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ENHANCING INDOOR COMFORT IN EXISTING APARTMENT BUILDINGS IN ATHENS USING NATURAL VENTILATION

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ABSTRACT

Computer simulation and field studies were conducted to investigate the implementation of natural cooling strategies in existing apartment buildings in Athens; the most typical urban domestic building type of Greece. Thermal performance analysis and airflow modelling in a specific apartment were conducted for the summer period using dynamic building energy simulation tools. The indoor thermal comfort was evaluated with reference to the adaptive thermal comfort theory. Changes to the fenestration and the utilisation of a light shaft, assist the natural cooling of the building and improve the previous single-sided ventilation strategy. Results indicate indoor air quality in the spaces being significantly enhanced, whilst the percentage comfort hours were increased, suggesting a significant reduction of the buildings' cooling demand.

INTRODUCTION

It is widely accepted that the high performance of mechanical cooling systems has led to a decline in passive strategies (Butera, 1994), although the increasing figure of energy consumption in buildings and the low indoor air quality (Theodoridou et al., 2012) indicate the importance of natural cooling techniques. Despite occupants' reliance on mechanical cooling, given the warm, dry climate of Greece (HNMS, n.d.) with the lowest levels of relative humidity and the highest wind speeds in the Mediterranean, occupants' thermal comfort expectations can be achieved by employing natural ventilation throughout the year (Santamouris and Asimakopoulos, 1996).

There has been a continuous increase of air-conditioning installations due to the growing internal heat gains (Butera, 1994), thermal comfort expectations, summer air temperatures, and poorly designed buildings. The city of Athens, is characterised by high summer air temperatures compared to the rural suburbs and an urban heat island (UHI) intensity of 10°C in the centre during daytime (Santamouris et al., 2001). It is worth noting that in cases where the UHI is up to 10°C the cooling load of the buildings can double and the peak electricity load triple (Kolokotroni et al., 2007). Likewise, the majority of the existing Greek building stock is considered highly energy consuming, constructed in the mid-20th century when no laws on energy conscious design (the 1st energy regulations was in 2010) and building insulation regulations (obligatory after 1979) (Theodoridou et al., 2011). The domestic sector makes up 79% of the existing building stock in Greece (Theodoridou et al., 2011), and accounts for the highest energy consumption in Europe (Asimakopoulos et al., 2012). It has been observed that, increasing fuel prices and inefficient thermal performance of multi-storey apartments are mostly effecting low income households leading more than 20% of Greek households into fuel poverty (Santamouris et al., 2007) and therefore the relative cost for comfort for lower income occupants in warm months is higher.

These findings suggest that improvements of the existing building stock and use of alternatives to conventional mechanical cooling systems, could improve the thermal comfort conditions and decrease the buildings' energy consumption. Building designers often turn to traditional architecture and design techniques for lessons on how to harness the climatic conditions to work to their advantage. Although there has been some research on the energy behaviour of Greek urban residencies and their possible renovation (Theodoridou et al., 2011; Papamanolis, 2006), little research has been carried out on the implementation of passive cooling solutions in existing apartment buildings and their potential performance (Santamouris et al., 2010; Yik and Lun, 2010).

This study proposes a low-energy cooling and ventilation strategy for existing multi-storey apartment buildings in hot climates. A case study in the city of Athens was selected for its typical Mediterranean climate of relatively warm, dry summers and mild, rainy winters (HNMS, n.d.; Santamouris and Asimakopoulos, 1996), a representative climate of the Greek region classified by Köppen Climate Classification System, as marine (C) and mainly Mediterranean climate types of Csa (56%), Cfa (13%) (Gialamas, 2011). The annual cycle is divided into two seasons; the cold and rainy and the warm and dry season (April until September) (HNMS, n.d.). In the warm season the maximum yearly temperature of Mediterranean ranges from 27°C to 34°C (Butera, 1994), and in Greece the highest temperature noted is 45°C during heat waves in mainland while the main relative humidity lied between 65% and 75%. (Papamanolis, 2005). The building studied, is a multi-storey apartment building, selected based on its design, year and type of construction, as a representative building of the vast majority of Greek urban dwellings (Papadopoulos et al., 2008).

