplest method to evaluate and to quantify in percentage terms the impact of every variable examined[i].

The study was carried out by considering one typological model as reference model (model I1), considering the characteristics previous defined for the new typological models for kindergarten, and by varying each factor within a specific range, keeping the remaining fixed.

To be through, the analysis was also performed in relation to the energy demand for heating and cooling as the influence of individual parameters could change with respect to the reference season.

In order to show the results of the sensitivity analysis, the sensitivity index has not been defined [31] but the variation in percentage of each individual parameter was calculated with respect to the model considered as the reference model (model I1). This choice was necessary because not only numerical parameters which vary in a precise range have been analysed, but also building distinguished features as shown in Table 4.12. The following table illustrates the range of these parameters: shape of the building, type of structure, façade and roof thickness of insulation for both climate zones D and B, green roof technological solution, the variation of WWR for South, East and West orientation, 4 different types of solar shading for functional units south oriented, use of vertical solar shading for East and West orientation, artificial lighting efficiency, attenuation temperature for heating system, air change per hour for mechanical ventilation, heat recovery efficiency for mechanical ventilation during winter season and any use of free cooling.

Table 4.12 Range of the considered parameters for on-a-time step sensitivity analysis

N.	Parameter	Range
1	Shape	2 types (Model I2 and I3)
2	Type of structure	3 types (B1.2 – B2.2 – C.4)
3	Façade thickness of insulation (D)	0.10 m – 0.26 m
	Façade thickness of insulation (B)	0.04 m – 0.16 m
4	Roof thickness of insulation (D)	0.10 m – 0.26 m
	Roof thickness of insulation (B)	0.06 m – 0.22 m
5	Green roof technological solution	use it – not use it
6	South WWR	33%; 50%; 76%
7	East WWR	17%; 29%; 36%
8	West WWR	17%; 23%; 29%
9	Type of solar shading (South)	4 types (9.1-9.2-9.3-9.4)
10	Vertical solar shadings	West – East orientation
11	Lighting efficiency	120 lm/W (LED); 22 lm/W (halogen lamps)
12	Attenuation temperature for heating	5°C; 10°C; 15°C; 20°C
13	Air change per hour	standard value (sv) [35]; 0.5 sv; 0.25 sv; off sv
14	Heat recovery efficiency	50 % – 90 % [36]
15	Free cooling	on - off

This analysis allows to identify the parameters that significantly affect the primary energy demand of a kindergarten. It means the contribution of the required energy for heating, cooling, auxiliary systems, equipment, lighting and service hot water.

4.3.3 *Sensitivity analysis*

In this paragraph some of the parameters considered (Table 4.12) for the on-at-a-time-step sensitivity analysis is described in detail in order to make more clear the variations performed, and their range of variation, for energy simulations to calculate energy demand and to quantify in percentage how much each considered aspect influences it.

Shape.

The first variation concerns the shape of the building. The model I1 is considered as the reference model. By comparison the two other configurations (model I2 and model I3) defined for new typological models to realize nZEB kindergartens in Italy were considered.

Type of structure.

3 different structural solutions were evaluate as an alternative to the wood structural solution of the reference model in XLAM: 2 with platform frame, one of which with double OSB panel (B.1.2) and one with single panel (B.2.2) and the other in reinforced concrete with brick for external wall (C.4).
To make a comparison, the same thermal transmittance in according to the reference building [16] and the same material of insulation (wood fiber) of base case were maintained.

Thickness of insulation for façade and for roof.

The variation of the thickness of insulation for external wall occurs in according to range in which the upper limit is different in every selected city:

- for the city of Florence (climate zone D) the range has as upper limit the one related to the thickness of insulation, equal to 26 cm, that allows to obtain a thermal transmittance equal to half of that one of the reference building [37] and at the same time it still results to be a reasonable technological solution;
- instead for the city of Palermo (climate zone B) the upper limit of the thickness of insulation is strictly linked to the reason that an excessive insulation leads to an increase in energy needs for cooling during summer season.
  Consequently, the maximum thickness of insulation is considered equal to 16 cm, because over this thickness as explained before the energy needs for cooling increases [20–22];
- moreover, as regards thickness of insulation variation for roof floor the standard adopted for both cities is the same and in this case the maximum thickness for the analysis is considered that allows to achieve a thermal transmittance equal to half of that one of reference building [37] as well.
  It is equal to 26 cm for Florence and 22 cm for Palermo.

Green Roof technological solution.

For modelling green roof technological solution the parameters defined in Table 4.13 that follows are assumed [38, 39].

Table 4.13 Design builder set up for green roof model

Parameter	Unit	Value
Conductivity of dry soil	W/mK	0.20
Density of dry soil	kg/m^3	1020

Specific heat of dry soil	J/kgK	1093
Saturation volumetric moisture content of the soil	-	0.13
Thermal absorptance	-	0.96
Solar absorptance	-	0.85
Height of plants	m	0.10
Leaf Area Index (LAI)	m^2/m^2	3.00
Leaf reflectivity	-	0.19
Leaf emissivity	-	0.97
Minimum stomatal resistance	$mmol/m^2s$	120
Maximum volumetric moisture content	-	0.5
Minimum residual volumetric content	-	0.01
Initial volumetric moisture content	-	0.15

Window-to-wall ratio.

The variation of window-to-wall ratio is considered for each orientation except for the north façade where it is maintained equal to the minimum value required by legislation in order to satisfy health-hygiene standards. This is necessary in order to avoid an increase in dispersions and consequently an increase in the energy consumption for heating of the kindergarten typological model.

Furthermore, the maximum WWR is equal to the one that can be achieved within the functional unit and setting as a limit for height the one corresponding to suspended ceiling inside rooms (Figure 4.25).

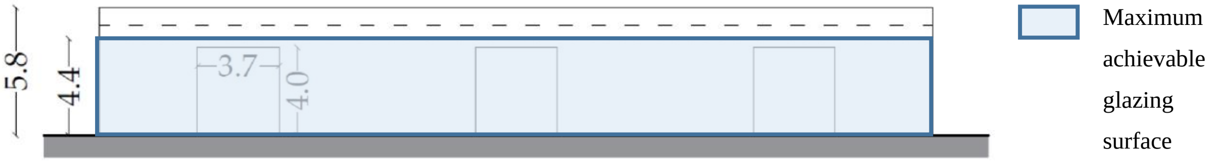


Figure 4.25: Definition of maximum WWR

The value of WWR is different for East and West orientation because in these orientations the functional units in the internal layout are different, as shown before, and consequently, they have different dimensions and distinct value of related WWR.

Solar shading.

For the variation of solar shadings system, it is necessary to consider separately the different orientations:

- as regards South orientation for the sensitivity analysis 4 different solutions (Figure 4.26) are varied in order to estimate the influence of the choice of solar shading on primary energy consumption (internal blinds with solar control with solar radiation equal to 120 W/m^2 – 9.1, combination of overhang of 2 m and internal blinds with solar control – 9.2, horizontal louvres – 9.3, external blinds with solar control with solar radiation equal to 120 W/m^2 – 9.4).
- for East and West orientation the possible use of vertical solar shadings is evaluated.

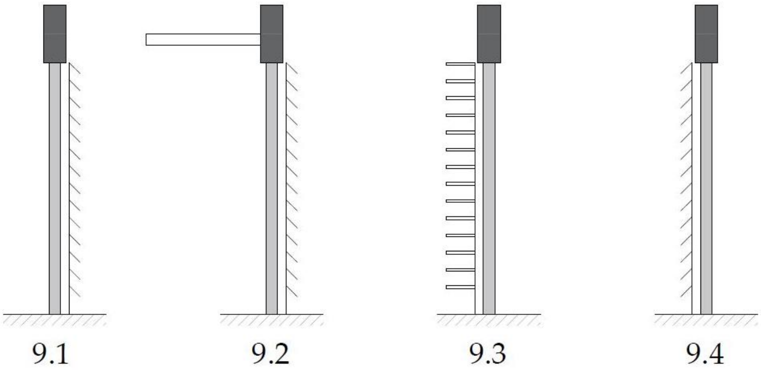


Figure 4.26 4 Different type of solar shading for South orientation

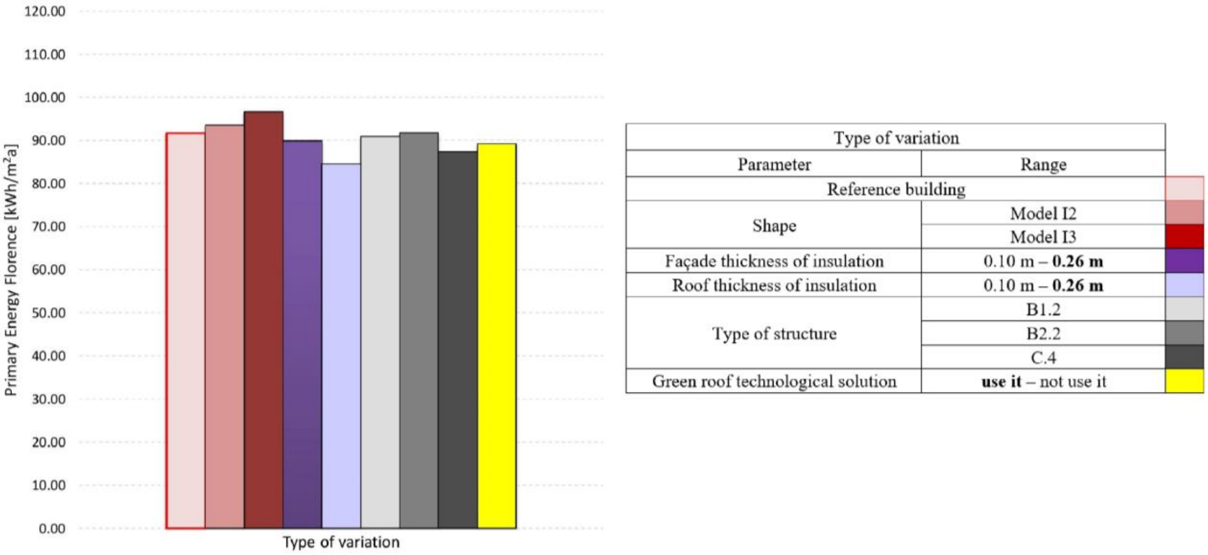
4.3.4 Main results and discussion

In this paragraph the mains results of the performed on-at-a-time step sensitivity analysis are presented and discussed in order to identify which parameters have the higher influence on primary energy demand.

Figure 4.27 and Figure 4.28 pertain morphological and technological characteristics and they are related to the city of Florence and they show the results of the sensitivity analysis by relating the primary energy demand of the reference model with the primary energy demand of the model obtained by assuming different variations.

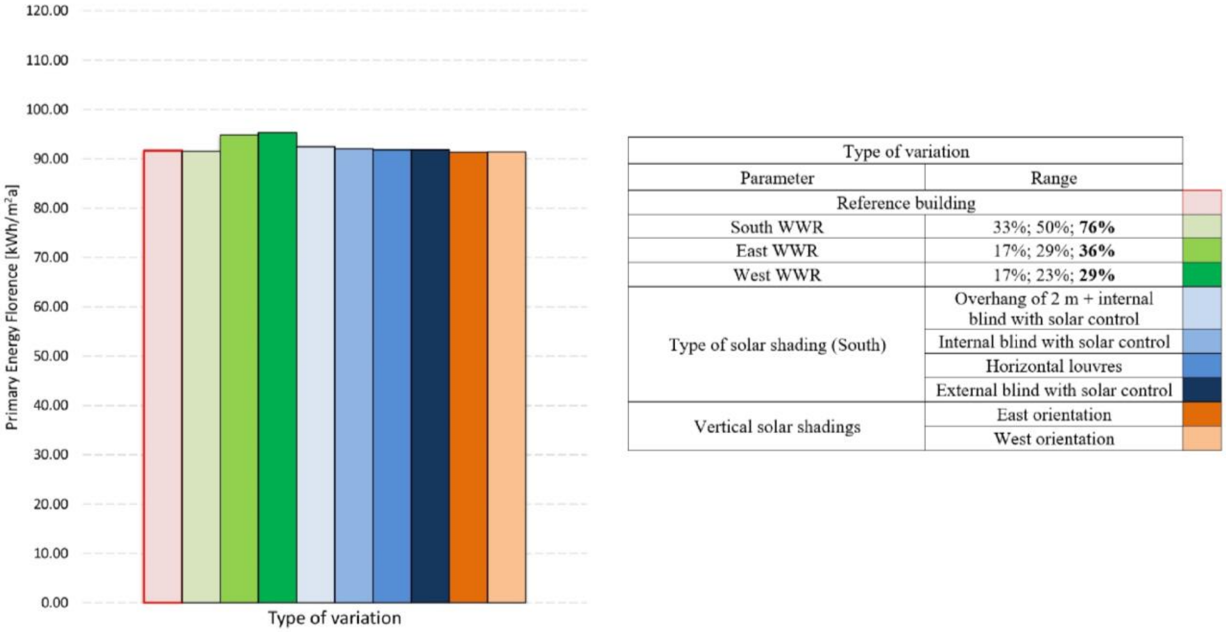
Before the discussion of the main results referred to the city of Florence, it is important to stress that:

- for the construction of presented following graphs for each variable analysed the minimum or maximum value was considered depending on how the single parameter affects (positively or negatively) the energy need;
- given the wide range of variables, as already explained, the value assumed (minimum or maximum) has been defined compatibly with the geometry of the building or with exclusively technological features;
- moreover, the main goal is to establish how the maximum variation of each individual parameter changes in percentage the primary energy demand with respect to the corresponding value of the building taken as a reference;
- finally, it is necessary to point out that the results of the sensitivity analysis listed below are strictly linked to functional bands and units’ distribution, orientation, intended use and occupancy level of analysed building.



Type of variation		
Parameter	Range	
Reference building		■
Shape	Model I2	■
	Model I3	■
Façade thickness of insulation	0.10 m – **0.26 m**	■
Roof thickness of insulation	0.10 m – **0.26 m**	■
Type of structure	B1.2	■
	B2.2	■
	C.4	■
Green roof technological solution	**use it** – not use it	■

Figure 4.27 Primary energy demand for Florence with respect to shape, insulation, structure and green roof – table 4.12



Type of variation		
Parameter	Range	
Reference building		■
South WWR	33%; 50%; **76%**	■
East WWR	17%; 29%; **36%**	■
West WWR	17%; 23%; **29%**	■
Type of solar shading (South)	Overhang of 2 m + internal blind with solar control	■
	Internal blind with solar control	■
	Horizontal louvres	■
	External blind with solar control	■
Vertical solar shadings	East orientation	■
	West orientation	■

Figure 4.28 Primary energy demand for Florence with respect to WWR and horizontal and vertical solar shadings – table 4.12

Figure 4.27 illustrates that for the city of Florence the compact shape with internal courtyard (model I1), that is considered as the reference model for the sensitivity analysis performed, has the better energy performance with respect to primary energy demand [kWh/m^{2}a]. Between the best model I1 and the worst one there is a difference of about 5 kWh/m^{2}a that means an increase of CO_2 emissions equal to 23000 kg$_{CO2}$/a, considering system configuration 1 and used area of each model.

Despite that the shape with predominant linear development with 6 classrooms (model I3) allows to achieve a saving of the final energy demand for heating (~ 30 %) compared to compact shape with internal courtyard (model I1). This is related to the shape of the building plan that has a predominant horizontal development with main direction along east-west axis. This grants to exploit solar gains and to reduce demand for heating while causing at the same time a noticeably increase (> 40 %) in demand for cooling. With respect to the demand for cooling the model I2 leads to a decrease in final energy of about 7% compared with the reference model I1.

In relation to the characteristics of the building, as can be seen from the previous graph (Figure 4.27), the choice of the type of structure and consequently the identification of the solution for the technological systems for the external envelope affect the primary energy consumption as well:

- the use of reinforced concrete structure (C.4) leads to a slight decrease in energy consumption equal to 5%;
- the use of OSB panel both in the case of single panel (B.1.2) and in the case of double panel (B.2.2), does not change in a significant way the primary energy consumption with respect to the model I1;
- in spite of that the final energy consumption for cooling a rise happens equal to about 10% considering the structural solutions with OSB panel (B.1.2 and B.2.2). This mainly related to the reason that the external walls do not have enough thermal mass and related periodic thermal transmittance to ensure a proper decrement factor and time shift of the thermal wave.

  The external wall solution with double panel (B2.2) is characterized by:

    - decrement factor f_D=0.48 [-];
    - time shift φ=7.98 h;
    - periodic thermal transmittance Y_{ie}=0.132 W/m^{2}K in according to UNI EN ISO 13786 [40].

  These values are definitely worse than those that are possible to obtain by adopting the solution with XLAM panel and insulation with wood fiber.

  The solution with reinforced concrete, external wall with bricks and insulation with wood fiber shows a better behaviour of above-mentioned values than the reference solution (XLAM) but it leads to a high value of CO_2 emissions for the construction;
- moreover, the increase in thickness of insulation on roof floor significantly affects the primary energy demand (~ 8.50%) compared to the same increase in thickness of insulation of external wall. It is set for both as upper limit the thickness of insulation that allows to achieve a thermal transmittance equal to half of that required by current legislation for reference building;
- finally, the use of green roof technological solution for roof floor primarily leads to a decrease in final energy demand for cooling (8%) but generally to a small decrease in primary energy demand equal to about 2.70%.

  The green roof allows to obtain a lower surface temperature because it absorbs lower solar energy than traditional solutions and it enables more control of the internal temperature of the building by minimizing the cooling demand [40].

As shown in Figure 4.28 for Florence the increase in WWR for South orientation leads to a benefit in terms of final energy demand for heating while for East and West orientation the increase in WWR negatively affects the energy balance but not significantly for a climate zone characterized by a climate with cold winter.

Furthermore, for a building characterized by this internal functional distribution the use of solar shadings for eastern and western façades does not remarkably influence the final energy demand. This result is mainly related to the reason that in the model there are not windows in these orientations for sections that are the functional units with higher occupancy density during teaching time.

To be through the results related to the change of the shape considered in this sensitivity analysis are illustrated in terms of CO_2 emissions as well. The following graph in Figure 4.29 exhibits the CO_2 emissions for each model of kindergarten during the operational phase of the building due to heating and cooling system, lighting, equipment, auxiliary energy system and service hot water.

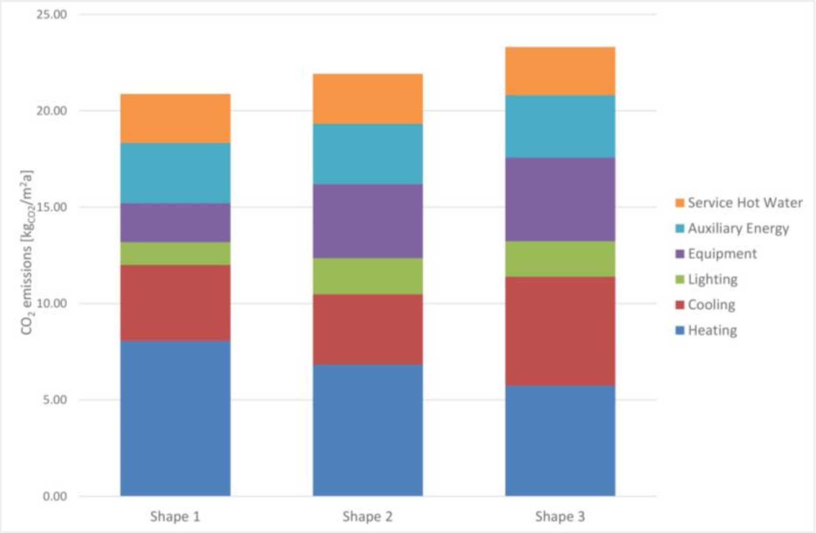
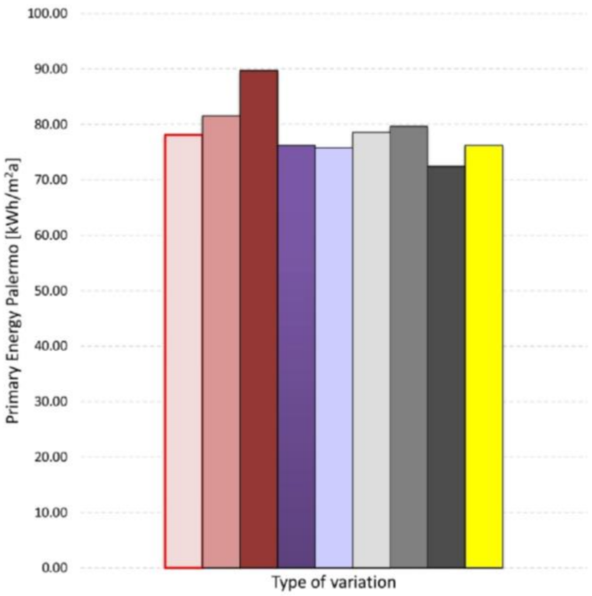


Figure 4.29 CO_2 emissions with respect to different shape located in the city of Florence

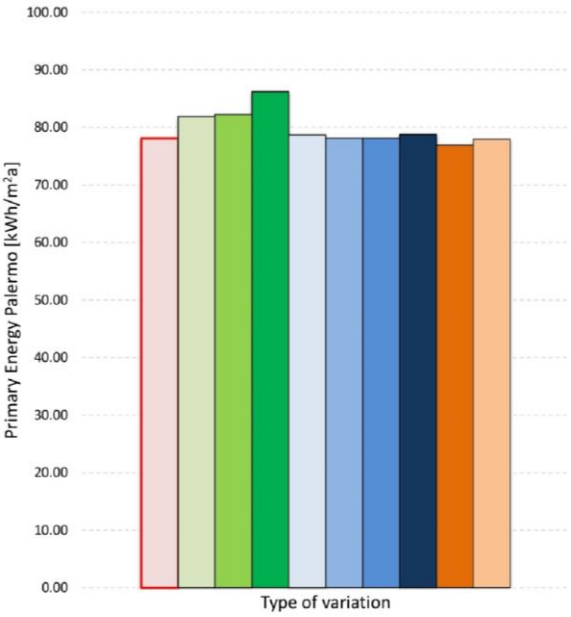
It is possible to state that with respect to the CO_2 emissions in the atmosphere during the operational phase the model I1 (shape 1) with compact shape and internal courtyard is the best one, even if the contribution related to heating system to CO_2 emissions is higher than the others. For the model I3 (shape 3) is the cooling that influences the most the amount of CO_2 emissions.

As regards the city of Palermo Figure 4.30 and Figure 4.31 concern the results of the sensitivity analysis concern morphological and technological characteristics.



Type of variation		
Parameter	Range	
Reference building		🟥
Shape	Model I2	🟥
	Model I3	🟥
Façade thickness of insulation	0.04 m – **0.16 m**	🟪
Roof thickness of insulation	0.06 m – **0.22 m**	🟪
Type of structure	B1.2	⬜
	B2.2	⬛
	C.4	⬛
Green roof technological solution	**use it** – not use it	🟨

Figure 4.30 Primary energy demand for Palermo with respect to shape, insulation, structure and green roof – table 4.12



Type of variation		
Parameter	Range	
Reference building		🟥
South WWR	33%; 50%; **76%**	🟩
East WWR	17%; 29%; **36%**	🟩
West WWR	17%; 23%; **29%**	🟩
Type of solar shading (South)	Overhang of 2 m + internal blind with solar control	🟦
	Internal blind with solar control	🟦
	Horizontal louvres	🟦
	External blind with solar control	🟦
Vertical solar shadings	East orientation	🟧
	West orientation	🟧

Figure 4.31 Primary energy demand for Palermo with respect to WWR and horizontal and vertical solar shadings – table 4.12

For the city of Palermo, the model I1 is the one that ensures the minimum primary energy demand and the difference with the model I3 is noticeably (~ 13%). In detail it is possible to point out:

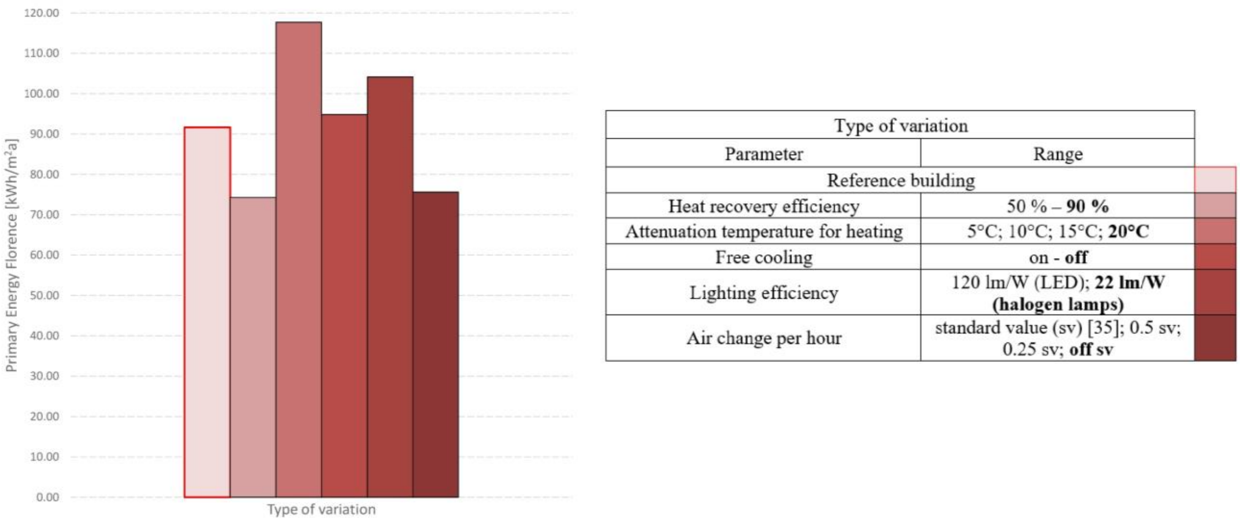
- as for the climate zone D the choice of the type of structure and the connected technological solution for external wall are the parameters that affect the final energy demand of the building as well, even if in a lower measure with respect to the shape;
- indeed, the structure with double OSB panel (B.2.2) leads to slight increase in primary energy demand equal to about 2% for a city with a mild climate where the demand for cooling is prevalent with respect to demand for heating.

With respect to the final energy for cooling the structure with double OSB panel causes a rise in final energy needs for cooling equal to about 10% compared to the reference model with XLAM structure;

- the use of green roof technological solution does not cause a remarkable advantage in terms of primary energy demand (< 2%);
- in contrast to the climate zone D for the climate zone B the increase in WWR in each orientation negatively influences the primary energy demand.

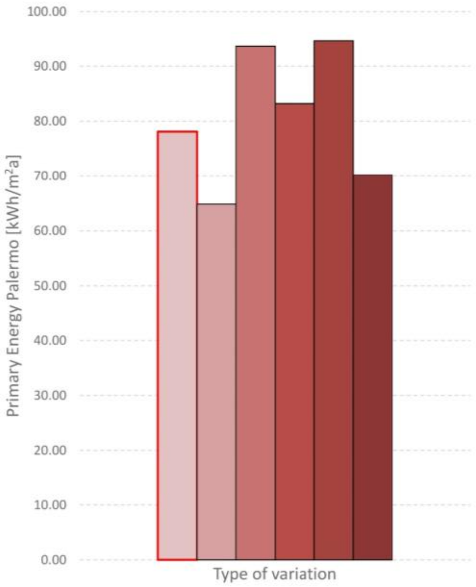
  For instance, for Palermo the increase in WWR for East façade leads to a corresponding increase of 9% of primary energy demand despite it is calculated in according to windows for areas with lower occupation during teaching time.

For both cities the parameters that have a greater effect are those related to systems (Heat recovery, attenuation temperature, free cooling, lighting efficiency, air change rate) as reported in the following graphs (Figure 4.32 – Figure 4.33).



Type of variation		
Parameter	Range	
Reference building		🟥
Heat recovery efficiency	50 % – **90 %**	🟥
Attenuation temperature for heating	5°C; 10°C; 15°C; **20°C**	🟥
Free cooling	on - **off**	🟥
Lighting efficiency	120 lm/W (LED); **22 lm/W (halogen lamps)**	🟥
Air change per hour	standard value (sv) [35]; 0.5 sv; 0.25 sv; **off sv**	🟥

Figure 4.32 Primary energy demand for Florence with respect to some system variables – table 4.12



Type of variation		
Parameter	Range	
Reference building		🟥
Heat recovery efficiency	50 % – **90 %**	🟥
Attenuation temperature for heating	5°C; 10°C; 15°C; **20°C**	🟥
Free cooling	on - **off**	🟥
Lighting efficiency	120 lm/W (LED); **22 lm/W (halogen lamps)**	🟥
Air change per hour	standard value (sv) [35]; 0.5 sv; 0.25 sv; **off sv**	🟥

Figure 4.33 Primary energy demand for Palermo with respect to some system variables – table 4.12

The contribution of mechanical ventilation to maintain the air change rate required by legislation for schools is so relevant that it influences the results related to the whole analysis.

To understand the influence of ventilation on primary energy demand a value equal to a quarter of that established for ventilation by the UNI 10339 for schools was evaluated:

- for Florence a saving on primary energy demand equal to 21% is achieved;
- for Palermo equal to 11%.

This statement is in according to the results of Maite Gil-Báez [21] that stress that for a school ventilation and infiltration affect the energy consumption for heating by 41.6% with respect other analysed variables, such as for instance the technological solution used for the external envelope and dispersions through windows. Furthermore, for this type of building is essential to keep the attenuation temperature for heating equal to 10°C for both climate zones. This is because this value leads to an improvement of energy performance of the building. In fact, for the city of Florence with colder winter an increase in attenuation temperature for heating of 5°C (from 10°C to 15°C) causes an increase in primary energy demand of 5% while for Palermo of 2%.

Finally, for what concerns Palermo, if the free cooling is not considered during the summer season the energy consumption for cooling increases of 22% with resulting increase of primary energy needs of building equal approximately to 6%.

Since it was not possible to calculate the sensitivity index for each single variation (Table 4.12) the table A.24 shows the variation in percentage of primary energy demand for both the city of Florence (Figure 4.34) and Palermo (Figure 4.35) with respect to the model considered as reference.

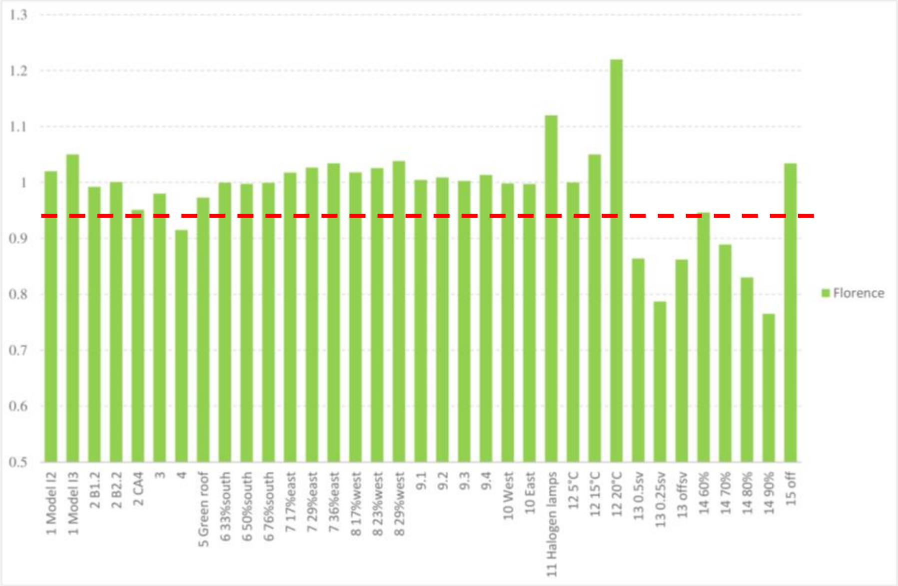


Figure 4.34 Results of the sensitivity analysis for the cities of Florence. The values are normalized with respect to model I1

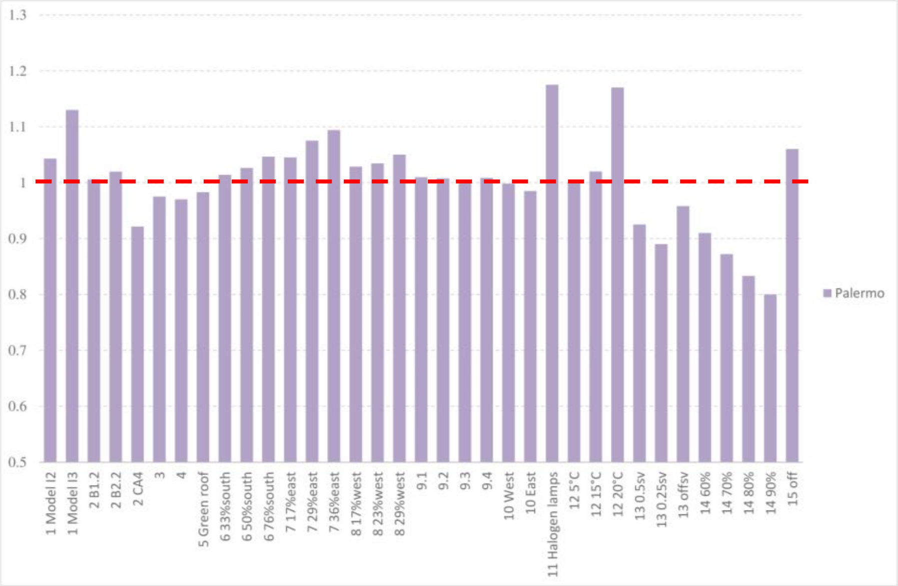


Figure 4.35 Results of the sensitivity analysis for the cities of Palermo. The values are normalized with respect to model I1

The performed simulations point out that the variation of different considered design features implies an influence on primary energy demand of the building in both examined climate zones that cannot be ignored to design neutral carbon schools. In the preliminary phase of the design process the proper combination of strategies and techniques to be used in the building necessarily affect the energy performance and consequently its environmental impact and greenhouse gas emissions in the atmosphere.

In conclusion, as the study shows:

- the parameters related to the systems that significantly affect the primary energy demand are the high air change rates required by Italian current legislation, in according to significant literature, the choice of attenuation temperature for heating and the efficiency of heat sensible recovery for controlled mechanical ventilation.

The high air change rates required for schools by UNI 10339 inevitably affect the results of sensitivity analysis related to building features;

- for what concerns the choice of a proper technological solution for the opaque external envelope for both Florence and Palermo the appropriate periodic thermal transmittance is essential to minimize the primary energy demand of the building;
- furthermore, for both climate zones the increase in thickness of insulation for roof floor leads to a significant decrease in primary energy demand.

  For the climate zone D, where the energy contribution for heating is prevalent, an increase of thickness of insulation for external wall results in a corresponding decrease in the related primary energy demand equal to about 8.50%;
- moreover, as regards Florence as well, the implementation of WWR equal to 76% for southern façade affects the final energy demand for heating approximately of 5%;
- to reduce the primary energy for cooling a technological solution for roof floor with green roof can be used.
- for climate zone B, the parameter that mainly affects the final energy demand is the WWR.

  For the city of Palermo to minimize primary energy demand primarily linked to the primary energy demand for cooling it is necessary to minimize windows and to maintain the WWR required by health-hygiene Italian standards.
- finally considering both climate zones the use of solar shadings for East and West façade does not cause a significant variation of primary energy demand, such as the variation of type of solar shading used for South orientation.

4.4 INFLUENCE OF WINDOW-TO-WALL RATIO ON MODELS' ENERGY PERFORMANCE

In this study some variations of window-to-wall ratio (WWR) for school building type were considered in order to obtain some evaluations referred to:

- the influence of the WWR typological factor on the demand for heating, cooling and lighting;
- the WWR impact on the primary energy demand considering one year;
- the calculation of the possible CO_2 emissions amount.

The next paragraphs show the method and the main results concern the analysis of the WWR for each orientation and considering different cities. The results were showed in terms of both primary energy demand and the CO_2 emissions during operational phase.

4.4.1 Method for the parametric analysis

To evaluate the influence of WWR on primary energy demand for different identified typological models for kindergarten, a parametric analysis was carried out considering as a minimum value that one defined by current health-hygiene standards in Italy and as a maximum that one that can be achieved within the functional unit setting and as a limit for height the one corresponding to suspended ceiling inside rooms.

The parametric analysis was performed by varying WWR for each orientation at a time keeping the remaining fixed to the minimum required by regulations.

It is important to stress that the only orientation where WWR was always maintained according to minimum regulatory requirement is the northern façade to avoid an increase of dispersion and consequently an increase in the energy consumption for heating. In functional units facing like this, secondary functions are designed with limited dimensions and often without continuous presence of people and so they have lower visual comfort requirements.

For each one of the 3 analysed typological models and in each orientation 4 different configuration of WWR were defined and analysed:

- model I1:
    - South (25%-33%-50%-76%);
    - East (7%-17%-29%-36%);
    - West (7%-17%-23%-29%);
- model I2:
    - South (19%-33%-50%-76%);
    - East (7%-17%-30%);
    - West (8%-17%-30%-60%);
- model I3:
    - South (20%-34%-51%-77%);
    - West (15%-33%50%-77%).

This parametric analysis allows to identify the advisable solution for WWR in each orientation in order to suggest a possible change for the defined school building type that could improve the energy and environmental performance.

In this context WWR refers to the ratio of glazed surface to the whole façade surface in each considered orientation.

The study of the variation of the window-to-wall ratio was conducted considering the thermal transmittance defined with the study of the opaque external envelope. The configuration for the system in this study is configuration number 1.

The parametric analysis and the study presented in this paragraph was conducted with respect to:

- firstly, final energy demand for heating, cooling and lighting that was evaluated separately;
- secondly, the advisable solution was found for each typological model and for each climate zone corresponding to that one that minimizes primary energy demand due to the required energy for heating, cooling, lighting, auxiliary system and service hot water.

  It is essential to point out that only the top 3 parameters are affected by WWR variation.

  Obviously, the results are illustrated in terms of CO_2 emissions as well in order to obtain advisable and proper configuration of WWR to build neutral carbon school buildings;
- then following parametric analysis a study was carried out to assess whether the WWR advisable solution for the city of Florence (climate zone D) entailed an increase in thickness of façade insulation or a change in the type of glass with respect to the one used for the basic model.

