Control Strategies of the Natural Ventilation for Passive Cooling for an Existing Residential Building in Mediterranean Climate

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ABSTRACT

Natural ventilation is increasingly considered one of the most efficient passive solutions to improve thermal comfort in buildings. However in order to support its planning and implementation, quantitative analysis on airflow paths and heat-airflow building interactions are needed. This requires an adequate accounting of both internal effects, from building layout and structure, and external forcings from atmospheric factors.

This paper has dealt to analyze the potential of building automation systems for ventilative cooling of residential buildings.

The case study focused on a Italian typical building of the '60s, situated in the Mediterranean climatic context (Bari - Italy, 41° 07'31 "N 16 ° 52'00" E, 5 m asl), with windowed sides faced to northwest and southeast.

Various operating controls of ventilation have been developed to reduce energy consumption for cooling, ensuring adequate levels of indoor comfort. In particular, automated bottom hinged windows have been hypothesized.

Different design solutions have been simulated in order to choose the optimal control of ventilation in relation to internal and external temperature and humidity (relative and absolute).

The air flows in the building have been calculated with a multizone airflow model, performed by TRNFLOW within the TRNSYS software.

Thermal comfort analysis, according to the adaptive thermal comfort theory (EN 15251-2007), have shown that a natural ventilation system, calibrated on a variable set-point based on the optimal temperatures (according to the theory of adaptive comfort) determines a significant reduction of overheating during the occupation hours.

Despite the benefits of such control logic, it has been necessary to provide a second control logic, calibrated on internal and external humidity (relative and absolute). The simulations results have underlined a significant reduction in relative humidity levels (generally in range 40- 60%), although some undercooling occurs due to the opening of the windows when the control on the temperature is set off.

Others simulations have regarded the combination of the above described natural ventilation system, with an air to air heat pump. The simulation results have showed that the control strategies of ventilation for passive cooling enable significant reduction in energy consumption.

This study have underlined that ventilation strategies for passive cooling of existing buildings in Mediterranean climate, can contribute even more effectively to the improvement of the behavior of the building envelope, integrating or replacing the conventional efficiency strategies, if properly integrated with adequate control systems.

KEYWORDS

Natural ventilation, thermal comfort, passive cooling, multizone airflow models, building automation

1 INTRODUCTION

Natural ventilation could significantly reduce building energy consumption for cooling and improve thermal comfort with the indoor environment (Brager et al., 2011).
Despite the natural ventilation is necessary to ensure adequate Indoor Air Quality levels and to dilute the pollutants originating in the building, it has the potential to save significant amounts of energy by reducing the demand for mechanical ventilation and air conditioning (Rowe, 1996; Zhao and Xia, 1998).
In residential buildings the ventilation is generally manual and not always aimed at cooling needs. Building automation systems and suitable control logics based on the building profiles of use and on the comfort performance are required.
In order to value indoor air temperatures in buildings, it is essential to have suitable methods to predict and valuate ventilation performance. The prediction of natural ventilation effects is complicated by the dynamic nature of ventilation itself; variables include change of wind speed and direction as well as the context, more or less densely populated, and the influence of users behaviour on the ventilation through building openings (Yan Li and Xiaofeng Li, 2014).
Several building simulation are able to integrate building’s thermal model with a multi-zone airflow network model. We selected the TRNFLOW tool within the TRNSYS software, because it allows to simulate different control strategies for the building automation.
The present paper analyses various operating controls of ventilation as retrofit solutions to improve thermal comfort in an existing residential building located in a suburban zone of the Bari’s city (Italy).

2 METHODOLOGY

The following study has focused on the potential of Building Automation Systems (BA) for the control of ventilation for passive cooling of buildings.
Several control strategies of natural ventilation have been simulated to reduce energy consumptions for cooling and ensure adequate levels of indoor comfort.
After setting up the building’s thermal model and the multi-zone airflow network model within the TRNFLOW–TRNSYS software, different ventilation strategies have been compared through:

- thermal comfort analysis, according to the standard UNI EN 15251, assuming the category n. II (relative to new construction and existing buildings subject to refurbishment)
- energetic analysis in dynamic regime.