The aim of this research work is to provide information on the explicit energy contribution of passive cooling techniques in apartment buildings in Athens and more specifically the modification required in the control patterns for the openings and the integration of an airshaft to the existing natural ventilation strategy. The ultimate aim of the research project is to define the role of different design parameters and develop a prototype for similar building designs in the same climatic context.

METHODS

In this work, natural ventilation strategies driven by wind and buoyancy forces are employed. The study was conducted in the form of a case-study analysis using dynamic thermal simulation (DTS) and network airflow methods. The resulting ventilation rate and indoor air temperatures are then used to evaluate the indoor thermal comfort with reference to the adaptive thermal comfort standard. Simulations were conducted using the IES software (IESVE, 2012). The aim was to enhance the ventilation rates and extend the percentage of time during warm months over which internal thermal conditions fall within the thermal comfort range. Therefore, changes in the fenestration operation were evaluated, along with the addition of new openings and the incorporation of airshafts.

Figure 1 Street view of the building (photograph by author, 2012)

It should be noted that, although the technique suggested is not an innovative method, dating back to the traditional wind catchers or malqafs (Fathy, 1986; Bahadori, 1985), it exploits the height of the multi storey buildings by using the light shafts, to enhance the previously single-sided ventilated spaces. It is also beyond the scope of this study to evaluate the buildings' envelope performance and the improvement of the building materials in order to comply with the current energy regulations of the country.

The adaptive theory was selected for the evaluation of the thermal simulation results as it is proven to be the most suitable theory for free running domestic buildings, having as its main principle that people respond to changes that cause discomfort in ways to restore comfort (Nicol and Humphreys, 2002). Comfort temperature is defined as the indoor operative temperature that most occupants would perceive as comfortable on the ASHRAE thermal sensation seven-point scale (McCartney and Nicol, 2002) and which can be related to the outdoor air temperature (Humphreys, 1978). The results of the simulations were plotted against the acceptable levels of the internal air temperatures for comfort, set by the Adaptive Control Algorithms (ACAs) in order to be assessed. Two ACAs were used to assess the performance of the system, one derived by the SCATs project[1] exclusively for Greece (McCartney and Nicol, 2002) expressed by the equation

$$T_c = 0.205T_{RM80} + 21.69 \qquad (1)$$

where T_c is the comfort temperature (^oC) and T_{RM80} the running mean outdoor temperature for index 0.80 (^oC). The second ACA was provided by EN15251 (BS EN15251 CEN, 2007) also derived by the SCATs measurements that is more applicable to Europe, and considered an improvement to the ASHRAE standard 55-2004 (Nicol and Humphreys, 2010) expressed as

$$T_c = 0.33T_{rm} + 18.8 \qquad (2)$$

where T_{rm} is the running mean outdoor temperature (^oC). The desired levels of internal temperatures according to national standards (Androutsopulos et al., 2012; BS EN15251 CEN, 2007) suggest internal air temperatures for dwellings of 26^{o}C during summer. Contrary to this, the results of the application of the ACAs (EQUATIONS 1 and 2), indicate that the occupants could feel comfortable at air temperatures higher to those suggested by the current Greek regulations (Figure 5).

DESCRIPTION OF THE BUILDING

An apartment building in the centre-North area of Athens, Galatsi, constructed in 1970 was selected for the purpose of this study (Figure 1). It is considered to be the most typical urban domestic building type of Greece. Thus, it was assumed to be a representative for this type of building, occupancy pattern described in detail in the next section. The building has 40 single bedroom residential units, comprises five main floors with the same layout (floor to ceiling height 2.80m), a single-apartment penthouse and one underground ancillary space. It is semidetached, adjacent to domestic buildings on both the north and south, and has its main entrance oriented on east (Figure 2).

[1] The EU Project Smart Controls and Thermal Comfort with measurements made in 26 European office buildings in different countries (Nicol and Humphreys, 2010)

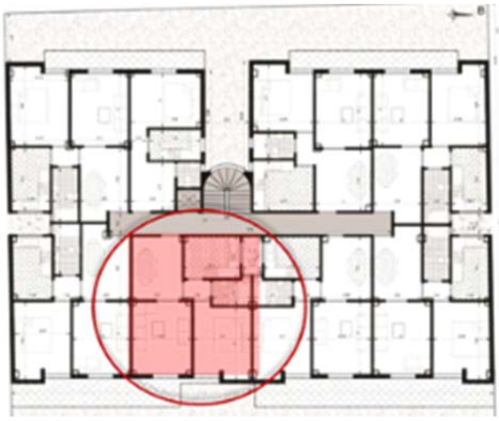

Figure 2 Foot print of case study building showing apartment studied (shaded)