  For this analysis the medium thermal transmittance of the elements of the envelope was calculated according to the ITACA protocols for schools [19] and to the global average heat transfer coefficient for Italian regulation [16].
- finally, for climate zone B, referring to the city of Palermo, a parametric analysis of properties of the used glass was performed, considering minimum WWR in the basic model.

  Properties taken into account are visible transmission (T_{vis}) and solar transmission (T_{sol}) of the outer pane of double-glazing unit. Type of glass was chosen from available templates in Design Builder. This study aims at understanding how the variation of optical and energy characteristics of glass affects energy demand for heating, cooling and lighting.

4.4.2 Parametric analysis and WWR advisable value

In the following section the main results of the parametric analysis are reported and discussed. Figure 4.36 and Figure 4.37 show the relationship between WWR variation on southern oriented façade and final energy demand respectively for heating and cooling considered for model I1 located in Milan, Florence and Palermo.

For brevity only the results related to Model I1 located in Milan, Florence and Palermo are shown throughout graphs. The other graphs related to model I2 and I3 and the other cities are in Appendix A. However, in the text all the results are discussed.

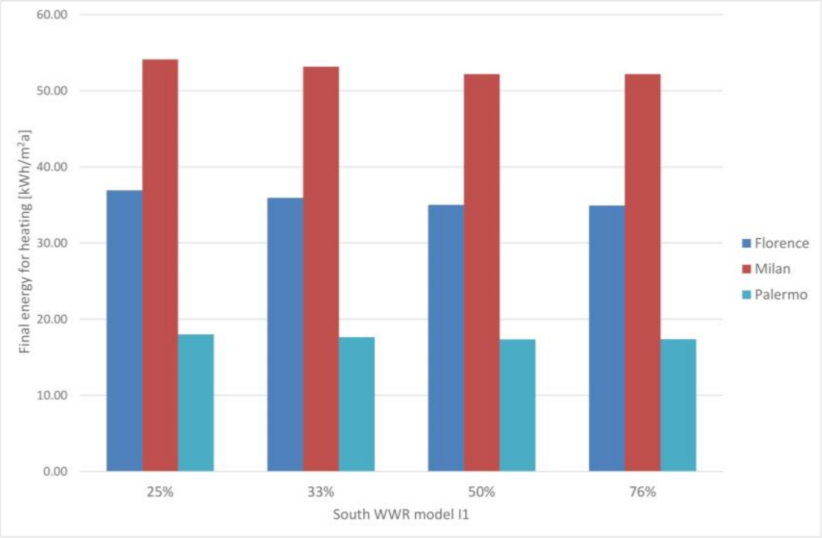


Figure 4.36 Final energy demand for heating with respect to South WWR variation in model I1

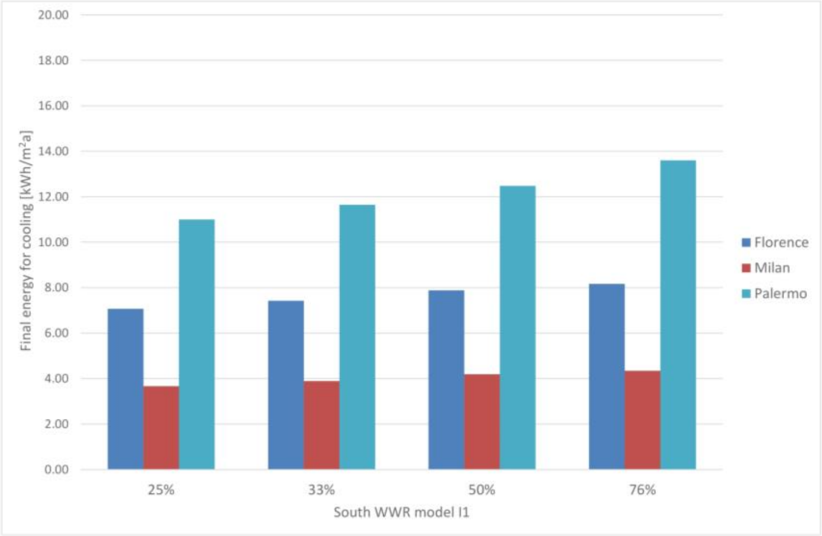


Figure 4.37 Final energy demand for cooling with respect to South WWR variation in model I1

From Figure 4.36 - Figure 4.37 (Figure A.1 – Figure A.2) it is possible to notice that:

- for Milan, Florence and Rome (climate zones E and D) the final energy demand variation required for heating from WWR value equal to 25% to 50% is remarkable because it leads to a decrease in energy consumption by 1.80 kWh/m^{2}a (~ 5%). This is mainly due to the increase in solar gains increasing WWR value that leads necessarily to a reduction in final energy demand for heating;
- for the city of Palermo the difference in terms of final energy demand for the winter season is basically irrelevant (about 0.60 kWh/m^{2}a);
- for Naples and Palermo (climate zones C and B) with a milder climate and the summer season with higher temperatures the most appreciable variation relates to cooling demand that increases considerably (about 20%) with south WWR increase as shown in Figure 4.37.

This also occurs with the use of overhang of 2.00 m on southern façade because for the autumn and spring season it does not ensure the total shading of glazed elements (for example for the month of September).

Furthermore, the type of glass used for Palermo is definitely characterized by a low energy performance compared to that one applied to the other climate zones because for B climate zone the law requires a less restrictive value of thermal transmittance. This affects the amount of final energy for both heating and cooling.

For models I2 and I3 the variation of final energy demand for heating is the same as model I1 as shown in Figure A.3 and in Figure A.4. As far as cooling is concerned, the increase in final energy demand is significant as shown in Figure A.5 and in Figure A.6 with the increase of WWR for models I2 and I3 considering Naples and Palermo cities. Especially for the model with 3 classrooms (model I2) with WWR equal to 76% for Naples there is an increase of 5 kWh/m^{2}a of cooling demand compared to the value of new building type, while for Palermo of 10 kWh/m^{2}a (+ 50% of cooling demand in one year).

Therefore, it is essential to carefully consider the energy performance of buildings also during the summer season in order to avoid unreasonably overheated rooms and consequently an oversize air conditioning system. Besides modern schools have become a real civic centre that is used by residents during extracurricular time and by students and teachers for extracurricular activities even during the summer season.

Moreover Figure 4.38 and Figure 4.39 (Figure A.7 – Figure A.8) depict the relationship between WWR variation on eastern oriented façade and final energy demand respectively for heating and cooling for model I1 characterized by compact shape with internal courtyard.

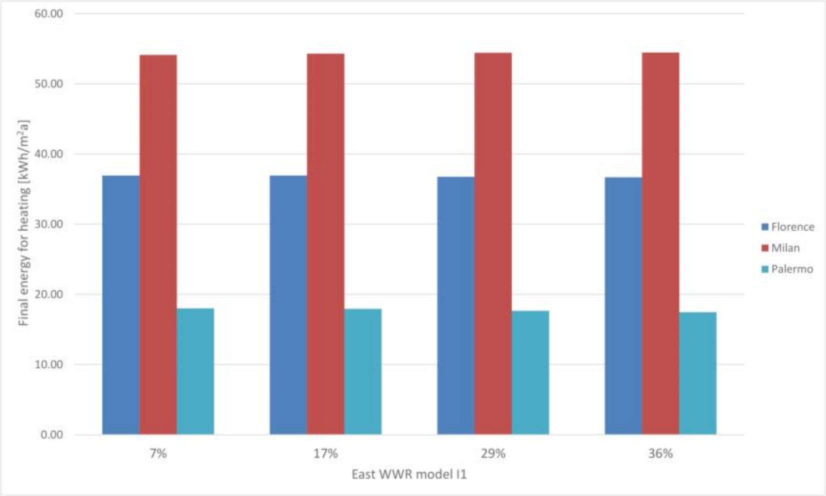


Figure 4.38 Final energy demand for heating with respect to East WWR variation in model I1. The graph clearly shows that the increase in WWR for East orientation does not result in any change concerns with final energy demand for heating

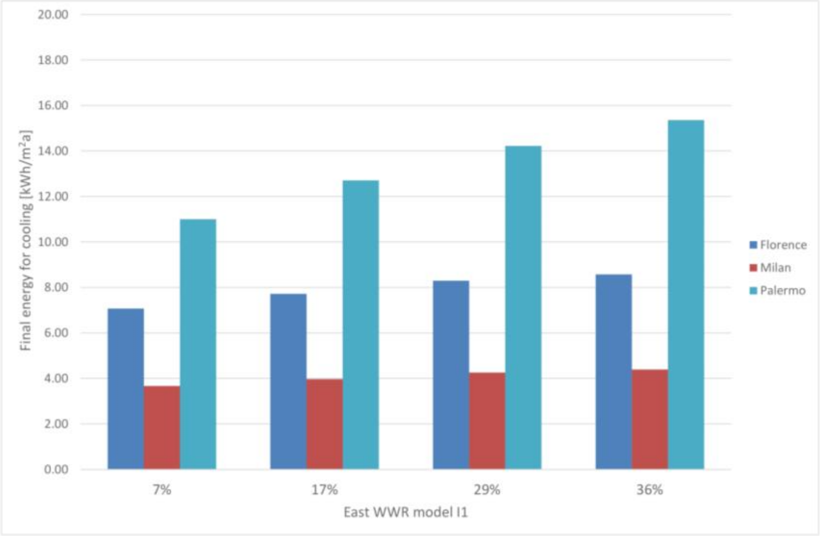


Figure 4.39 Final energy demand for cooling with respect to East WWR variation in model I1

Graphs analysis (Figure 4.38 – Figure A.9) allows to assert that for kindergarten model with compact shape and internal courtyard (model I1) the WWR variation on eastern and western orientation is practically irrelevant with regard to demand for heating.

While for what concerns cooling it is necessary to discuss results considering different climate zones:

- for Milan, Florence and Rome with the highest WWR available (36% east or 29% west) there is not a noticeable increase of final energy demand for cooling;
- however, for Naples and Palermo, an increase of WWR on eastern façade leads to a more relevant rise in final energy demand for the summer season with respect to western façade (Figure A.10). This increase of energy consumption can be compared with that one on southern façade and it occurs on the same scale;
- consequently, it is possible to state that the increase of WWR on eastern façade mainly affects final energy demand for cooling with respect to the same increase on western façade for a building with compact shape, distinguished by this orientation of functional bands and by this distribution of internal functional units characterized by particular occupancy and air change rate.

Talking about the other two models I2 and I3 the increase in WWR on eastern and western façade affects final energy demand both for cooling and heating of the analysed building to a definitely lesser extent compared to that one on the southern façade. This is mainly linked to the shape of basic models that have a more predominant linear shape with one dimension than the other one with a prevailing axis along East-West direction.

Finally, WWR influences to a lesser extent lighting energy consumption. As a matter of fact, for each model and for each climate zone there is not a significant decrease of lighting consumption. The increase of southern WWR is the most influential with regard to this parameter (Figure A.11), for instance, with respect to the variation of WWR for South.

In order to understand which is the advisable configuration for the value of WWR with respect to the one defined with new building type that is required by health-hygiene Italian standard the value of both the CO_2 emissions due to heating and cooling consumption and the primary energy demand was evaluated. In fact, as already described in the methodology, the advisable solution for WWR for each typological model is that one that minimizes the primary energy demand and therefore the CO_2 emissions during the operational phase. The results are reported for the model I1 for the city of Florence and Palermo (Appendix A).

Firstly, Figure 4.40 and Figure 4.41 exhibits the CO_2 emissions in the atmosphere during the operational phase of the kindergarten (model I1) respectively related to heating and cooling system for the city of Florence. While Figure A.12 and Figure A.13 illustrate the same results but referred to the city of Palermo.

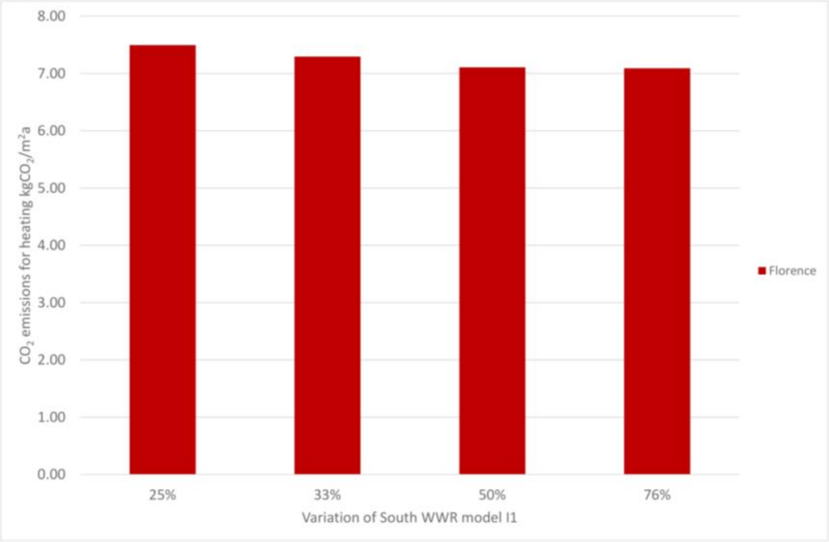


Figure 4.40 CO_2 emissions due to heating with respect to South WWR variation in model I1 located in Florence

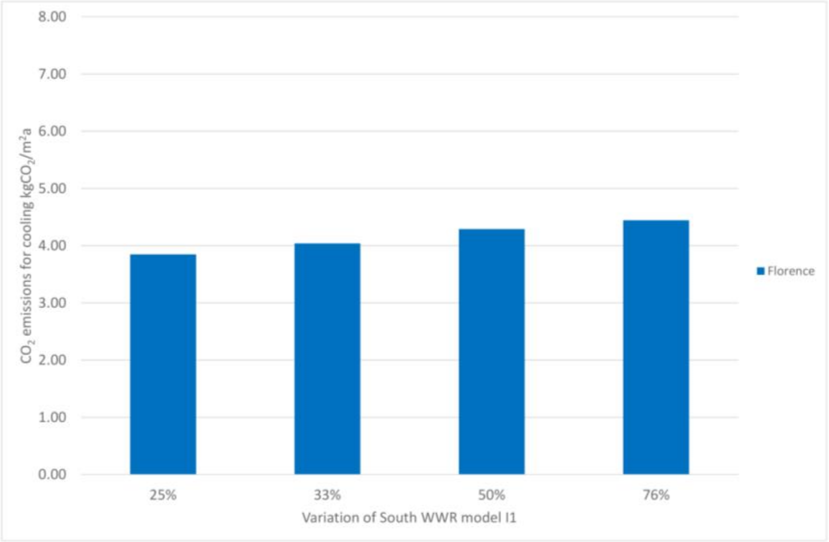


Figure 4.41 CO_2 emissions due to cooling with respect to South WWR variation in model I1 located in Florence

By analysing these graphs, it is possible to admit that:

- for the city of Florence, a rise in southern WWR leads to a decrease in CO_2 emissions owing to the heating system by 5% from a value of WWR equal to 25% to 50%. Despite a meaningless difference in the amount of CO_2 emissions from 50% to 76% occurs.
  This is mainly related to the exploitation of the solar gains that rise with increasing WWR;
- for the city of Florence, when WWR increases from 25% to 76%, the CO_2 emissions amount due to the cooling system increases by 506 kg_{CO2}/a;
- while, for the city of Palermo a slight decrease in CO_2 emissions amount because of heating system despite a significant rise in CO_2 emissions referred to cooling system happens from WWR equal to 25% to 76% by 1207 kg_{CO2}/a during the operational phase.

Secondly, the next graphs exhibit for model I1 situated in the city of Florence the variation of primary energy demand with respect to the variation of WWR for South (Figure 4.42) and East (Figure 4.43) orientation.

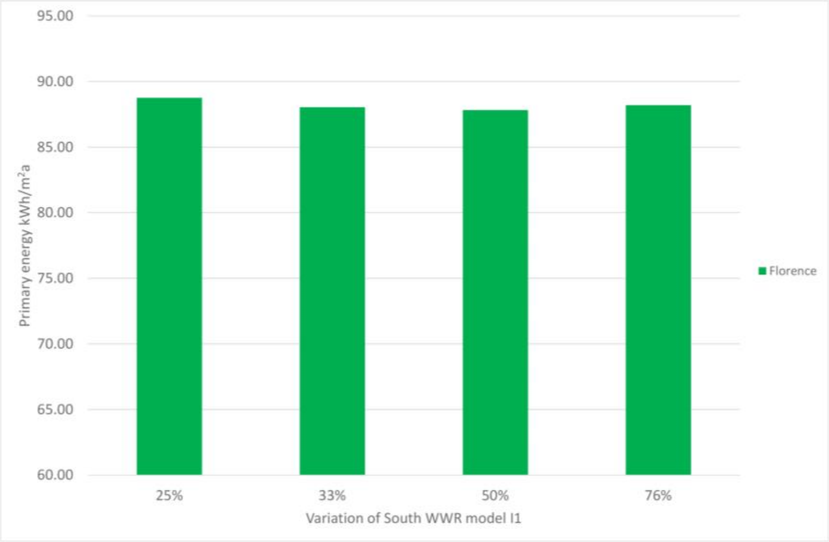


Figure 4.42 Primary energy demand with respect to South WWR variation in model I1 located in Florence

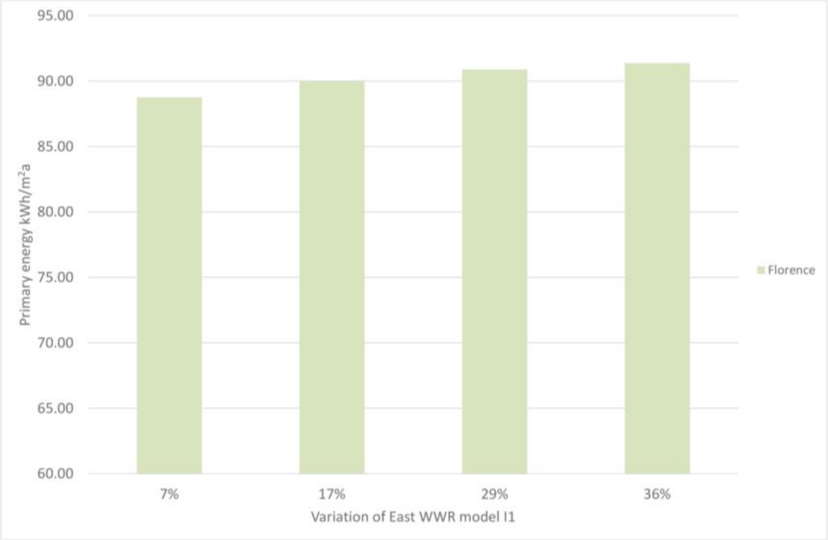


Figure 4.43 Primary energy demand with respect to East WWR variation in model I1 located in Florence

As shown in the prior graphs for climate zone D and so far as E, for each typological model the lowest energy demand is obtained by having on southern façade WWR equal to 50% and keeping WWR of other façades to the minimum level required by Italian standards. In such climate zones, this is because the highest energy consumption for school building occurs during winter season.

This occurs also for the other 2 typological models considered for the study on the variation of WWR.

However, for what concerns Palermo (Figure A.14 – Figure A.15 – Figure A.16) and so for Naples, cooling gives the most significant contribution in terms of energy during the summer season. Then, the optimal solution is that one with the minimum WWR in each orientation and for each typological model considered.

As shown in the previous graphs for the city of Palermo:

- for South orientation rising WWR leads to a remarkably increase in primary energy demands equal to about 4%;
- for eastern and western orientation increasing WWR from 7% to respectively 36% and 29% induces to a significant rise in primary energy demand of about 4 kWh/m^{2}a and 8 kWh/m^{2}a.

The search of WWR configuration in complex building cannot ignore internal functional distribution and site geographic location. An improper design of WWR of a building during the preliminary phase of the design process involves both an oversizing of a system and an increase of energy needs of the building.

It is important to point out that in schools, due to the typical high crowding of the intended use of this building, the contribution of ventilation exerts a considerable influence on energy balance and consequently on primary energy demand. Necessarily, the presented results are significantly influenced by the high ventilation required for air change rate to comply with regulations especially for classrooms and the canteen.

To conclude, the performed simulations point out that:

- WWR exerts a considerable influence on the primary energy demand even for a building school designed on a single ground floor;
- as shown by the study window-to-wall ratio cannot ignore the identification of the climate zone where a building is located, the shape and finally the orientation and the distribution of functional bands and units;
- regarding colder climate zones, the increase in WWR positively affects the final energy demand for heating that decreases when the South oriented glazed surface increases (Milan with WWR 76% - decrease of 5% in heating final energy needs), while for those zones, WWR does not affect cooling consumption considerably;
- for the cities of Naples and Palermo, that are characterized by a milder climate with higher temperatures during the year, the cooling demand increases substantially with an increase in the South WWR (Naples with WWR 76% - increase by 18.8%; Palermo with WWR 76% - increase by 23.5%). This condition is particularly accentuated in model I2 and I3 defined by a predominant linear shape with a prevailing axis along East-West direction;

- the analysis of the variation on East and West façade allows to stress that South orientation is not the only critical one, especially for the typological model with a compact shape and for milder climates. Increasing WWR mainly for East orientation leads to a noticeable increase of energy demand for cooling. It occurs at the same scale and in the conditions of South orientation.
  This situation changes for models with a predominant linear shape that presents limited dimensions along East and West directions.

Summing up the advisable configuration of WWR with respect to the one of the new school building type (required for health-hygiene Italian standard) that lets to obtain a reduction of both the primary energy demand and CO_2 emissions should be:

- for climate zone D and so far as E a value of WWR on southern façade equal to 50% and a value of WWR for other orientations equal to the minimum level required by Italian standards. In such climate zones, this is because the highest energy consumption for school building occurs during winter season;
- for climate zone C and D the solution for WWR is that one with the minimum value of WWR in each orientation.

For completeness, the value of WWR for each orientation has been analysed also with respect to medium thermal transmittance of the elements of the envelope in according to the ITACA protocols for schools [19] and to the global average heat transfer coefficient for Italian regulation [16].

For instance, Table 4.14 illustrates results related to mode I1 for the city of Florence (climate zone D). The table illustrates: the windows area for each orientation [A_{window}], the global average heat transfer coefficient limit for climate zone D ($H'_{T,lim}$), the global average heat transfer coefficient limit for the analysed school building (H'_T), the medium thermal transmittance limit of the elements of the envelope ($U_{m,lim}$) and the medium thermal transmittance of the elements of the envelope for the examined school building (U_m).

Once the advisable WWR for each orientation has been defined according to previous considerations, the variation of the medium thermal transmittance was evaluated by varying WWR for South orientation only and only for the city of Florence. For Palermo no variations on WWR occurs as demonstrated before.

As maximum reference limits, the value of the medium thermal transmittance was considered equal to 0.362 W/m^{2}K for climate zone D, assessed in according to ITACA protocol for schools, and the value of global average transfer coefficient limit equal to 0.58 W/m^{2}K in line with Italian energy regulation with respect to surface - volume ratio.

Table 4.14 Medium thermal transmittance and global average heat transfer coefficient

City	Model	Advisable WWR	A_{window} [m^2]	$H'_{T,lim}$ [W/m^{2}K]	H'_T [W/m^{2}K]	$U_{m,lim}$ [W/m^{2}K]	U_m [W/m^{2}K]
Florence	I1	South = 50%	South = 109.50	0.580	0.258	0.362	0.258
		North = 11%	North = 17.30				
		East = 7%	East = 12.00				
		West = 7%	West = 12.00				

Table 4.14 shows that for the advisable WWR of model I1 and for the climate characteristics of the city of Florence there is a significant increase in the medium thermal transmittance of the external wall (from 0.46 W/m^{2}K to 0.85 W/m^{2}K) due to the increase in the glass surface with respect to the basic model.

However, it minimally affects the medium thermal transmittance of the elements of the envelope that remains under the value of 0.3 W/m^{2}K.

According to this result it is possible to point out that for these new typological models for kindergarten it is not necessary either to increase the thickness of insulation for the opaque vertical external envelope (14 cm) or to change the type of the basic glass used.

Finally, the last considerations concern the variation of the properties of the external pan of double-glazing windows for Palermo, located in climate zone B.

This study has been conducted because this city is characterized by a climate characterised by 5 months with temperature above 20°C during the summer season. Under such conditions, glass properties and its dimension significantly affect the energy performance of buildings, energy needs for cooling and nonetheless well-being of the occupants.

Table 4.15 indicates the main characteristics of the different types of external pans used to performed simulations.

The transmittance value is not indicated because it is the same as the basic solution in order to avoid its influence on the results of the analysis. While the solar transmittance (Ts) and the visible transmittance (Tv) have been changed. The model I1 of kindergarten with a compact shape with an internal courtyard is analysed in this case as well.

Table 4.15 Main characteristics of different type of glass – AGC manufacturer

Name of glass	Type	Ts [%]	Tv [%]
Stratobel DB	55.1	0.713	0.868
Stratobel DB	66.1	0.685	0.858
Stratobel DB	66.2	0.673	0.858
Clearvision	12	0.879	0.908
Solarshield green	6	0.37	0.704
Krystal clear	12.AFG	0.881	0.908
Defender Ti-R	090.AFG	0.406	0.704
Defender embedded	DefCS73	0.573	0.807
Defender comfort E72	DrClrE2	0.611	0.831
Comfort select73	CS73Lami	0.586	0.812
Flatglass Philippines	FL6.AFP	0.785	0.882
ASAHI GLASS	FL5.AGC	0.829	0.895

Figure 4.44 shows the final energy demand for heating, cooling and lighting with respect to different types of external pans of double-glazing windows for Palermo.

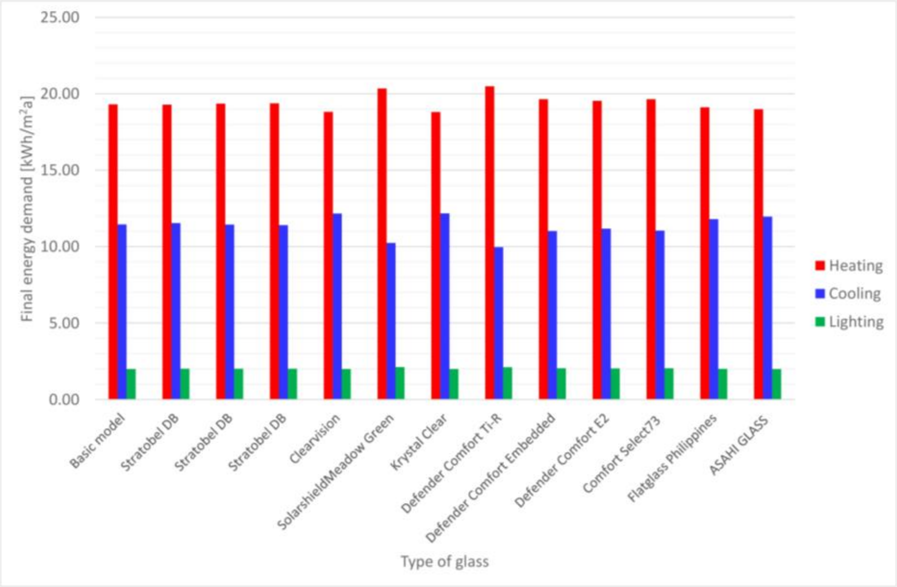


Figure 4.44 Final energy demand for heating, cooling and lighting consumption in relation to different type of glass. The graph intends to show the slight difference in final energy demand for heating, cooling and lighting due to the use of one glass solution with respect to other ones. The aim is to give an idea of the influence on final energy demand of different type of glass that the designer could be chose and used for a school.

Figure 4.44 shows that visible transmittance and solar transmittance affect energy needs of buildings compared to the basic solution in the case of optimal solution for South WWR (WWR equal to 25%) for Palermo.

This applies especially for energy consumption for cooling. The solution that adopts *Defender Comfort Ti-R* as external pane allows to have a benefit of about 1.5 kWh/m^{2}a for cooling. It is characterised by a value of solar transmittance approximately equal to half of that of the basic solution.

In addition, concerning energy consumption for lighting the optimal solution is that one characterised by a high visible transmission and a low solar transmission. The best solution is the use of a *Clearvision pane*.

However, cooling requirement for Palermo affected more significantly the energy consumption than the lighting one. Consequently, in both these situations and regarding WWR, the advisable solution is certainly the one that minimizes cooling demand. For the city of Palermo, a solution with a glass with external pane with solar transmittance equal to about 0.406 % is advisable for a school building.

4.5 STUDY ON SOLAR SHADING SYSTEMS

The main objective of this study is the evaluation of the efficiency of the most common solar shading systems that could be used for new building type for kindergarten in Italy [41] as different alternatives.

It is essential to understand, in relation to the intended use of the building, whether a fixed system or a mobile shielding system with relative control device is more convenient and fruitful in terms of energy requirements.

Furthermore, it is necessary to evaluate the natural lighting conditions inside the classrooms (UNI 10840) [42] to establish which is the advisable arrangement of the openings in the façade and the optimal combination of the shielding systems to ensure a correct value of the daylighting factor and uniformity of lighting and to avoid glare in the areas where visual tasks are performed.

In the next paragraphs the methodology for the study and the main results are discussed.

4.5.1 Method

The methodology for the study on solar shading systems to use in kindergarten in Italy for different orientation is divided in several steps:

- initially the analysis applied to the 3 new typological models for kindergarten concerns the comparison of the most common shielding systems (Figure 4.26) for South orientation, where the sections are located:
    - external venetian blinds with high reflection coefficient of the slats with control on the incident solar radiation;
    - fixed solar shading system realized with an overhang equal to 2 m;
    - horizontal louvres;
    - combination with overhang and internal blinds with incident solar radiation control;
    - external venetian blind with solar control.

The influence of the application of the different solutions was assessed not only in relation to the energy demand, but also in relation to the individual heating, cooling and lighting contributions;

- subsequently, the possibility of adopting a fixed or automated horizontal blinds system with different types of control was analysed (Table 4.16);

Table 4.16 Definition of different type of solar shading control system

Type of solar shading control system	Control definition[11]
Always on	Shading devices are always activated
Schedule	It is defined by a time only through a schedule (schedule equal to 1 then shading operates)
Solar	Solar radiation > 120 W/m^2
Glare	Maximum glare index > 22
Outside air temperature	Outside temperature > 24°C
Inside air temperature	Inside temperature > 24°C

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[11] Design builder contents; https://designbuilder.co.uk/helpv4.5/#_Window_shading_internal_1.htm?Highlight=solar%20shading

Cooling	Shading is on if zone cooling rate in the previous time step is non-zero
Night outside low air temperature	Air temperature < 0°C
Night inside low air temperature	Air temperature < 15°C
Horizontal solar	Solar set point >120 W/m^2

The previous analysis was carried out for the cities of Florence and Palermo, also considering the variation of the ratio between opaque and transparent parts on the façade (WWR) only for climate zone D.

- furthermore, the influence on the energy performance of the new building type for kindergarten of the insertion of vertical shadings to the East and West was also evaluated considering the city of Florence and Palermo.

  The study carried out allowed to understand the solar shading system to be adopted for the construction of neutral carbon school buildings in Italy.
- finally, in order to evaluate the correct natural lighting inside the classrooms, the natural light maps of the classes were built for each individual city.

  The average factor of daylight was calculated, so as to verify the minimum value in compliance with the UNI 10840 [42] for school premises, and the uniformity ratio, in relation to the minimum and average value of the daylight factor, with respect to the different positioning of the façade openings and to the advisable WWR value for each individual city considered.

  Since the class has in all the models the same shape and organization in plan, as shown before, the analysis has been carried out considering the 3 classrooms in model I1 situated in all cities considered (Mila, Florence, Rome, Naples, Palermo) while the 3 classrooms of the model I2 in the cities of Florence and Palermo to have a comparison, evaluating the natural lighting for June 21st and December 21st at 12:00 with model of CIE sky (clear sky) and a worktop height of 75 cm.

The configuration for the system in this study is configuration number 1.

4.5.2 Results concern with solar shading analysis

To demonstrate the influence on the final energy demand for heating, cooling and lighting of the use of solar shading (for instance a fixed overhang of 2 m) for the South-facing functional units for the different typological models, a comparison was made with the basic models with the same characteristics but without the insertion of the solar shield.

The results of this first simple analysis show that:

- the use of shielding on the South-oriented front significantly influences the energy demand for cooling, and in all climatic zones, especially for the model I2, while it affects to a lesser extent on the demand for lighting;
- in the model I1, on the other hand, the most significant figure is the demand for heating with a decrease in energy demand of around 55% for the city of Palermo;
- regarding the city of Florence, the demand for heating fell by about 3% for the model I2.

> It is necessary to underline that the insertion of the solar shading to the South is required by the current Italian legislation on energy [12] and allows to obtain an adequate value of the ratio between the equivalent summer solar area of the building ($A_{sol,east}$) and the useful surface of the building ($A_{sup,useful}$) in relation to the performance of the external envelope for the summer season.

Regarding the variation of the type of shielding on the southern front, the simulations carried out on the 3 typological models in the cities of Florence and Palermo show that this change marginally (~ 1%) affects the final energy demand of the buildings analysed.

For the sake of completeness, however, an analysis was carried out with respect to the individual contributions of the energy balance to understand which parameters mainly influenced the change in the type of shielding considering the three models located in the cities of Florence and Palermo.

Figure 4.45, referring to the city of Florence, shows in fact the percentage variation with respect to the basic model with fixed shielding (2.00 m overhang) of the final energy demand for cooling and heating relative to the 3 typological models, with reference to the different alternatives of solar shading (Figure 4.26) that can be adopted for the southern front.

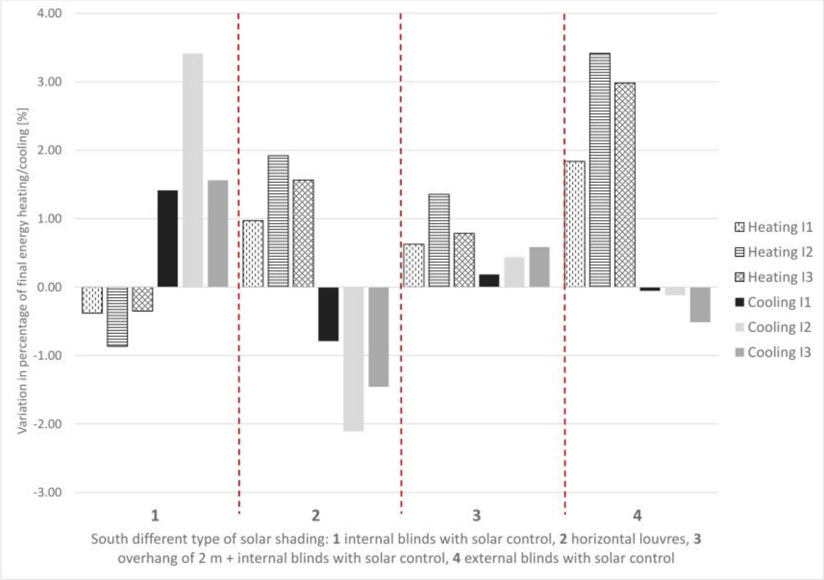

Figure 4.45 Variation in percentage of final energy demand for heating and cooling for Florence for the 3 models and different types of solar shading

It can be seen that for models with mainly horizontal development (model I2 and model I3) the use of an internal shield with solar control (120 W/m^2) involves a significant increase for cooling demand (~ 3.5%) while the use of the same external shielding implies an increase in heating demand of the same order of magnitude.

For cities belonging to climatic zones E and D where the contribution of the energy required for heating is predominant in the energy balance, the advisable shield for the South orientation is the internal one with control over the maximum solar radiation (120 W/m^2).

Figure 4.58 illustrates the percentage change in final energy consumption for heating and cooling compared to the reference model with overhang referred to the city of Palermo.

The graph (Figure A.17) shows that for cities like Palermo, characterized by a mild climate with very hot summers, especially for the models with an elongated shape (model I2 and model I3) in the direction of the East-West axis, the advisable solar shading for the South orientation is the one realized with an overhang of 2.00 m and an internal venetian blind with control on the incident solar radiation (120 W/m^2) as it allows to obtain a reduction of the energy requirement for cooling of around 6.5%.

Finally, compared to artificial lighting the use of the overhang of 2 m is the solution for all the climatic zones considered as a solution that allows greater savings for all the models studied (Figure 4.46).

It is important to underline that for a school building the energy consumption for lighting is a contribution that has a minimal impact on the energy balance compared to the need for ventilation, heating and cooling.

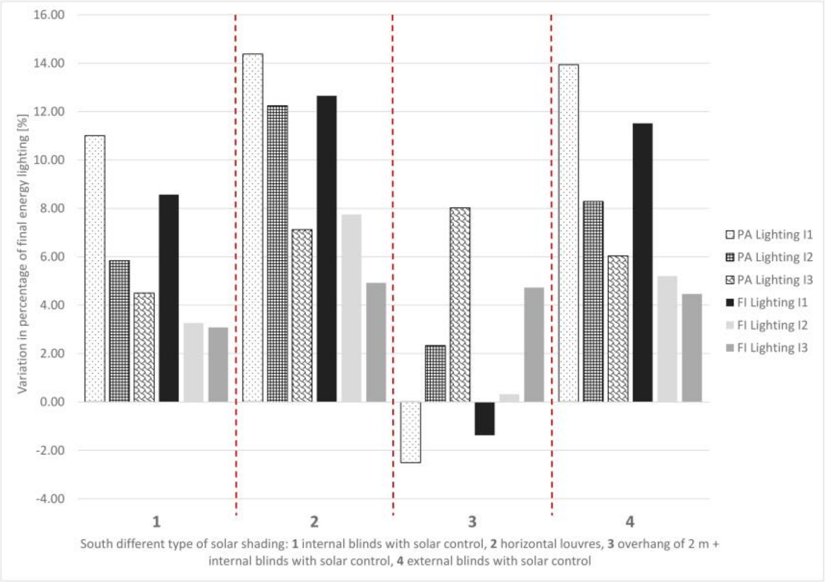

Figure 4.46 Variation in percentage of final energy demand for lighting for Florence and Palermo for the 3 models and different types of solar shading

In relation to the various control systems (reported in Table 4.16), an internal venetian blinds shield was considered for the South-oriented classes and a study was carried out on the model I1 located in the cities of Florence and Palermo (Figure A.18).