Simulations are performed during the cooling season (1 June – 30 September) to analyse the passive behaviour of the building.
In particular, relatively to the occupation hours, the discomfort due to overheating and undercooling has been calculated, in reference to the upper and lower temperature limit.
In relation to internal and external temperature and humidity (relative and absolute), four design solutions have been simulated in order to choose the optimal control of ventilation. Three cases are performed without any active cooling system. In a case (Case 4) the combination of a natural ventilation system with an air to air heat pump has been simulated to evaluate the reduction of cooling energy consumptions.

2.1 Building Description

The case study has regarded a multi-family residential building typical of the '60s. The apartment analyzed situated at the intermediate floor has a net floor area of about 100 m^2 and is characterized by:

- windowed sides faced to northwest and southeast;
- compactness index (ratio between enveloping surface and heated volume) equal to 0.65, as result of the building type;
- bedroom, kitchen and bathroom faces to northwest, and living/dining/ room, bedroom and study room faces to southeast (fig.1)

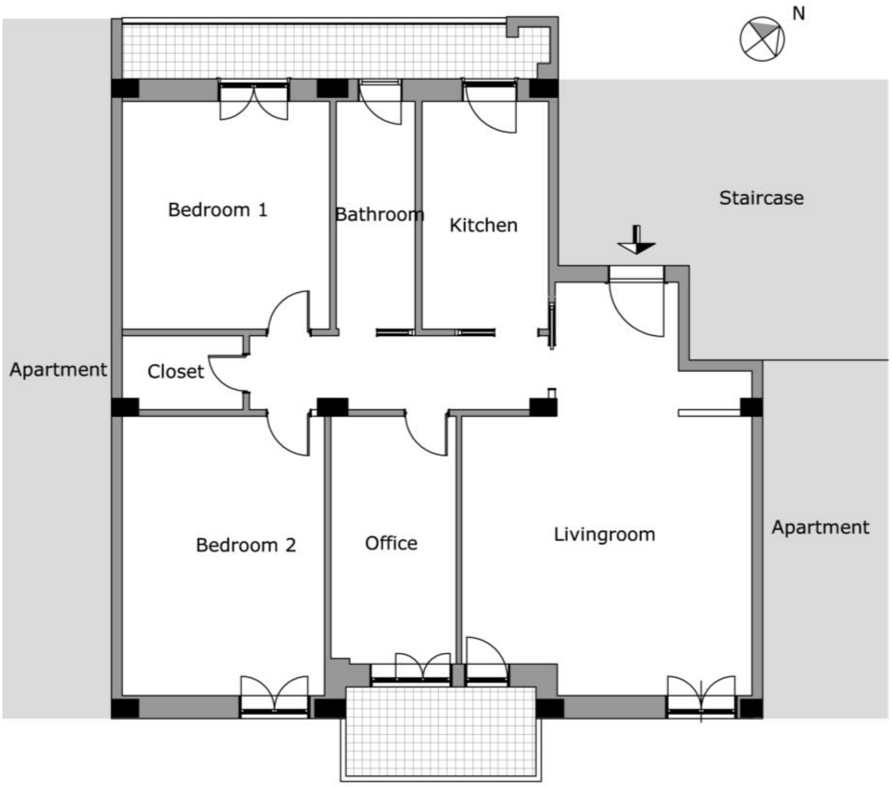

Figure 1: Apartment floor plan

The building envelope parameters (tab.1) were determined according to the typical envelope for the Italian residential buildings of '60s:

Table 1: Thermal characterstics of the envelopes

Items	U-value (W/m^2 K)
External wall	1,10
Internal wall	1,54
Roof	0,83
Window	5,6

In order to consider the *internal heat gains* for occupancy, lighting and domestic appliances, several typical schedules of a residential building have been implemented in the TRNSYS software.