Balconies in the form of projected overhangs cover the full length of both the north and south façades (max1.60m wide) with operable awnings of canvas blinds in metal frame for sun control. Three light/air shafts of about 2.5m assist the day lighting and extraction of stale air of the bathrooms and kitchens of the apartments. They are connected to each apartment by two windows (kitchen and bathroom), have a total height equal to the total height of the building and they are open on the top protected from the rain with a suspended roof at 1m height. The residential unit selected for this study is a centred first floor apartment ($53m^2$), oriented east, with the two bedrooms having one balcony door each on their east wall, the living room without access to light and the kitchen and bathroom with one window each on the light shaft walls (Figure 3).

The external vertical opaque elements of the building are of non-insulated double brick wall construction, whilst the internal partitions are single brick. The supporting structure, roof and floors are of reinforced concrete. All opening windows are single-glazed wooden framed with external shutters.

SIMULATION MODELS

Dynamic thermal simulation (DTS) software was employed (IESVE, 2012), to evaluate to what extent natural ventilation could be an effective passive cooling solution and to estimate the energy saving potential (Figure 4). The building has access to daylight and fresh air from east and west, and thus each room has only one opening on the external walls, thus resulting in single-sided ventilation. Windows and balcony doors act both as inlets and as outlets for the mainly buoyancy-driven airflow. Based on the performance analysis of the existing ventilation strategies, changes were made to the fenestration and the operation of the existing openings. New openings were added, in order to enhance the natural cooling of the building. In addition, a single light/air shaft connected to a number of rooms of the apartment was employed to improve the original single-sided ventilation strategy, to cross ventilation.

The weather files provided with the software were considered insufficiently accurate due to altitude differences with the site, as well as terrain variations (urban-rural sites) and thus wind speed differences. Comparison with the meteorological data collected at a local (private owned) weather station (Koukousianos, 2011) confirmed these inaccuracies. The weather file used in the DTS calculations was created for the specific site, and directly imported from meteonorm software (Meteonorm 7, 2012) after being validated using the weather data provided by the local station. The cooling season is defined as the period between the 15th of May and the 15th of September according to the national regulations (Androutsopulos et al., 2012).

Figure 3 Floor Plan of case study apartment

Internal gains and Occupancy patterns

In free running buildings, controls are consciously used by occupants in response to discomfort (Raja et al., 2001; Yun and Steemers, 2008; Zhang and Barrett, 2012) and therefore occupants' interaction with the building must be considered by designers (Andersen et al., 2009). Roetzel et al. (2010) concludes that energy performance modelling that neglects occupant behaviour may be a source of error, whilst the lack of guidelines or standards related to occupants' behaviours create a gap in knowledge in the world of building energy simulation (Andersen et al., 2009).

According to literature, there is a substantial correlation between occupants' interaction with windows and indoor temperature (Yun and Steemers, 2008), outdoor temperature (Andersen et al., 2009), and time of day, although the driving forces of occupants' interaction with the openings have not thus far been defined (Fabi et al., 2012). In dwellings the percentage of opening of the windows reaches a maximum during the morning and early afternoon (Fabi et al., 2012), but it is also dependant on the occupants simultaneous activities (Papakostas and Sotiropoulos, 1997). All these are important factors influencing the operation of the openings, the cooling strategy employed and define the occupants' perception of thermal comfort.

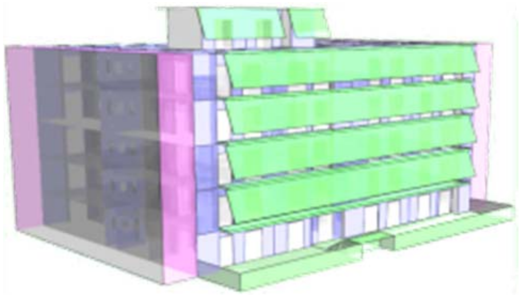

Figure 4 Computer model used for dynamic thermal simulation

An occupancy schedule was created based on the results of the field study research conducted by Papakostas and Sotiropoulos (1997) in 158 domestic buildings in Greece. Percentages of population characteristics were developed and related to the percentages of presence. The daily occupancy profile as well as the daily profile for heat gains from lights and equipment (created based on Papakostas and Sotiropoulos (1997) and Papadopoulos et al. (2008) work) are presented in Table 1.