Figure 4.47 illustrates the primary energy demand of the model I1 during the operational phase with different type of control on the internal venetian blinds. For completeness Figure 4.48 exhibits the related amount of CO_2 emissions in the atmosphere with respect to the same situation.

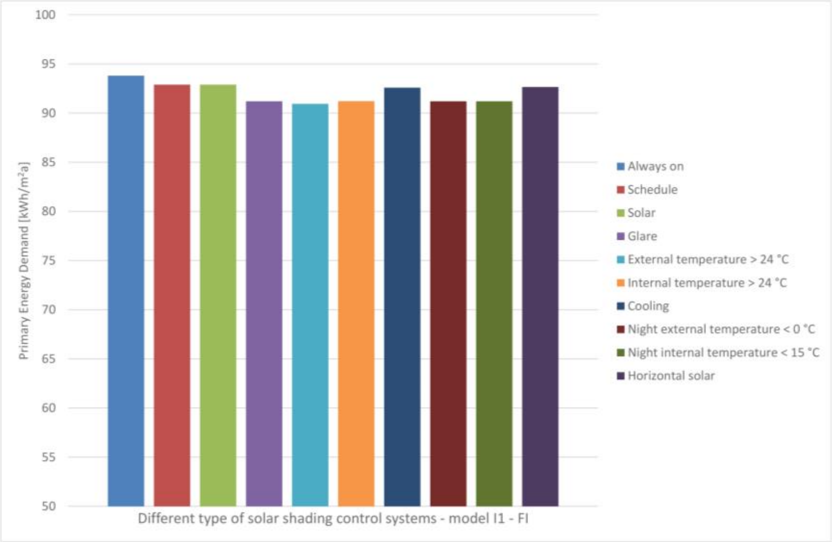

Figure 4.47 Primary energy demand for different type of solar shading control systems for Florence on model I1. The range of variation of the different solutions is between about 91 kWh/m^{2}a and 94 kWh/m^{2}a. The graph is useful to understand that anyway there is a slight difference between the different solutions analysed.

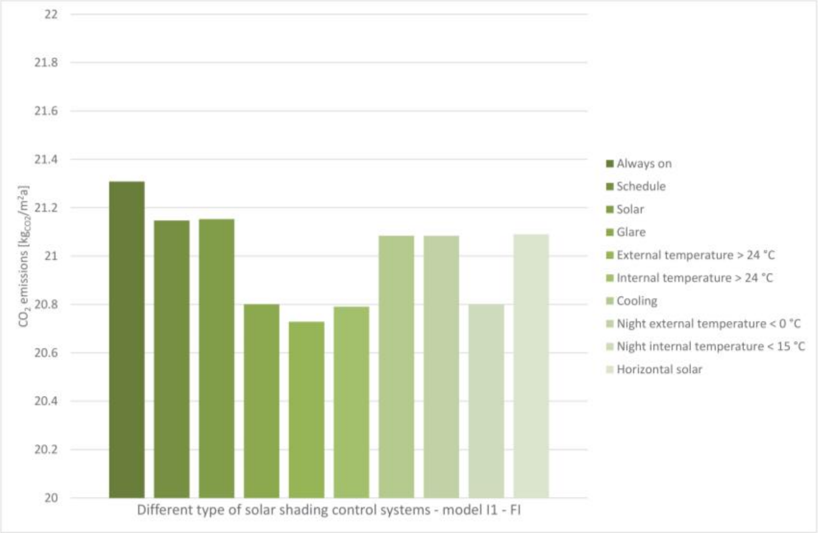

Figure 4.48 CO_2 emissions for different type of solar shading control systems for Florence on model I1. The range of variation is between 20.5 kg_{CO2}/m^2a and 21.5 kg_{CO2}/m^2a. The graph does not show a significant difference between the different type of control.

The study was carried out for the city of Florence (Figure A.19) for which the advisable value of the WWR in the South is 50% and therefore different from the minimum required by the current health and hygiene regulations in Italy, adopted in the building type for kindergarten. In this case as well, considering the city of Florence, the trend of the variation in primary energy demand with respect to the control system adopted is the same as in the previous case, even if the decrease in energy demand is slightly higher.

Concluding:

- the use of the fixed overhang allows to obtain a summer performance of the external envelope according to the standards imposed by the DM 26 June 2015 for the construction of a nZEB building. The utilisation of it also allows to respect the requests of the new teaching and pedagogical methods that support a visual link between the class and the external natural environment;

- for both climatic zones the automated blinds reduce the primary energy demand and the CO_2 emissions compared to the fixed solar reference solar shading. This happens for any type of control analysed;
- the advisable type of control for automated solar shading is for both climatic zones (D and B) the one which imposes a limit on the external temperature, considered equal to a maximum of 24 °C;
- for climate zone D the second-best solution is the one with the glare control with a Discomfort Glare Index (DGI) [18] considered, in the case under examination, to be a maximum of 21 according to the regulations for kindergarten;
- for climate zone B, characterized by warmer summers and a more limited heating period, the second-best solution is the one with cooling control;
- the simulations concerning the insertion of vertical shields to the East and West for the compact typological model with internal courtyard (model I1) demonstrate that their use does not entail significant benefits in terms of consumption for heating, cooling and lighting (<1%). This situation is most evident in the I2 and I3 models which have most of the openings along the East-West axis.

Summing up the advisable configuration of solar shading system with respect to the one defined for the new school building type should be:

- for climate zones E and D a fixed overhang of 2.00 m and an automated internal blinds with high reflection slats and control on the external temperature (24°C) or on DGI (21) for South orientation. For East and West orientation, a solar shading system is not necessary;
- for climate zones C and B a fixed overhang of 2.00 m and an automated internal blinds with high reflection slats and control on the external temperature (24°C) or on cooling for South orientation. For East and West orientation, a solar shading system is not necessary[ii].

To assess the visual comfort within the classes with the previous configurations of solar shading system, maps of natural lighting have been created in terms of daylighting factor and uniformity of illuminance [43]. The WWR considered for the realization of the maps for natural lighting is both the minimum considered for the new building type (*Chapter 3*) and the advisable one (*Chapter 4*):

- South WWR = 50% (I1 - I2) for Florence, Milan and Rome;
- South WWR = 25% (I1) and 19% (I2) for Naples and Palermo.

The solutions with only one window for classrooms and 2 windows have been taken into consideration as well in order to suggest the adequate configuration for the façade.

For the sake of brevity, only some maps of natural lighting are reported.

So Figure 4.49 illustrates the natural lighting map for the I1 model with reference to the functional range of the classrooms on June 21st at 12 noon for Florence. In this case the advisable WWR is considered for the classrooms with only one window. Despite Figure 4.50 exhibits the natural lighting map always for the model I1 but with the minimum value of WWR with only one windows. It is obvious that the distribution in the area where main teaching tasks are performed as evidently different.

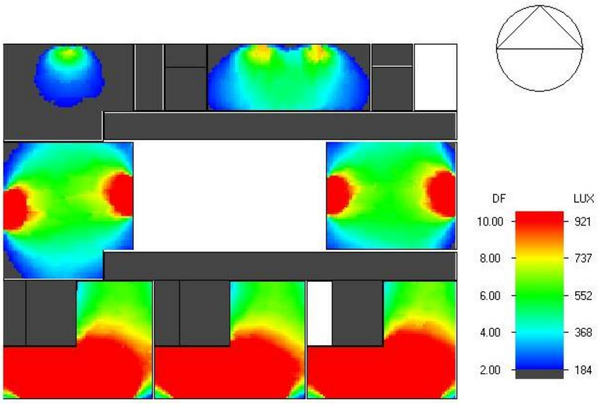

Figure 4.49 Maps of natural daylight for the model I1 in the city of Florence for the 21st June with advisable WWR

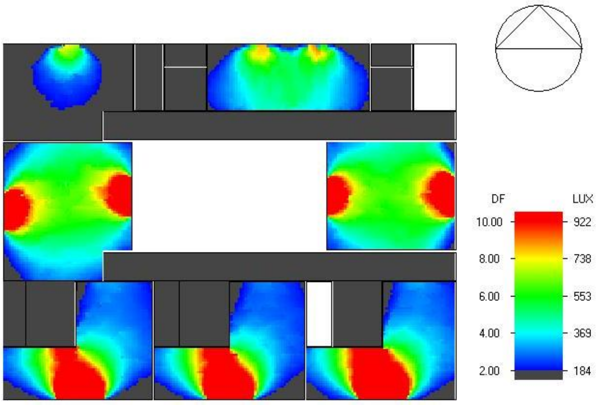

Figure 4.50 Maps of natural daylight for the model I1 in the city of Florence for the 21st June with minimum WWR

The next Figure 4.51 and Figure 4.52 illustrate the maps of natural daylight in each classroom for the model I1 respectively for Florence and Palermo considering the advisable value of WWR using 2 windows.

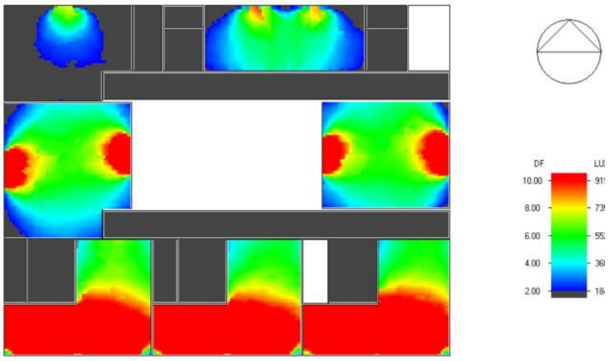

Figure 4.51 Maps of natural daylight for the model I1 in the city of Florence for the 21st June with advisable WWR and 2 windows

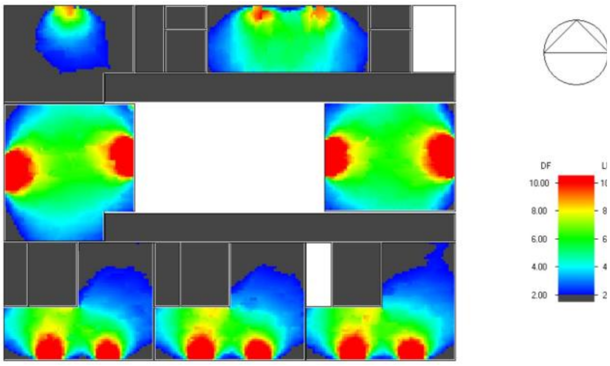

Figure 4.52 Maps of natural daylight for the model I1 in the city of Palermo for the 21st June with advisable WWR and 2 windows

Finally, Table 4.17 shows instead the values of the average daylight factor (η_m) and of the illuminance uniformity (η_{min}/η_{med}) relative to the model I1 for all cities in both 21st of June and 21st of December.

While Table 4.18 illustrates the results related to model I2 situated in the cities of Florence and Palermo for each classroom. It is important to stress out that the values of illuminance uniformity are calculated based on the area of the entire class and not where the visual tasks are mainly concentrated.

Table 4.17 Daylighting factor and illuminance uniformity for the model I1 3 classrooms for all cities with advisable WWR

City	Class	η_m [%]		η_m Uniformity (η_{min} / η_m)	
		21.06	21.12	21.06	21.12
Milan	1	14.60	20.30	0.20	0.10
	2	14.10	19.80	0.18	0.09
	3	13.70	19.70	0.17	0.09
Florence	1	14.50	20.40	0.20	0.09
	2	13.90	19.80	0.16	0.08
	3	13.77	19.90	0.18	0.085
Rome	1	14.30	20.30	0.21	0.10

	2	13.40	19.80	0.18	0.09
	3	13.30	19.70	0.18	0.09
Naples	1	5.70	7.90	0.14	0.04
	2	5.40	7.70	0.12	0.05
	3	5.40	7.75	0.12	0.05
Palermo	1	5.70	8.50	0.15	0.06
	2	5.50	8.30	0.11	0.07
	3	5.30	8.20	0.12	0.06

Table 4.18 Daylighting factor and illuminance uniformity for the model I2 3 classrooms for the cities of Florence and Palermo with advisable WWR

City	Class	η_m [%]		η_m Uniformity (η_{min} / η_m)	
		21.06	21.12	21.06	21.12
Florence	1	15.70	24.00	0.14	0.09
	2	17.60	24.90	0.125	0.09
	3	18.00	25.40	0.13	0.10
Palermo	1	5.90	9.40	0.10	0.05
	2	6.50	10.00	0.145	0.07
	3	6.40	9.70	0.10	0.05

The previous tables and natural lighting maps figures show:

- how the minimum value of the average daylight factor required by the UNI 10840 standard [18] is respected in each class and for both models since it is higher than 5% in the 5 cities considered;
- that for what it concerns the uniformity of lighting inside the classrooms, especially during the winter season and mainly for the city of Palermo, it must be guaranteed using artificial lighting mainly due to the closure of the internal solar shielding in order to avoid glare;
- that it is however important to point out that the minimum value of illuminance during the winter season is recorded at the corners of the classroom, sideways to the windows, and in the part of the classroom furthest from the window, where the area for the rest of the children is usually organized;
- that if looking at the values for the 2 models, it is clear that despite having both openings for each class, the I1 model has a more advantageous performance in terms of natural lighting as it ensures better uniformity of illuminance and an appropriate value of the daylighting factor in all climate zones.

Summing up the advisable solar shading system for the new school building type lets to guarantee an appropriate value of the average daylight factor as required by national standard. Moreover, the adoption for each class of a double opening in the façade involves a correct uniformity of lighting in both seasons in the area where visual tasks are performed.

4.6 INTEGRATION WITH RENEWABLE ENERGY: PHOTOVOLTAIC PANELS

The main aim of this study is to suggest a solution exploiting renewable source to satisfy energy demand of the new defined building type for kindergarten. Consequently, the design of a photovoltaic system was performed in order to obtain the advisable configuration of PV system for the new building type with the aim at maximising the electricity production (maximisation of the PV panels area [m^2] on the roof).

The design of this kind of PV system that exploits the entire available surface on roof definitely leads to a surplus electrical energy production measured in kWh/m^2a (with respect to the entire ground surface of the building) intended as the difference between the energy produced by PV system in one year and the final energy required by the building always in one year.

In detail this analysis aims at investigating the influence on electrical energy produced by PV system of some design parameters, for instance: the location of the PV system, the shape of the roof considering the 3 new typological models for kindergartens (model I1, model I2 and model I3), the tilt of the panel for which a parametric analysis was performed and finally the orientation of the PV panels that necessarily affects the available surface on the roof top. The configurations for the system in this study is configuration number 4.

4.6.1 Used methodology

First, to evaluate the influence of some design criteria on the PV system performance 3 different locations are considered belonging to 3 different Italian climate zones [1] which are representative of Italian climate: Milan (climate zone E), Florence (climate zone D) and Palermo (climate zone B).

Furthermore, different architectural parameters are considered and investigated:

- the shape of the building.

  For this analysis the 3 new typological models for kindergarten are examined and this choice obviously changes the available surface [m^2] on the roof top of PV panels;
- the orientation of the PV system.

  In order to maximize the production of the electrical energy 2 different configurations of PV panels and 2 different orientations are deemed (South and East/West) (Figure 4.53).

  This design criteria affects first the monthly energy production due to the different solar radiation received by the surface of the PV panel but the available and exploitable surface of PV system on the roof top too;
- the tilt angle of PV panels indicated with β that depends mainly by the latitude of the location and the inclination of the sunrays during the whole year.

  This value deeply affects the minimum distance between panels in order to guarantee no mutual shading (x_{min}) and consequently the surface of PV panels on roof top.

In this case a parametric analysis was performed, and it allows to identify the optimal tilt angle for winter and summer season that maximises the surface of PV panels and consequently the producibility.

For completeness, the tilt angle varied within a range between 10° to 80° in order to individuate and to define the proper value for the different cities considered and the 3 typological models.

This parametric analysis allows to identify the optimal distribution of the PV panels on the roof with the aim of maximising the annual electricity production (considered in this case as the sum of surplus electricity production for each month).

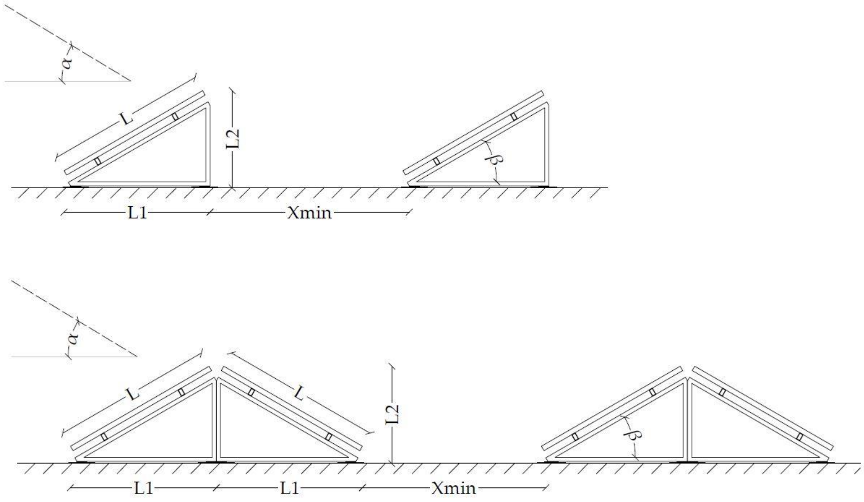

Figure 4.53 Different configuration of PV panels for South and East/West orientation

The simulation of PV panel was carried out with PVGIS-5 software[12] available online.

With this free application defining the slope angle (tilt), the azimuth angle (orientation of the panel), the system losses, the PV technology used and the kWp of the PV installed on the roof is possible to estimate:

- the average monthly electricity production of the system [kWh];
- the average monthly sum of global irradiation per square meter received by the modules [kWh/m^2];
- the standard deviation of the monthly electricity production due to year-to-year variation [kWh].

In this study the following set up of the online application PVGIS-5 was established:

- horizon: calculated by PVGIS (default option). In this case "*PVGIS use information about the local horizon to estimate the effects of shadows from nearby hills or mountains*"[13];
- database used: PVGIS-CMSAF. This database of solar radiation data has been calculated from satellite images (by the CM SAF collaboration). The data covered the period 2007-2017 and they have hourly time resolution;
- PV technology: crystalline silicon grid connected;

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[12] https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html#PVP

[13] https://re.jrc.ec.europa.eu/pvg_static/en/manual.html#horizon

- PV installed peak power[14]: 0.15 kWp. This value is referred to 1 m^2 of PV panel;
- system losses[15]: 14%.

The PV system was considered installed on the flat roof with a mounting system.

For the calculation of the maximum PV area [m^2] (Equation 4.4 Calculation of the area of PV panels according to the geometry of the roof) [44] (Figure 4.54) that could be installed on the flat roofs of the models of kindergarten, it is necessary to stress out the following aspects:

- the main dimensions of one panel are equal to A = 1 m x B = 1.70 m;
- in this situation of installation, it is necessary to leave an empty space (X_{min}) in order to avoid mutual shading between one row of the PV panels and the other one (Equation 4.5 Calculation of the minimum distance between the PV panels rows). This value depends on the latitude of the considered location and consequently on the inclination of sunrays, on the tilt angle and the geometry of the panel.
- in this study the X_{min} is set at least equal to 70 cm in order to guarantee the minimum space for maintenance. So, when the value of X_{min} is lower than 70 cm in according to the latitude of the location (the inclination of the sunrays) and the tilt angle, it is considered however equal to 70 cm. For the calculation of the minimum distance between panels (X_{min}) and so to establish the inclination of sunrays (α) the winter solstice (21st of December) at midday was considered[16];
- moreover, for the calculation of the PV panels surface on the flat roof a minimum distance between the panels and the railing must be guarantee equal to 50 cm;
- furthermore, with this kind of solution, contrary to sloped roof, it is not possible to exploit the totally surface of the roof not only because of the empty space equal to 70 cm in alternation with a row of the panels, but also due to a considerable surface equal to about 50 m^2 dedicated to the air handling unit (AHU) for mechanical ventilation and all connected auxiliary systems;
- in addition, for the calculation of the East/West maximum surface of the PV panels on the kindergartens' roof the best orientation of the building is obviously keeping the same and the inclination of the solar rays for all the cities analysed is considered equal to 10°.

$$\textit{Equation 4.4} \quad A_{PV,max} = \frac{b_1}{(L_1 - X_{min})} * (a - 2i) * L + 2 * \frac{d}{(L_1 - X_{min})} * (a_1 - 2i) * L$$

where: $\boldsymbol{b_1}$ dimension of the roof floor plan [m] (Figure 4.54);

$\boldsymbol{L_1}$ projection of the PV panel on horizontal plane [m] (Figure 4.53);

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[14] "*This is the power that the manufacturer declares that the PV array can produce under standard test conditions, which are a constant 1000W of solar irradiation per square meter in the plane of the array, at an array temperature of 25°C*" https://re.jrc.ec.europa.eu/pvg_static/en/manual.html#gridpv

[15] "*The estimated system losses are all the losses in the system, which cause the power actually delivered to the electricity grid to be lower than the power produced by the PV modules*" https://re.jrc.ec.europa.eu/pvg_static/en/manual.html#gridpv

[16] https://www.sunearthtools.com/dp/tools/pos_sun.php?lang=it

$\boldsymbol{X_{min}}$ means the minimum distance between PV panels rows [m];

$\boldsymbol{a}$ dimension of the roof floor plan [m] (Figure 4.54);

$\boldsymbol{i}$ minimum distance from the parapet [m] (Figure 4.54);

$\boldsymbol{a_1}$ dimension of the roof floor plan [m] (Figure 4.54);

$\boldsymbol{L}$ length of the PV panel [m];

Equation 4.5 $$X_{min} = L * \sin\beta * \cot\alpha$$

where: $\boldsymbol{L}$ length of the PV panel [m];

$\boldsymbol{\beta}$ angle of the PV panel with the horizontal plane [°] (Figure 4.53);

$\boldsymbol{\alpha}$ inclination of solar rays at midday, the 21st of December [°] (Figure 4.53);

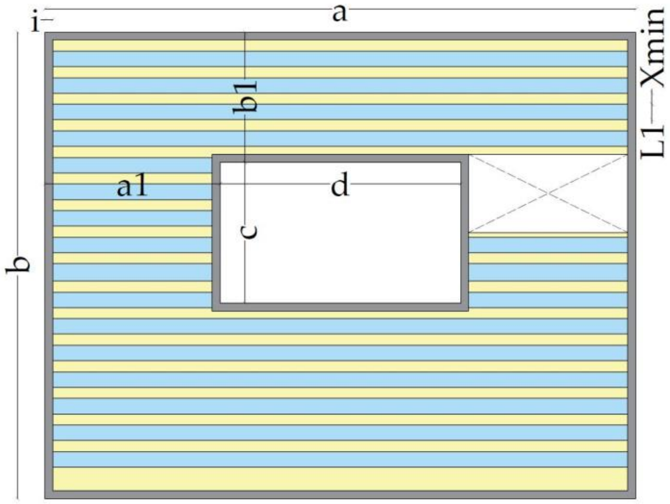

Figure 4.54 Exemplificative sketch Calculation of the maximum area of PV panels

4.6.2 Results and discussion

In the following paragraph the main results of the parametric analysis of the PV systems installed on the kindergartens' roof (model I1, model I2 and model I3) are illustrated and discussed. For brevity the graph reported are referred to the model I1 and to the city of Florence. The other graphs cited in the test related to the other 2 models and the other 2 cities are cited in the text and reported in Appendix A.

Figure 4.55 is related to the model I1 located in the city of Florence and it illustrates the available area measured in m^2 for each tilt angle considered (from 10° to 80°) for South oriented PV panels (blue columns) and East/West ones (pink columns in the graph). Figure A.20 is referred to Model I1 located in Milan and Palermo. Figure A.21 and Figure A.22 are referred to model I2 and model I3.

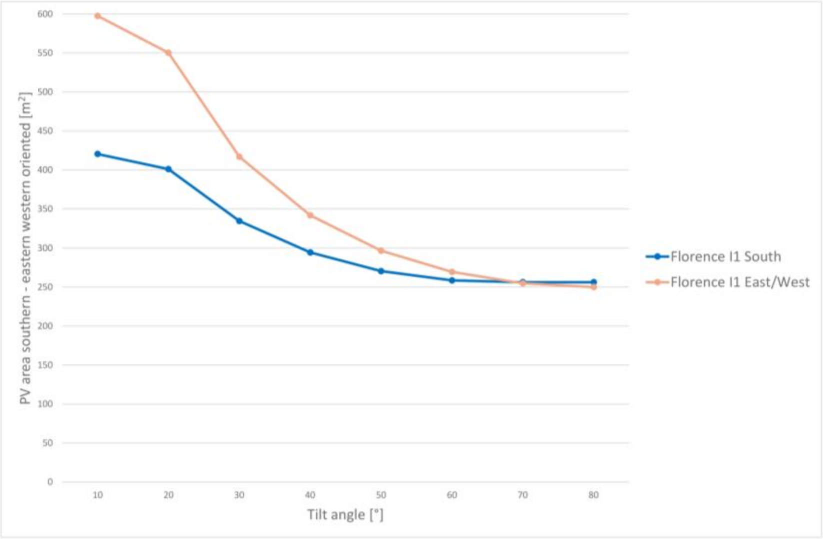

Figure 4.55 PV panels area for model I1 in Florence

While the next graphs in Figure 4.56 show the PV output in kWp. Figure A.23 is referred to Model I1 located in Milan and Palermo. Figure A.24 and Figure A.25 are referred to model I2 and model I3.

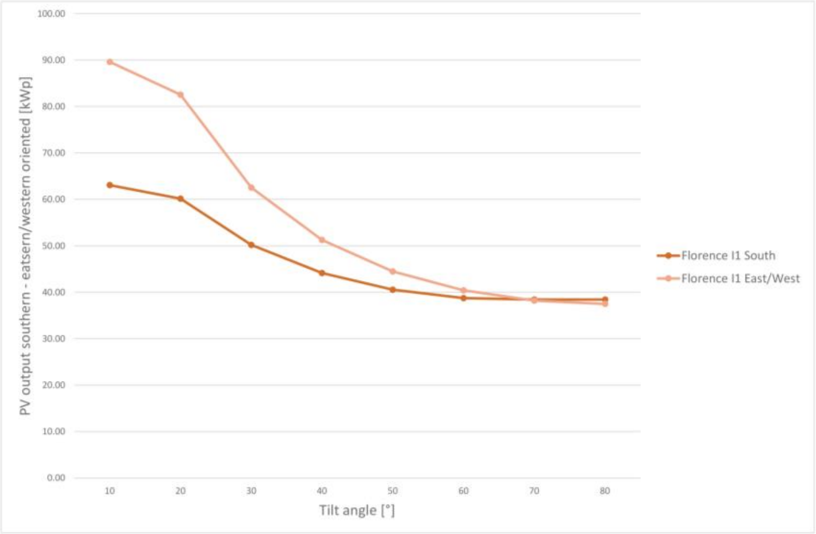

Figure 4.56 PV output for model I1

As showed in previous graphs:

- for South orientation, obviously, the models (I1, I3, I3) situated in the city of Palermo (Figure A.20 – Figure A.21 – Figure A.22) let to have the major available surface of PV panels with the tilt angle equal to 20°. This is strictly linked to the value of the inclination of the solar rays (α = 28.43°) that allows to obtain a smaller value of the minimum distance between PV panels rows;
- for Florence and so far as for Milan, considering South orientation, the higher available area on the roof for the installation of the PV panels is obtained with a tilt angle equal to 10° with a minimum distance between panels rows equal to 70 cm.
- in general, the model I3 (Figure A.22) permits to obtain the higher surface of PV panels for all the cities and considering both orientation because it presents a superior value of the available surface

on the roof (for instance with respect to the model I1 with PV southern oriented there is for a tilt angle equal to 10° an increase in the surface of about 60%).

In addition, the most interesting thing that graph related to PV panels area demonstrated is that:

- the PV panels eastern/western oriented lets to obtain the most electrical energy production with a tilt angle equal to 10°C inasmuch the available area for PV panels increases of about 30% with respect to the same tilt angle for South orientation. This is valid for all the analysed city;
- for model I1 considering the cities of Florence and Milan eastern/western orientation is the utmost one within the variation of the tilt angle with respect to the surface of PV panels that is possible to install on the roof.

  Despite for Palermo south orientation is recommended since an inclination equal to 40°;
- while for model I2 and model I3 for Florence the South orientation is advisable starting from a tilt angle equal to 40°, whereas for Milan since 50° and finally for Palermo the same situation of model I1 occurs;
- furthermore, the graphs concern with PV output [kWp] showed that until a tilt angle equal to 30° the East/West orientation are better than South one for all the cities. It is important to stress this because 30° is the most recurrent inclination for the considered latitude;
- for all the cities there is a decrease in both the area and the PV output until the tilt angle equal to 60° and then within 80° a slight increase is happened. This is valid for all the analysed models.

The next graphs in Figure 4.57 show the results of the energy produced by PV panels related to the entire area of the considered building (model I1). Figure A.26 is referred to Model I1 located in Milan and Palermo. Figure A.27 and Figure A.28 are referred to model I2 and model I3.

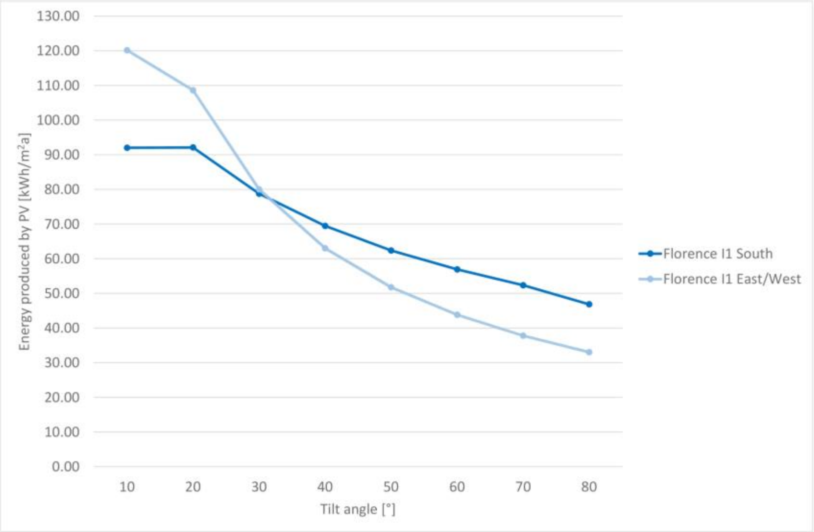

Figure 4.57 Energy produced by PV system model I1 in Florence

From the analysis of the previous graphs it is possible to admit that:

- for the all the typological models the city of Palermo, as demonstrated before as well, leads to the most fruitful energy produced by PV system for East/West orientation with a tilt angle equal to 10°;
- for the city of Florence, the trend changes at a value of 30° with respect to model I1 while for model I2 and I3 for 40° of the tilt;
- finally, for the city of Milan this occurs by 40°. These graphs validate the results illustrated and discussed before.

Therefore, it is essential to carefully analyse the surplus electrical energy production in order to calculate the total amount of CO_2 emissions avoided with the production of this electricity that can fed in the public grid and used by others building in the context of realizing smart cities in the next future.

It is a significant step to evaluate the environmental impact of the construction of a PV system and the related payback period, considering the whole available area on a roof with the aim of maximising the producibility.

Figure 4.58 exhibits the plus energy production examining the all cities and both orientation of the PV panels rows for each tilt angle considered. Figure A.29 is referred to Model I1 located in Milan and Palermo. Figure A.30 and Figure A.31 are referred to model I2 and model I3.

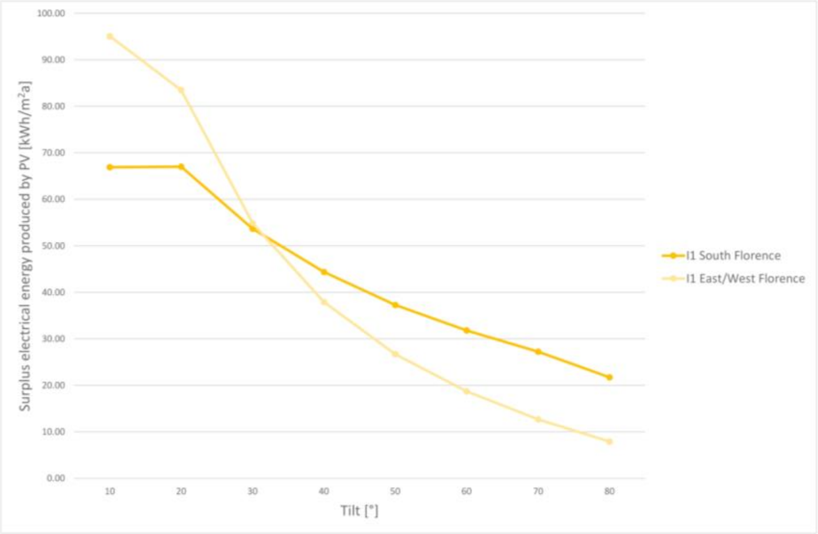

Figure 4.58 Surplus electricity production for model I1 in Florence

The results reported are rigorously linked to the final energy demand of the models in each city and it is important to remind that for the city of Milan the most considerable energy demand is required because of the heating system being in climate zone E. The city of Milan presents the lower value of the surplus of electrical energy that can fed in public grid, while Palermo, obviously the higher one.

Furthermore, as showed in previous graphs the uppermost production of surplus electrical energy is obtained for all the cities where the models are situated for the energy simulation for East/West orientation of the PV panels with a tilt angle of 10°.

For instance, for model I1:

- for the city of Florence, considering a tilt angle equal to 10°, the difference between South and the East/West orientation in the plus electrical energy production is of about 28 kWh/m^{2}y;
- for Palermo there is the most noticeable difference between the two examined configurations with a value of about 38 kWh/m^{2}y.

Thereafter, it is possible to admit that the first configuration is the one that leads to an increase in surplus electrical energy production due to the maximisation of the area of the panels and so it is the most environmental-friendly.

The Figure 4.59 illustrates the avoided CO_2 emissions due to the surplus energy production.

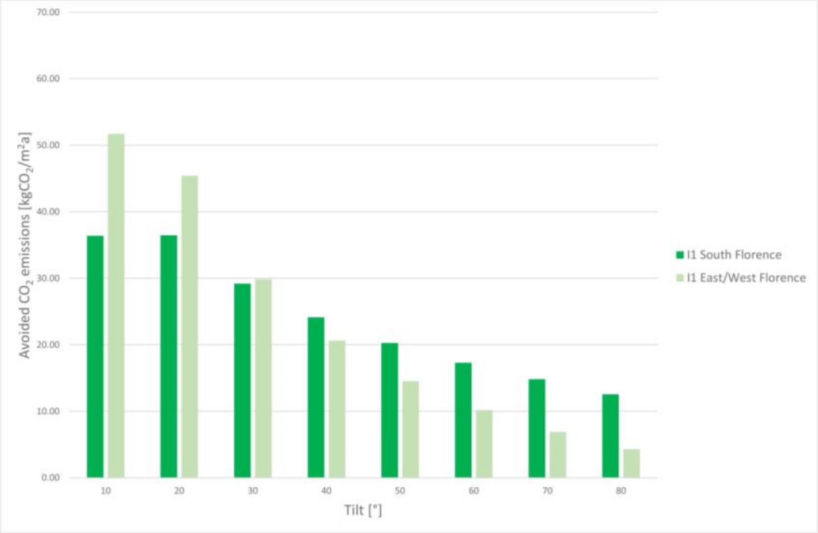

Figure 4.59 Avoided CO_2 emissions with the surplus energy production – Model I1 in Florence

Consequently, considering for instance the city of Florence, for East/West orientation the CO_2 avoided for other buildings connected to the public grid that exploits the surplus energy produced by the school PV system is equal to about 52 kg$_{CO2}$/m^{2}y versus an amount of about 30 kg$_{CO2}$/m^{2}y considering the most recurrent tilt angle (30°) and orientation (South) of the PV panels in Italy.

As shown in the graph in Figure A.25 for the city of Palermo for model I1 with a PV system eastern/western oriented and with a tilt of 10° it is feasible to avoid in one year 57142 kg$_{CO2}$.

In conclusion, as a matter of fact, for the new building type the suggestion in order to maximise the producibility of a PV system installation in Italy, it is necessary to decrease the inclination of the PV panels from the most recurrent one equal to 30° until 10° and to change the orientation of PV panels rows from South to East/West.

This is strictly linked with inclination of solar rays that for this advisable orientation does not cause shade between panels rows during the day. This is leads to a reduction of the CO_2 emissions as well (for instance ~ 44500 kg$_{CO2}$/a for model I1) because this configuration lets to obtain a higher production of plus electrical energy that can fed the public grid and can be exploited by other buildings in the district. So, it can be considered as the most environmental-friendly installation.

Speaking about these results it is fundamental to remark that between the monthly simulation and the hourly time step simulation there is a difference of about 10% (for instance for Florence for model I1 there is a difference of about 5300 kWh in one year between hourly and monthly simulation for the optimal configuration). The most advantageous simulation is the hourly time step one for the surplus energy production. This is linked to the consideration of the simultaneity of the production of the surplus electrical energy in the hourly time step evaluation, which does not happen in the monthly one.

Therefore, with monthly calculation there is an underestimation of both the plus electrical energy production and the electrical energy required from grid when the one powered by PV panels is not available. In order to understand this observation, the graph below (Figure 4.60) exhibits the real difference obtained considering the Model I1 in the city of Florence with eastern/western oriented PV system with tilt angle equal to 10° performing a monthly and hourly dynamic simulation with Design Builder.

