Summer indoor comfort levels in the Mediterranean area

THE IMPACT OF DIFFERENT WINDOW CONFIGURATIONS, NATURAL VENTILATION AND SOLAR SHADING STRATEGIES ON THE INDOOR COMFORT LEVEL IN SIMPLE ROOMS.

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1 Abstract

The case studied is related to a residential family house, which is a typical residential building in the South Mediterranean Sea. The house type is also representative for second home. It is a two-storey house that is assumed to be located in Rome.

The objective of the research is to compare indoor comfort conditions of two kitchens (in which internal gains are defined and taking into account a traditional use of the kitchen in Southern Italy) with different window configurations, natural ventilation and solar shading strategies to avoid overheating in summer.

Both rooms have the same floor area and the same total window area. One kitchen has a facade window with shutter; the other kitchen has a facade window and two roof windows including shutters.

The aim of the research is to ascertain the differences in indoor comfort, temperature, air flow and solar distribution for two window/shutter control regimes, in four main orientations and with different roof constructions.

The simulation tool ESP-r from the University of Strathclyde has been used in the report and the ESP-r model has been verified by the University. This research project has been sponsored by VELUX A/S.

Keywords: indoor comfort, natural ventilation, energy saving.

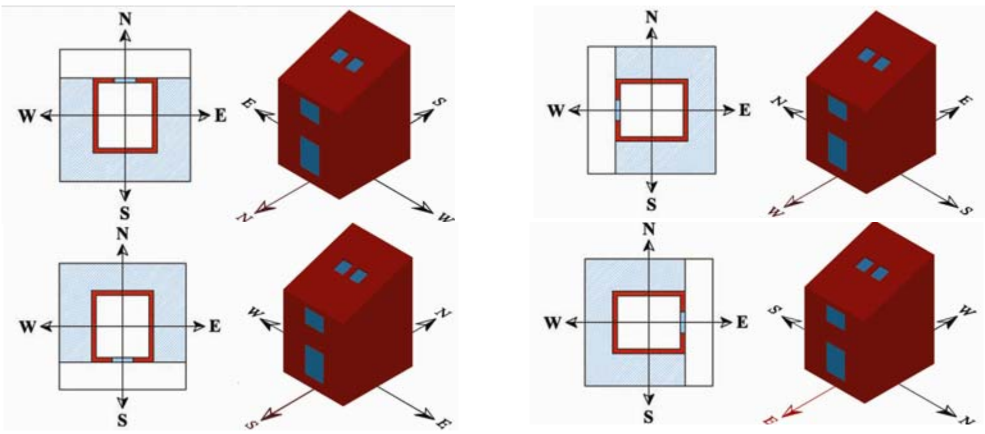

Figure 1. The simple model facing north, west, south and east

2 Construction Materials

All building constructions are the same in all models, except roof constructions.

It has been requested to evaluate differences due to concrete roof and wooden roof constructions with different thermal insulation thicknesses.

Two concrete roofs have been considered, the first one with 4cm of thermal insulation material, the second one with 8cm of thermal insulation material.

The models that adopt concrete roof are named "c4" and "c8". The thermal insulation adopted is panel in extruded Polystyrene.

Wooden roofs have different thermal insulation material thickness: one with 8cm of glass-wool "w8", the other one with 16cm of glass-wool "w16".

The concrete roof is characterised by an higher density value compared to the wooden roof.

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INTERNAL GAINS							
	type	start	stop	sensible	latent	radiant fraction	convective fraction
Weekdays, Saturdays, Sundays	equipment	0	24	38.6	0	0.300	0.700
	equipment	7	9	100	0	0.500	0.500
	equipment	12	14	100	0	0.500	0.500
	equipment	19	21	100	0	0.500	0.500
	light	7	8	100	0	0.800	0.200
	light	19	21	100	0	0.800	0.200
	occupant	7	9	380	180	0.200	0.800
	occupant	12	14	380	180	0.200	0.800
	occupant	19	21	380	180	0.200	0.800

Table 1. Description of internal gains: equipment, light and occupant

2.1 External Wall

The external wall, chosen for simulations, is characterized by a U value of 0.42 W/m^{2}K; it is a cavity wall with 4 cm of thermal insulation and it is the most common wall construction used in the Mediterranean area.