None *solar shielding* system has been adopted in the various simulations for not alter the flow air when the windows are open and it will be the object of future studies. The adoption of solar shielding systems will be deepened in later stages of the search.

The type of windows in the rooms are *tilt-turn windows*, with possible bottom hinged opening automated.

2.2 Thermal - Multizone Airflow Simulation Model

The building thermal model has been set up in TRNSYS v.17 and the multi-zone air flow model has been integrated with TRNFLOW.
TRNFLOW integrates the multi-zone air flow model COMIS into the thermal building module of TRNSYS (Type 56). With TRNFLOW the air flows between airnodes (coupling), from outside into the building (infiltration) and from the ventilation system (ventilation) can be calculated.
Multizone air flow models idealize the building as a network of nodes and airflow links. The nodes represent the rooms and the building surrounding. The links depict openings, doors, cracks, window joints and shafts as well as ventilation components like air inlets, outlets, ducts and fans. The wind pressures on the façade and the indoor and outdoor air temperatures are the important boundary conditions.

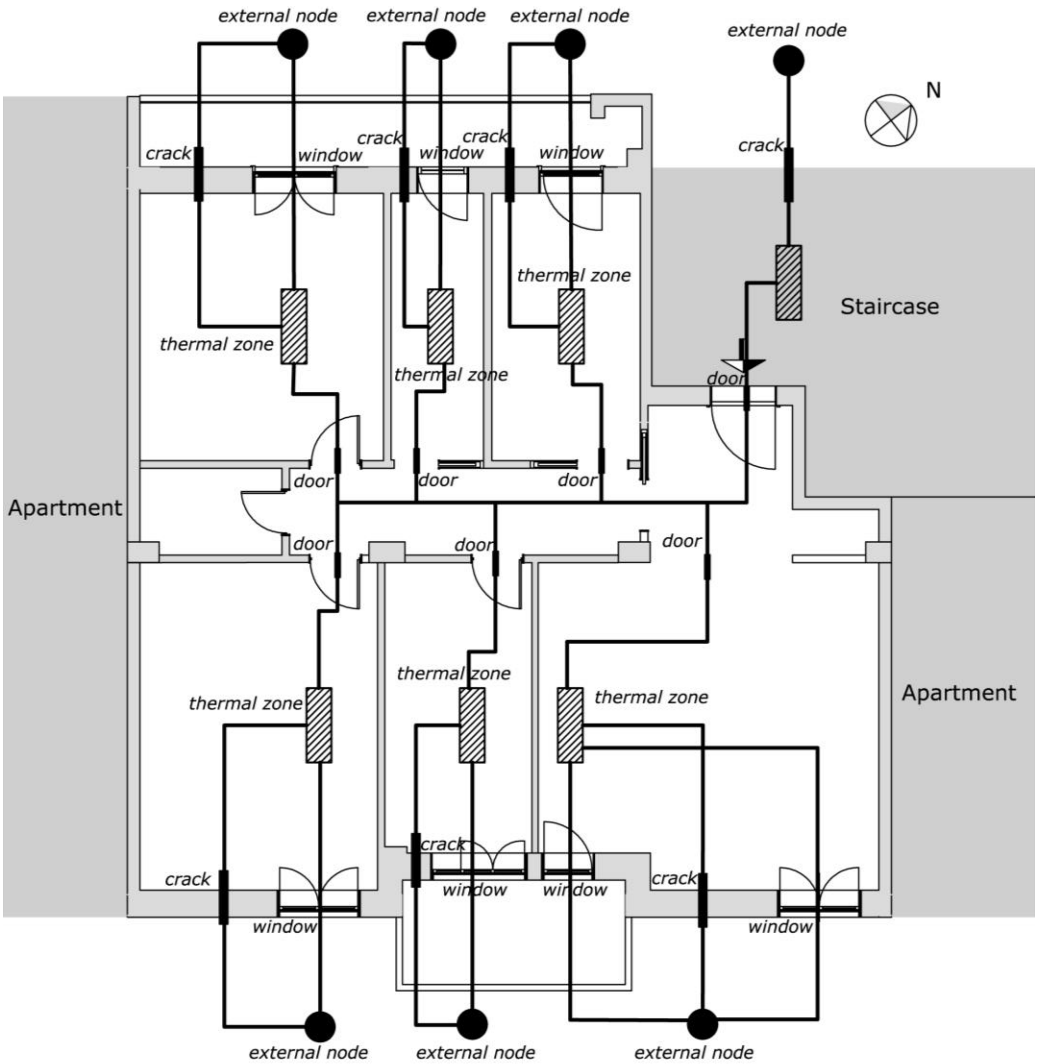

Figure 2: Network model of the building

The air permeability characteristics used in the various simulations that describe a low air tightness of the building envelope are shown in the tab.2

Table 2: Air permeability characteristic of building envelope

Item	Air Mass Flow Coefficient Cs (Kg/sPa) crack (Kg/s m Pa) large opening	Air Flow Exponent n	Discharge Coefficient Cd
Crack _External Wall	0,00002	0,85	-
Large Opening _Window	0,0003	0,6	0,6
Large Opening _Door	0,0015	0,6	0,6

Weather data for the city of Bari are used and wind speed profile has been modified by terrain roughness parameters for suburbs.