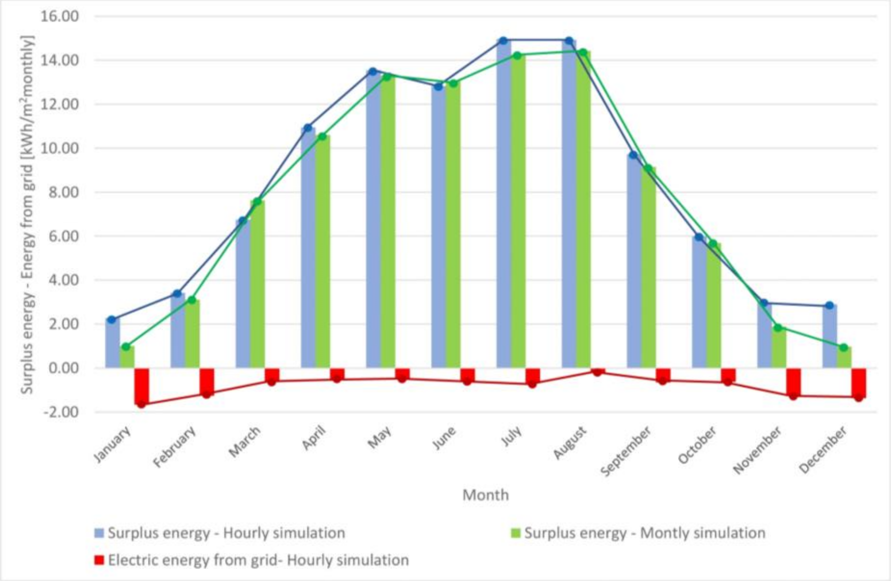

Figure 4.60 Difference between hourly and monthly simulation of Model I1 advisable configuration - Florence

This analysis was performed also for the most recurrent situation of installation of PV system: southern oriented wit tilt equal to 30° (Figure 4.61).

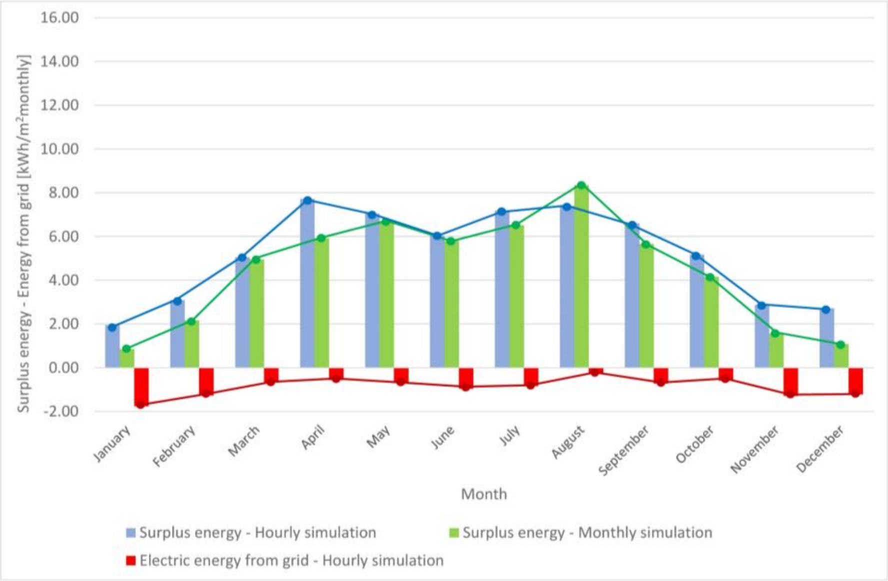

Figure 4.61 Difference between hourly and monthly simulation of Model I1 recurrent configuration - Florence

The following graphs in Figure 4.62, Figure 4.63, Figure 4.64 and Figure 4.65 outline the trend of building load, PV output (advisable configuration), the surplus of PV output and finally the load amount required from grid to satisfy the model I1 building loads in 4 representative days of the year (24 hours): 21st of January, 15th of April, 21st of July and 15th of October.

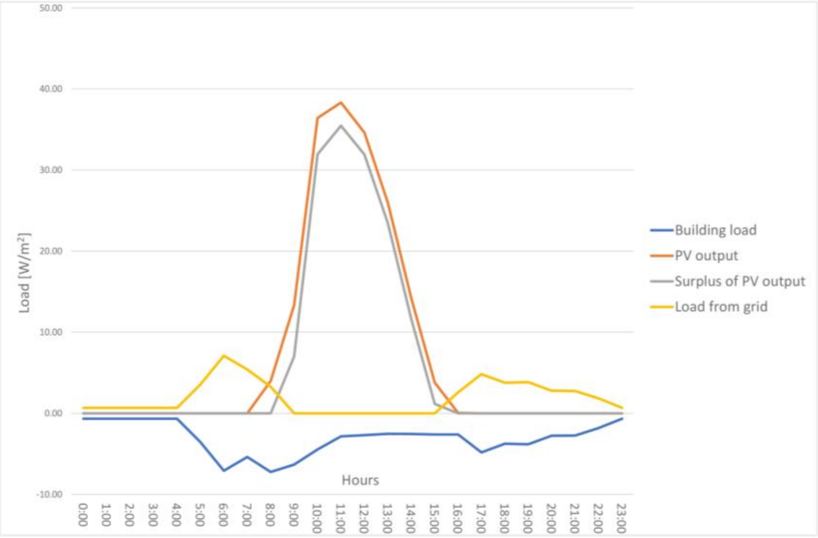

Figure 4.62 Hourly simulation for 21st of January

During wintertime as shown in the previous graph an increase in building loads occurs at the opening time of the school (7:00 a.m.) and the load for systems is got from grid because the electrical output of PV system begins one hour later (8:00 a.m.). Anyway, during the opening time of the building (until 6 p.m.) the electricity provided by PV panels on the roof satisfies the building load.

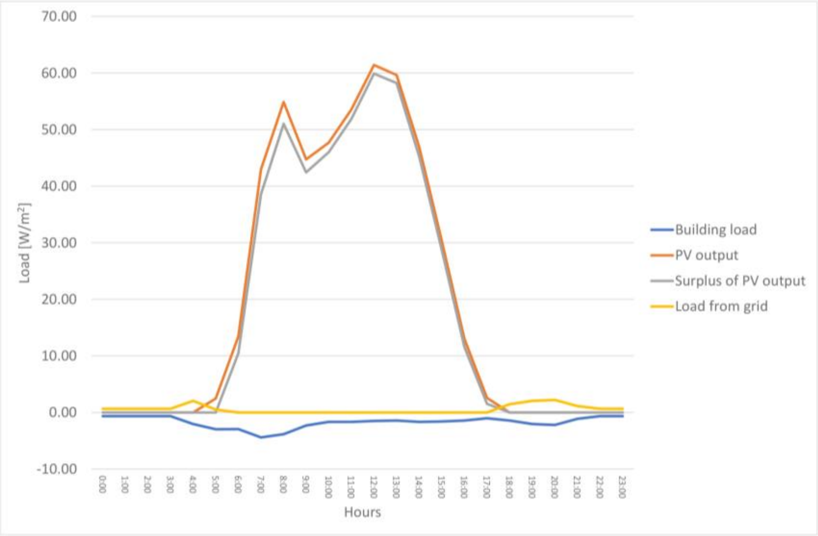

Figure 4.63 Hourly simulation for 15th of April

With respect to the building load on 15th of April the PV system eastern/western oriented with a tilt angle equal to 10° is advisable because it produces enough for the school during the opening time and a peak of surplus PV output at 1 p.m. o'clock equal to about 61 W/m^2.

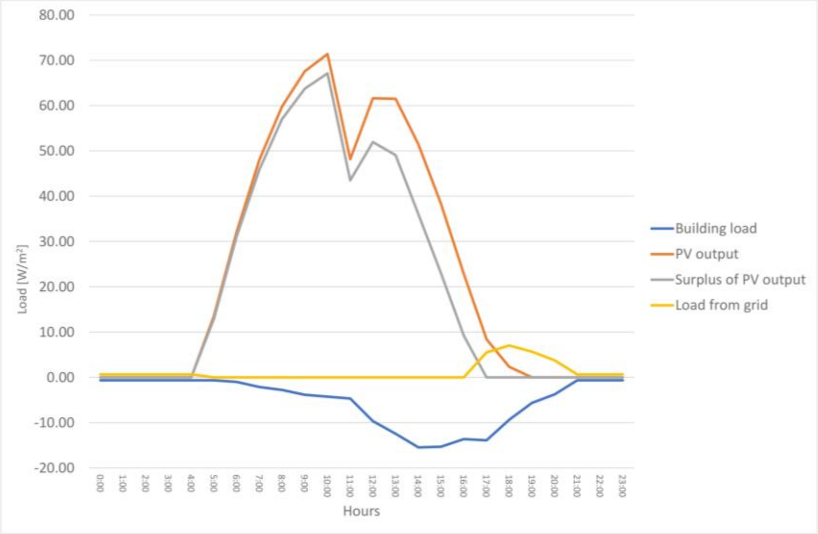

Figure 4.64 Hourly simulation for 21st of July

During summertime there is a remarkable peak of building load at the end of the opening time of the school and for 2 hours after, that is maybe linked to keep the proper attenuation temperature for cooling system inside the school. The load of PV system has a maximum at 11 a.m. by about 72 W/m^2.

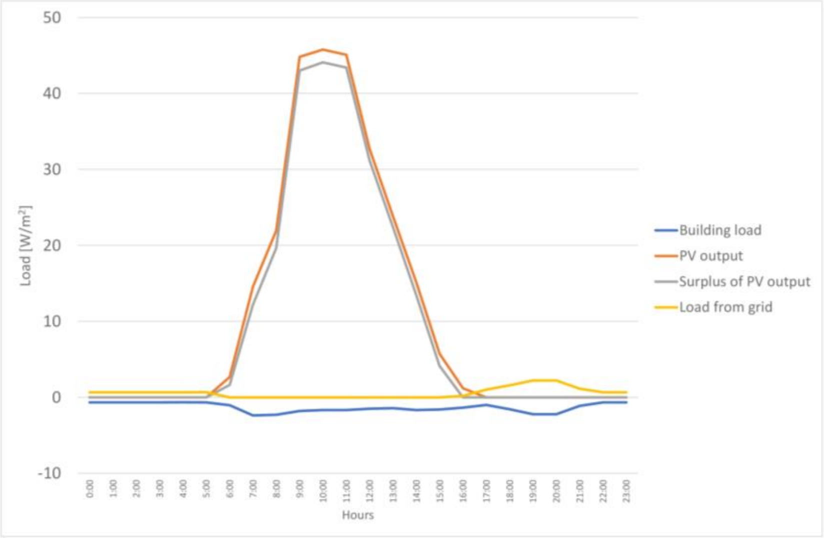

Figure 4.65 Hourly simulation for 15th of October

For the 15th of October as well as illustrated in the previous graph the building load of the model I1 is largely fulfilled during the opening time of the school with respect to the simultaneity.

4.7 CO_2 emissions

In this paragraph the main results related to the evaluation of the environmental impact of the new building type for kindergarten are shown and discussed. Some different analyses are performed in order to understand the influence on the amount of CO_2 emissions of different configuration of the typological building factors.

For brevity, the results presented are referred to the 3 new typological models for kindergarten located in the city of Florence and so in climate zone D.

The main results illustrate in this paragraph are:

- first of all the detailed calculation of the CO_2 emissions for both the structure for the new typological models, with envelope thermal properties and systems characteristics required for the reference building [16] (*Chapter 3*) and for the consumptions during the operational phase.

  In this case, in order to have the further possibility to make a comparison of the available systems that can be used for the 3 typological models, first of all system configuration number 1 was considered;
- after that, the estimation of CO_2 emissions related to any single different configuration of many building typological factors was performed considering the model I1 as example.

  The configurations are referred to:
  - the thickness of the insulation of the external wall from 0.10 m to 0.14 m;
  - the thickness of insulation of the roof from 0.10 m to 0.22 m;
  - the window-to-wall ratio for each orientation:

    from South WWR = 25% to South WWR = 50%.

    The other orientations have been keeping the same required by health-hygiene standards with respect to the functional units

    East WWR = 7% West WWR = 7% North WWR = 7%;
  - the change of the efficiency of sensible heat recovery for mechanical ventilation from 50% to 90%;
  - the introduction of a heat pump with respect to the gas boiler (efficiency of 90%) characterized by a coefficient of performance (COP) equal to 3.2 and an energy efficiency ratio (EER) equal to 2.5 (configuration number 3);
  - the consideration of a more efficient heat pump (COP = 3.6; EER = 3.2) with respect to the previous one that has the same characteristics of reference building (configuration number 3 with a more efficient heat pump);
- the comparison of the production of CO_2 emissions of the 4 different kinds of system configurations that are explained in detail at the beginning of this Chapter 4;

- the detailed calculation of the CO_2 emissions for the structure and consumptions during operational phase considering system configuration number 3 considering all the advisable configuration for the different building typological factors.
- the calculation of the payback period related to the photovoltaic system manufacture and to the whole structure, with the purpose of understand the number of years needed to recover the CO_2 emissions of the construction process with the production of surplus electrical energy feeds into the national grid. In this case two different configuration of the PV system are considered:
    - a system configuration number 4 integrated with a PV system southern oriented and with tilt angle equal to 30° was considered. This tilt angle and this orientation are used for this analysis because they are the most recurrent ones in literature and for the installation of PV panels in Italy.
    - a system configuration number 4 integrated with the advisable configuration for PV system was considered (East/West orientation and tilt angle of 10°) in order to maximise surplus energy production in order to try to obtain an energy plus school building.

The main aim in this phase in to obtain a yearly value of CO_2 emissions for new building type for kindergarten within 25 kg_{CO2}/m^2a.

4.7.1 Method for the study deals with CO_2 emissions

The estimation of CO_2 emissions of the analysed models was performed with eLCA software.
It is an online application[17] that required login credentials and it is developed by Bundesinstitut fur Bau-, Stadt-und Raumforschung. This application allows to calculate the environmental impact for instance in terms of the Global Warming Potential (GWP) measured in $kgCO_2$ for net floor area (NGF).
The GWP is an index defined as: "*the cumulative radiative forcing, both direct and indirect effects, over a specified time horizon resulting from the emission of a unit mass of gas related to some reference gas. It is intended as a quantified measure of the relative radiative forcing impacts of a particular greenhouse gas*"[18].
It is an index to measure the global warming mainly due to CO_2 emissions in the atmosphere and it gives a measure of the environmental impact caused by greenhouse gas considering a time range of 100 years.
The online tool used to calculate the environmental impact of the new typological model for kindergartens in the final value measured in kg_{CO2} considered the following building life cycle phases [45]:

- product stage
  A1 raw material supply
  A2 transport
  A3 manufacturing;
- use stage

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[17] https://www.bauteileditor.de/
[18] "*Air Pollution Control technologies*" Chapter 14 *Environmental managment*, published by Elsevier Inc. 2017, ISBN 978-0-12-811989-1, http://dx.doi.org/10.1016/B978-0-12-811989-1.00014-2

B6 operational energy use;

- end of life stage

  C3 waste processing

  C4 disposal;
- benefits and loads beyond the system boundary

  D1 reuse

  D2 recovery

  D3 recycling

  D4 exported energy/potential.

In this study for the calculation of the possible environmental impact of new building type for kindergarten the next settings are considered:

- the service life of the 3 models is assumed equal to 50 years. This choice relates to the real service life of a school building considering ordinary and extraordinary maintenance;
- the service life of the photovoltaic system installed on the roof is considered equal to 30 years;
- the CO_2 emissions are calculated considering the entire area of the ground floor of each model;
- the CO_2 emissions related to the operational phase (CO_2 emissions OP) of the building are estimated taking into account the final energy demand (Q_E) for heating, cooling, equipment, lighting, service hot water and auxiliary energy determined with design builder energy dynamic simulation, multiplied for the related conversion factor defined by the National System for Environmental Research and Protection (ISPRA) [19] for the electricity and ENEA[20] for gas.

  The conversion factors (CO_2 factor) for the different energy carriers considered for the calculation of the CO_2 emissions are the following:

  - gas from grid 0.210 kg_{CO2}/kWh
  - electricity from national grid 0.544 kg_{CO2}/kWh
  - electricity from renewables 0 kg_{CO2}/kWh;
- the CO_2 emissions for the manufacturing process of photovoltaic system is considered equal to 50 g_{CO2}/kWh (CO_2 PV factor) [46].

The calculation of the payback period was carried out for each one of the 3 models defined for kindergarten considering both the PV panels manufacture and the structure construction (for the advisable configuration and for the most recurrent one).

The estimation of the payback period was performed taking into account the plus energy produced by PV systems that means the difference between the electrical energy produced by the PV system ($E_{el,PV,out}$) and

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[19] "*Fattori di emissione atmosferica di CO_2 e altri gas a effetto serra nel settore elettrico*" Rapporto ISPRA 257/2017

[20] www.efficienzaenergetica.enea.it/regioni/siape/poteri-calorifici-inferiori-dei-combustibili-e-fattori-di-emissione-della-co2

the final energy demand (Q_E) needed by the building and consequently the CO_2 emissions avoided, and the CO_2 emissions for both whole structure construction and only PV system construction.

The equations used for instance for the calculation of payback period (number of years) on the PV system is the following one (Equation 4.6 Calculation of the payback period):

Equation 4. 6

$$PV\ Payback = \frac{(E_{el,PV,out} * CO_2\ PVfactor * 30)}{[(E_{el,PV,out} - Q_E) * CO_2 factor]}$$

where: $\boldsymbol{E_{el,PV,out}}$ means the electricity produced by PV system installed [kWh/m^2a];

$\boldsymbol{CO_2\ PVfactor}$ is the conversion factor for the calculation of CO_2 emissions for PV panels construction equal to 50 g_{CO2}/kWh in this case;

$\boldsymbol{30}$ years is the operational life of a PV system;

$\boldsymbol{Q_E}$ means the final energy needed by the building [kWh/m^2a];

$\boldsymbol{CO_2 factor}$ is the conversion factor for the estimation of CO_2 emissions avoided with the production of plus electrical energy equal to 0.544 kg_{CO2}/kWh.

4.7.2 Results and discussion

The main results related to the analysis of the CO_2 emissions are presented and discussed.

In the following table (Table 4.19) the CO_2 emissions (included A1-A3, B6, C3, C4) related to the structure, the system and the operational phase consumptions (final energy demand for heating, cooling, equipment, service hot water, auxiliary energy) of the 3 basic models for kindergarten are presented, measured in kg_{CO2}/m^2a. The last column illustrates the total value of CO_2 emissions.

Table 4.19 CO_2 emissions of the basic 3 models in Florence

Basic Model	CO_2 emissions for structure kg_{CO2}/m^2a	CO_2 emissions for systems kg_{CO2}/m^2a	CO_2 emissions for demand kg_{CO2}/m^2a	Total of CO_2 emissions for basic model kg_{CO2}/m^2a
I1	17	0.90	21	38
I2	15	0.90	22	39
I3	14	0.90	23	38

The data reported in this table stress out that the CO_2 emissions related to the school building type defined with the same features of the reference building defined by the current Italian law are considerably high compared with respect to the main goal set for this analysis (of about 25 kg_{CO2}/m^2a). This is mainly due to the dynamic and thermal characteristics of the external envelope that deeply affect the energy consumption for heating and cooling and obviously to the initial choice of a gas boiler for the heating system.

It is important to consider that for the schools located in the climate zone D the energy consumption for heating is noticeably high compared to the other energy needs of the building.

For instance, for the city of Florence analysed in this case, the CO_2 emissions referred to the energy demand for heating, considering in percentage, is the largest part of the total amount and it happens for all the 3 models:

- model I1 39% for CO_2 emissions for the heating consumption with respect to the total amount;

- model I2 30% for CO_2 emissions for the heating consumption with respect to the total amount;
- model I3 25% for CO_2 emissions for the heating consumption with respect to the total amount.

To be thorough, the following Figure 4.66, Figure 4.67 and Figure 4.68 indicate the CO_2 emissions owing to each contribution to final energy demand of the building for the 3 considered typological model in the other cities were the analysis was performed. In the next graphs the contribution to the CO_2 emissions due to the construction of the structure and the systems is not considered.

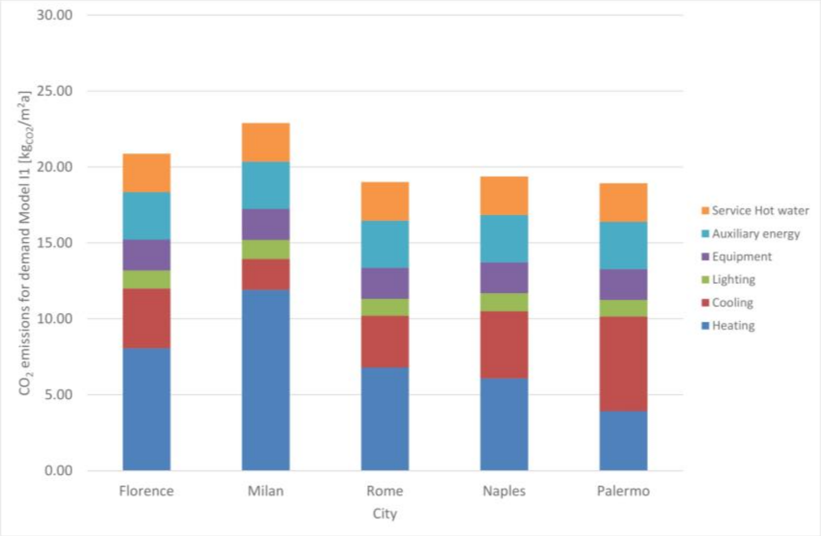


Figure 4.66 Calculation of CO_2 emissions for model I1

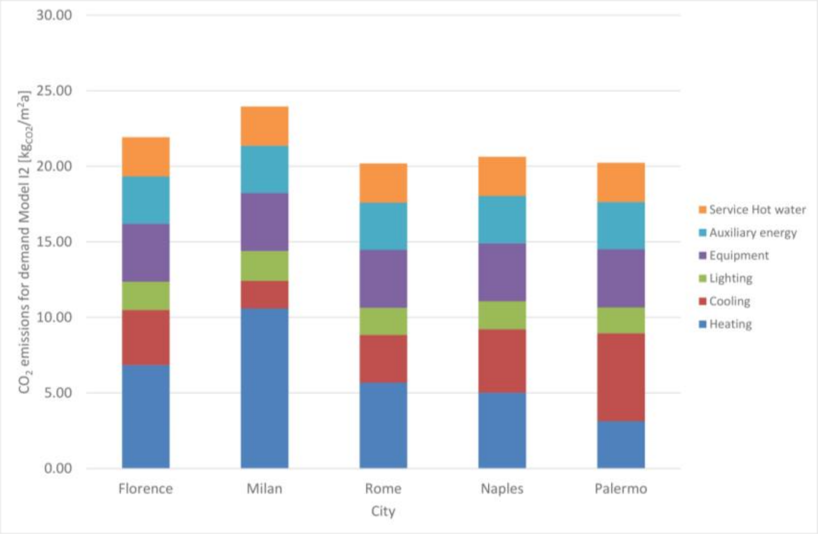


Figure 4.67 Calculation of CO_2 emissions for model I2

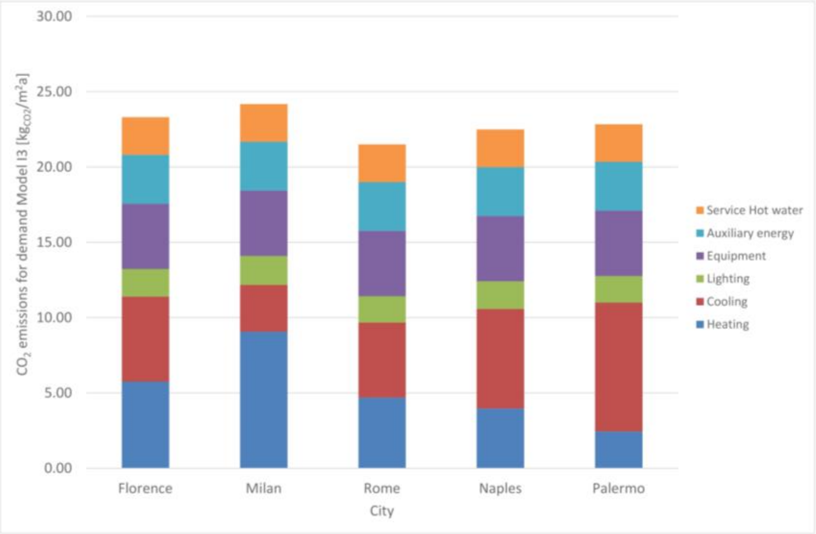


Figure 4.68 Calculation of CO_2 emissions for model I3

The previous 3 figures stressed out that for all typological models analysed, situated in each chosen city, the CO_2 emissions owing to the consumption during the operational phase of the building are too high.

The total amount of CO_2 emissions for energy consumption almost achieves the limit that was established as the maximum feasible for the sum of structure construction, system manufacture and consumption as well (25 kg_{CO2}/m^2a).

For instance:

- especially for the basic model I2 for the city of Milan the CO_2 emissions due to the heating demand are about 52% with respect to the total amount;
- moreover, for the city of Palermo the worst situation from an environmental point of view is strictly linked to the cooling demand. For example, in the basic model I3 the CO_2 emissions owing to cooling demand are approximately 38% with respect to the total amount.

Since the CO_2 emissions calculation concerns with the new building type are evidently elevated with respect to the previous maximum limit imposed for this study, it is necessary to understand the amount of CO_2 emissions that can be avoided with any single different advisable configuration of typological building factors applied to the building type before the introduction of PV panels. This is necessary in order to suggest a proper configuration of all typological factors that affect the environmental performance of the new building type for kindergarten and to include it in the guidelines.

The graph that follows (Figure 4.69) represents the amount of CO_2 emissions of different advisable configuration of building distinguishing features, analysed in detail in the previous studies of this research in order to change the defined new school building type with the aim at minimising CO_2 emissions.

The results are expressed in kg_{CO2}/m^2a considering the entire area of the model I1. In each column of the graph the different colours represent the various contribution to the total CO_2 emissions value.

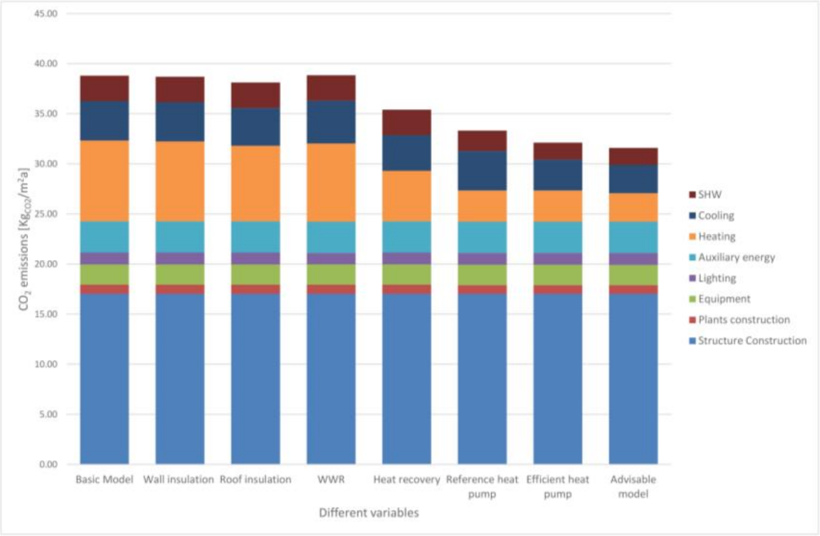


Figure 4.69 Calculation of CO_2 emissions for any single different advisable configuration for model I1 for the city of Florence

The previous graph (Figure 4.69) illustrates that the CO_2 emissions related to the structure construction is the highest one and the increase in the thickness of the roof insulation leads to a slight increase in this value. The change in the WWR for South orientation resulted in the increase in the total amount of CO_2 emissions due to the rise in the cooling demand. This is strictly linked to the value of the WWR that is equal to 50%. In fact, the internal gains during summer season deeply affect the energy needs of the model I1.

The best way to reduce the total amount of CO_2 emissions of the model I1 appears the change in the characteristics of the system:

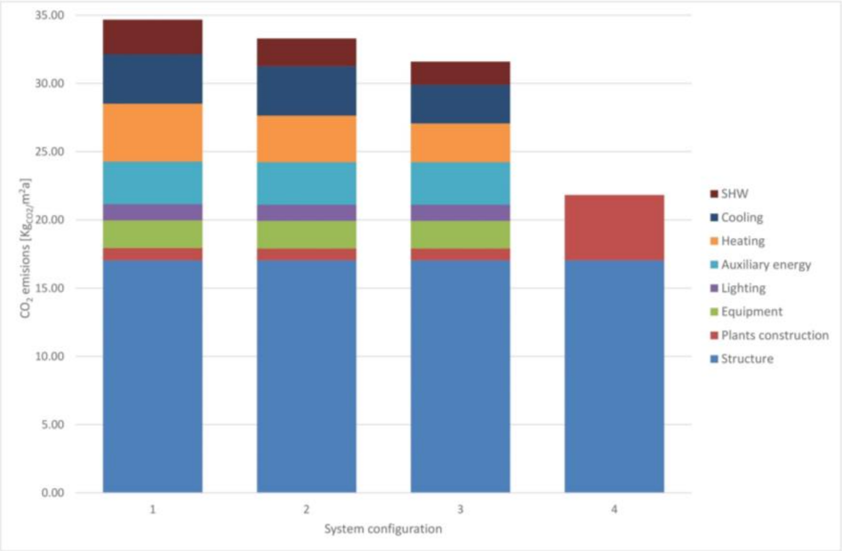
- the rise of the efficiency of heat recovery leads to a decrease in CO_2 emissions of about 8%;
- the introduction of a heat pump with the same characteristics of the reference building resulted in the reduction of CO_2 emissions of about 5%;
- the use of a more efficient heat pump involves in the reduction of CO_2 emissions in the atmosphere of about 10%.

As showed in the last column of this graph the application of all these changes to the building type defined for the model I1 for the city of Florence leads to a decrease in CO_2 emissions equal to 16.50% with respect to the CO_2 emissions of the school building type showed in the first column of the same graph.

This result concerns with this considerable reduction of CO_2 emissions is important for the purpose of obtain neutral carbon school buildings in Italy and to suggest different configurations of the main building typological factor in the guidelines.

Since the system is one of the most influence feature, it is necessary to make a comparison in order to understand the value of this impact on CO_2 emissions related to the type of system for heating and cooling and the possible integration with the installation of a PV system for the production of renewable energy.

The graph below shows the difference on the amount of CO_2 emissions of the 4 configurations of system analysed for model I1 for the city of Florence.



1. Gas boiler (efficiency 90%) + heat pump (EER = 2.5) + ventilation system heat recovery (efficiency 50%)
2. Heat pump (COP = 3.2 – EER = 2.5) + ventilation system heat recovery (efficiency 50%)
3. Heat pump (COP = 3.6 – EER = 3.2) + ventilation system heat recovery (efficiency 50%)
4. Heat pump (COP = 3.6 – EER = 3.2) + ventilation system heat recovery (efficiency 65%) + renewables (PV)

Figure 4.70 Calculation of CO_2 emissions for each system configuration for model I1

The previous graph in Figure 4.70 clearly shows that the introduction of a more efficient heat pump with both a higher coefficient of performance and energy efficiency ratio (configuration number 3) leads to a decrease in CO_2 emissions for model I1 for the city of Florence of about 8% compared to a traditional system with gas boiler.

Moreover, with the use of a PV system (system configuration 4) (most recurrent configuration: tilt angle equal to 30° and South oriented) installed on the roof top in order to produce electric energy:

- the CO_2 emissions related to the plants construction increases of the value referred to PV system manufacture equal to 3.96 kg_{CO2}/m^2a;
- the value of the CO_2 emissions due to the entire electricity consumption of the building is null because the conversion factor of renewables is equal to 0 kg_{CO2}/kWh;
- it leads to a decrease in the value of CO_2 emissions equivalent to 32% with respect to traditional system with gas boiler.

The following table (Table 4.20) exhibits the calculation of the CO_2 emissions for the 3 models for kindergarten considering the city of Florence taking into account both the system configuration 3 and 4.

In this calculation for all the models, all the advisable configuration for the building typological features of the new building type related to the architectural features and to the technological system (wall insulation, roof insulation, WWR, efficiency of heat recovery for mechanical ventilation, more efficient heat pump) showed previously are considered.

For the configuration system number 4 the PV system is considered installed on the roof top for the whole available area for each model, southern oriented and with tilt angle equal to 30° (most recurrent configuration for these latitude).

In the table are reported the value of the CO_2 emissions for:

- the construction of the building and the system;
- the contribution of the consumption during the operational phase for both configuration 3 and 4 of the system;
- the manufacture of PV system considered for system configuration 4;
- and finally, the total value of the CO_2 emissions in the environment for both configuration 3 and 4 of the system.

The CO_2 emissions are measured in kg_{CO2}/m^2a considering the entire groundfloor area of each typological model of kindergarten in order to have a common system of evaluation.

Table 4.20 Calculation of CO_2 emissions for the advisable configuration of models for kindergarten considering the city of Florence

Model	CO_2 emissions for structure kg_{CO2}/m^2a	CO_2 emissions for systems kg_{CO2}/m^2a	CO_2 emissions for demand kg_{CO2}/m^2a		CO_2 emissions for PV system kg_{CO2}/m^2a	Total of CO_2 emissions for advisable model kg_{CO2}/m^2a	
			3	4	4	3	4
I1	17	0.86	14	0	4	32	22
I2	16	0.86	16	0	5	32	21
I3	14	0.86	17	0	5	32	19

As illustrated in the previous table:

- the model I2 is the which one with the higher CO_2 emissions related to the structure construction;
- the value of the total CO_2 emissions (configuration system 3) diminishes of an average value between the 3 considered models of about 11.50% with respect the traditional system configuration with gas boiler (configuration system 1);
- the value of the total CO_2 emissions (configuration system 4) decreases of an average value between the 3 considered models of about 38% compared to the traditional system configuration with gas boiler (configuration system 1).

This noticeably decrease in CO_2 emissions is related to the electrical energy produced by PV system because in case of renewables the conversion factor is equal to 0 kg_{CO2}/kWh. So, in the last configuration of system (configuration system 4) the only CO_2 emissions of the models are due to the structure construction and the manufacture of PV system.

For completeness the CO_2 emissions referred to the structure, the systems and the consumption during the operational phase of the 3 typological models for kindergarten situated in each city considered was calculated for the configuration of the system number 3 (Figure 4.71 - Figure 4.72 - Figure 4.73).

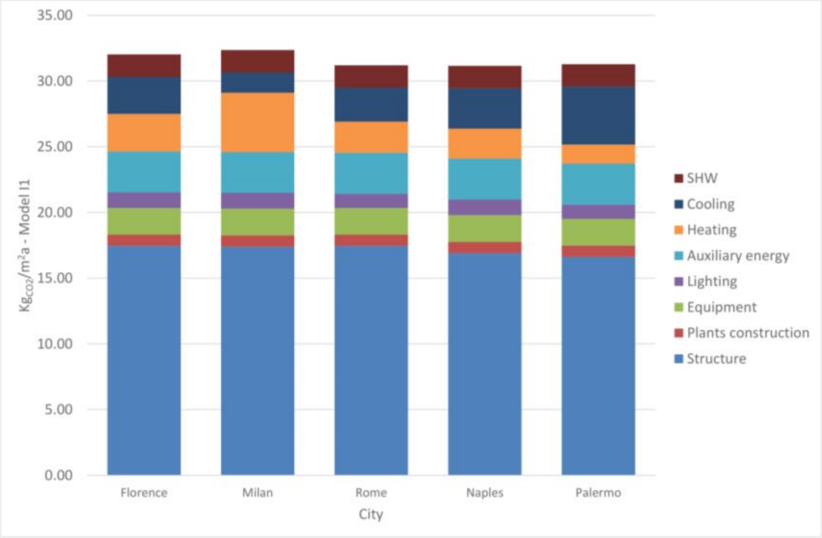


Figure 4.71 CO$_2$ emissions for model I1 in each city analysed considering configuration system 3

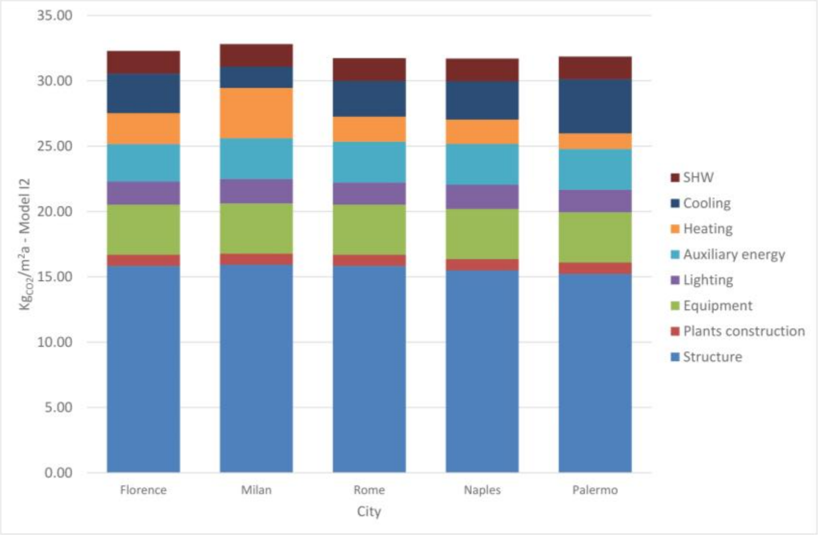


Figure 4.72 CO$_2$ emissions for model I2 in each city analysed considering configuration system 3

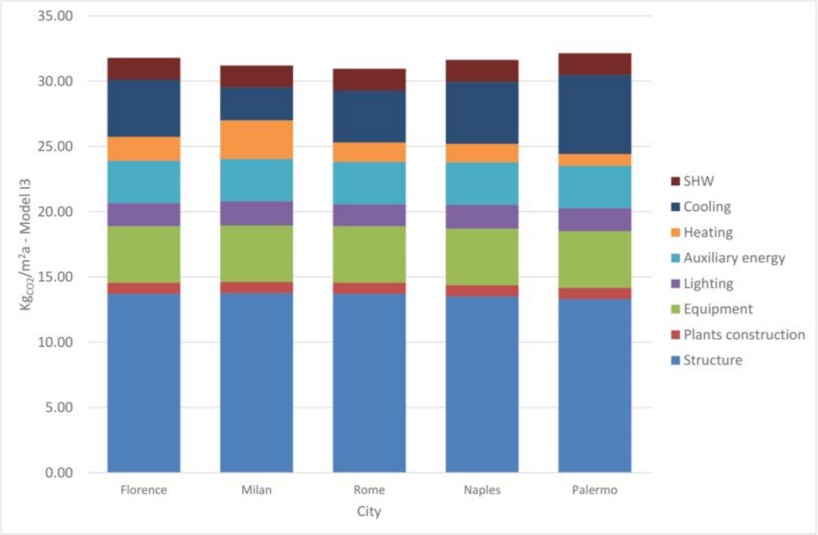


Figure 4.73 CO$_2$ emissions for model I3 in each city analysed considering configuration system 3

As shown in the previous graph about CO_2 emissions for all the 3 typological models in the 5 cities considered:

- for the CO_2 emission related to final energy demand for heating with respect to the configuration of the new building type (Figure 4.66 - Figure 4.67 - Figure 4.68) there is an average difference of about 4 kg_{CO2}/m^2a considering all the cities that is a significant value if compared with the total amount expected equal to 25 $kgCO_2/m^2a$;
- for the CO_2 emissions related to final energy demand for cooling an average of about 2 kg_{CO2}/m^2a occurs that is a remarkable value as well with respect to the total amount waited for the 3 typological models;
- the higher contribution to the total amount of CO_2 emissions in the atmosphere is due to the structure even if natural materials are considered, it is basically representing the 50% of the emissions for all models situated in all cities analysed.