2.3 Windows and Shutters

The kitchens fulfils the minimum window area required which is 1/8 of the floor area. The windows have been defined as glazing area without frame and with external roller shutters.

Both kitchens have the same transparent surface but a different area distribution: the room on the lower floor has 2.66 m^2 of facade window, the room on the upper floor has two roof windows (0.56 m^2 each) and one facade window (1.54 m^2) with a total transparent area of 2.66 m^2.

The glazing systems are defined as double glass units with 4 mm of float glass, 16 mm of air and 4 mm of float glass (glazing U value= 2,8 W/m^{2}K).

The roof windows are described with an air gap between the aluminium shutter and the glazing system, and façade windows with an air gap between the PVC shutter and the glazing system.

The facade windows are represented as a pair of windows with hinges on the left and right vertical frame opening inwards by about 10cm. The roof windows are horizontal centre pivot with equal upper and lower openings.

The windows are represented geometrically as two surfaces – one for the shuttered glazing and one for the exposed glazing. No attempt was made to define frames of facade windows or roof windows.

3 Internal gains

The presence of occupants in rooms is defined as internal gains – that includes equipments and artificial light – according to the common usage of kitchens; they are defined in the ESP-r operation file and exposed in the table 1.

4 Natural ventilation Strategies

The objective of the research is to compare two kitchens with different window configurations and natural ventilation strategies to avoid summer overheating by applying and studying different natural ventilation strategies. The ESP-r model includes a base case (upper_bc and lower_bc zones), natural ventilation strategy 1 (upper_sch1 and lower_sch1

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zones) and natural ventilation strategy 2 (upper_sch2 and lower_sch2 zones).

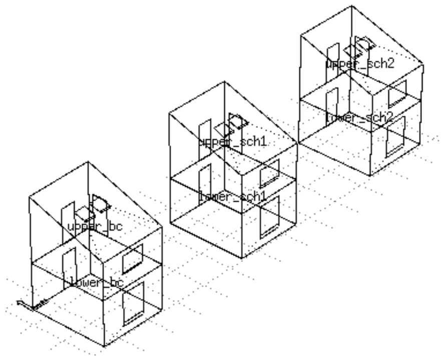

Figure 2. The base-case, natural ventilation strategy 1 and natural ventilation strategy 2.

Base Model: it was created to compare with natural ventilation strategy 1 and natural ventilation strategy 2. It keeps all windows closed without natural ventilation strategies applied, with air change rate of 0.5 ac/h plus a crack infiltration. Base case model is also without shutters.

Model with applied natural ventilation strategy 1: control strategy 1 has no human intervention during the day. There is an automatic window and shutter control. During the day, unless the inside temperature is lower than the outside temperature, the shutters are opened to 11% of the area and the windows are opened to 11% of the area. At night the shutters are fully open and the windows are opened according to a range-based air flow control law, see chapter 4.4 where the controls are described.

Model with applied natural ventilation strategy 2: control strategy two has human intervention during the day and will track occupancy in the kitchen.

When there are occupants during the day they will open the windows and shutter to 11% and they will do this whether or not the outside temperature is above or below kitchen temperature. When there are no occupants the windows will be closed whether or not the outside temperature is above or below kitchen temperature.

Control for night: at night the same control logic will be used in both kitchens and for strategy 1 and 2. At night the shutters are fully open on all roof and facade windows. The air flow logic is a range-based controller where:

- If the kitchen temperature falls below 18°C, the apertures associated with the windows will contract to 1% opening area.
- If the kitchen temperature is between 18°C and 22°C, the nominal area of the window aperture (~10%) will be used.
- If the kitchen temperature is above 22°C, a 15% opening area is used, and if the kitchen temperature rises above 26°C, a 20% opening will be used.