In the various simulations the air change rate depends on the logics of window opening and on the air permeability of windows. In particular, to ensure conditions of Indoor Air Quality (IAQ), it has been assumed a schedule opening-windows at certain hours (8 a.m. - 10 a.m.; 1 p.m.- 2 p.m.; 8 p.m. - 9 p.m.). These periods correspond to the activities of preparing and cooking foods and of household cleaning. During these hours it has been hypothesized a bottom hinged opening. Thus, the *opening factor of window* has been multiplied for a factor (Ck) depending on the maximum window tilt according to the UNI EN 15242 – 2008.

Table 3: Opening window parameters

Item	Maximum window tilt	Opening Coefficient Ck
Window_(h=2,2 mt)	13°	0,22
Window_(h=1,2 mt)	25°	0,39

The IAQ opening during these hours, managed directly by the user and independent by automation systems, it is the same in all the cases simulated.

2.3 Natural Ventilation Strategies and Automation Systems

Energy efficiency solutions have involved the installation of a network of sensors (wireless low-power) and actuators for the implementation of natural ventilation strategies.

In order to keep a comfortable temperature and humidity, four control strategies of natural ventilation are simulated. Opening actuators can be applied to existing windows, controlled by temperatures and humidity sensors.

Except Case 0 (with opening windows only for IAQ and no cooling system), and the Case 5 (equipped with an air to air heat pump for cooling, that operate only in presence of users with setpoint temperature of 26 °C), during the hours not included for IAQ, the windows are opened if:

Case I (actuators operated by temperature sensors)

- T indoor > T optimal (valuated according UNI EN 15251);
- T indoor – 3°C < T outdoor < T indoor (in order to avoid undercooling discomfort).

Case II (actuators operated by temperature or humidity sensors)

- T indoor > T optimal;
- T indoor – 3°C < T outdoor < T indoor.

  Or if:
- R.H. indoor (relative indoor humidity) > 70%;
- absolute indoor humidity > absolute outdoor humidity.

Case III (actuators operated by temperature and humidity sensors)

- T indoor > T optimal;
- T indoor – 3°C < T outdoor < T indoor.

  Or if:
- R.H. indoor (relative indoor humidity) > 70%;
- absolute indoor humidity > absolute outdoor humidity.
- T indoor > T optimal;

Case IV (hybrid system with cooling system)

- T indoor > 26°C;
- T indoor – 3°C < T outdoor < 26°C.