Summing up in the definition of the configuration of the main typological factors for the new building type, it is essential to consider the calculation of the environmental impact in order to suggest some possible changes in the building type that can improve the environmental performance.

4.7.2.1 Payback period calculation

Finally, it is fundamental to estimate the payback period in order to understand the number of years needful to recover the CO_2 emissions caused by the construction.

In this paragraph some evaluation about the payback period the most recurrent configuration of PV panels (southern oriented with tilt equal to 30°) and the advisable one (eastern/western oriented with tilt equal to 10°) will be made in order to have a comparison. Some consideration from an economical point of view are considered in this analysis because to build a school also the expenditure is essential as well.

The results are referred to the city of Florence considering the 3 typological models for kindergarten.

The following tables below illustrate respectively the calculation of the payback period of the PV system construction (first the most recurrent configuration) and the entire building construction.

Both tables illustrate:

- the value of the plus energy produced by PV system [kWh/m^2a];
- the CO_2 avoid with this plus electrical energy generation [kg_{CO2}/m^2a];
- the amount of CO_2 emissions respectively for PV system in 30 years (Table 4.21) and for the building in 50 years (Table 4.22);
- lastly, the calculation of the payback period for the PV system (Table 4.21) and the whole construction (Table 4.22).

Table 4.21 Calculation of the payback period for the most recurrent PV construction for the city of Florence – model I1

Model	Surplus energy produced by PV system kWh/m^2a	CO_2 emissions avoid kg_{CO2}/m^2a	CO_2 emissions for PV system construction kg_{CO2}/m^2	Payback period years

I1	54	29	118	4
I2	63	34	138	4
I3	62	34	140	4

Table 4.22 Calculation of the payback period for the building construction for the city of Florence – model I1

Model	Surplus energy produced by PV system kWh/m^{2}a	CO_2 emissions avoid kg$_{CO2}$/m^{2}a	CO_2 emissions for building construction kg$_{CO2}$/m^2	Payback period years
I1	54	29	1208	41
I2	63	34	940	28
I3	62	34	871	26

According to the literature the payback period calculated in terms of CO_2 emissions of the PV system is about 4 years for all the 3 models.

This number of years necessarily depends on:

- the efficiency of the installed PV panels on the roof and consequently on the system loss considered in this case equal to 14%.

  This value influences the power of PV system during the operational phase;
- the value of the conversion factor of the CO_2 emissions avoided with the plus energy production.

  As reported in the ISPRA report 2017 the trend of the emissions factor from 1990 to 2015 is constantly decreasing (from 708 g$_{CO2}$/kWh in 1990th to 544 g$_{CO2}$/kWh in 2015th) even if the increasing of the production of electric energy. It depends mainly on the use of sources with different composition characterized by lower specific emissions.

  In fact, the emissions factors are estimated starting from the carbon content and the calorific value of the of the different fuels of the sources.

As highlighted the second table only the model I1 needed the almost the entire useful life (~ 41 years with respect to 50 years) in order to recover all the amount of the CO_2 emissions for the construction of the building included the PV manufacture with the plus energy produced with PV panels installed on the roof. In this case it is important and interesting to stress out that if an energy simulation with hourly time step was considered the payback period of the model I1 in the city of Florence for the whole construction is equal to about 35 years.

The next Table 4.23 shows the results concern the calculation of the payback period considering the advisable configuration for the installation of the PV system on the roof.

The table illustrates: the value of the plus energy produced by advisable PV system [kWh/m^{2}a], the CO_2 avoid with this plus electrical energy generation [kg$_{CO2}$/m^{2}a]; the amount of CO_2 emissions for PV system in 30 years, and finally the calculation of the payback period.

Table 4.23 Calculation of the payback period for the PV advisable configuration construction for the city of Florence – model I1

Model	Surplus energy produced by PV system	CO_2 emissions avoid kg$_{CO2}$/m^{2}a	CO_2 emissions for PV system	Payback period years

	kWh/m^{2}a		construction kg$_{CO2}$/m^{2}a	
I1	95	52	120	2
I2	108	59	130	2
I3	96	52	128	2.5

If the payback period for Florence city for model I1 is evaluated in terms of CO_2 emissions for the construction of the PV panels, considering an operational life of 30 years, the results reported in the previous table stressed out that:

- for the advisable configuration with a tilt angle of 10° and East/West orientation of the PV panels rows the payback period is equal to about 2 years;
- for the most recurrent configuration for the Mediterranean area is of about 4 years;
- the payback period of a PV systems with an angle of 30° and southern oriented can be considered double in terms of the environmental impact.

Table 4.24 and Table 4.25 illustrates the results related to a simple and brief economic analysis that was performed with the purpose of comparing the 2 PV system configurations with regard to financial investment. In the next tables for the 3 models located in the city of Florence are reported: the total investment cost for the whole installed PV system [€], the total amount of energy cost for the surplus electrical energy production [€] and the payback period measured in years. The following aspects were considered within a period equal to one year:

- the cost of PV panel is deemed equal to about 600 €/kWp;
- the cost of the electrical energy equal to 0.2 €/kWh.

Table 4.24 Calculation of the payback period by economical point of view considering the city of Florence – recurrent configuration

Model	Cost of the PV system [€]	Cost of the surplus electrical energy [€]	Payback period years
I1	37843	9144	4
I2	41119	12745	3.2
I3	76308	22954	3.3

Table 4.25 Calculation of the payback period by economical point of view considering the city of Florence – advisable configuration

Model	Cost of the PV system [€]	Cost of the surplus electrical energy [€]	Payback period years
I1	53768	16197	3.5
I2	61340	18396	3.3
I3	114437	33594	3.4

Despite if an economical point of view is considered the initial investment cost for the advisable configuration is higher than the most recurrent one of about 30% for all the typological models considered.

Analysing the results related to the payback period for the construction of the whole PV system it is possible to admit ad to conclude that:

- for the model I1 it is of about 4 years while for the advisable configuration for producibility is 3 years and a half;
- for the model I2 and the model I3 the most solution is the one with the inclination of PV system equal to 30° and South orientation because the initial investment cost is definitely lower that the other one analysed, and the payback period is basically the same.

So, for the public administration that builds the construction of a school where there is a precise budget to spend also this consideration is equally substantial to consider.

All the results presented can help the designer during the preliminary phase of the design process in order to choose the proper configuration of the main building typological features and technological solution as well to obtain environmental-friendly school. In the context of the Paris Agreement with the purpose of a carbon free economy within 2050, in order to face the problems deal with pollutants emissions and climate change in the future, and the smart and sustainable cities where most of the required energy is the electrical one, the realization of plus energy schools could be a possibility as well.

Concluding, in order to understand the results of all these analyses (in terms of energy and environmental performance of the new school building type) obtained with some possible changes of the building typological factors with respect to new building typed defined (*Chapter 3*) it is necessary to make some comparisons. For brevity the results are reported for the city of Florence and the advisable configuration is the one that include all the changes of the main typological factors that could improve the energy and environmental performance that before are described in detail.

The next graphs below represent:

- the final energy demand for both heating and cooling [kWh/m^{2}a];
- the primary energy demand related to the different types of consumptions (heating, cooling, lighting, auxiliary energy, equipment and service hot water) [kWh/m^{2}a];
- the CO_2 emissions referred both to structure, system and PV construction and consumptions during operational phase [kg$_{CO2}$/m^{2}a].

The next graphs show the final energy demand for heating (Figure 4.74) and for cooling (Figure 4.75).

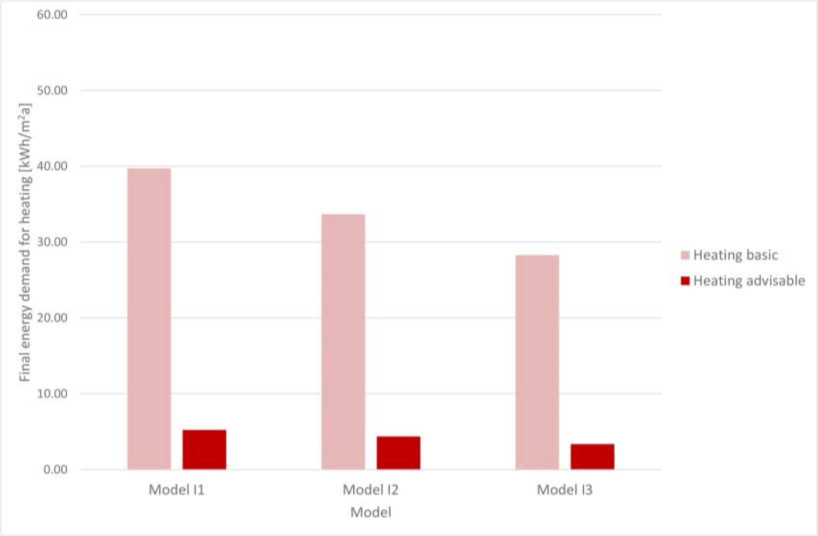


Figure 4.74 Final energy demand for heating for Florence. The advisable configuration is the one that include all the changes of the main typological factors of building type that could improve the energy and environmental performance

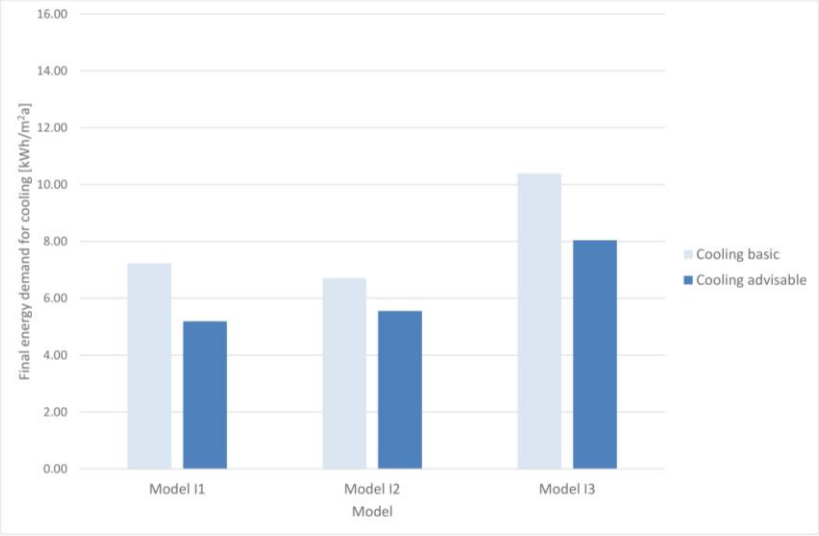


Figure 4.75 Final energy demand for cooling for Florence. The advisable configuration is the one that include all the changes of the main typological factors of building type that could improve the energy and environmental performance

For instance, for climate zone D there is a significant reduction (of about an average of 87.5%) in final energy demand for heating. Even if a more temperate winter season the final energy demand for heating is the higher contribution with respect to the amount of energy demand in order to keep the proper internal conditions. The final energy demand for heating is under 10 kWh/m^{2}a with a maximum value for model I1. This is due to the greater exploitation of solar gains for the model with a linear shape with East-West axis prevailing direction (model I2 and model I3). Furthermore, the final energy demand for cooling is under 8 kWh/m^{2}a for all models with the minimum value at about 5 kWh/m^{2}a for the model I1.

The ensuing Figure 4.76 illustrate the comparison on the value of primary energy demand of the new typological models defined for the new building type (Model I1 – system configuration 1) and the typological models with all the possible changes of the main building typological factors (Advisable I1 – system configuration 3).

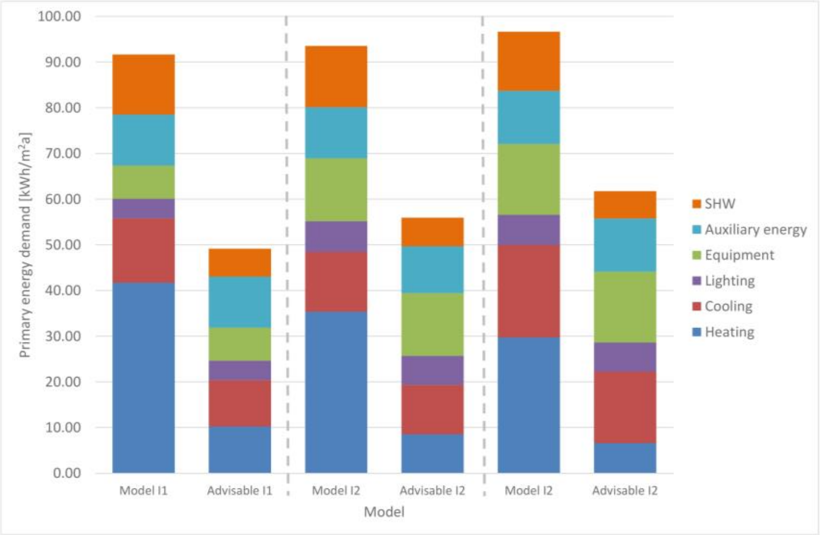


Figure 4.76 Primary energy demand for the city of Florence. The advisable configuration is the one that include all the changes of the main typological factors of building type that could improve the energy and environmental performance

As definitely shown in the previous graph, it is evidently that all the advisable configurations of the building typological factors let to obtain a significant reduction in primary energy demand (equal to about 35%). The most significant reduction for model I1 and model I2 is the heating primary energy demand while for model I3 the 2 most influential contributions to building primary energy demand are heating and cooling as well. Maybe it is partly related to the value of advisable WWR for South orientation equal to 50% which in any case involves slight increase in energy demand for cooling even if the use of solar shading system for each functional unit southern oriented.

Finally, the last graph in Figure 4.77 illustrates the amount of CO_2 emissions comparing the model I1 with configurations system 3 (model) and the configuration system 4 (advisable).
For climate zone D there is a considerable reduction in the total amount of CO_2 emissions:

- of about 20% for the model I1 and the model I2;
- and approximately 30% for the model I3.

The model I2 has the higher value of the total amount of CO_2 emissions with respect to the ground floor surface. It is related also to the PV advisable configuration construction, but it is still always under 25 kg_{CO2}/m^2.

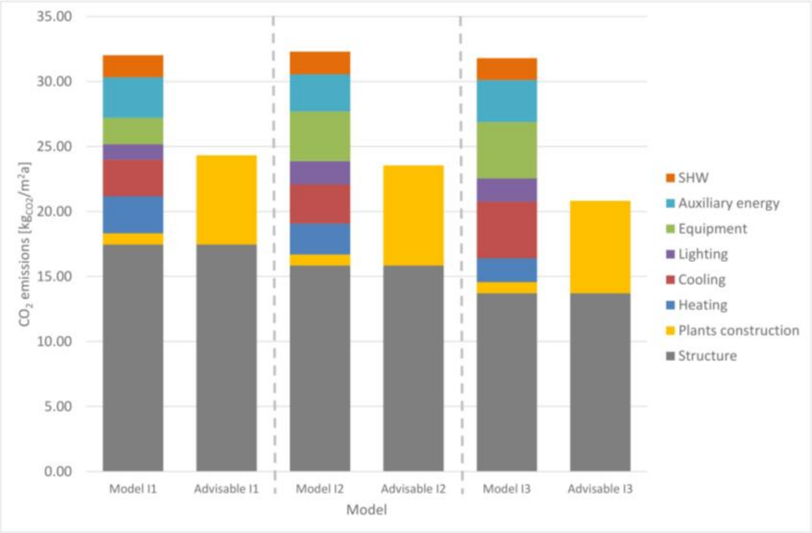


Figure 4.77 CO_2 emissions for all models in Florence. The advisable configuration is the one that include all the changes of the main typological factors of building type that could improve the energy and environmental performance

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CLOSING NOTES

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[i] One of the methods used to identify these parameters is the sensitivity analysis. Use since 1970 [26], this method can be helpful to the designer to establish the contribution of each elements of the project that can be parameterized (input) in relation to the primary energy consumption of the building (output) for example.

Many studies in literature concerning the application of this methodology with respect to the energy needs are related to office buildings [27-28] and residences. For instance:

- Hemsath et al. [29] performed 2 different types of sensitivity analysis (definition of local sensitivity index and Morris global sensitivity analysis) with the intention of studying the influence of the shape of the building and the relation of two dimensions (vertical and horizontal proportions) of the floor with respect to the energy needs according to different climate conditions.

  In conclusion, they state that generally the choice of the shape affects the energy consumption more than the choice of technological solution and materials for the external envelope.
- Smith et al. [30] consider the roof solar absorptance, the air exchange rates and the sub-roof R-value for the analysis with respect to heating and cooling loads and annual total energy needs.

  These parameters affect the energy balance of the examined residential building as they greatly affect the value of dispersions and internal gains and they outline a different energy performance of the building depending on the considered reference season.

  For summer season the roof solar absorptance is the most influence parameter while for winter season the sub-roof R value is less meaningful than the air change rate. Moreover, they demonstrate that some of the traditional strategies to save energy, for example the increase in R-value, are often not so useful to save energy.
- Instead, Heiselberg et al. [31] performed a global sensitivity analysis, defining a sensitivity index with respect to the primary energy use, by varying 21 parameters (for instance heat capacity, windows thermal transmittance, solar factor, shading, overheating, mechanical ventilation rate during daytime in winter and summer season, efficiency of heat recovery, lighting power) within a fixed range considering a multi-storey office building in Denmark.

  For this building type the results show that artificial lighting control and the air change rate through mechanical ventilation during winter season are the factors that mostly affect the energy consumption.
- Furthermore Harkouss et al. [32] use this type of analysis to understand the robustness of the results of their analysis in order to find the best combination of strategies in order to achieve a Nearly Zero Energy Building and to optimize each considered variable (external walls and roof insulation thickness, windows glazing type, cooling and heating setpoints and window-to-wall ratio).
- Finally, Premrov et al. [33] study 216 different types of timber box-house performing a parametric analysis considering the aspect ratio (south and north orientation) and the horizontal and vertical extension of the building located in 2 cities in Spain.

  The study describes the influence of these parameters on annual energy demand in order to define a guideline to help the designers in order to avoid overheating with the choice of the optimal solution. They stated that the shape has a significant influence on annual energy needs and for both the considered cities the single storey building has evidently a better energy performance than the two storey one. Furthermore, they

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conclude that an increase in aspect ratio leads to a significant rise in energy needs for cooling considering a warm climatic area.

[ii] The assumption of this external temperature limit value for the control of the shielding system is independent of the climatic zone. Although, the choice of value is closely linked to the conditions that must be maintained within the environments. Since the internal temperature is one of the most incident parameters on the comfort conditions of the rooms and as it is conventionally equal to 26 ° C, providing for the activation of the external 24 ° C solar shading avoids the need to use the systems to make up for the cooling by intake solar radiation for direct radiation, in addition to the inevitable one due to direct heat exchange. So, this is independent of the climate zone.

CHAPTER 5. Qualitative and quantitative guidelines to build neutral carbon kindergartens in Italy

The qualitative and quantitative guidelines connect the new building type for schools with an estimation of their energy and environmental performance. They will lead to the definition of qualitative references but at the same time they will suggest some evaluations and some possible changes related to the main building typological factors that could improve the building energy and environmental performance.

In a country like Italy characterised by different type of climate zones with distinct characterisation of winter and summer season, it is fundamental to study and to define the building distinguished features related to several climate zones in order to obtain a proper configuration of the building type to build neutral carbon kindergartens in Italy. It is important because a new building type was defined through the environmental and technological system but with respect the characteristics of the construction site that include climate and environmental data with respect to the building as well.

Therefore, in this paragraph the qualitative and quantitative guidelines concern the construction of kindergartens in Italy are delineated for each different climate zone with respect to all the factors that define a building type (environmental and technological system):

- some general characteristics mainly related to the school and neighbourhood community relationship;
- the external layout;
- the energy strategies to reduce energy needs in summer season;
- the energy strategies to reduce energy needs in winter season;
- the environmental strategies;
- the main architectural features:
    - geometry;
    - orientation;
    - building organisation;
    - structure;
    - technological solutions chosen for the external envelope;
    - window – to – wall ratio;
- the systems;
- the design data.

Only some characteristics related to the climate zone are described separately. When it is not specified it means that they are valid for all the climate zones considered.

General characteristics

Firstly, a brief focus on general characteristics of new typological models for kindergarten are listed below and so they are applicable for all the cities considered:

- they should become civic centers connected with the external environment and the city itself.

  For instance, the functional units where free activities are performed, the Agorà as well, and the canteen are space that could be used by the neighbourhood community in extra-school hours for social event or activities. They should be meant such as a place of reference for community.

  They should be designed and built in such a way as to be completely independent from an architectural point of view, as regards access and the system of exit routes, but also from a plant point of view.

  A direct relationship with neighbourhood should occur with efficient infrastructure connection system, and proximity to public transport, but also with large windows that allow a continuous connection between inside the building and the outside natural environment;
- they should become a kind of connection with students' families which are involved more often in teaching activities. The new functional unit especially designed to do that is the Agorà. This functional area is essential as the parents can stop with the children according to their needs.
- they should be an example of sustainable and quality architecture that could start a redevelopment of suburbs as well. In addition, they should become real 3D textbooks from which children can learn sustainability and respect for the surrounding natural environment.

Energy strategies for winter season

To reduce the primary energy demand during winter season, especially for the climate zone E and D where the final energy demand for heating is the contribution that affect the most the energy needs of the building, is advisable:

- low value of aspect ratio through the design of internal open courtyard or recesses in the geometry of the building. The new defined building type for kindergarten have a value of the ratio between the whole dispersing façade and the volume of the building $< 0.55\ m^{-1}$;
- the prevailing orientation along East-West axis leads to obtain lower amount of final energy demand for heating owing to the exploitation of solar gains. This is possible if the surrounding urban context allows it without shadow phenomena;
- the southern oriented functional band should have a depth greater than one exposed to North at least in a ratio of 2:1. In the new typological models the South facing functional band is characterised by a depth equal to a medium value around 9.6 m;
- in the southern functional band there should be the main functional units that have practically a continuous presence of people during opening time of the school (such as classrooms), whereas in the northern one the areas that have an occasional presence of people (for instance teachers' area);

- the classrooms should be oriented to the South in order to take advantage of free solar gains during winter season where methodical activities are performed;
- the value of WWR for climate zones E and D should be greater than that imposed by health-hygiene regulations;
- on the northern front, openings should be dimensioned with the minimum size required by current health hygiene standards;
- the sensitive recovery for controlled mechanical ventilation for air change rate should be considered at least equal to 65%, especially for the climate zones E and D with a significant energy requirement for heating.

Energy strategies for summer season

To reduce the primary energy demand during summer season, especially for the climate zone C and B where the final energy demand for cooling is the contribution that affect the most the energy needs of the building, is advisable:

- on the southern façade for climate zones C and B the windows size should be kept equal to that required by current health hygiene regulations for the functional units so oriented as will be detailed in the following paragraph related to window-to-wall ratio;
- the use of solar shading system for all South-facing functional units in order to avoid overheating during hot spring and summer days and to guarantee control on glare in the areas where visual tasks are performed.

Environmental strategies

To reduce the CO_2 emissions in the atmosphere and to build an environmental-friendly school is recommended:

- the natural materials should be used for the main technological solutions in compliance with CAM requirements in order to reduce greenhouse emissions in the atmosphere.
  It is important to utilise natural material for the main technological solutions of the building because they permit to reduce the value of the GWP and so to mitigate the greenhouse gas emissions in the atmosphere;
- the use of renewables. For instance, the installation of PV system on roof to produce electricity in order to satisfy the building needs but also to have the possibility to fed into public grid the amount of surplus electrical energy usable by neighbourhood buildings.
  The use of different kinds of system that makes use of solar, wind and geothermal energy are appropriate depending on the availability of renewables in the construction site.

External layout

The surrounding natural environment evolves into a space for teaching with for instance different thematic environment. Besides many of teaching or collective activities should be organised in the external garden. The classrooms must be directly connected with the external natural environment in order to create a strict relationship between students and nature.

However, these guidelines did not deal in detail with the specific design of the area outside the kindergarten and the construction site. Otherwise some suggestions are here outlined:

- the access to the construction site should be reached through secondary arteries;
- the stops of the public transport vehicles should be almost always at a distance less than 200-300 m and all the schools should have a special rubber parking area for public transport that allows the ascent and descent of the students in complete safety (this also happens for private parking for parents);
- the parking area should be outside of the school garden and it should be reserved for external staff and teachers who can use the secondary entrance located along the North side of the building. The parking area should be at least 1 m^2 for 10 m^3 of the building;
- at least 25% of whole external surface should be permeable (lawn, self-locking floors for parking);
- the play area with accident-prevention finishing or cultivated and work/educational garden (outdoor sensory paths, educational greenhouses) should be expected for the teaching activities on the external environment.

The study of surrounding building shadows on the construction site should be considered.

Geometry

The building type for the kindergarten is developed in one ground floor without vertical connections due to the age of children. The possible and advisable shapes for a new kindergarten in order to follow the new pedagogical and didactic methods and to obtain a proper energy performance with low primary energy demand and consequently minimum CO_2 emissions are the following ones:

- compact shape with open internal courtyard with 3 sections (model I1 – Figure 5.1);
- linear shape with 3 sections (model I2 - Figure 5.2);
- linear shape with 6 sections (model I3 - Figure 5.3).

The geometrical characterisation of each typological models for kindergarten are detailed in the following table (Table 5.1). The illustrated characteristics are: length (C), depth (B), internal height (H_{int}), floor area (A) and building volume (V), shape ratio (S/V), number of students (NS), surface area per student compared to the total area of the building (S_{stud}), orientation, number (NC) and class sizes (E width; D depth).

Table 5.1 Geometrical characterisation of typological models for neutral carbon kindergartens

	Building						Students		Classrooms			
	C [m]	B [m]	H_{int} [m]	A [m^2]	V [m^3]	S/V [m^{-1}]	NS	S_{stud} m^2/stud	Orientation	NC	E [m]	D [m]
I1	37.80	29.80	4.40	1036	6008	0.53	78	14.44	South	3	12.6	10.00
I2	75.60	14.90	4.40	1064	6172	0.51	78	14.44	South	3	12.6	7.90

I3	100.8	19.50	4.80	1631	10116	0.46	156	12.60	South	6	12.6	11.00

As illustrated in the previous table:

- the new defined typological models for kindergarten have a value of the ratio between the whole dispersing façade and the volume of the building $< 0.55\ m^{-1}$;
- with respect to the classrooms the minimum width is equal to 12.6 m whereas the average value for the depth is around 9.3 m that is strictly linked also with the depth of the building;
- all the classrooms for all the models are South oriented.

Building organisation

With respect to the building organisation the advisable and proper configurations for each shape considered (model I1, model I2 and model I3) are the following ones:

- the model with compact shape is organised according to 5 horizontal functional bands of different dimensions with a ratio of 1.70 between the depth of South-facing functional band and the North-facing one;
- the models with horizontal shape are designed following 3 horizontal functional bands distribution with main horizontal connection placed in the center. In these 2 cases the dimensions in plan (depth and length) are in a ratio of about 1:5.

In the South facing functional band the home base should be designed, whereas in the functional band northern oriented, the area with a lower occupation during school opening time should be organised such as teachers' area, kitchen and storages for the external staff.

From an internal functional distribution point of view a kindergarten:

- it should be designed in order to guarantee the integration and operability of the several functional areas;
- it should ensure the flexibility and adaptability of the available spaces for teaching activities (multifunctionality of the functional units);
- the horizontal connections should become spaces for free and social activities.

The functional units that must be considered inside a kindergarten are the next ones:

- home base mainly for the teaching and collective activities. In the case of a kindergarten this functional unit includes toilets as well, to perform practical activities;
- free activities area for collective and playing activities that is a flexible space adaptable on specified teaching needs;
- canteen/kitchen area. In the case of kindergarten, canteen could be missing due to the age of the students that could eat also inside classrooms or in free activities area with removable furniture;
- care area that includes teachers' area.

The kindergarten functional unit related to the home base (Figure 3.41) should be organised in 4 identifiable different areas in order to performed different types of task:

- the area for the practice activities that includes toilets. In the of kindergarten toilets must be inside the classroom to be easily accessible to the young children to performed practical activities;
- the area for the methodical activities to carry out teaching tasks;
- the area for the free and collective activities or play area;
- the area for rest and relaxes.

The functional characterisation of each typological models for kindergarten are detailed in the following table (Table 5.2). The exhibited characteristics are: depth of functional horizontal bands (Functional bands$_{\text{Horizontal}}$) and vertical bands (Functional bands$_{\text{Vertical}}$) according to orientation (South/middle/North - East/middle/West) measured in meters, the percentage relative to each functional unit in relation to the total area (%$_{\text{TOTAL}}$), the ratio between the southern functional zone and the northern one (R) and finally the surface area for student compared to the home base (HB).

Table 5.2 Functional characterisation of typological models for neutral carbon kindergartens

	Functional bands$_{\text{Horizontal}}$ [m]			Functional bands$_{\text{Vertical}}$ [m]			Functional units [% $_{\text{TOTAL}}$]					R	HB
	South	middle	North	East	middle	West	MA	FA	C/K	CA	C	S/N	m^2/ stu
I1	10	9.00	5.80	-			38.3	10.3	22.4	9.5	14.8	1.7	4.85
I2	7.9	2.50	4.50	-			37.4	14.2	16.7	14.8	18.6	1.8	5.10
I3	11	2.50	6.00	-			44.3	14.5	21.4	8.0	11.7	1.8	5.33

With respect to the Home Base considering only the methodical activities and the special ones the advisable surface measured in square meters per students is 3.40 m^2/stud.

The medium value in percentage related to the main functional units for a kindergarten are:

- for the home base is equal to 40%;
- for the free activities area (including Agorà) of about 13%.

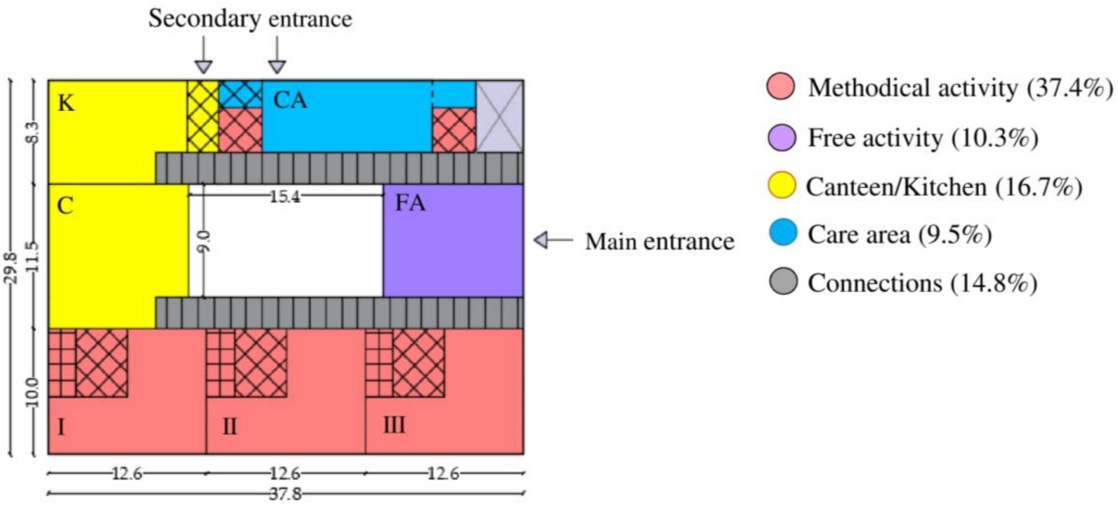

Figure 5.1 Model I1 for kindergarten

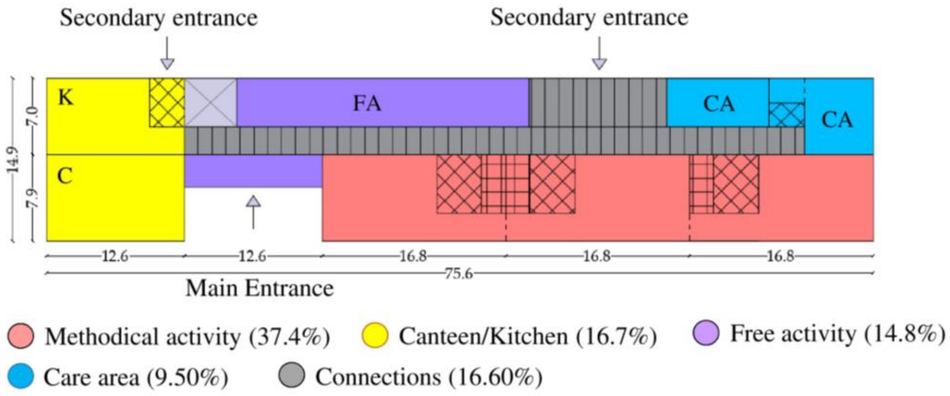

Figure 5.2 Model I2 for kindergarten

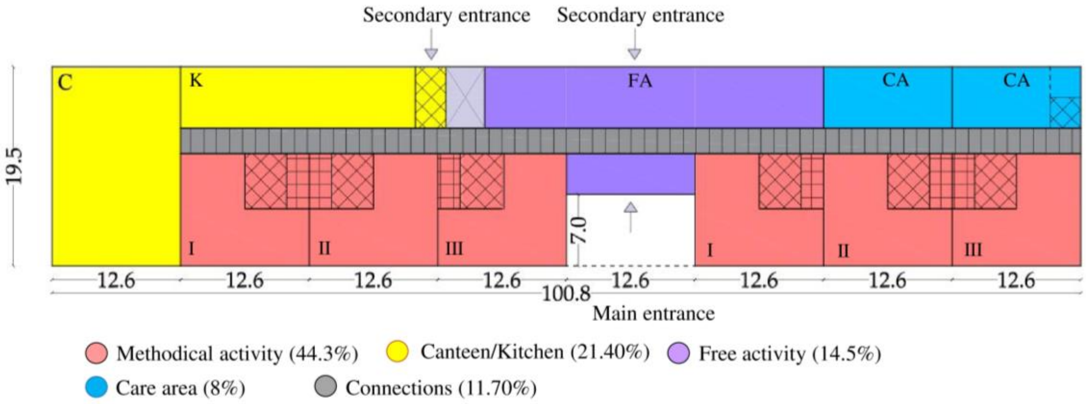

Figure 5.3 Model I3 for kindergarten

<u>Orientation</u>

- The typological model I1 does not have a prevalent geometric orientation having a compact shape but the functional band dedicated to the home base is oriented to the South. The rotation with respect to the North-South axis should be between 0° and 30°;
- the typological models I2 and I3 have a prevalent orientation according to East-West axis in order to allow greater exploitation of solar gains during winter season. In this case as well the home base is oriented to the South and canteen and partly functional units for free activities too.

<u>Structure</u>

A reinforced concrete structure for the foundation elements is considered for the new building type.
The vertical structural solution can be:

- wooden structure in XLAM with 5 layers structural panel (at least 130 mm of thickness);
- wooden structure with platform frame with single/double OSB panel (thickness from 12.5 to 20 mm and for instance with wooden columns of 50 mm X 100 mm).
  The solution with double OSB panels is advisable to ensure better thermal dynamic properties;
- reinforced concrete structure;
- steel structure.

For the horizontal supporting structure, 3 different structural solutions could be used depending on the vertical supporting structure:

- wooden floor with XLAM structural panel of 5 layers of 130 mm thickness for the main vertical structure in XLAM;
- slab with platform frame structure with horizontal wooden beams and OSB panel from 12.5 mm to 20 mm thick for the 2 main platform frame structures;
- brick and concrete floor slab (at least 250 – 320 mm) for the reinforced concrete structure;
- steel corrugated sheet (at least 1.5 mm of thickness and 53 mm of height) and concrete slab (at least 50 mm).

It is clear that the choice of the structural solutions depends not only on the environmental impact or the energy performance but on many factors as well such as the construction traditions and the materials available near the construction site.

Envelope composition

- For the floor slab the solution with disposable plastic molds could be adopted to create ventilation above the floor foundation in order to prevent humidity and rising water, completed with a functional insulation layer in EPS ($\lambda \sim 0.035$ W/mK) to avoid water infiltration, furthermore radiant panels for heating and cooling (EPS/wood fiber panel), and finally interior wood flooring.

  The advisable value of thermal transmittance for the floor slab is equal to 0.25 W/m^{2}K for climate zones E and D and 0.30 W/m^{2}K for climate zone C and B.
  In this case it is not necessary to increase the thickness of insulation because the dispersions are towards the ground that conventionally it is considered conventionally at a temperature equal to 15°C.
  The choice of this solution is mainly related to the cited advantageous and a standardised rule of construction art in Italy. In fact, this solution is the most used also in the contemporary construction analysed.