This approximates to an occupant who will close the windows if the room gets cool and will progressively open the windows as the room temperature rises.

5 Analysed Models and Results

Simulations were run for the summer season, **from 1st of June until 30th of September** (2928 hours).

The following scheme shows the studied models and describes the constructions.

C4: c4_e, c4_n, c4_s, c4_w
Concrete (c) roof with 4 cm of thermal insulation material oriented to the east (e), the north (n), the south (s), the west (w)
C8: c8_e, c8_n, c8_s, c8_w
Concrete (c) roof with 8 cm of thermal insulation material oriented to the east (e), the north (n), the south (s), the west (w)
W8: w8_e, w8_n, w8_s, w8_w
Wooden (w) roof with 8 cm of thermal insulation material oriented to the east (e), the north (n), the south (s), the west (w)
W16: w16_e, w16_n, w16_s, w16_w
Wooden (w) roof with 16 cm of thermal insulation material oriented to the east (e), the north (n), the south (s), the west (w)

We have simulated 16 models, with two natural ventilation strategies (32 cases) for upper and lower zones (64 results). Following: tables with main results.

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ORIENTATION / MODEL TYPOLOGY		c4 concrete roof with 4 cm of insulation, U (W/m2K) = 0.55 — Tmax (°C)		c8 concrete roof with 8 cm of insulation, U (W/m2K) = 0.35 — Tmax (°C)		w8 wooden roof with 8 cm of insulation, U (W/m2K) = 0.41 — Tmax (°C)		w16 woodenroof with 16 cm of insulation, U (W/m2K) = 0.25 — Tmax (°C)	
		Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2
NORTH	Upper	32.04	32.08	32.01	32.06	32.35	32.39	32.19	32.21
	Lower	32.55	32.64	32.51	32.61	32.57	32.67	32.54	32.65
SOUTH	Upper	33.47	33.58	33.41	33.53	33.97	34.05	33.68	33.78
	Lower	33.99	34.18	33.97	34.14	33.96	34.19	33.93	34.15
WEST	Upper	32.62	32.78	32.59	32.77	33.11	33.23	32.92	33.06
	Lower	33.67	33.93	33.64	33.90	33.67	33.94	33.65	33.93
EAST	Upper	32.98	33.11	32.94	33.08	33.41	33.55	33.18	33.32
	Lower	33.65	33.80	33.61	33.77	33.66	33.84	33.63	33.79

TEMPERATURE ANALYSIS

Table 2. Maximum temperature for all analysed models for the summer period: the upper floor obtains in general maximum temperatures at the same level as the lower floor. Ventilation strategy 2 obtains a higher maximum temperature than ventilation strategy 1. The maximum temperature with a north orientation is approximately 1.5°C lower than south orientation. West-oriented model reaches a lower temperature than the east-oriented model.

ORIENTATION / MODEL TYPOLOGY		c4 concrete roof with 4 cm of insulation, U (W/m2K) = 0.55 — hours		c8 concrete roof with 8 cm of insulation, U (W/m2K) = 0.35 — hours		w8 wooden roof with 8 cm of insulation, U (W/m2K) = 0.41 — hours		w16 woodenroof with 16 cm of insulation, U (W/m2K) = 0.25 — hours	
		Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2
NORTH	Upper	1155 (39.44%)	1090 (37.22%)	1174 (40.09%)	1106 (37.77%)	1116 (38.11%)	1045 (35.68%)	1148 (39.20%)	1064 (36.33%)
	Lower	1068 (36.47%)	1000 (34.15%)	1073 (36.64%)	995 (33.98%)	1066 (36.40%)	1000 (34.15%)	1073 (36.64%)	1002 (34.22%)
SOUTH	Upper	1134 (38.72%)	941 (32.13%)	1159 (39.58%)	946 (32.30%)	1101 (37.60%)	909 (31.04%)	1124 (38.38%)	935 (31.93%)
	Lower	821 (28.03%)	745 (25.44%)	826 (28.21%)	747 (25.51%)	827 (28.24%)	738 (25.20%)	833 (28.44%)	742 (25.34%)
WEST	Upper	1159 (39.58%)	991 (33.84%)	1170 (39.95%)	995 (33.98%)	1140 (38.93%)	984 (33.60%)	1168 (39.89%)	994 (33.94%)
	Lower	847 (28.92%)	755 (25.78%)	847 (28.92%)	759 (25.92%)	854 (29.16%)	758 (25.88%)	854 (29.16%)	759 (25.92%)
EAST	Upper	1071 (36.57%)	986 (33.67%)	1077 (36.78%)	995 (33.98%)	1020 (34.83%)	936 (31.96%)	1049 (35.82%)	950 (32.44%)
	Lower	859 (29.33%)	779 (26.60%)	863 (29.47%)	779 (26.60%)	860 (29.36%)	772 (26.36%)	862 (29.43%)	776 (26.50%)