  The operation of air to air heat pump for cooling, during the hours of occupation, if:
- T indoor > 26°C;
- T outdoor > 26°C.

2.4 Results

The first three cases proposed have been compared in terms of adaptive thermal comfort and relative humidity conditions.
According the European standard UNI EN 15251, three comfort categories limited by three temperatures ranges are defined. Thermal comfort is evaluated on the difference between the optimal operative temperature and the simulated operative temperatures. The operative temperatures outputs during the occupation hours are compared with the Upper Temperature limit and Lower Temperature limit.
Simulation results have shown the efficacy of the proposed ventilative cooling strategies. A natural ventilation system, calibrated on a variable set-point based on the optimal temperatures (according to the theory of adaptive comfort) determines a significant reduction of overheating during the occupation hours.
The Bedroom2 has presented the more situations of discomfort for overheating. The orientation non-optimal and the absence of any shielding system, the night- ventilation lack and the high internal gains are the main causes. Furthermore the simulations showed high levels of relative humidity (>70%) in the bedrooms.
In order to reduce the high level of relative indoor humidity (>70 %), a natural ventilation strategy controlled by humidity sensor has been necessary. In fact in the Case 2, when the control of relative humidity is independent by indoor temperature, the discomfort situations for high levels of relative humidity have halved, although some undercooling occurs due to the opening of the windows when the control on the temperature is set off. In the other cases relative humidity discomfort percentages were almost the same.

Table 4: Thermal comfort simulation percentages.

Room	**Case 0**		**Case 1**		**Case 2**		**Case 3**	
	Overheat.	Undercool.	Overheat.	Undercool.	Overheat.	Undercool.	Overheat.	Undercool.
Bedroom1	2,3 %	3,7%	0,0 %	3,9%	0.0 %	9,3%	0,0 %	4,4%
Bedroom2	10,7%	0,9%	2,5%	0,9%	4,7%	5,4%	2,3%	1,6%
Study room	9,7%	1,6%	3,5%	1,6%	5,4%	5,1%	3,4%	2,0%
Living room	10,7%	1,2%	2,9%	1,3%	5,0%	4,7%	2,9%	1,8%

Table 5: Relative Humidity discomfort percentages (R.H.>70%)

Room	Case 0	Case 1	Case 2	Case 3
Bedroom1	50,3 %	51,3%	23,3%	50,4%
Bedroom2	37,1%	38,6%	17,2%	37,9%
Study room	10,0%	11,7%	4,6%	10,7%
Living room	15,6	18,9%	3,8%	17,7%

Activation system controlled by humidity and temperatures sensors with logics above described (Case 3) have allowed significant overheating discomfort reductions as shown in following figures.