- For the vertical perimeter wall the recommended technological solutions (related to different type of structure) are the following ones (external layer to internal layer):
  - solution A: XLAM structure – XLAM structural panel of 5 layers (at least 130 mm thickness), with external insulation thermal layer and external plaster as finishing and internal false wall of about 100 mm constituted by a single/double gypsum board panel (15 mm of thickness) and air cavity (~ 70 mm);
  - solution B: platform frame structure and double OSB panel - external insulation (thickness equal to 20 mm) and external plaster as finishing, OSB panel (20 mm), thermal insulation layer, OSB panel (20 mm) and internal false wall as solution A;

- solution C: reinforced concrete structure - external thermal insulation and external plaster as finishing, lightweight brick (thickness: one of 120 mm and one of 250 mm) and internal false wall as solution A;
- solution D: steel structure – external wall made of dry solution with cement board external panel (12.5 mm), waterproofing sheet (1.8 mm), thermal insulation layer, plasterboard panel (15mm) and internal false wall as solution A.

The vertical perimeter wall of both reinforced concrete structure and steel one could be made also with aerated concrete blocks that have a better thermal performance with respect to the lightweight bricks.

The internal cavity of the internal false wall could be completed with an acoustic insulation in mineral wool (50 mm) in order to ensure the adequate acoustic insulation of the façade ($R_w > 50$ dB). A double internal plasterboard is advisable because of impact.

The advisable value of thermal transmittance for external wall is in a range between 0.17 W/m^{2}K and 0.20 for climate zones E and D, 0.25 W/m^{2}K for climate zone C and 0.40 W/m^{2}K for climate zone B. The periodic thermal transmittance could be lower than 0.01 W/m^{2}K and the time shift higher than 8 hours in order to maintain the proper internal thermal comfort.

The solution that guarantees the higher time shift (> 20 h) and the higher mass surface (> 230 kg/m^2) is the one with lightweight bricks because of bricks density equal to about 800 kg/m^3. It is important to stress that for the climate zones with hot summers (C, B) it is advisable to use technological solution with high surface mass (for instance solution A – solution C).

The insulation layer could be made of different materials, such as wood fiber, mineral wool, recycled EPS, glass wool. The only advice is to use an insulation material with density at least equal to 60 - 70 kg/m^3 for the dry solution, otherwise the appropriate time shift could be guarantee only with an excessive thickness of the insulation layer. For instance, if the material EPS (density ~ 35 kg/m^3) is chosen for the solution 4, 320 mm of thickness occur to have a time shift equal to 8 hours.

It is useful to point out that an increase in insulation thickness above 140 mm for each technological solution for the external wall and for each different type of insulation does not improve the energy performance of the building considering both the heating and cooling demand.

Otherwise a low value of thickness of insulation for the external walls is suggested for climate zone with hot summers (for instance C and B) because an excessive insulation leads to a significant increase in energy demand for cooling during summer season.

These different solutions are suggested because the designers' choice of the most adequate technological solutions for the external envelope it is not related only to the energy demand of the building and to its environmental impact but also to many other factors, such as the initial investment cost, the construction time, the constructability, the flexibility for the location and sizing of windows, materials availability and also construction tradition for the building site.

- As far as the openings are concerned, frames should be chosen with aluminium thermal break profile with minimum transmittance equal to U_f =1.7 W/m^{2}K.

The glazing recommended for kindergarten according to the climate zone (B-C-D-E) have the characteristics detailed in the following Table 5.1. The illustrated characteristics are the type of glass, the thermal transmittance of the glass plate (U_g), the solar factor (g) and finally light transmission (T_L).

Table 5.3 Possible glazing characteristics for neutral carbon kindergartens

Climate zone	Type of glass	Ug [W/m^{2}K]	Solar factor [%]	Light transmittance [%]
B	Like type AGC: 66.2 Stratophone 2 x Planibel Clearlite – 20 mm Argon 90% – 44.2 Stratobel 2 x Planibel Clearlite	2.5	69	78
C-D	Like type AGC: 66.2 Stratophone 2 x Planibel Clearlite – 12 mm Argon 90% - 4 mm ilplu Advanced 1.0 on clearlite pos. 3	1.2	50	74
E	Like type AGC: 66.2 Stratophone 2 x Planibel Clearlite – 20 mm Argon 90% - 4 mm iplus Advanced 1.0 on clearlite pos. 3	1.1	52	75

For the city of Palermo, located in climate zone B, in order to further reduce the final energy demand for cooling it is advantageous to use a glass with a lower value of solar transmittance approximately equal to half (~ 0.406%) of the solution presented in the table for climate zone B.

- For the roof floor a ventilated solution is recommended. The possible configurations of the roof floor could be (internal layer to external layer):
  - solution 1: XLAM structure – XLAM panel (thickness equal to 125 mm), 0.45 mm vapor barrier, insulation layer, waterproof sheet of 0.004 mm and 50 mm of ventilation created with double warping of wooden strips and 0.5 mm thick metal cover;
  - solution 2: platform frame structure - 120 mm thick OSB panel, carried by a structure with wooden beams every 60 cm, 0.45 mm vapor barrier, insulation layer, waterproof sheet of 0.004 mm and 50 mm of ventilation created with double warping of wooden strips and 0.5 mm thick metal cover;
  - solution 3: reinforced concrete structure – thick masonry floor (250 mm – 320 mm), 0.45 mm vapor barrier, insulation layer, waterproof sheet of 0.004 mm and 50 mm of ventilation created with double warping of wooden strips and 0.5 mm thick metal cover;
  - solution 4: steel structure - steel corrugated sheet (at least 1.5 mm of thickness and 53 mm of height) and concrete slab (at least 50 mm), 0.45 mm vapor barrier, insulation layer, waterproof sheet of 0.004 mm and 50 mm of ventilation created with double warping of wooden strips and 0.5 mm thick metal cover.

All the solutions could be completed as an alternative to the ventilated roof with a layer of gravel (at least 50 mm, it depends on wind load).

The advisable value of thermal transmittance for the roof is in a range between 0.12 W/m^{2}K and 0.13 for climate zones C and D, 0.15 W/m^{2}K for climate zone C and B.
The insulation layer could be made of different materials such as wood fiber, recycled EPS or XPS but it is important to verify the compression loading that it can bear. The thickness of the insulation layer could be implemented for the climate zones with cold winter until 240 mm (maximum thickness considering technological point of view and installation). It influences the primary energy demand more than the insulation layer of the façade (~ 9%) for the climate zones E and D.

If the environmental impact was considered, all these solutions (combined each one with the related type of structure) could be used as valid alternatives to build a carbon-zero kindergarten in Italy. All of them let to obtain a value of CO_2 emissions for the whole construction within 7 kg_{CO2}/m^2a and 17 kg_{CO2}/m^2a (considering for instance the model I1). The solution with the highest impact is obviously the one with reinforced concrete load-bearing structure. With respect to the energy performance as well all these solutions could be considered as applicable solutions to build zero-carbon schools in Italy. They permit to reach a value of primary energy demand of about 25 kWh/m^{2}a (considering for instance model I1).

Window to wall ratio

Obviously, the size of the façade openings for the new building type for kindergarten for each individual functional unit, and so for each orientation, has been outlined by the minimum sanitary requisites required by the current hygiene regulations in the national territory in reference to both the rate of air exchange necessary for ventilation and the exploitation of natural light, essential in a school building.
Specified this, some changes could occur in order to improve the energy and environmental performance of the new typological models for kindergarten.

- For all climate zones considering North orientation the lower value according to health-hygiene standards is advisable to reduce the heat dispersions during wintertime.
- For all climate zones increasing the windows sizing for East and West orientations there is no advantages with respect to the energy performance and consequently neither as regards to the amount of CO_2 emissions. So, for these orientations as well the advisable configuration for the WWR is the minimum required by regulation.
- For climate zone E and D a value of South WWR within the minimum required by Italian law and 50%. However, large windows for these climate zones should be adopted for South orientation with a WWR equal to 50% in order to exploit solar gains during winter season and save energy to heat the building (~ 5%). An increase in the value of WWR over this value does not lead to a benefit in terms of heating demand, rather it could lead to an increase in cooling demand.

  As regard to the number of windows for classrooms it is important to remind that for these climate zones (E-D) in order to achieve a better value of uniformity of illuminance due to natural light it is appropriate to have 2 windows.

- For climate zone C and B the value of WWR for each orientation should be kept the minimum required by legislation in order to avoid overheating and an over-size of cooling system.
  In these 2 climate zones is better to have one window for each classroom in order to achieve a proper value of uniformity of illuminance and average daylighting factor.

Solar shading system

- The advisable solar shading system for all the functional units southern oriented is a fixed overhang of 2 m combined with an automated internal venetian blind (built with high reflective material) with control on the value of the external temperature (> 24°C). For climate zone E and D, the control on the DGI could be used, while for the climate zone C and B the control on cooling is recommended as well;
- as regard to East, West and North orientation if the internal functional distribution should be the same of the typological models presented in these guidelines the solar shading system is not necessary because they do not lead to any advantages in terms of energy or environmental performance.

Internal partitions and finishes

The internal partitions between the different functional units could be made of plasterboard with a steel substructure.

The advisable interior finishes are made of wood to ensure adequate environmental quality in terms of emissions of harmful substances into the environment so as to safeguard children's health but also in order to have a minimum environmental impact of the construction in terms of greenhouse gas.

Systems

The advisable system configuration for a school is the following one:

- heating system:
  - generation system: heat pump with coefficient of performance (COP) equal at least to 3.6.
  - end of distribution system: ground floor radiant panel for each functional unit.
- cooling system:
  - generation system: heat pump with energy efficiency system (EER) equal at least to 3.2.
  - end of distribution system: ground floor radiant panel for each functional unit.
- ventilation system: air handling unit with sensible heat recovery at least equal to 65% and free cooling.

For all the climate zones in Italy the advisable configuration of PV panels in order to maximise the electricity production and so to avoid the maximum amount of CO_2 emissions should have East-West orientation and a tilt angle equal to 10°. The minimum distance between the panel rows should be at least equal to 70 cm in order to guarantee the minimum space for maintenance.

Main design data

In order to complete these qualitative and quantitative guidelines related to the construction of kindergarten in Italy the main design data referred to the main legislation concern with school and valid for all climate zones are briefly outlined:

- the occupancy and so the density of people for each functional unit [person/m^2]:
  - Class 0.4 person/m^2 with a maximum number of student equal to 26;
  - Canteen 0.6 person/m^2;
  - Free activities 0.4 person/m^2;
  - Teachers area 0.3 person/m^2.
- the setpoint temperature for the building:
  - for heating system, it is set equal to 20°C with the attenuation temperature equal to 10°C;
  - for cooling system, it is set equal to 26°C with the attenuation temperature equal to 36°C.
- the minimum air change rate in l/s per person or l/s per m^2 for each functional unit:
  - Class 4 l/s person;
  - Canteen 10 l/s person;
  - Free activities 4 l/s person;
  - Toilets 2.5 l/sm^2;
  - Connections 2.5 l/sm^2.
- the level of illuminance [lux] in order to ensure the appropriate visual comfort with natural lighting:
  - Class 300 lux;
  - Canteen 300 lux;
  - Free activities 300 lux;
  - Toilets 100 lux;
  - Connections 100 lux.
- the maximum index of glare equal to 21 in order to teaching tasks inside classrooms with the proper visual comfort due to the exploitation of natural light during school opening time;
- the average daylighting factor:
  - Kindergarten 3%;
  - Elementary school 5%.
- the possible internal loads:
  - Class Computer 5 W/m^2;
  - Canteen Additional equipment 1 W/m^2;
  - Kitchen Food preparation 4.5 W/m^2;
  - Teachers area Computer 3.5 W/m^2;

  - Toilets Additional equipment 0.5 W/m^2.

A table (Table 5.4) related to the city of Florence considering the new building type for kindergarten (3 different typological models) and all the advisable changes for the main building typological features are reported below in order to understand the improvement that could be obtained with all these modifications of the building distinguishing features. As an example (only because it is one of the most recurrent in literature) the structural solution is the one with wooden structure in XLAM panel and so solution A for the wall and solution 1 for the roof floor were considered. In appendix A are illustrated the tables referred to the other cities (Table A.25 – Table A.28). All the results are discussed.

Table 5.4 Example of one of the possible applications of guidelines for the city of Florence

Florence	**Model I1**	**Model I2**	**Model I3**
Structure	XLAM structural solution with structural panel with 5 layers of 130 mm of thickness		
Façade technological solution	External insulation		
Material of insulation	Wood fiber		
Wall thickness of insulation	140 mm		
Wall thermal transmittance	0.199 W/m^{2}K		
Roof thickness of insulation	220 mm		
Roof thermal transmittance	0.133 W/m^{2}K		
Type of Glass	66.2 Stratophone 2 x Planibel Clearlite – 12 mm Argon 90% - 4 mm iplus Advanced 1.0 on clearlite pos. 3		
Glass main characteristics	solar factor = 50% – light transmittance = 74%		
Glass thermal transmittance	1.2 W/m^{2}K		
Window frame thermal transmittance	1.7 W/m^{2}K		
South WWR	50%		
North WWR	8%	9%	13%
East WWR	7%	7%	-
West WWR	7%	8%	15%
South solar shading	Fixed overhang (2 m) + automated internal venetian blinds with control on external temperature > 24°C or on discomfort glare index (DGI) > 22		
West/East solar shading	Not necessary		
Mechanical ventilation system	Air handling unit with free cooling on enthalpy (15 vol/h) with sensible heat recovery with efficiency at least 65% - Air change per hour based on UNI 10339		
Heating system	Heat pump COP = 3.6 (configuration 4)		
Cooling system	Heat pump EER = 3.2 (configuration 4)		
Primary energy demand [kWh/m^{2}a]	25.20	28.68	31.67
PV panels configuration	East/West orientation – tilt = 10°		
PV panels surface [m^2]	547.93	681.56	1271.52
PV surplus energy production [kWh/m^{2}a]	95.05	107.96	96.10
Avoided emissions [kg$_{CO2}$/m^{2}a]	51.71	58.73	52.28
Total amount CO_2 emissions (configuration 4)	24.32	23.54	20.82

Summing up, tables referred only to one possible configuration point out that:

- for the city of Milan, located in climate zone E, the proper insulation layer for both the external wall (140 mm) and roof top (240 mm) permits to achieve a low value of final energy demand for heating of about 8 kWh/m^{2}a for the model I1, 7 kWh/m^{2}a for the model I2 and 5.40 kWh/m^{2}a for the model I3. This value for the climate zone E depends on the use of system configuration 4 as well, that includes a heat pump for heating and cooling system with coefficient COP = 3.6 and EER = 3.2.

  In Milan as well it is possible to produce enough electrical energy to satisfy the building energy needs and to feed the surplus energy into public grid in the context of the smart cities with the installation of a PV system on the roof (average value between the models of about 93 kWh/m^{2}a);
- for the cities of Florence and Rome, both located in the climate zone D, the advisable conditions in these quantitative guidelines are the same in order to obtain a primary energy demand < 35 kWh/m^{2}a and an amount of CO_2 emissions within 20–25 kg_{CO2}/m^2a considering the building construction including PV system and the operational phase consumptions.
- for the cities of Naples and Palermo, located respectively in climate zone C and B, the final energy demand for cooling affects the most both the total primary energy demand and the amount of CO_2 emissions. In order to avoid an oversizing of cooling system the better insulation for the thickness of insulation for the external walls for these cities is up to 80 mm for Naples and 40 mm for Palermo and for the roof equal to 180 mm. This low value of thickness of insulation for the external walls is owing to the reason that an excessive insulation leads to a significant increase in energy demand for cooling during summer season.

  In these cities, due to the high value of the solar radiation, the exploitation of the whole surface of the roof with PV panels lets to achieve a surplus electrical energy production for all the typological models for kindergarten > 89 kWh/m^{2}a with a maximum value for the city of Palermo for typological model I2 equal to about 140 kWh/m^{2}a.

Concluding, with respect to this configuration presented in the previous tables, if a comparison (with respect to the representative school building analysed) was considered for climate zone D, if model I1 with compact shape and 3 classrooms is deemed, the primary energy needs is equal to about 25.20 kWh/m^{2}a, on the other hand for the kindergarten "*M. Montessori*" located in San Frediano (PI) it is equal to 28 kWh/m^{2}a. In addition, if the final energy demand for heating typological model I1 located in Milan is compared with the kindergarten "*Anna Frank*" located in Nichelino (TO) the difference is of about 20 kWh/m^{2}a with minimum energy demand for the first one equal to 8.20 kWh/m^{2}a. Furthermore, the comparison between the model I2 with elongated shape and 3 classrooms situated in climate zone D, and kindergarten belonging to "*Istituto comprensivo 7 – L. Orsini*" located in Imola (BO) demonstrates a difference of about 30 kWh/m^{2}a for the final energy needs for heating. At the same time for the kindergarten "*Balenido*" (BO) the difference is lower, but still equal to about 20 kWh/m^{2}a.

Finally, if a comparison was made in terms of environmental impact between the typological model I3 situated in Milan and the kindergarten "*KIGA*" the amount of CO_2 emissions for the first one is equal to 21.10 kg_{CO2}/m^2a including the construction of the building and PV panels on the roof, despite for the second one only for operational phase and so due to consumptions it is equal to 37 kg_{CO2}/m^2a.

CHAPTER 6. Conclusions

6.1 SUMMARY and CONCLUSIONS

The main aim of the research is to outline qualitative and quantitative guidelines to help the designers during the preliminary stage of the design process in order to design carbon-zero school building with low primary energy demand in Italy, and in the context of smart cities, plus-energy school buildings that can fed into public grid electrical energy produced with renewables.

These school guidelines aim at connecting the new school building type with an estimation of its energy and environmental performance that could be improved with some modifications of the main building typological factors according to the different climate zone.

It is obvious that the quantitative indications and evaluations in these school guidelines could be used as rough reference for feasibility projects. It is because of for a real building design which differs in part from the building type the overall energy/environmental performance will certainly have significant variations.

This goal is reached with first the definition of a new building type for schools (through the definition of environmental and technological system) and then with the evaluation of some possible changes to the main building distinguishing features (such as technological solution for the external envelope and thickness of insulation, WWR, solar shading systems, systems configuration) that particularly affect the primary energy demand to improve energy performance and to reduce the environmental impact of the outlined new building type.

To conclude:

- at present, there is not in literature any guideline about the definition of a building type (considering also different building types not only schools) that give also some suggestions and modifications related to the main building typological features that could improve energy and environmental performance;
- the used methodology is a general roadmap that could be used for the analysis of different type of complex buildings, in order to obtain an overall overview on both environmental and technological system and on the real influence of the main building typological factors on energy and environmental performance of a building type;
- this new outlined school building type could be used as a useful reference to build schools which follow the new pedagogical and teaching methods and the energy requirements to be environmental-friendly with a view of free-carbon economy within 2050;
- it is demonstrated that it is possible to develop and to suggest for the building typological features a possible range of variation in order to give to the designers the possibility to improve the energy

and environmental performance of the building type with only some changes and modifications that can be decided in the preliminary stage of the design process;

- these qualitative and quantitative guidelines could help also public administrations that build schools because at present they chose the winning project to design a new kindergarten or elementary school within a public invitation to tender, the one that used all the active/passive strategies to improve energy performance and all the environmental ones to reduce the environmental impact without realizing that any of these adopted strategies is useless and it merely increases the price of the construction;
- the use of the proposed technological solutions (many alternatives) for the external envelope and the possible advisable modifications regarding some building typological factors could lead to the possibility to construct a school building with primary energy demand lower than at least 25 kWh/m^{2}a, CO_2 emission for both construction and operational phase lower than 25 kg$_{CO2}$/m^{2}a and so with low environmental impact or even plus-energy schools that produced more energy than their needs in the context of smart cities.

6.2 FUTURE DEVELOPMENTS

The research illustrated could be the first parts of a broader work on sustainable and neutral carbon school buildings. For instance, some proposals and outlooks for a future development of this research should be:

- the detailed analysis performed to validate the new building type for kindergarten and to individuate some possible modifications of building typological features should be carried out also for the new 4 typological models of elementary school still considering several different climate zones;
- the parametric analysis should be implemented also for the main characteristics of the considered system as regard to the different climate zones as well;
- the additional energy simulation in dynamic regime should be conducted, also with more adequate software, in order to evaluate some passive strategies that could improve the energy performance of the defined new building type such as solar greenhouse, thermal mass or solar chimney that are recurrent in sustainable schools;
- the improvement in the models of renewables in order to exploit not only solar energy but also wind energy and geothermal one with the integration of different type of systems;
- the configuration of a participatory design procedure in order to validate the outlined new typological models both for kindergarten and elementary school from an architectural, dimensional and functional point of view should be arranged. Besides, get the opinion about the configured models by students, teachers and families that lives the school every day should be an interesting study in order to improve the new building type for schools with something missed or to validate them in this new defined internal layout.

References

This paragraph shows the bibliography of the thesis divided in different topics. For each one there is a brief description about the main issues and why the specific group of references has been chosen for the research work.

The references that follow are divided with respect to the different subjects covered by the thesis:

- pedagogical and didactic issue (the new teaching and pedagogical methods, analysis of representative buildings);
- the students' wellbeing and the comfort inside school building (national and international standards, ventilation and indoor air quality, visual comfort);
- schools' energy and environmental performance (national and international standards, definition of nZEB building, sustainability, analysis of sustainable representative buildings, study on opaque external envelope, window to wall ratio, solar shading system, PV system and CO_2 emissions).

1. NEW TEACHING and PEDAGOGICAL METHODS

These references allow to identify the changes suffered over time by the school buildings for primary education in relation to the evolution of didactic methods and needs of teaching and to outline the main characteristics of the school building in relation to the concept of modern school.

During the 20th century, several schools of thought followed one another, outlining the concept of modern school with radical and considerable changes and rethinking of teaching and pedagogical methods. The main changes concern the teaching method, the communication between teacher and child and their relationship in the school environment, how to educate children also through free and manual activities, life inside the school building and the method of learning.

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2. RELEVANT NATIONAL and INTERNATIONAL STANDARDS and DESIGN MANUALS

This bibliography lets to understand all the national and international requirements that a low carbon school building (kindergarten or elementary school) must meet in order to be built in Italy. Indeed, the design of a building cannot neglect the minimum requirements imposed by the current building regulations for building in general and for the specific intended use. The new defined typological models must necessarily be in line with the main regulations in force in Italy, as well as being suitable for children in respect of both the needs of children and families and the needs of teaching.

These standards and laws concern different topics such as dimensional requirements, health and hygiene regulations (indoor air quality), overcoming and elimination of architectural barriers and fire prevention, thermal, acoustic and visual comfort, energy and low emissions requirements.

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2. MIUR (2013). Norme tecniche-quadro, contenenti gli indici minimi e massimi di funzionalita' urbanistica, edilizia, anche con riferimento alle tecnologie in materia di efficienza e risparmio energetico e produzione da fonti energetiche rinnovabili, e didattica indispensabili a garantire indirizzi progettuali di riferimento adeguati e omogenei sul territorio nazionale.
3. Decreto del Presidente della Repubblica n. 81 del 20 Marzo 2009. Norme per la riorganizzazione della rete scolastica e il razionale ed efficace utilizzo delle risorse umane nella scuola.
4. UNI 10339 (2015). Impianti aeraulici a fini di benessere. Generalità, classificazione e requisiti. Regole per la richiesta d'offerta, l'offerta, l'ordine e la fornitura.
5. D.M. n. 236 del 14 giugno 1989. Prescrizioni tecniche necessarie a garantire l'accessibilità, l'adattabilità e la visitabilità degli edifici privati e di edilizia residenziale pubblica, ai fini del superamento e dell'eliminazione delle barriere architettoniche.
6. Decreto del Presidente della Giunta Regionale n. 41/R del 29 luglio 2009. Regolamento di attuazione dell'articolo 37, comma 2, lettera g) e comma 3 della legge regionale 3 gennaio 2005, n. 1 (Norme per il governo del territorio) in materia di barriere architettoniche.
7. D.M. n. 218 del 29 agosto 1992. Norme di prevenzione incendi per l'edilizia scolastica.
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9. Decreto del Presidente del Consiglio dei Ministri n. 297 del 5 dicembre 1997. Determinazione dei requisiti acustici passivi degli edifici
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11. UNI 10840 (2007). Locali scolastici. Criteri generali per l'illuminazione naturale ed artificiale.
12. UNI 7697 (2015). Criteri di sicrezza nelle applicazioni vetrate.
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energetico per usi termici negli edifici.
14. Direttiva 2002/91/CE sul rendimento energetico nell'edilizia.
15. Direttiva Europea 2010/31/UE sulla prestazione energetica nell'edilizia.
16. Direttiva (UE) 2018/844 che modifica la direttiva 2010/31/UE sulla prestazione energetica nell'edilizia e la direttiva 2012/27/UE sull'efficienza energetica.
17. D.P.R. 26 agosto 1993, n. 412. Regolamento recante norme per la progettazione, l'installazione, l'esercizio e la manutenzione degli impianti termici degli edifici ai fini del contenimento dei consumi di energia.
18. UNI/TS 11300-1 (2014). Prestazioni energetiche degli edifici. Parte 1: Determinazione del fabbisogno di energia termica dell'edificio per la climatizzazione estiva ed invernale.
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Moreover, there are some papers and reports of National Agency (for instance ENEA or Legambiente) concern with the current situation about Italian and European existing school buildings stock that point out the low energy performance of these buildings (only 0.3% of school buildings were in class A in 2016), the inadequate thermo-hygrometrical wellbeing, the lack of visual comfort and the poor indoor air quality.

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3. nZEB: NEARLY ZERO ENERGY BUILDINGS

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4. SUSTAINABLE SCHOOL BUILDINGS IN THE PAST and SUSTAINABILITY

The analysis of these references allows to understand which are the school buildings in the past (kindergartens or elementary schools) that can be considered as an example/precursor of a sustainable and bioclimatic architecture.

Furthermore, through this bibliography the concept of sustainability in literature was studied in order to understand the main and important features to be considered for the definition of new typological models to build low-carbon kindergartens and elementary schools in Italy.

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5. *VENTILATION STRATEGIES, INDOOR AIR QUALITY and STUDENTS' PERFORMANCE*

These references concern the main topic of past studies and research that are performed about school buildings in literature: ventilation and indoor air quality in classrooms. This is important to understand what has been done in the past about the study of school buildings.

Ventilation and air change rate are mainly related to the school productivity and concentration of the students because the poor quality of the air, the inadequate internal temperature, the low natural lighting and the noise pollution inevitably affect the students' performance at school.

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7. REPRESENTATIVE BUILDINGS

These references are useful to identify and analyse representative sustainable buildings that are characterized by an internal configuration which reflects the demands of current teaching and pedagogical methods and by a high energy performance for which they have been rewarded nationally and/or internationally.

Indeed, all these references present a series of school buildings built between the 2003rd and the 2015th that receives awards because of optimum energy performance or low CO_2 emissions during operational phase and/or represents from a dimensional and distributive point of view the needs of new pedagogical and didactic method. Through the analysis of these buildings it is possible to identify the factors and features that characterized the contemporary school buildings, the technological solutions and materials used, to outline the most recurrent environmental and energy strategies, to collect a series of data regarding the energy performance of the buildings in order to define the new typological models for building low carbon schools in Italy.

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These references permit to understand which are the features that usually are analysed to choose the optimum technological solution for the opaque external envelope (global thermal transmittance, thickness of insulation, insulation types, dynamic thermal characteristics) and the most recurrent technological solutions. The external envelope is undoubtedly one of the passive strategies used to reduce the primary energy demand of the building because it controls the energy flow between the inside and the outside of the building. So, it is fundamental to choose the proper technological solution for the external opaque envelope for building nZEB kindergartens and elementary schools in Italy.

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These references are fundamental in order to understand the methodology to perform a sensitivity analysis to be applied to the new typological models for low carbon schools. With this analysis it was possible to define which are the factors characterising the building that most affect the energy needs for cooling and heating, primary energy demand and the environmental impact. In literature many parameters were considered such as the shape of the building, the roof solar absorptance, the air exchange rates, heat capacity, windows' thermal transmittance, shading, lighting power, efficiency of heat recovery. Most of the studies were conducted for residential and office buildings.

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10. WINDOW-TO-WALL RATIO

These references that follow are fundamental in order to understand if for a school building has been analysed one on the typological building factor that affects the most the energy needs: the window to wall ratio (WWR). The definition of the proper WWR during the early stage of design process is remarkable to minimize primary energy consumption, indeed the first studies about the influence of WWR date to 1977. Most of the research in past literature are concerned with office buildings as demonstrate in the analysis of these references. There are only some studies about the analysis of WWR pertain with schools and they are referred to a single classroom and they do not consider the primary energy consumption of the whole building.

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These references permit to understand if some studies about the variation of the type of solar shading system for a school building have been done. In this bibliography the description of the different type of solar shading are presented especially for office buildings because they are one of the most important bioclimatic passive strategies for the façade. Many studies concern with the use of fixed solar shading systems or automated ones. There aren't studies specifically related to school buildings. The analysis of different type of solar shading system is necessary because they affect the energy balance due to the regulation of the solar gains inside the building and consequently the energy needs for heating, cooling and lighting.

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13. CO_2 EMISSIONS

These references let to understand which are the studies about CO_2 emissions in schools that have been done in the past literature. Most of the considerable studies in literature about CO_2 emissions in school buildings deal with the refurbishment of existing schools: the transition of existing school in low-carbon buildings, the Life Cycle Assessment and the definition of some tool to improve energy and environmental performance. In the context of the Paris Agreement and of the decarbonisation of the entire building stock within 2050 (2050 free-carbon economy), it is fundamental to design and to build neutral carbon school building or even energy positive schools.

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A. APPENDIX A

A.1 Analysis of representative buildings (Chapter 3 – pp. 68)

In these tables the presence of the element is indicated with "**X**", if the box is empty it indicates the non-presence and with "/" the lack of information. Some values are expressed as a percentage and indicate:

- *Functional bands distribution* indicates in percentage the area occupied by a functional area with respect to the total of the building;
- *Fullness/Emptiness* represents the surface of full and empty spaces with respect to the total area of the analysed building;
- *WWR* indicates the percentage ratio between the windowed area and the total surface of the external wall indicated for each orientation;
- *Solar panels* identify in percentage the area relative to the different types of coverage with reference to the total area of the roof of the analysed building.

Table A. 1 Summary chart of kindergartens studied

	Summary Kindergartens					
Features	Summary 1	Summary 2	Summary 5	Summary 7	Summary 8	Summary 11
Location	Cascina	Guastalla	Imola	Mazzè	Nichelino	Bisceglie
North				X	X	
Centre	X	X	X			
South						X
Year of construction	2013	2015	2005	2010	2007	2010
Shape						
Compact	X				X	X
Horizontal development		X	X	X		
Irregularly			X			
Prevailing orientation						
NS						
EW			X	X		
SW - NE		X				
Angle of rotation North axis	20°	50°	33.5°	0°	0°	22°
Functional area distribution						
Methodical Activities Area	45%	58%	51%	43%	62%	52%
Free Activities Area	15%	12%	12%	0%	11%	2%
Canteen/Kitchen Area	23%	10%	13%	19%	10%	13%
Care Area	9%	5%	11%	5%	8%	9%
Connections	8%	15%	13%	33%	9%	24%
Fullness/Emptiness						

Full	96%	94%	99%	100%	93%	84%
Empty	4%	6%	1%	0%	7%	16%
Classrooms orientation						
N						
S	X			X	X	
E						
W						X
SE		X				X
SW			X			
Toilets						
Common dedicated space				X		
Classrooms dedicated space	X	X	X		X	X
Vertical connections						
Horizontal connections						
Central	X			X	X	
Side		X				X
Common space for collective activities			X	X		X
Structure						
Reinforced concrete						
Steel						
Wood	X	X	X	X		X
Masonry					X	
Façade technological solution						
Traditional					X	X
Ventilated	X		X	X		
External insulation						
Double skin			X			
Load-bearing walls						X
Shading system						
Internal		X				
External	X		X	X		X
Blinds						
Automatic curtains		X				
Horizontal louvres						
Automatic horizontal slabs	X		X			
Façade shading system	X					
External gallery				X		X
Overhang (building geometry)					X	X
External shelter					X	
External vegetation		X	X		X	X
WWR						
South				34.48%	44.10%	
North				20.90%	16.30%	
East					10.90%	
West				1.80%	10.90%	
South-West	68.67%	23.79%	20.60%			40.20%
South-East	35.34%	100%				15.86%
North-East	9.00%	19.68%	12.00%			28.00%

North-West	44.66%	50.88%				52.20%
Roof floor						
Flat	X (70%)	X	X		X	
Sloped	X (30%)			X		X
Skylight		X				
Green roof						
Ventilated	X				X	
Materials						
Traditional		X (K/C)				
Natural	X	X	X	X	X	X
Energy from renewables						
Solar greenhouse	X	X			X	X
Skylight		X				
Solar chimney			X			
Thermal mass			X			
South glazed façade	X	X	X	X		X
Solar panels	X	X		X	X	X
PV panels	X	X		X		X
Wind energy	X					
Geothermal				X		X
Roof floor cooling			X			
Natural ventilation and passive cooling						
Natural ventilation	X	X	X	X	X	X
Cross natural ventilation	X				X	
Natural ventilation by stack effect		X				X
Ventilation chimney			X			
Geothermal exchanger				X		X
Night passive cooling	X	/	/	/	X	
Internal courtyard	X		X		X	X
Plants						
Generation system						
Condensing boiler	X	X	X		X	
Biomass boiler						
Air heat pump						
Geothermal heat pump						X (with rainwater)
Water heat pump				X		
Air to water heat pump		X				
Reversible heat pump		X		X		X
Air conditioning system		X		X (radiant panel)	X (radiant panel)	X
Cogeneration						
Heating collector	X			X		
Distribution system						
Underfloor heating system	X	X	X	X	X	X
Ceiling heating system						
Wall radiant panel			X			
Heaters						

Fan coils						
Ventilation system						
Heat recovery	X	X			X	/
Air Pre-heating	X	X		X	X	/
Air dehumidification		X		X	X	/
Air pre-cooling						/
Controlled mechanical ventilation	X	X		X	X	/
Ventilation wind tower						
Control strategies						
Temperature	/	X	/	/	/	/
Humidity	/	/	/	/	/	/
Service hot water consumption	X	X	X	/	X	/
Lightings	/	/	/	/	X	/
CO_2	X	X	/	/	/	/
VOC	X	X	X	X	/	/
BACS	/	/	/	/	/	/
Service hot water						
Solar panels	X (62.7%)	X (40.5%)		X	X	X
Condensing gas boiler	X	X	X			X
Biomass boiler						
Heat pump				X		X
Electric water heater						
Solar Boiler		X				
Rainwater storage						
Rainwater storage	X	X	X	/	X	X
Irrigation water	X	X	X	X	X	X
Toilet water	X	X	X	X	X	X
Underground water				X		
Lifting electric pump				X		X

Table A. 2 Summary chart of elementary schools studied

	Summary Elementary schools				
Features	Summary 3	Summary 4	Summary 6	Summary 9	Summary 10
Location	Romarzollo	Laion	Montelupo	Chiarano	Ponzano
North	X	X		X	X
Centre			X		
South					
Year of construction	2011	2006	2013	2013	2009
Shape					
Compact	X	X		X	X
Horizontal development			X		
Irregularly	X				
School shape					
Rectangular			X		
Compact	X	X		X	X
Gym shape					
Rectangular	X				X
Compact					

Canteen shape	Inside building	Another building	Another building	Inside building	Inside building
Rectangular	X		X		X
Compact				X	
Prevailing orientation					
NS					
EW		X	X		
SW - NE					
Angle of rotation North axis	27°	32°	0°	11°	157°
Functional bands distribution					
Methodical Activities Area	47%	50%	57%	39%	39%
Free Activities Area	28%	34%	18%	22%	18%
Canteen/Kitchen Area	12%	1%	0%	9%	7%
Care Area	5%	4%	6%	6%	7%
Connections	8%	11%	19%	24%	29%
Fullness/Emptiness					
Full	96%	100%	100%	96%	85%
Empty	4%	0%	0%	4%	15%
Classrooms orientation					
N					X
S	X		X	X	
E	X				
W	X				
SE					X
SW		X			X
Toilets					
Common dedicated space	X	X	X	X	X
Vertical connections					
Central	X (school)	X	X		
Side	X (gym)			X	X
External	X				
Common space for collective activities	X				
Horizontal connections					
Central	X		X	X	X
Side			X		
Common space for collective activities		X			
Structure					
Reinforced concrete	X	X		X	X
Steel					X
Wood		X	X	X	
Masonry					
Façade technological solution	/				
Traditional		X			X
Ventilated					
External insulation			X	X	X
Green wall solution			X		
Shading system					

Internal		X	X		
External	X		X	X	X
Blinds			X		
Automatic curtains	X			X	X
Curtains		X			
Horizontal louvres (fixed)					
Horizontal louvres (automatic)					
External gallery			X		
Overhang (building geometry)		X	X	X	X
External shelter			X		
External vegetation	X				X
WWR					
South			52.70%	98.00%	
North				14.50%	
East					
West			6.90%	10.00%	
South-West	62.50%	133%			
South-East	70.50%	12%			
North-East	84%	130.9%			
North-West	62.50%	8.00%			
Roof floor					
Flat	X			X	X
Sloped		X	X		
Skylight				X	
Green roof	X		X		X
Ventilated		X			
Materials					
Traditional	X				
Natural		X	X	X	X
Energy from renewables					
Solar greenhouse					
Skylight		X		X	
Solar chimney					
Thermal mass					
South glazed façade	X (gym)	X	X	X	X
Solar panels		X			X
PV panels	X	X	X		X
Wind energy					
Geothermal	X	X	X		X
Roof floor cooling					
Natural ventilation and passive cooling					
Natural ventilation	X	/	/		X
Cross natural ventilation					X
Natural ventilation by stack effect	X				
Ventilation chimney					X
Geothermal exchanger	X	X	X		X
Night passive cooling	X				
Internal courtyard	Atrium			X	X
Plants					