NUMBER OF HOURS EXPRESSING PPD LOWER THAN 10%

Table 3. Number of hours in which PPD (Predicted Percentage of Dissatisfied) is less than 10%. For the PPD evaluation it was assumed to be an activity level of 1.2 met, clothing 0.5 and air velocity 0.15 m/s. Data are collected for the summer season 1st of June until 30th of September. Conclusion: see below table 4.

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ORIENTATION	MODEL TYPOLOGY	c4 concrete roof with 4 cm of insulation, U (W/m2K) = 0.55, hours		c8 concrete roof with 8 cm of insulation, U (W/m2K) = 0.35, hours		w8 wooden roof with 8 cm of insulation, U (W/m2K) = 0.41, hours		w16 woodenroof with 16 cm of insulation, U (W/m2K) = 0.25, hours	
		Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2	Ventilation Strategy 1	Ventilation Strategy 2
NORTH	Upper	1947 (66.50%)	1860 (63.52%)	1960 (66.94%)	1876 (64.07%)	1871 (63.90%)	1759 (60.01%)	1904 (65.03%)	1810 (61.81%)
	Lower	1801 (61.50%)	1726 (58.95%)	1809 (61.78%)	1735 (59.25%)	1805 (61.65%)	1717 (58.64%)	1809 (61.78%)	1726 (58.95%)
SOUTH	Upper	1857 (63.42%)	1591 (54.34%)	1870 (63.86%)	1612 (55.05%)	1814 (61.95%)	1573 (53.72%)	1839 (62.80%)	1606 (54.85%)
	Lower	1437 (49.07%)	1324 (45.22%)	1443 (49.28%)	1331 (45.46%)	1435 (49.00%)	1321 (45.12%)	1442 (49.25%)	1327 (45.32%)
WEST	Upper	1868 (63.80%)	1631 (55.70%)	1887 (64.45%)	1642 (56.08%)	1855 (63.35%)	1635 (55.84%)	1867 (63.76%)	1641 (56.04%)
	Lower	1479 (50.51%)	1353 (46.20%)	1483 (50.64%)	1358 (46.38%)	1480 (50.55%)	1354 (46.24%)	1482 (50.61%)	1353 (46.21%)
EAST	Upper	1750 (59.76%)	1557 (53.17%)	1757 (60.00%)	1560 (53.28%)	1676 (57.24%)	1502 (51.30%)	1717 (58.64%)	1524 (52.05%)
	Lower	1464 (50.00%)	1355 (46.27%)	1470 (50.20%)	1358 (46.38%)	1472 (50.27%)	1346 (45.97%)	1473 (50.30%)	1351 (46.14%)

NUMBER OF HOURS EXPRESSING PPD LOWER THAN 20%

Table 4. Number of hours in which PPD is less than 20%. In both natural ventilation strategies upper floors allow more hours with less than 20% and 10% PPD. The automatic opening control (ventilation strategy 1) gives better results. A light construction with more insulation gives approximately the same results as a concrete construction with less insulation.
The west orientation performance is better than the east orientation, because one of the walls of the house is an external wall with 40 mm insulation and in an east orientation this wall is exposed to the south.