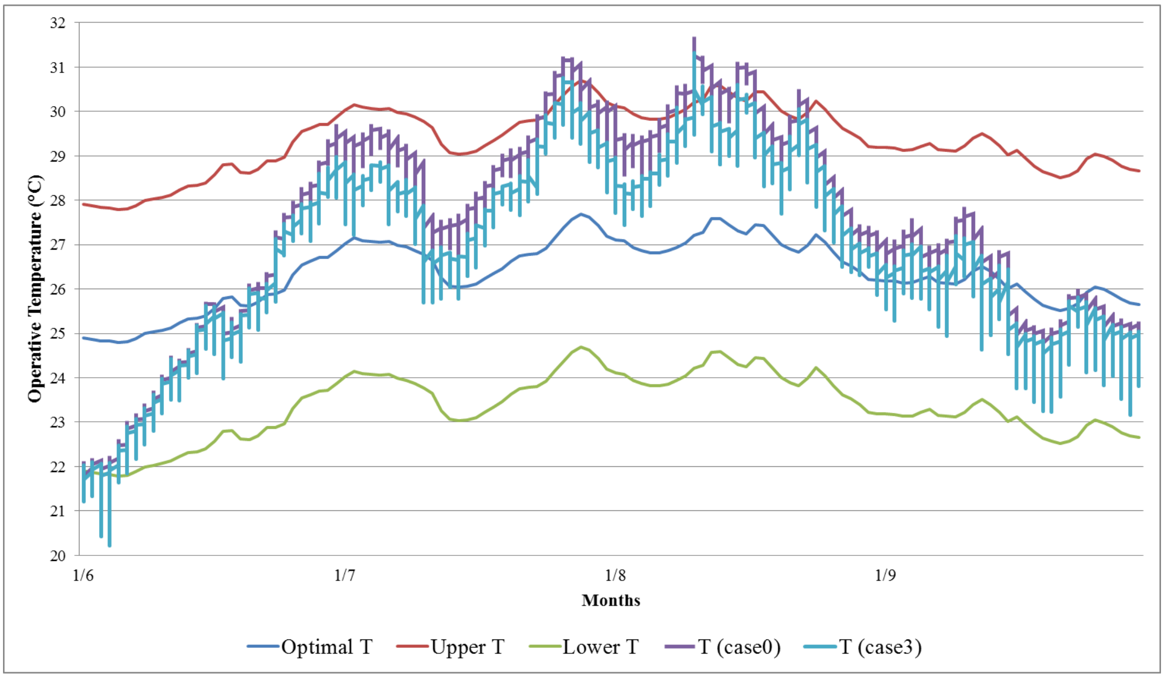

Figure 3: Thermal comfort simulation results – Bedroom2 (Case 0 – Case 3)

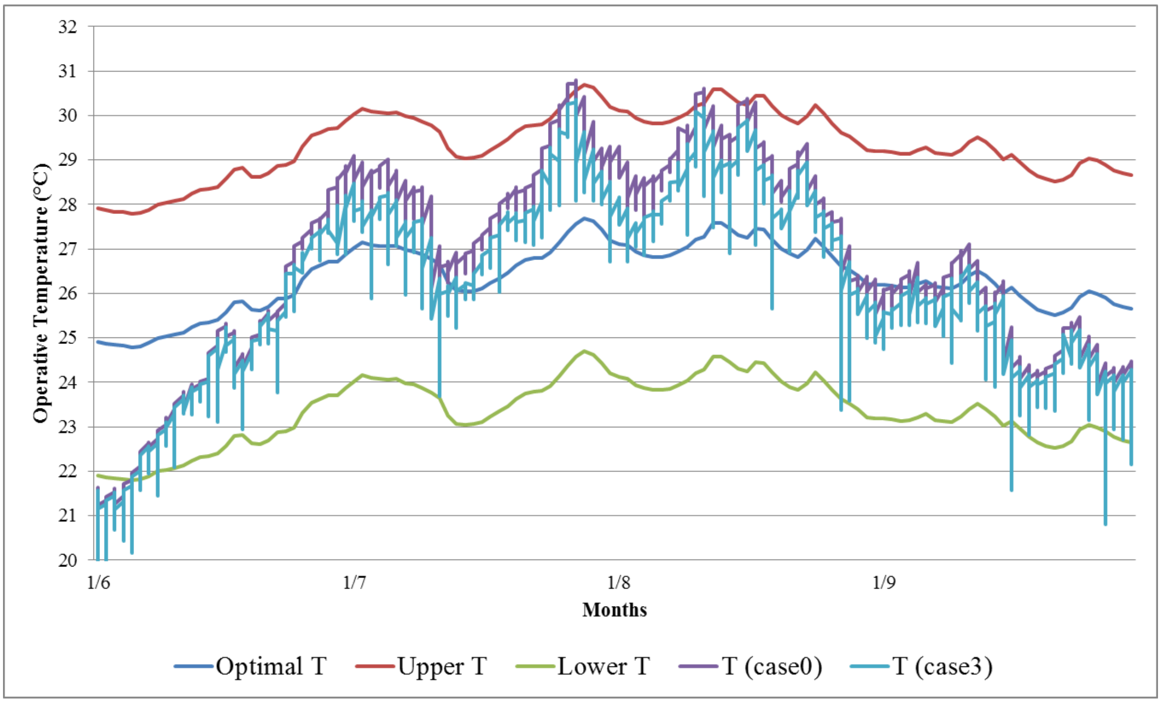

Figure 4: Thermal comfort simulation results – Bedroom1 (Case 0 – Case 3)