Heat gains are estimated by Androutsopulos et al., (2012) to be 6.4W/m^2 for lighting (200lm/m^2 at a measuring level of 0.80m), 80W per occupant (4W/m^2 and average presence rate of 0.75) and 4W/m^2 for equipment. As the building was assumed to be in free-running mode, the thermal effects of heating and air conditioning were excluded in the simulations.

Simulation 1-Existing condition

A window opening profile was created based on previous studies of Drakou et al. (2011) and Papakostas and Sotiropoulos (1997). The windows remain closed during night-time and during the less occupied hours of the day (between 6.30am and 2pm). All other times the windows are opened according to occupants discomfort (i.e. when the internal temperature exceeds the external). It was assumed that the sliding shutters are controlled and remain open between the hours 6am to 9pm. The main door of the apartment was assumed to remain closed throughout the day, the internal flat doors remain open from 6am to 9pm, whilst the windows between the light shaft and the kitchen and bathroom walls are open 50% throughout the day.

Simulation 2-Proposed window opening profile

In this group of simulations, the external and the shaft windows were open throughout the day at all times when the internal temperature exceeded the external (for external temperatures less than 32^{o}C). It was intended that this would enhance the passive cooling strategy by using night ventilation. The operation of all other openings remained the same as simulation 1.

Simulation 3-Airshaft

In this simulation, the false ceiling of the bathroom, initially used as an ancillary space, was connected to the light shaft using an additional opening (free area 0.30m^2) to enable fresh air into and stale air out of the living spaces via the ancillary space above the bathroom. The ventilation air could flow in and out of the living spaces through the hallway and purpose-provided openings made above the party walls of the hallway. As the hallway would now be used as a distribution space, the cross ventilation of the spaces will now not be dependent on the openings of the bathroom and kitchen, ensuring privacy and provision of merely fresh air. Simulations were conducted with the external windows having the same operational profile as simulation 2. The kitchen and bathroom windows on the shaft now open for internal air temperatures higher than the simultaneous external temperatures and wind speeds higher than 5m/s. Additionally, the new openings on the hallway remain open throughout the day, while the internal doors are considered to remain open between noon and 6pm only.

DISCUSSION AND RESULT ANALYSIS

The results of the simulations were plotted against the acceptable levels of the internal air temperatures given by the adaptive theory models employed. Further, the mean monthly outside temperature and the two comfort temperatures (from the

Table 1
Occupants' daily percentage of presence profile, lighting and equipment operation profiles (data provided by Papakostas and Sotiropoulos (1997) and Papadopoulos et al. (2008))

Time	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00
Occupants Presence	99%					78%	39%	31%	28%			31%	43%	53%	74%	85%		88%		95%		98%			
Lighting	15%					39%		31%	28%			31%	43%	53%	74%	85%		88%		95%		98%		49%	
Equipment	11%							13%	22%	54%	56%	50%	20%	17%			23%	32%	37%	42%	32%	24%	15%	3%	