Based on the conclusions in table 2 and 4, it has been decided to analyse results for south-oriented models and for the worst concrete (c4_s) and wooden roofs (w8_s). Following, temperatures and results for models c4_s and w8_s.

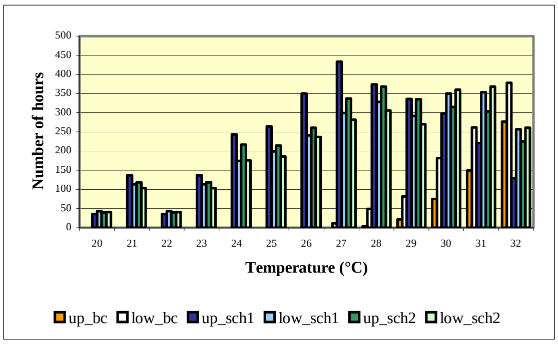

Table 5. Temperature Histogram: Results for model c4 south-oriented. The histogram explains the number of hours in which each model reaches a specific temperature.

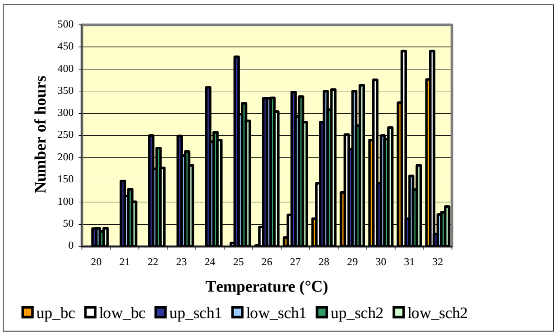

Table 6. Temperature histogram: Results for model w8 south-oriented.

If we simulate an occupant situation with just an imposed air volume of change of 0.5 ac/h, without a window opening control, such as in the base case model, we have a situation in which during all summer season we are not able to reach temperatures below 25°C in a kitchen on the lower floor; the minimum temperature we obtain on the upper floor is 26°C.
The base case shows the lower performance because it is unable to take

advantage of night cooling and it has closed shutters during the day.

In the base case model, during summer season, we have the maximum total number of hours above 31°C, in very uncomfortable indoor conditions.

The automatic control of windows opening is the suggested natural ventilation strategy; it guarantees the best indoor comfort level during summer season.

5.1 Conclusions

The study was based on a simple model simulating two rooms with different window configurations and natural ventilation strategies: one room with façade window, the other room has one façade and two roof windows. Both rooms have the same floor area and the same window area.

The simple model includes a base case and two ventilation and solar shading strategies. Simulations are conducted in ESP-r tool.

The study points out the following main findings:

- In both natural ventilation strategies the upper floors always have significantly more hours with less than 10% PPD (Predicted Percentage of Dissatisfied) compared to the lower floor, which indicates a higher occupant's satisfaction on the upper floor.
- The use of a ventilation schedule (night cooling) can lower the temperature at the start of the day.
- The use of sun screening is vital for protection against overheating, both in upper and lower floor.
- The upper floor obtains in general maximum temperatures at the same level as the lower floor.

Also, the study has shown that:

- In the north orientation the maximum temperature in the upper floor is approximately 1,5°C lower than in the south orientation.
- The numbers of hours with less than 10% PPD are at the same level for the wooden roof construction with 80 mm insulation as for the concrete roof construction with 40 mm insulation. The use of a wooden roof construction with 160 mm insulation is also comparable with the concrete roof construction with 80 mm insulation. The 80 mm and 160 mm insulated wooden roof construction would however have advantages in the winter situation as regard to heat loss. It would be relevant to conduct further investigations of the impact of thermal mass and insulation.
- The maximum temperature during the summer period is approximately the same for all 4 roof construction types.
- The investigation also finds that the solution with roof windows in combination with a façade window provides a better ventilation possibility during the summer period, due to the stack effect and cross ventilation.

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