Generation system					
Condensing boiler	X			X	/
Biomass boiler					/
Heat pump	X			X	/
Electric heat pump		X			
Air heat pump					
Geothermal heat pump			X		
Water heat pump					
Reversible heat pump					
Air conditioning system					
District heating					
Cogeneration					
Distribution system					
Underfloor heating system	X	X	X	X	X
Ceiling heating system					
Heaters					
Fan coils					
Ventilation system					
Heat recovery			X	X	
Air pre-heating	X	X			X
Air pre-cooling	X				X
Controlled mechanical ventilation	X		X	X	
Ventilation wind tower	X	X			
Control strategies					
Temperature	X	/	/	X	X
Humidity	/	/	/	X	X
Service hot water consumption	X	/	/	/	/
Lightings	X	/	/	/	/
CO_2	/	/	/	/	/
VOC	/	/	/	/	X
Service hot water					
Solar panels		X		/	X
Condensing gas boiler					
Biomass boiler	X				
Heat pump	X		/		
Electric water heater					
Rainwater storage					
Rainwater storage	X	/	X	/	X
Irrigation water	X				
Toilet water	X		X		

Table A. 3 Summary chart of Kindergartens without detailed sheet

	Kindergartens without summary – Building features								
Features	1	2	Manual scheme	3	4	5	6	7	8
Location	CO	TO		MI	BO	RA	BZ	Cacem	Tokyo
North	X	X		X			X		
Centre					X	X			
South									

Year of construction	1936	1963	1975		2003	2007	2008	2010	2005	2011
Shape										
Compact	X		X	X	X			X	X	
Horizontal development						X	X			
Irregularly		X								X
Prevailing orientation			-	-				-		
NS	X	X								
EW					X	X	X		X	X
SW - NE										
Angle of rotation North axis	30°	86°	-	-	0°	13°	24°	29°	0°	25°
Functional area distribution		-								-
Methodical Activities Area	32%		50%	48%	44%	38%	50%	31%	48%	
Free Activities Area	22%		15%	18%	33%	34%	17%	22%	18%	
Canteen/ Kitchen Area	29%		21%	22%	0%	5%	15%	19%	22%	
Care Area	4%		9%	12%	7%	13%	3%	7%	12%	
Connections	13%		5%	0%	16%	10%	15%	21%	0%	
Fullness/ Emptiness*	-	-	-			-		-	-	-
Full				93%			93%			
Empty				7%			7%			
Classrooms orientation			-	-						
N										
S					X	X		X	X	X
E		X								
W		X								
SE	X						X	X		X
SW										X
Toilets										
Common dedicated space	X				X					
Classrooms dedicated space		X	X	X		X	X	X	X	X
Vertical connections	-	-	-	-	X	-	-	X	X	X
Horizontal connections										
Central	X				X			X	X	
Side					X		X			

Common space for collective activities		X				X				X
Structure								/		
Reinforced concrete	X	X							X	
Steel										X
Wood					X	X				
Masonry							X			
Façade technological solution								/		
Traditional	X	X					X		X	
Ventilated					X					
External insulation						X				
Double skin										
Load-bearing walls										
Shading system	Curtain		/	/						
Internal	X	X					X			
External	X	X				X			X	
Blinds							X			
Automatic curtains										
Horizontal louvres					X			X Vertical		
Automatic horizontal slabs		X				X				
Façade shading system									X	X
External gallery		X				X	X			
Overhang (building geometry)										
External shelter										X
Roof floor**			/	/						
Flat	X	X				X			X	X
Sloped					X		X	X		
Skylight		X						X		
Green roof						X		X		
Ventilated					X					
Materials										
Traditional	X	X							X	X
Natural					X	X	X	X		

Table A. 4 Summary chart of Elementary schools without detailed sheet

	Elementary schools without summary – Building features								
Features	1	2	3	4	5	6	7	8	9
Location		VI	VA	TO	UD				
North	Holland	X	X	X	X	Finland	China	Finland	Germany
Centre									
South									
Year of construction	1960	1972	1976	2010	2007	2010	2010	2012	2011
Shape									
Compact	X	X							
Horizontal development				X (2 blocks)	X		X		
Irregularly			X			X		X	X
Prevailing orientation	SE-NW								
NS		X				X		X	
EW			X	X	X		X		X
SW - NE									
Angle of rotation North axis	125° clockwise		72°	0°	35°	0°	28° clockwise	40°	7°
Functional area distribution					-				
Methodical Activities Area	66%	55%	41%	42%		41%	42%	45%	37%
Free Activities Area	25%	29%	18%	15%		32%	25%	18%	36%
Canteen/ Kitchen Area	0%	0%	11%	12%		7%	7%	18%	0%
Care Area	6%	0%	4%	5%		9%	7%	4%	4%
Connections	3%	16%	24%	26%		11%	19%	15%	23%
Fullness/ Emptiness*									
Full			88%	96%			99%		
Empty			12%	4%			1%		
Classrooms orientation									
N							X	X	
S					X		X	X	X
E	X	X	X			X			
W	X	X				X			
SE							X		
SW				X					
Toilets									
Common dedicated space	X		X	X	X	X	X	X	

Classrooms dedicated space		X							X
Vertical connections	-								
Central		X	X				X		
Side				X	X	X		X	X
Common Area		X							
Horizontal connections									
Central	X	X			X	X	X	X	
Side			X	X					X
Common space for collective activities	X						X	X	
Structure	/	/	/			/	/	/	
Reinforced concrete				X					X
Steel				X					
Wood				X	X				
Masonry									
Façade technological solution	/	/	/				/		
Traditional						/			X
Ventilated									
External insulation				X	X				
Double-skin	/	/	/						
Load-bearing walls									
Shading system				X	X	X	X	X	X
Internal									
External									
Blinds									
Automatic curtains									X
Horizontal louvres									
Automatic horizontal slabs									
Façade shading system						X	X	X	
External gallery				X	X				
Overhang building geometry									

External vegetation					X				
Roof floor									
Flat	X		X			X	X		
Sloped		X			X				
Skylight			X						
Green roof		X					X		X
Ventilated					X				
Materials		/							
Traditional	X		X						
Natural				X	X	X	X	X	

A.2 Study on the opaque external envelope (Chapter 4 - pp. 136)

The tables (Table A.5 – Table A.23) illustrate the different kinds of the most recurrent technological solution for the external wall and the related roof stratigraphy corresponding to each structural solution considered (A – B.1 – B.2 – C). The tables show the stratigraphy from external to internal layer with the indication of the material, the thickness of the layer t [m], the thermal conductivity of the material λ [W/mK] and the thermal transmittance U [W/m^{2}K] of the whole technological solution for each climate zone indicated in the tables with the corresponding letter (B-C-D-E).

Table A. 5 Stratigraphy for the opaque external wall A.1

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
A.1	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	
	4.B	Wood fiber	0.02	0.038	U_B = 0.391
	4.C	Wood fiber	0.04	0.038	U_C = 0.324
	4.D	Wood fiber	0.06	0.038	U_D = 0.277
	4.E	Wood fiber	0.08	0.038	U_E = 0.242
	5	XLAM	0.13	0.12	
	6	Mineral wool	0.02	0.048	
	7	Gypsum board	0.015	0.21	

Table A. 6 Stratigraphy for the opaque external wall A.2

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
A.2	1	External plaster	0.025	0.9	
	2.B	Wood fiber	0.04	0.038	UB = 0.42
	2.C	Wood fiber	0.08	0.038	UC = 0.29
	2.D	Wood fiber	0.10	0.038	UD = 0.25
	2.E	Wood fiber	0.10	0.038	UE = 0.25
	3	XLAM	0.13	0.12	
	4	Air cavity	0.05	-	
	5	Gypsum board	0.015	0.21	

Table A. 7 Stratigraphy for the opaque external wall A.3

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
A.3	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	
	4.B	Glass wool	0.02	0.034	U_B = 0.388

	4.C	Glass wool	0.04	0.034	$U_C = 0.333$
	4.D	Glass wool	0.06	0.034	$U_D = 0.281$
	4.E	Glass wool	0.08	0.034	$U_E = 0.241$
	5	XLAM	0.13	0.12	
	6	Mineral wool	0.02	0.048	
	7	Gypsum board	0.015	0.21	

Table A. 8 Stratigraphy for the opaque external wall A.4

A.4	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External plaster	0.025	0.9	
	2.B	Glass wool	0.04	0.034	$U_B = 0.402$
	2.C	Glass wool	0.06	0.034	$U_C = 0.325$
	2.D	Glass wool	0.10	0.034	$U_D = 0.273$
	2.E	Glass wool	0.10	0.034	$U_E = 0.235$
	3	XLAM	0.13	0.12	
	4	Air cavity	0.05	-	
	5	Gypsum board	0.015	0.21	

Table A. 9 Stratigraphy for the roof A

A	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	Metal sheet	0.00005	1.07	
	2	Air cavity	0.5	-	
	3	Waterproof sheet	0.004	0.23	
	4.B	Wood fiber	0.06	0.038	$U_B = 0.30$
	4.C	Wood fiber	0.06	0.038	$U_C = 0.30$
	4.D	Wood fiber	0.10	0.038	$U_D = 0.23$
	4.E	Wood fiber	0.12	0.038	$U_E = 0.21$
	5	Vapour barrier	0.0003	0.17	
	6	XLAM	0.125	0.21	

Table A. 10 Stratigraphy for the opaque external wall B.1.1

B.1.1	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	
	4.B	Wood fiber	0.02	0.038	
	4.C	Wood fiber	0.02	0.038	
	4.D	Wood fiber	0.02	0.038	
	4.E	Wood fiber	0.02	0.038	
	5	OSB panel	0.02	0.12	
	6.B	Wood fiber	0.02	0.038	$U_B = 0.429$
	6.C	Wood fiber	0.06	0.038	$U_C = 0.296$
	6.D	Wood fiber	0.08	0.038	$U_D = 0.256$
	6.E	Wood fiber	0.08	0.038	$U_E = 0.256$
	7	OSB panel	0.02	0.12	
	8	Mineral wool	0.02	0.048	
	9	Gypsum board	0.015	0.21	

Table A. 11 Stratigraphy for the opaque external wall B.1.2

B.1.2	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External plaster	0.025	0.9	
	2.B	Wood fiber	0.02	0.038	
	2.C	Wood fiber	0.02	0.038	

	2.D	Wood fiber	0.02	0.038	
	2.E	Wood fiber	0.02	0.038	
	3	OSB panel	0.02	0.12	
	4.B	Wood fiber	0.04	0.038	$U_B = 0.385$
	4.C	Wood fiber	0.06	0.038	$U_C = 0.320$
	4.D	Wood fiber	0.08	0.038	$U_D = 0.274$
	4.E	Wood fiber	0.10	0.038	$U_E = 0.239$
	5	OSB panel	0.02	0.12	
	6	Mineral wool	0.02	0.048	
	7	Gypsum board	0.015	0.21	

Table A. 12 Stratigraphy for the opaque external wall B.1.3

B.1.3	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	
	4.B	Glass wool	0.02	0.034	
	4.C	Glass wool	0.02	0.034	
	4.D	Glass wool	0.02	0.034	
	4.E	Glass wool	0.02	0.034	
	5	OSB panel	0.02	0.12	
	6.B	Glass wool	0.02	0.034	$U_B = 0.408$
	6.C	Glass wool	0.04	0.034	$U_C = 0.329$
	6.D	Glass wool	0.06	0.034	$U_D = 0.276$
	6.E	Glass wool	0.08	0.034	$U_E = 0.237$
	7	OSB panel	0.02	0.12	
	8	Acoustic insulation	0.02	0.048	
	9	Gypsum board	0.015	0.21	

Table A. 13 Stratigraphy for the opaque external wall B.1.4

B.1.4	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External plaster	0.025	0.9	
	2.B	Glass wool	0.02	0.034	
	2.C	Glass wool	0.02	0.034	
	2.D	Glass wool	0.02	0.034	
	2.E	Glass wool	0.02	0.034	
	3	OSB panel	0.02	0.12	
	4.B	Glass wool	0.04	0.034	$U_B = 0.359$
	4.C	Glass wool	0.06	0.034	$U_C = 0.297$
	4.D	Glass wool	0.08	0.034	$U_D = 0.253$
	4.E	Glass wool	0.08	0.034	$U_E = 0.253$
	5	OSB panel	0.02	0.12	
	6	Acoustic insulation	0.02	0.048	
	7	Gypsum board	0.015	0.21	

Table A. 14 Stratigraphy for the roof B

B	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	Metal sheet	0.00005	1.07	
	2	Air cavity	0.5	-	
	3	Waterproof sheet	0.004	0.23	
	4.B	Wood fiber	0.08	0.038	$U_B = 0.34$
	4.C	Wood fiber	0.10	0.038	$U_C = 0.289$
	4.D	Wood fiber	0.16	0.038	$U_D = 0.25$
	4.E	Wood fiber	0.16	0.038	$U_E = 0.198$
	5	Vapour barrier	0.0003	0.17	

	6	OSB panel	0.02	0.12	

Table A. 15 Stratigraphy for the opaque external wall B.2.1

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
B.2.1	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	
	4.B	Wood fiber	0.02	0.038	$U_B = 0.378$
	4.C	Wood fiber	0.04	0.038	$U_C = 0.315$
	4.D	Wood fiber	0.06	0.038	$U_D = 0.270$
	4.E	Wood fiber	0.08	0.038	$U_E = 0.237$
	5	OSB panel	0.02	0.12	
	6	Acoustic insulation	0.05	0.048	
	7	Gypsum board	0.015	0.21	

Table A. 16 Stratigraphy for the opaque external wall B.2.2

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
B.2.2	1	External plaster	0.025	0.9	
	2.B	Wood fiber	0.04	0.038	$U_B = 0.351$
	2.C	Wood fiber	0.06	0.038	$U_C = 0.296$
	2.D	Wood fiber	0.08	0.038	$U_D = 0.256$
	2.E	Wood fiber	0.10	0.038	$U_E = 0.256$
	3	OSB panel	0.02	0.12	
	4	Acoustic insulation	0.05	0.048	
	5	Gypsum board	0.015	0.21	

Table A. 17 Stratigraphy for the opaque external wall B.2.3

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
B.2.3	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	
	4.B	Glass wool	0.02	0.034	$U_B = 0.378$
	4.C	Glass wool	0.04	0.034	$U_C = 0.309$
	4.D	Glass wool	0.06	0.034	$U_D = 0.262$
	4.E	Glass wool	0.08	0.034	$U_E = 0.227$
	5	OSB panel	0.02	0.12	
	6	Acoustic insulation	0.05	0.048	
	7	Gypsum board	0.015	0.21	

Table A. 18 Stratigraphy for the opaque external wall B.2.4

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
B.2.4	1	External plaster	0.025	0.9	
	2.B	Glass wool	0.02	0.034	$U_B = 0.419$
	2.C	Glass wool	0.04	0.034	$U_C = 0.336$
	2.D	Glass wool	0.06	0.034	$U_D = 0.281$
	2.E	Glass wool	0.08	0.034	$U_E = 0.241$
	3	OSB panel	0.02	0.12	
	4	Acoustic insulation	0.05	0.048	
	5	Gypsum board	0.015	0.21	

Table A. 19 Stratigraphy for the opaque external wall C.1

	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
C.1	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	

	4.B	EPS	0.02	0.036	U_B = 0.390
	4.C	EPS	0.04	0.036	U_C = 0.321
	4.D	EPS	0.06	0.036	U_D = 0.272
	4.E	EPS	0.08	0.036	U_E = 0.236
	5	Brick block	0.25	0.25	
	6	Brick block	0.12	0.25	
	7	Internal plaster	0.015	0.8	

Table A. 20 Stratigraphy for the opaque external wall C.2

C.2	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External plaster	0.025	0.9	
	2.B	EPS	0.04	0.036	U_B = 0.350
	2.C	EPS	0.06	0.036	U_C = 0.293
	2.D	EPS	0.08	0.036	U_D = 0.252
	2.E	EPS	0.08	0.036	U_E = 0.256
	3	Brick block	0.25	0.25	
	4	Brick block	0.12	0.25	
	5	Internal plaster	0.015	0.8	

Table A. 21 Stratigraphy for the opaque external wall C.3

C.3	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External wood lath	0.025	-	
	2	Air cavity	0.03	-	
	3	Waterproof sheet	0.003	0.23	
	4.B	Wood fiber	0.02	0.038	U_B = 0.395
	4.C	Wood fiber	0.04	0.038	U_C = 0.327
	4.D	Wood fiber	0.06	0.038	U_D = 0.279
	4.E	Wood fiber	0.08	0.038	U_E = 0.243
	5	Brick block	0.25	0.25	
	6	Brick block	0.12	0.25	
	7	Internal plaster	0.015	0.8	

Table A. 22 Stratigraphy for the opaque external wall C.4

C.4	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	External plaster	0.025	0.9	
	2.B	Wood fiber	0.04	0.038	U_B = 0.357
	2.C	Wood fiber	0.06	0.038	U_C = 0.300
	2.D	Wood fiber	0.08	0.038	U_D = 0.259
	2.E	Wood fiber	0.08	0.038	U_E = 0.259
	3	Brick block	0.25	0.25	
	4	Brick block	0.12	0.25	
	5	Internal plaster	0.015	0.8	

Table A. 23 Stratigraphy for the roof B

C	Layer	Material	t [m]	λ [W/mK]	U [W/m^{2}K]
	1	Metal sheet	0.00005	1.07	
	2	Air cavity	0.5	-	
	3	Waterproof sheet	0.004	0.23	
	4.B	Wood fiber	0.06	0.038	U_B = 0.317
	4.C	Wood fiber	0.06	0.038	U_C = 0.317
	4.D	Wood fiber	0.10	0.038	U_D = 0.240
	4.E	Wood fiber	0.12	0.038	U_E = 0.211
	5	Vapour barrier	0.0003	0.17	
	6	Concrete-brick slab	0.32	0.36	
	7	Internal plaster	0.025	0.8	

A.3 Global sensitivity analysis (Chapter 4 - pp. 158)

The Table A.24 shows the variation in percentage of primary energy demand for both the city of Florence and Palermo with respect to the model considered as reference.

The negative values state the decrease in percentage in primary energy demand obtained by varying the corresponding parameters with respect to the model considered as reference (Model I1).

Table A. 24 Results in percentage of sensitivity analysis

N	Parameter	Range/Changes	Florence	Palermo
1	Shape	Model I2; Model I3	2.00%; 5.00%	4.30%; 13%
2	Type of structure	B.1.2; B.2.2; C.4	~0%; ~0%; -5%	0.5%; 2.00%; -8.00%
3	Façade thickness of insulation (D)	0.26 m (D)	-2.00%	-
	Façade thickness of insulation (B)	0.16 m (B)	-	-2.50%
4	Roof thickness of insulation (D)	0.26 m (D)	-8.50%	-
	Roof thickness of insulation (B)	0.22 m (B)	-	-3.00%
5	Green roof technological solution	Use of Green roof	-2.70	-1.70%
6	South WWR	33%; 50%; 76%	<1%; <1%; -0.1%	1.40%; 2.60%; 4.60%
7	East WWR	17%; 29%; 36%	1.70%; 2.60%; 3.40%	4.40%; 7.50%; 9.30%
8	West WWR	17%; 23%; 29%	1.80%; 2.50%; 3.40%	2.80%; 3.40%; 5.00%
9	Type of solar shading (South)	9.1; 9.2; 9.3; 9.4	<1%; <1%; <1%; 1.40%	<1%; <1%; <1%; 1%
10	Vertical solar shadings	West - East	-0.2%; -0.3%	-0.2%; -1.50%
11	Lighting efficiency	Halogen lamps	12.00%	17.50%
12	Attenuation temperature for heating	5°C; 15°C; 20°C	~0%; 5%; 22%	~0%; 2%; 17%
13	Air change per hour	0.5 sv; 0.25 sv; off sv	-13.60%; -21.30%; -13.80%	-7.50%; -11.00%; -4.10%
14	Heat recovery efficiency	0.6%; 0.7%; 0.8%;0.9%	-5.40%; -11.10%; -17%; -23.50%	-9%; -12.80%; -16.70%; -20%
15	Free cooling	Off	3.40%	6.00%

A.4 Influence of Window-to-wall ratio on model's energy performance (Chapter 4 - pp. 171)

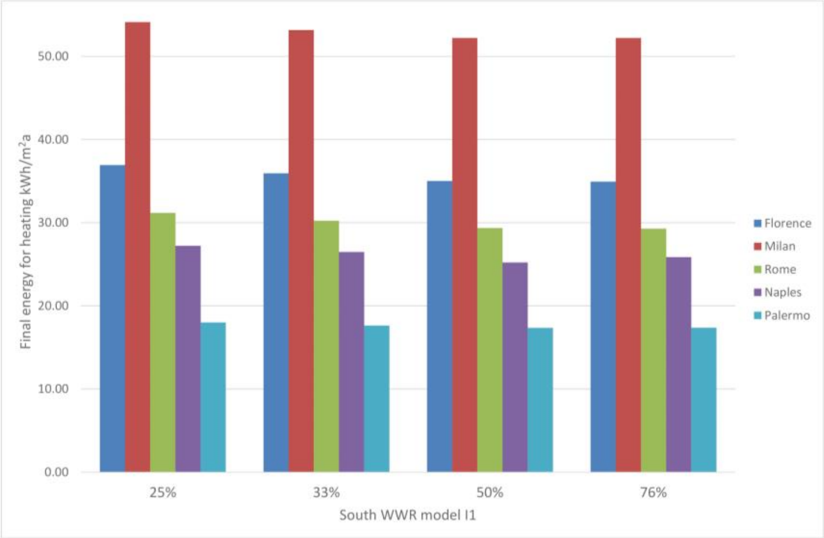

Figure A. 1 Final energy demand for heating with respect to South WWR variation in model I1

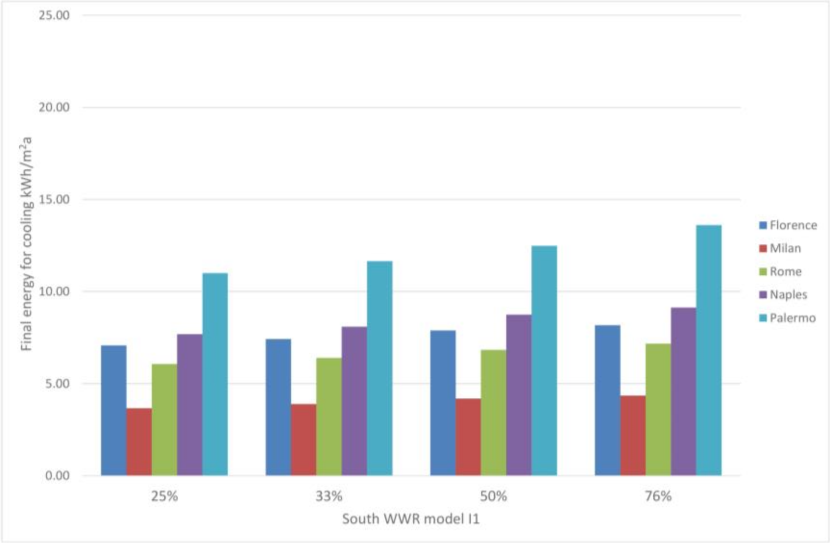

Figure A. 2 Final energy demand for cooling with respect to South WWR variation in model I1

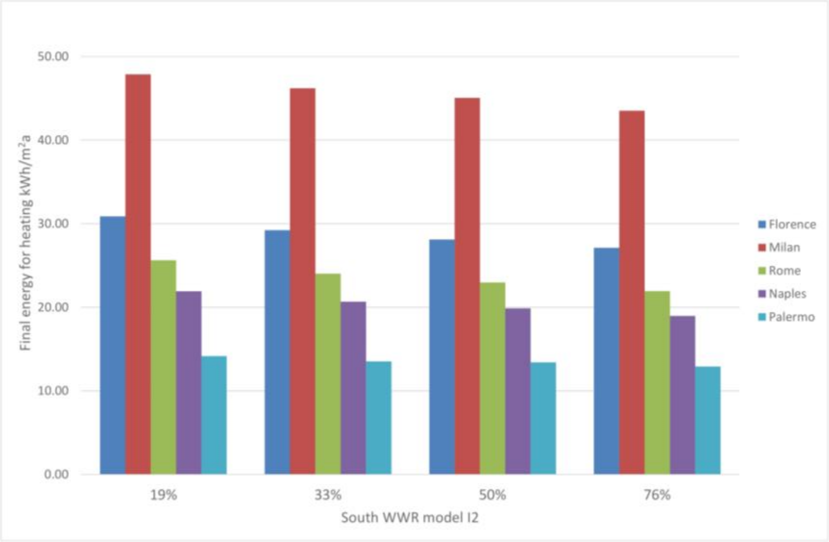

Figure A. 3 Final energy demand for heating with respect to South WWR variation in model I2

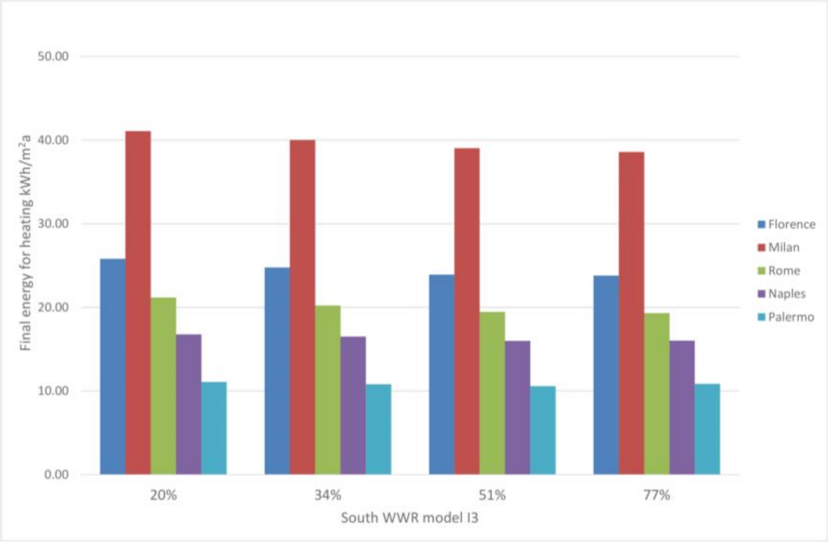

Figure A. 4 Final energy demand for heating with respect to South WWR variation in model I3

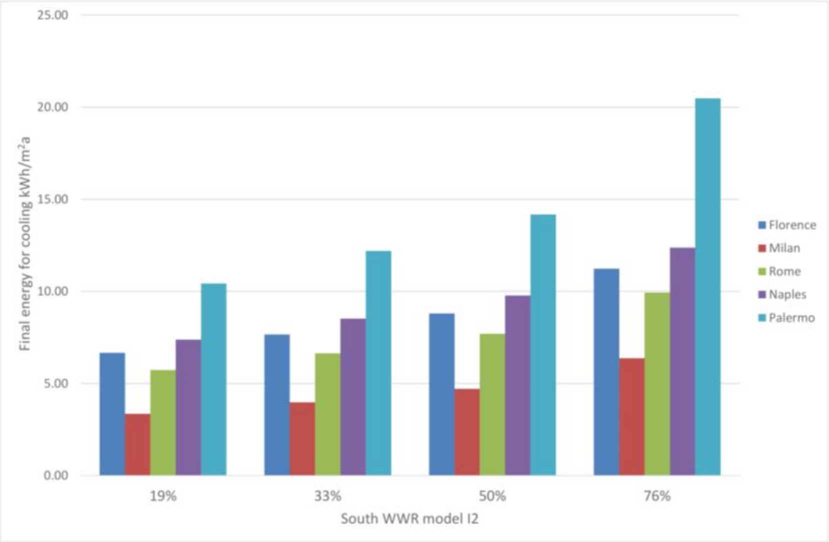

Figure A. 5 Final energy demand for cooling with respect to South WWR variation in model I2

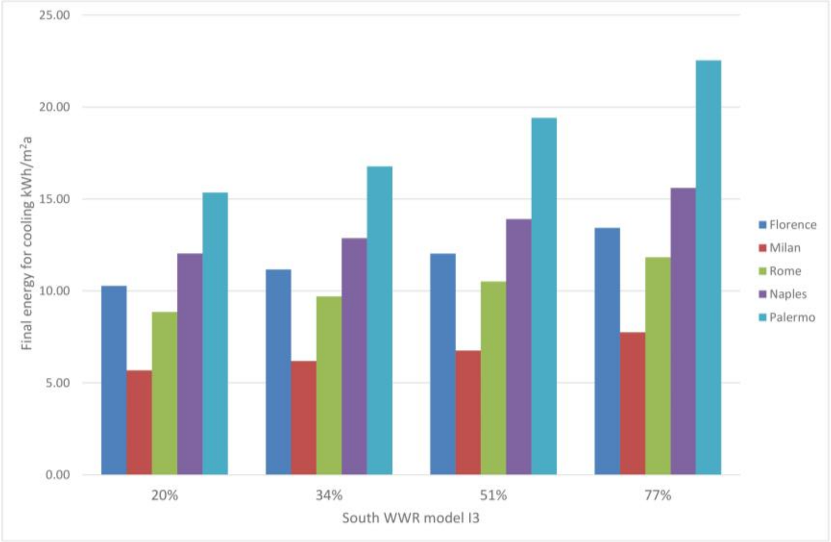

Figure A. 6 Final energy demand for cooling with respect to South WWR variation in model I3

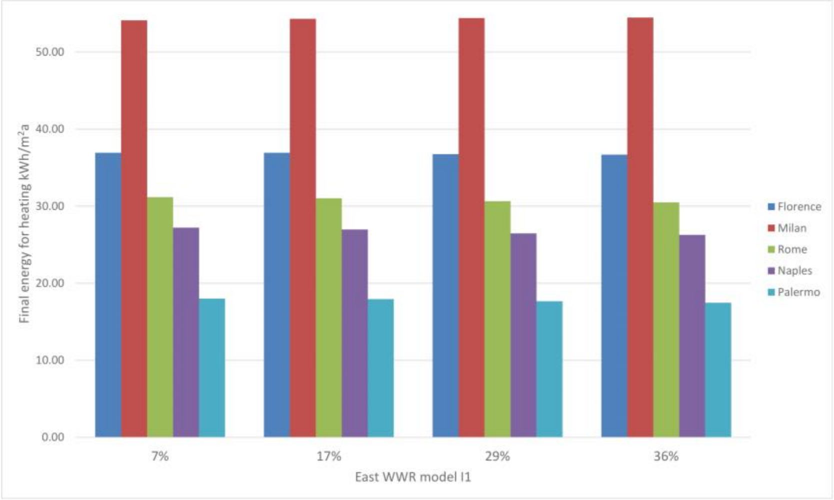

Figure A. 7 Final energy demand for heating with respect to East WWR variation in model I1

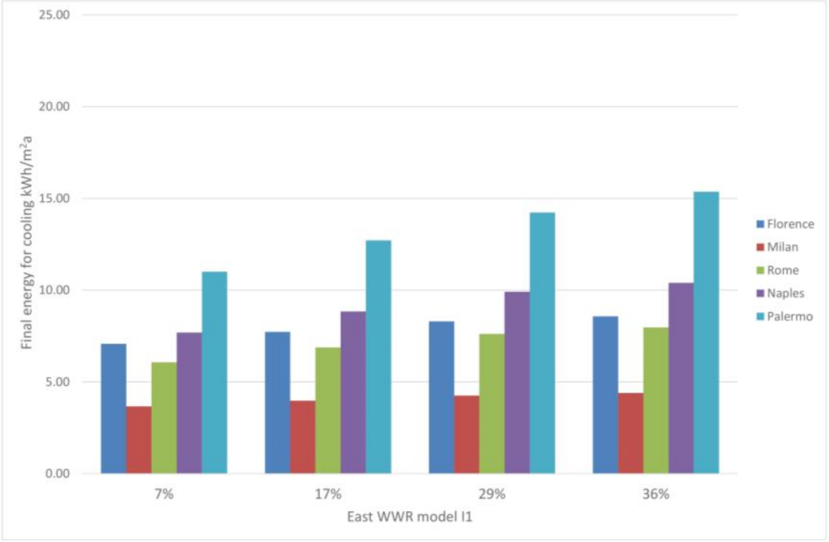

Figure A. 8 Final energy demand for cooling with respect to East WWR variation in model I1

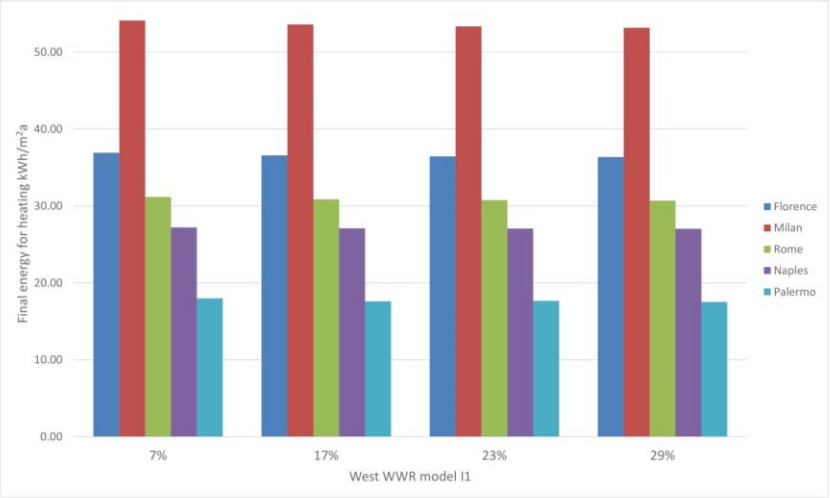

Figure A. 9 Final energy demand for heating with respect to West WWR variation in model I1

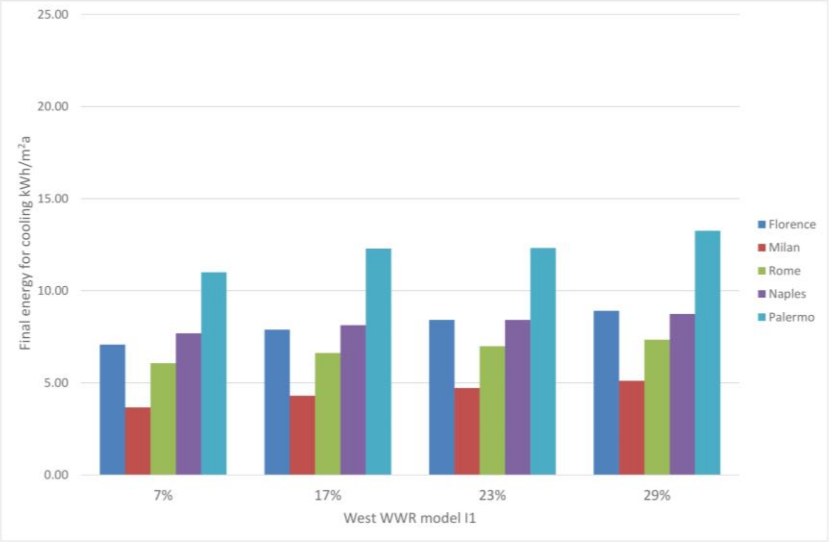

Figure A. 10 Final energy demand for cooling with respect to West WWR variation in model I1

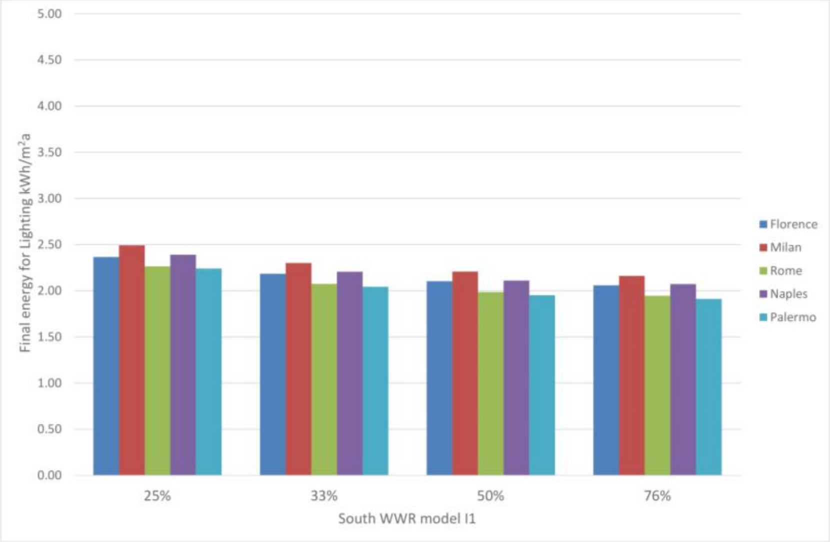

Figure A. 11 Final energy demand for lighting with respect to South WWR variation in model I1

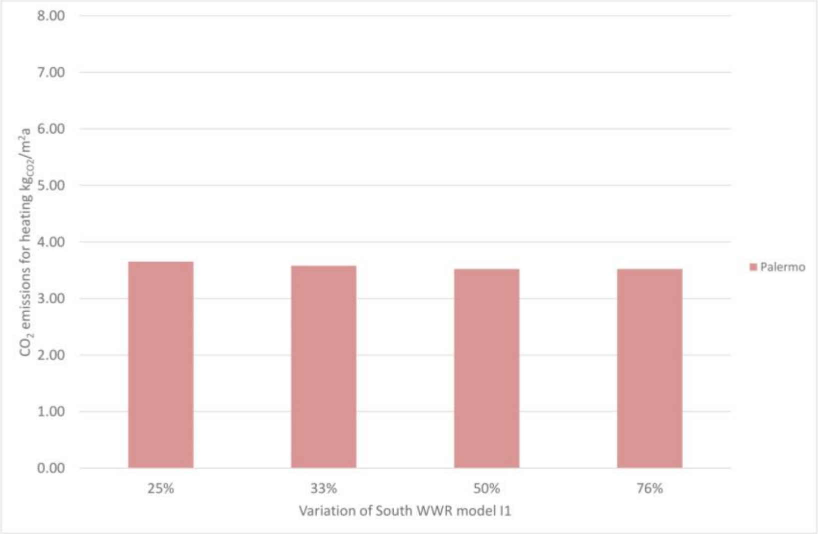

Figure A. 12 CO_2 emissions due to heating demand with respect to South WWR variation in model I1 located in Palermo