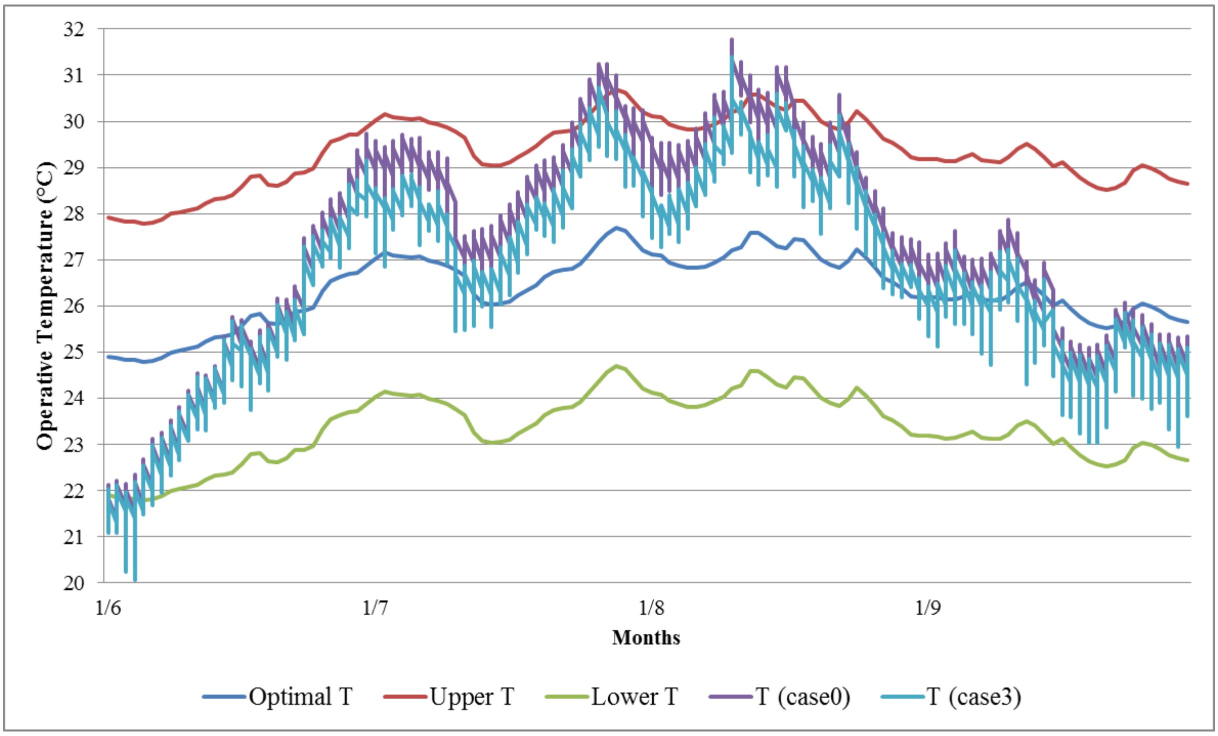

Figure 5: Thermal comfort simulation results – Living room (Case 0 – Case 3)

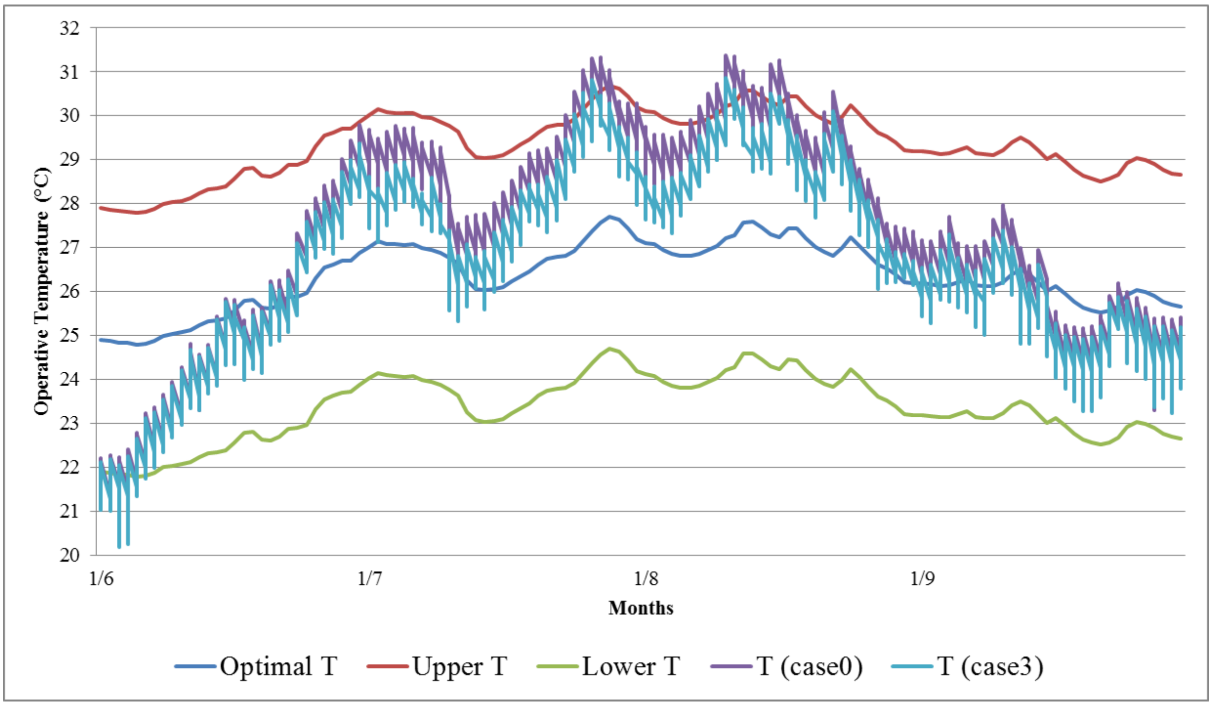

Figure 6: Thermal comfort simulation results – Study room (Case 0 – Case 3)

For the Case 4, where natural ventilation strategies are combined with air to air heat pump of cooling system, energy needs for cooling have been evaluated and compared with the Case 5. The simulation results have showed that the control strategies of ventilation for passive cooling enable a 50% reduction of energy consumption, from 905 kWh to 445 kWh, in similar comfort conditions.

3 CONCLUSIONS

In this paper the potential of natural ventilation in an existing residential building in Mediterranean climate has been studied.
With logics based on temperature and humidity, four strategies have been proposed to ensure adequate comfort conditions. Air flow dynamic simulation models have been created in order to choose the optimal control of ventilation. Assuming a likely occupation profile for the various rooms, adaptive thermal comfort analyses have been conducted according UNI EN15251.
The natural ventilation activation logics for passive cooling allow significant reductions in hours of discomfort due to overheating. To reduce the conditions of discomfort induced by high humidity levels, sensors for humidity control are necessary that activate the windows opening.
The study have underlined that ventilation strategies for passive cooling, can contribute even more effectively to the improvement of the behaviour of the building envelope, integrating or replacing the conventional efficiency strategies, if properly integrated with adequate control systems. With low investment costs the natural ventilation could reduce the high energy consumptions of cooling systems
Passive cooling through automatically controlled natural ventilation could allow the reduction of energy consumptions for cooling, reducing peak cooling power.
Future developments will concern the integration of control strategies with those relating to solar shielding systems.

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