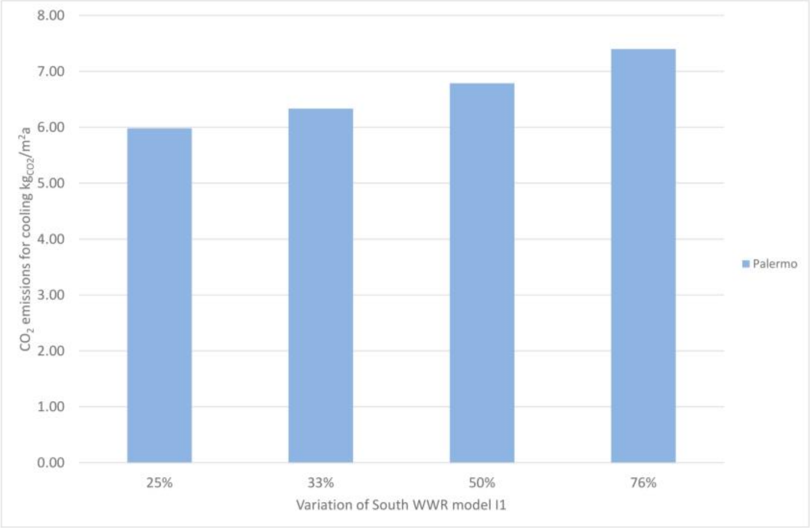

Figure A. 13 CO_2 emissions due to cooling demand with respect to South WWR variation in model I1 located in Palermo

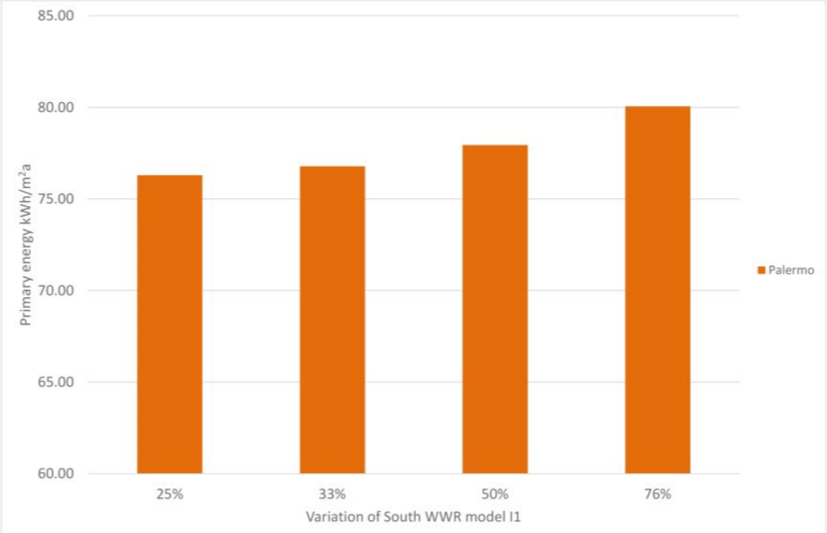

Figure A. 14 Primary energy demand with respect to South WWR variation in model I1 located in Palermo

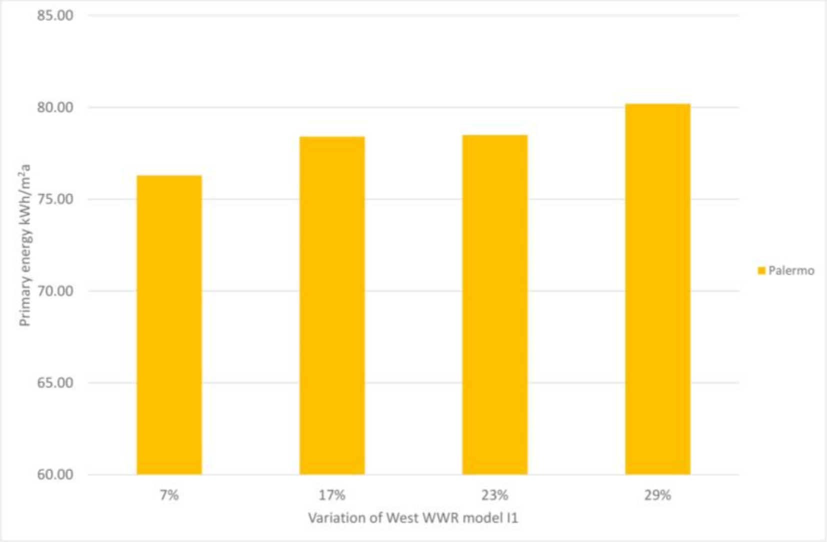

Figure A. 15 Primary energy demand with respect to West WWR variation in model I1 located in Palermo

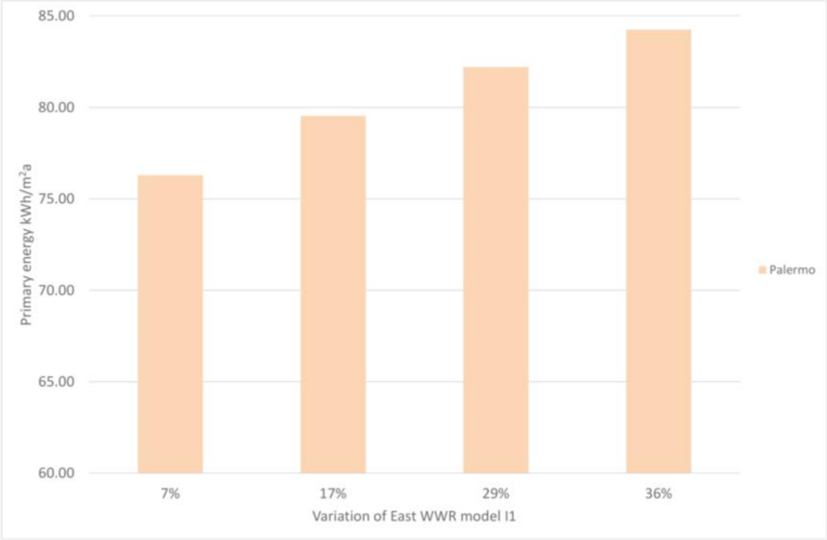

Figure A. 16 Primary energy demand with respect to East WWR variation in model I1 located in Palermo

A.5 Study on solar shading systems (Chapter 4 – pp. 182)

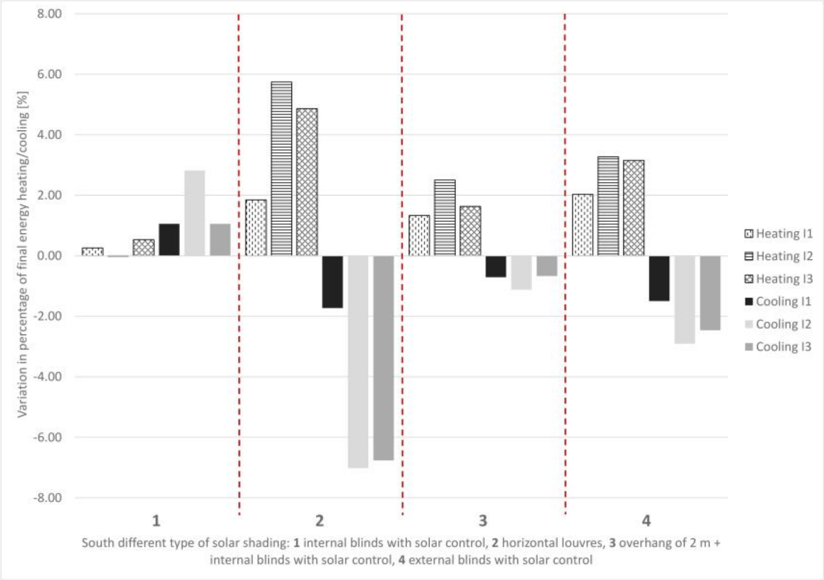

Figure A. 17 Variation in percentage of final energy demand for heating and cooling for Palermo for the 3 models and different types of solar shading

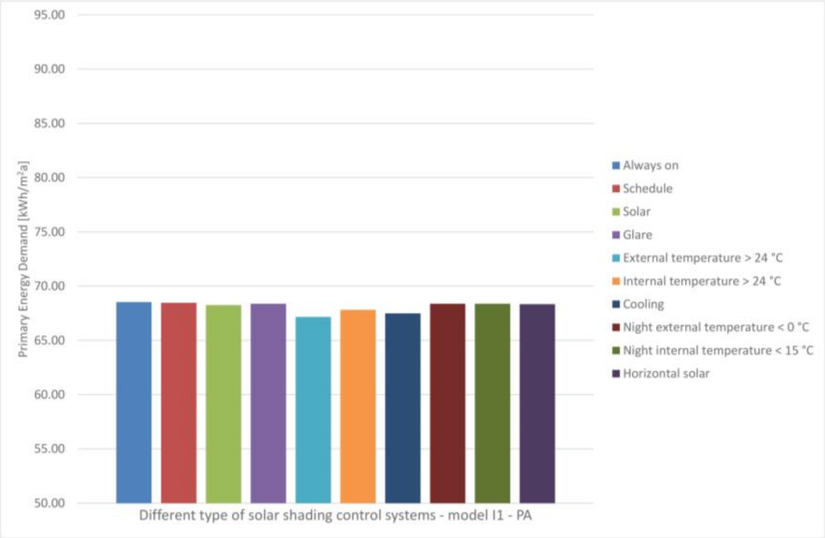

Figure A. 18 Primary energy demand for different type of solar shading control systems for Palermo on model I1

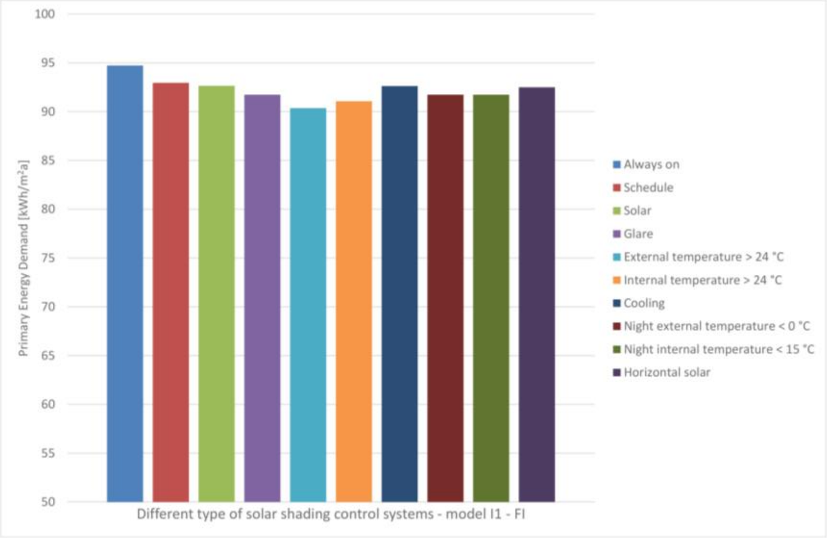

Figure A. 19 Primary energy demand for different type of solar shading control systems for Firenze on model I1 with advisable value of WWR

A.6 Integration with renewable energy: photovoltaic panels (Chapter 4 – pp. 190)

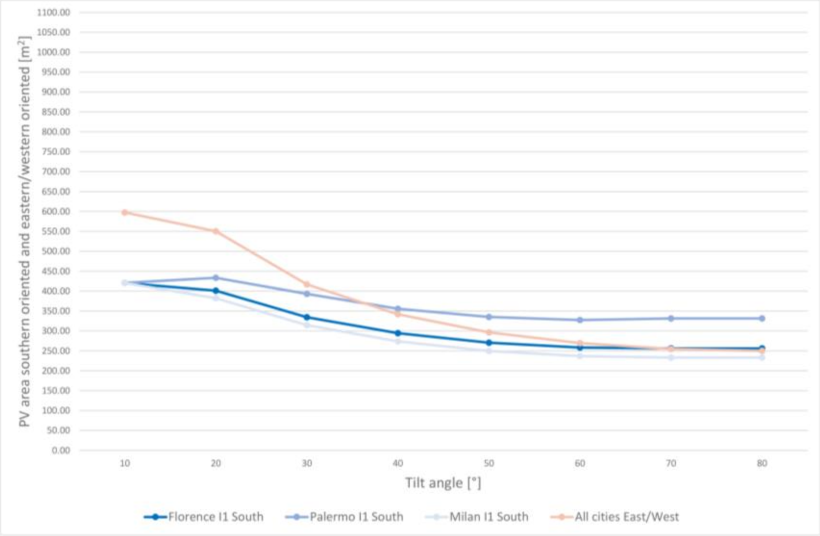

Figure A. 20 PV panels area for model I1

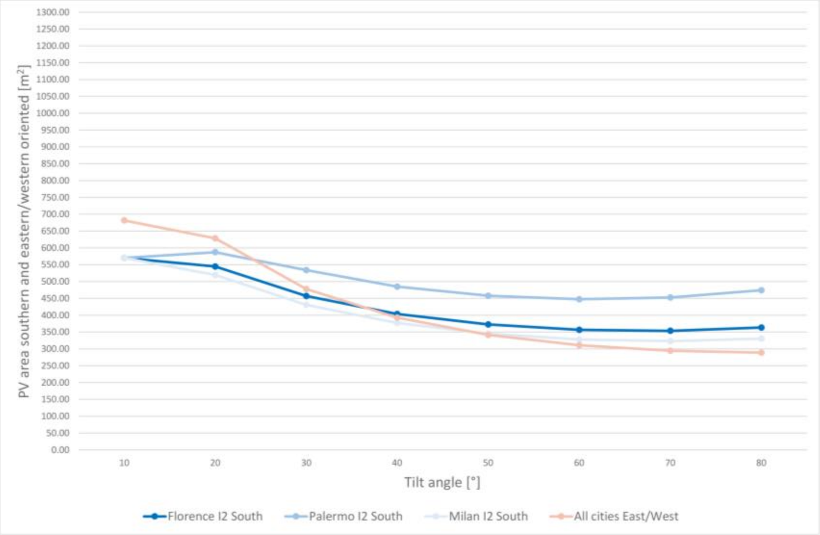

Figure A. 21 PV panels area for model I2

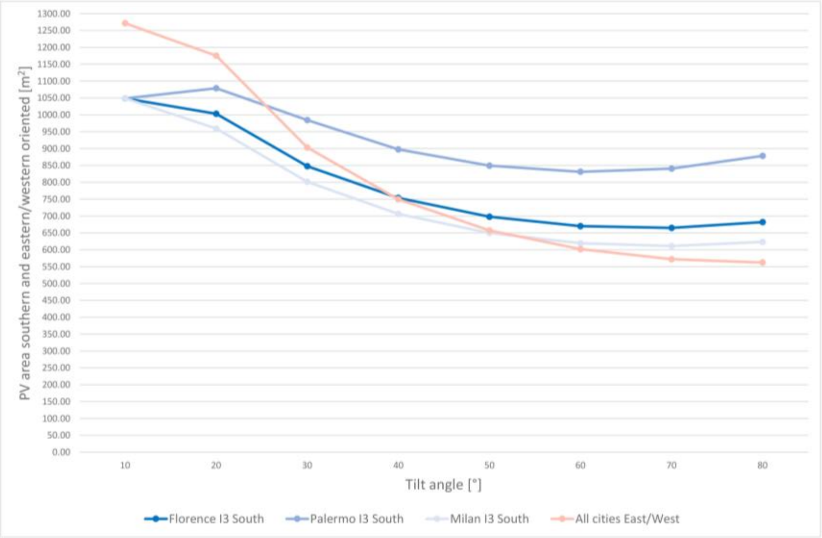

Figure A. 22 PV panels area for model I3

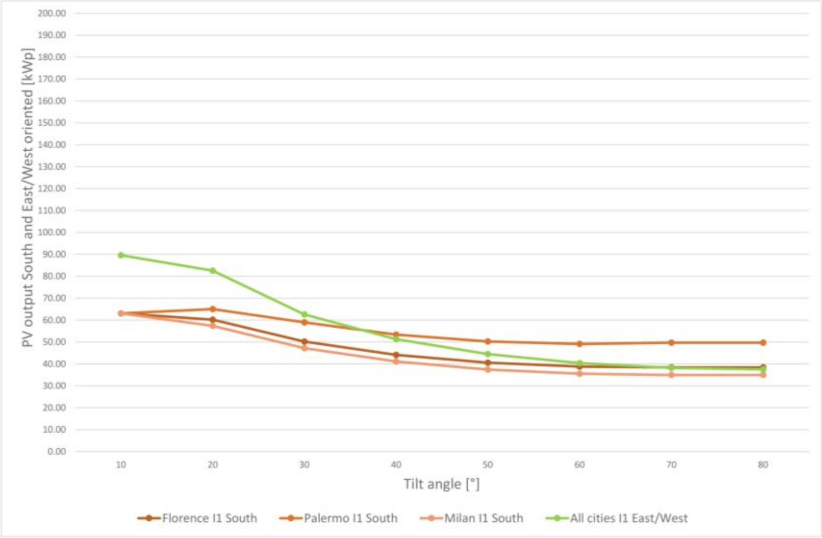

Figure A. 23 PV output for model I1

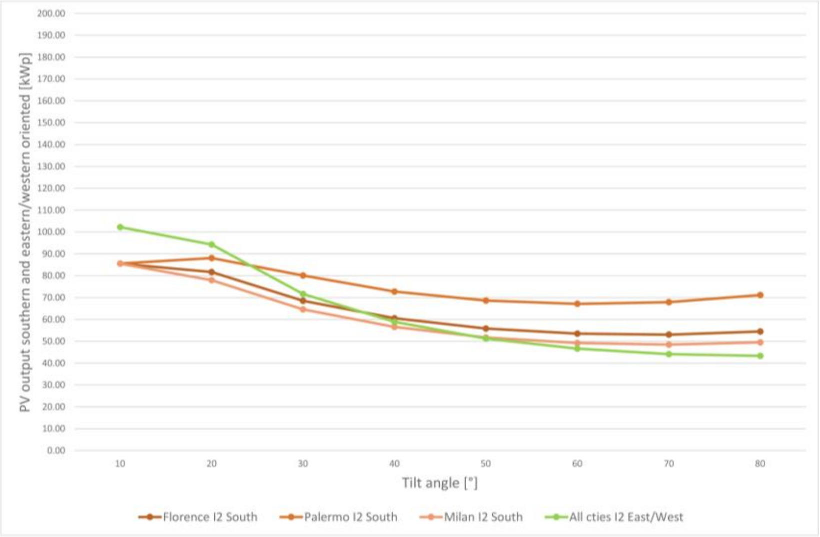

Figure A. 24 PV output for model I2

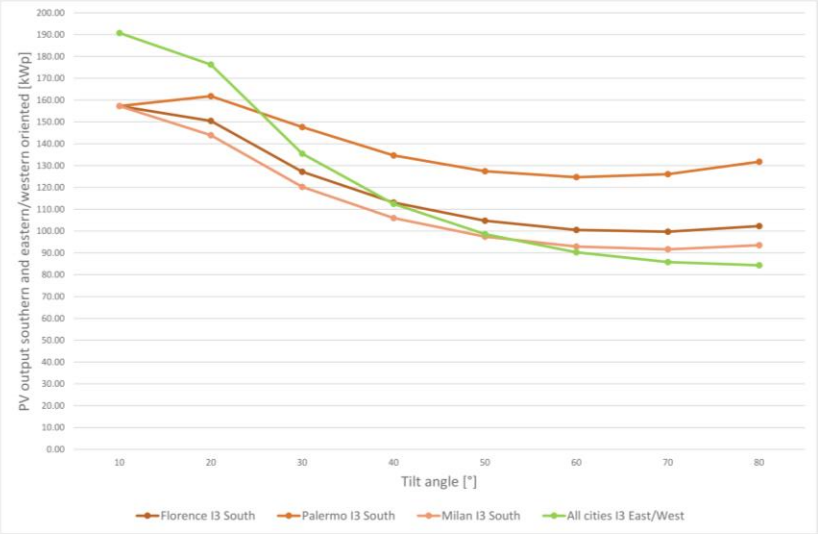

Figure A. 25 PV output for model I3

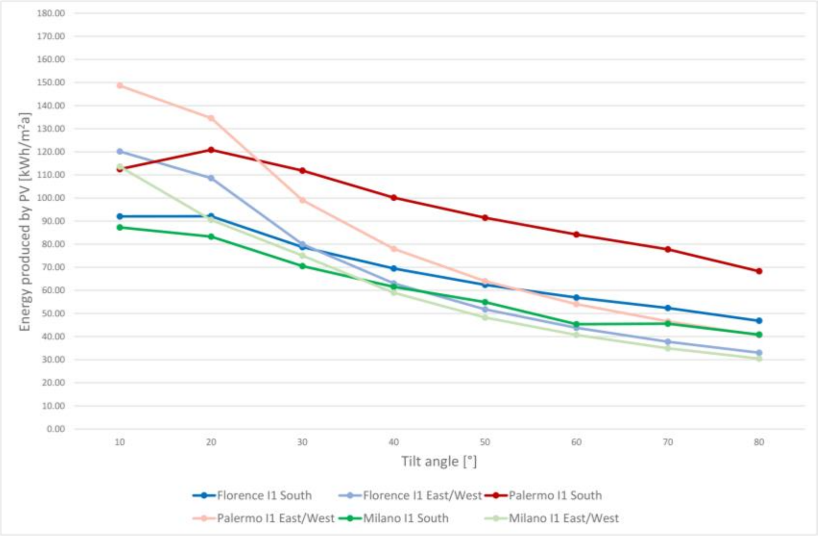

Figure A. 26 Energy produced by PV system model I1

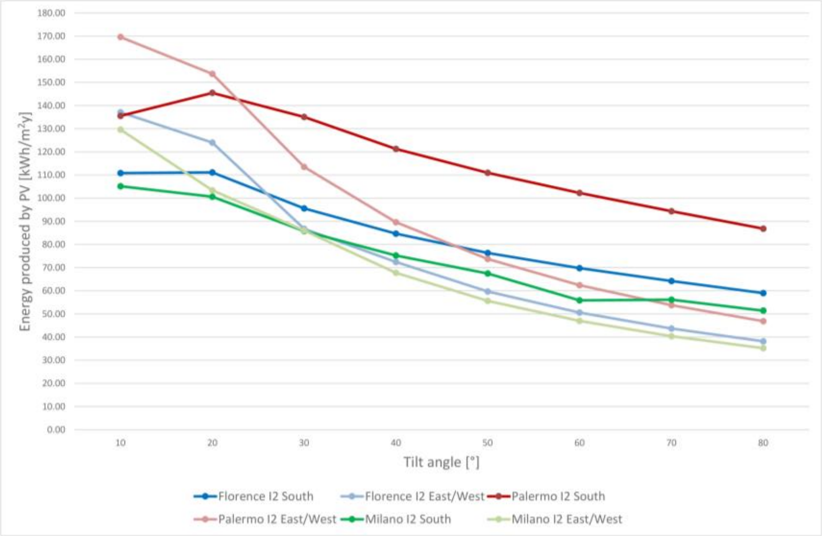

Figure A. 27 Energy produced by PV system model I2

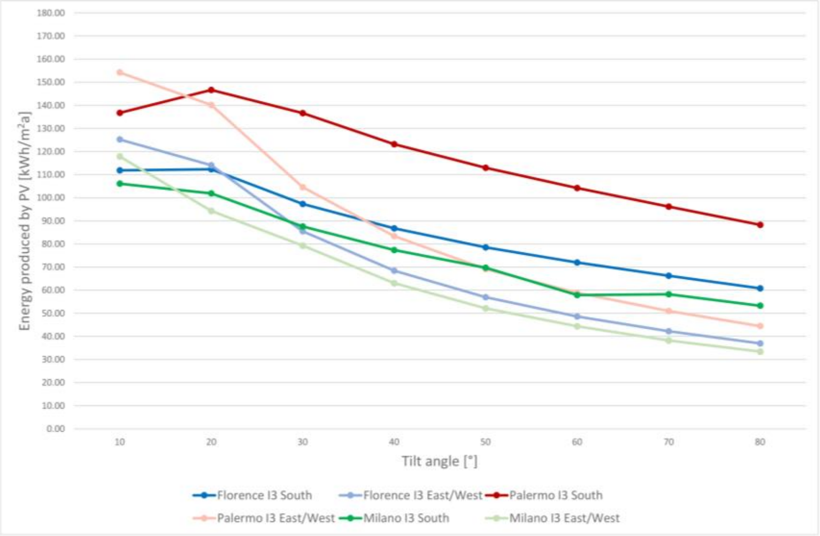

Figure A. 28 Energy produced by PV system model I3

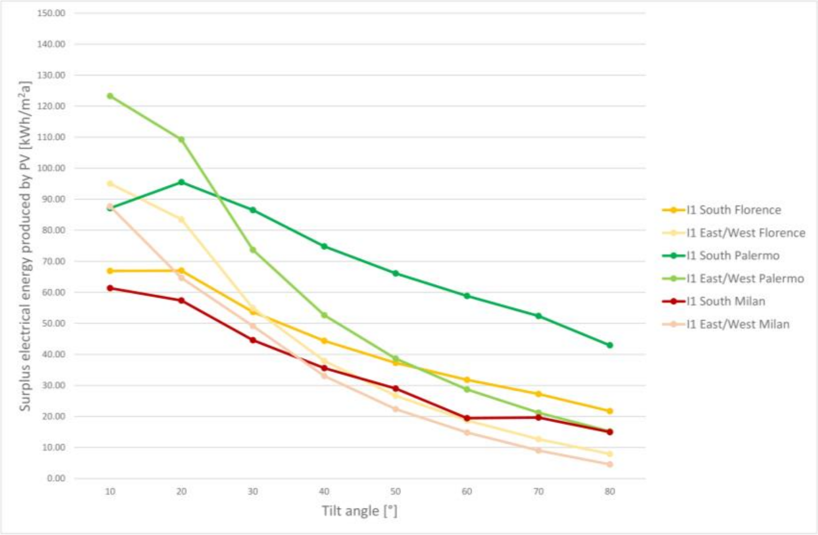

Figure A. 29 Surplus electrical energy production for model I1 in all cities

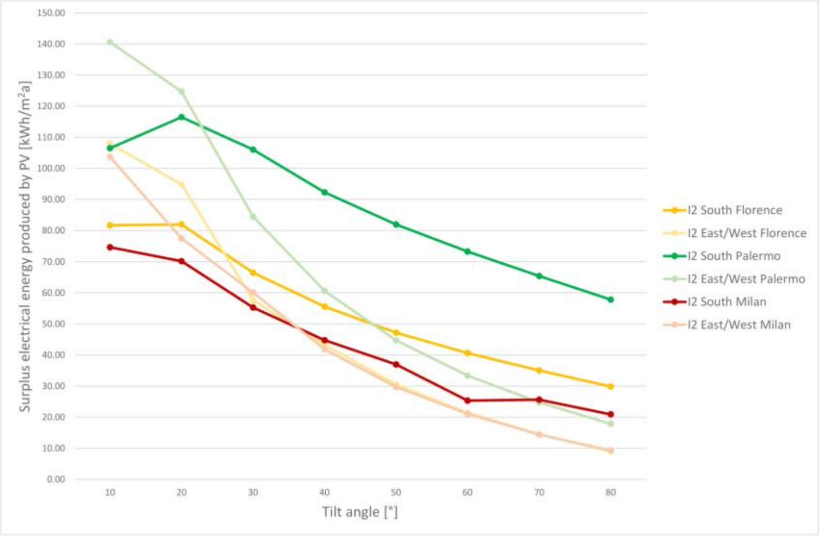

Figure A. 30 Surplus electrical energy production for model I2 in all cities

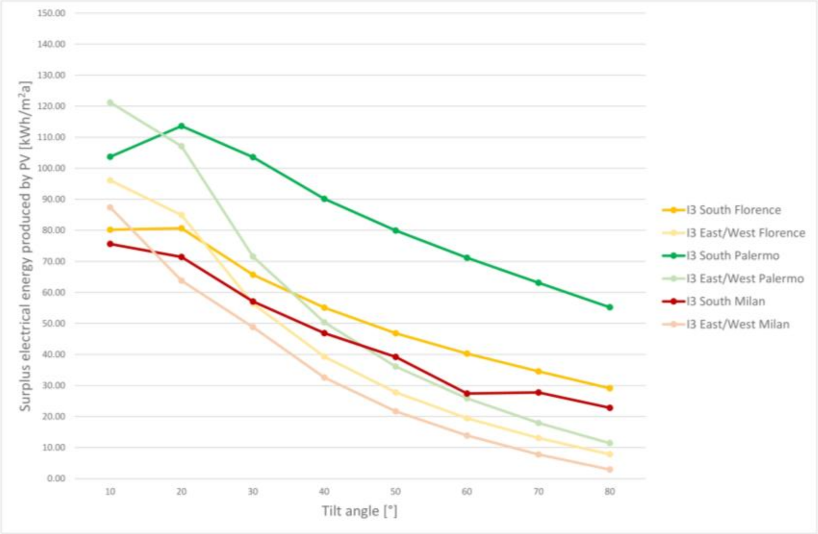

Figure A. 31 Surplus electrical energy production for model I3 in all cities

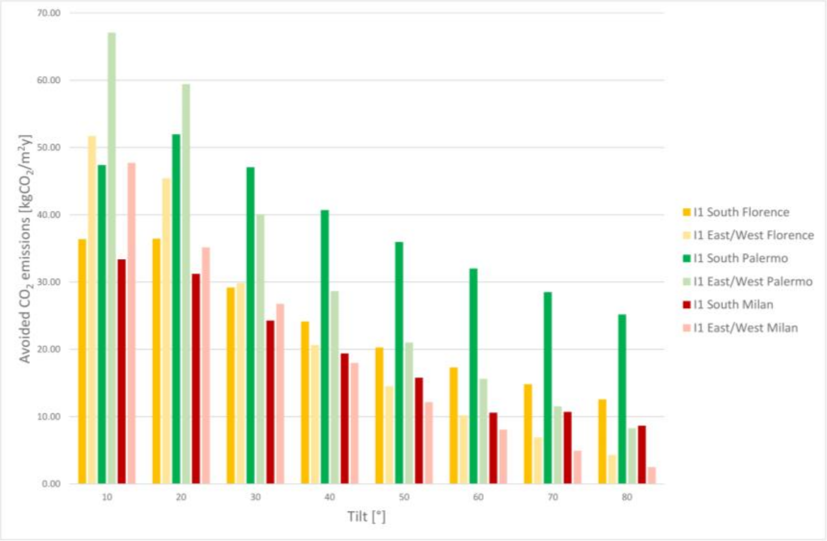

Figure A. 32 Avoided CO$_2$ emissions with the surplus energy production – Model I1

A.7 Qualitative and quantitative guidelines (Chapter 5 – pp. 224)

Table A. 25 Example of one of the possible applications of guidelines for the city of Milan

Milan	Model I1	Model I2	Model I3
Structure	XLAM structural solution with structural panel with 5 layers of 130 mm of thickness		
Façade technological solution	External insulation		
Material of insulation	Wood fiber		
Wall thickness of insulation	140 mm		
Wall thermal transmittance	0.199 W/m^2K		
Roof thickness of insulation	240 mm		
Roof thermal transmittance	0.125 W/m^2K		
Type of Glass	66.2 Stratophone 2 x Planibel Clearlite – 20 mm Argon 90% - 4 mm iplus Advanced 1.0 on clearlite pos. 3		
Glass main characteristics	solar factor = 52% – light transmittance = 75%		
Glass thermal transmittance	1.1 W/m^2K		
Window frame thermal transmittance	1.7 W/m^2K		
South WWR	50%		
North WWR	8%	9%	13%
East WWR	7%	7%	-
West WWR	7%	8%	15%
South solar shading	Fixed overhang (2 m) + automated internal venetian blinds with control on external temperature > 24°C or on discomfort glare index (DGI) > 22		
West/East solar shading	Not necessary		
Mechanical ventilation system	Air handling unit with free cooling on enthalpy (15 vol/h) with sensible heat recovery with efficiency at least 65% - Air change per hour based on UNI 10339		
Heating system	Heat pump COP = 3.6 (configuration 4)		
Cooling system	Heat pump EER = 3.2 (configuration 4)		
Primary energy demand [kWh/m^2a]	25.92	29.47	30.48
PV panels configuration	East/West orientation – tilt = 10°		
PV panels surface [m^2]	547.93	681.56	1271.52
PV surplus energy production [kWh/m^2a]	87.69	103.69	87.39
Avoided emissions [kg_{CO2}/m^2a]	47.71	70.50	47.54
Total amount CO_2 emissions (configuration 4)	23.93	22.67	21.10

Table A. 26 Example of one of the possible applications of guidelines for the city of Rome

Rome	Model I1	Model I2	Model I3
Structure	XLAM structural solution with structural panel with 5 layers of 130 mm of thickness		
Façade technological solution	External insulation		
Material of insulation	Wood fiber		
Wall thickness of insulation	140 mm		
Wall thermal transmittance	0.199 W/m^2K		
Roof thickness of insulation	220 mm		
Roof thermal transmittance	0.133 W/m^2K		
Type of Glass	66.2 Stratophone 2 x Planibel Clearlite – 12 mm Argon 90% - 4 mm iplus Advanced 1.0 on clearlite pos. 3		

Glass main characteristics	solar factor = 50% – light transmittance = 74%		
Glass thermal transmittance	1.2 W/m^{2}K		
Window frame thermal transmittance	1.7 W/m^{2}K		
South WWR	50%		
North WWR	8%	9%	13%
East WWR	7%	7%	-
West WWR	7%	8%	15%
South solar shading	Fixed overhang (2 m) + automated internal venetian blinds with control on external temperature > 24°C or on discomfort glare index (DGI) > 22		
West/East solar shading	Not necessary		
Mechanical ventilation system	Air handling unit with free cooling on enthalpy (15 vol/h) with sensible heat recovery with efficiency at least 65% - Air change per hour based on UNI 10339		
Heating system	Heat pump COP = 3.6 (configuration 4)		
Cooling system	Heat pump EER = 3.2 (configuration 4)		
Primary energy demand [kWh/m^{2}a]	23.68	27.65	30.13
PV panels configuration[1]	East/West orientation – tilt = 10°		
PV panels surface [m^2]	547.93	681.56	1271.52
PV surplus energy production [kWh/m^{2}a]	96.49	109.44	95.11
Avoided emissions [kg_{CO2}/m^{2}a]	52.50	59.53	51.74
Total amount CO_2 emissions (configuration 4)	24.32	23.54	20.82

Table A. 27 Example of one of the possible applications of guidelines for the city of Naples

Naples	**Model I1**	**Model I2**	**Model I3**
Structure	XLAM structural solution with structural panel with 5 layers of 130 mm of thickness		
Façade technological solution	External insulation		
Material of insulation	Wood fiber		
Wall thickness of insulation	100 mm		
Wall thermal transmittance	0.251 W/m^{2}K		
Roof thickness of insulation	180 mm		
Roof thermal transmittance	0.155 W/m^{2}K		
Type of Glass	66.2 Stratophone 2 x Planibel Clearlite – 12 mm Argon 90% - 4 mm iplus Advanced 1.0 on clearlite pos. 3		
Glass main characteristics	solar factor = 50% – light transmittance = 74%		
Glass thermal transmittance	1.2 W/m^{2}K		
Window frame thermal transmittance	1.7 W/m^{2}K		
South WWR	25%	19%	20%
North WWR	8%	9%	13%
East WWR	7%	7%	-
West WWR	7%	8%	15%
South solar shading	Fixed overhang (2 m) + automated internal venetian blinds with control on external temperature > 24°C or on cooling		
West/East solar shading	Not necessary		

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[1] It is considered the same configuration of the city of Florence (same climate zone D)

Mechanical ventilation system	Air handling unit with free cooling on enthalpy (15 vol/h) with sensible heat recovery with efficiency at least 65% - Air change per hour based on UNI 10339		
Heating system	Heat pump COP = 3.6 (configuration 4)		
Cooling system	Heat pump EER = 3.2 (configuration 4)		
Primary energy demand [kWh/m^{2}a]	24.61	28.23	31.74
PV panels configuration[2]	East/West orientation – tilt = 10°		
PV panels surface [m^2]	547.93	681.56	1271.52
PV surplus energy production [kWh/m^{2}a]	98.68	112.36	89.44
Avoided emissions [kg$_{CO2}$/m^{2}a]	53.68	61.12	48.65
Total amount CO$_2$ emissions (configuration 4)	25.19	24.83	22.08

Table A. 28 Example of one of the possible applications of guidelines for the city of Palermo

Palermo	**Model I1**	**Model I2**	**Model I3**
Structure	XLAM structural solution with structural panel with 5 layers of 130 mm of thickness		
Façade technological solution	External insulation		
Material of insulation	Wood fiber		
Wall thickness of insulation	40 mm		
Wall thermal transmittance	0.416 W/m^{2}K		
Roof thickness of insulation	180 mm		
Roof thermal transmittance	0.155 W/m^{2}K		
Type of Glass	66.2 Stratophone 2 x Planibel Clearlite – 20 mm Argon 90% – 44.2 Stratobel 2 x Planibel Clearlite		
Glass main characteristics	solar factor = 69% – light transmittance = 78%		
Glass thermal transmittance	2.5 W/m^{2}K		
Window frame thermal transmittance	1.7 W/m^{2}K		
South WWR	25%	19%	20%
North WWR	8%	9%	13%
East WWR	7%	7%	-
West WWR	7%	8%	15%
South solar shading	Fixed overhang (2 m) + automated internal venetian blinds with control on external temperature > 24°C or on cooling		
West/East solar shading	Not necessary		
Mechanical ventilation system	Air handling unit with free cooling on enthalpy (15 vol/h) with sensible heat recovery with efficiency at least 65% - Air change per hour based on UNI 10339		
Heating system	Heat pump COP = 3.6 (configuration 4)		
Cooling system	Heat pump EER = 3.2 (configuration 4)		
Primary energy demand [kWh/m^{2}a]	24.36	28.99	33.07
PV panels configuration	East/West orientation – tilt = 10°		
PV panels surface [m^2]	547.93	681.56	1271.52
PV surplus energy production [kWh/m^{2}a]	123.29	140.59	121.28
Avoided emissions [kg$_{CO2}$/m^{2}a]	67.07	76.48	65.92
Total amount CO$_2$ emissions (configuration 4)	24.90	24.57	21.88

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[2] It is considered the same configuration of the city of Palermo