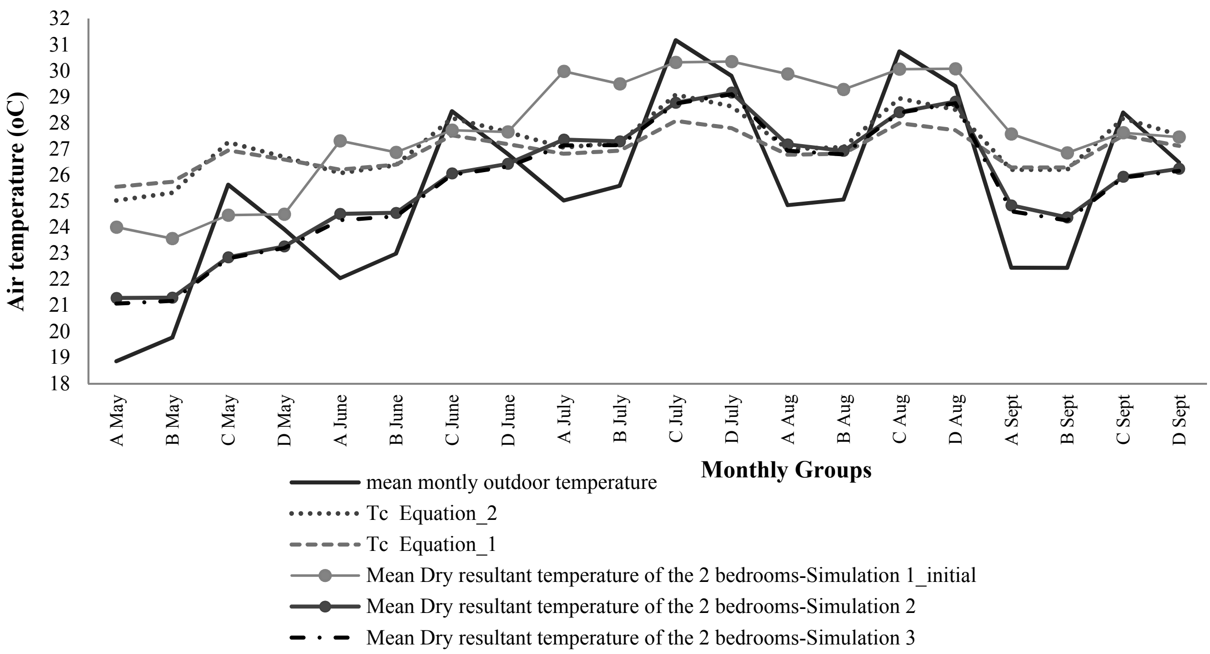

Figure 5 External air temperature, comfort temperatures and internal dry resultant temperatures before and after the changes in the cooling strategy.

EQUATIONS 1 and 2) were compared with the mean dry resultant temperatures of the living spaces from the three simulation results (Figure 5). The mean monthly values for dry resultant temperature, CO_2 concentration and ventilation rates were calculated for 4 different groups of the day every six hours (A, B, C and D). These groups divide the day in 4 sessions of similar occupancy patterns as well as climatic conditions and they were created based on previous research conducted by Prajongsan and Sharples (2012).

The thermal simulation results of the initial condition of the spaces (simulation 1) predicted internal temperatures above the comfort temperature values (Figure 5). Specifically, the mean monthly dry resultant temperature of the two bedrooms for each group of the day was up to 2.5^{o}C higher than the *Tc*. During the warmest months (June, July, August) the air temperature in the living spaces was at its lowest levels during the early hours of the morning and then steadily increases during the day, until it reaches its maximum levels at night due to high internal gains and heat radiation from the thermal mass. During the sleeping period, the internal air quality (IAQ) of the spaces was predicted to be very low with temperatures reaching the 30^{o}C and increased CO_2 levels up to 1150ppm (Figure 7). As this is also the point in time with the highest levels of occupancy, night ventilation seems to be the only way to ensure thermal comfort.

In contrast, simulations 2 and 3 show a reduction in dry resultant temperature in the occupied spaces of 1 to 2^{o}C which closely follows the comfort temperatures as shown in Figure 5. In addition, as the external windows remain open during the night, the ventilation rates increased by up to 200l/s, which reduces the CO_2 concentration to ambient levels (Figure 7) during sleeping hours (1150ppm to 400ppm).

Although the implementation of the airshaft has slightly improved the internal air temperatures, it has a larger effect on IAQ. Further, the ventilation strategy used in simulation 3 shows that, early in the morning and until noon the airflow through the external openings is higher than the airflow of the initial strategy used in simulation 1 (Figure 6). However, night ventilation is continued until noon or until the internal air temperature exceeds the external. Moreover, this strategy is attained by external air flowing through the external openings of the bedrooms (there is flow both in and out through these openings), passing through the open hallway windows to the hallway and then through the suspended ceiling of the bathroom to the airshaft, and finally escaping from the top of the shaft. As the internal air temperature slowly rises above the external (group C) the flow in the airshaft reverses from upwards to downdraught, with fresh air entering (due to higher wind speeds) from the opening at the top of the shaft opening to the hallway, and then distributed to the spaces. The external wall openings of the bedrooms remained closed, creating therefore an internal airflow until they open again, creating a reverse airflow pattern. It was noted that during the day the CO_2 levels increased, but always remained lower than 750ppm, decreasing again when the windows opened at night. In general, groups C and D

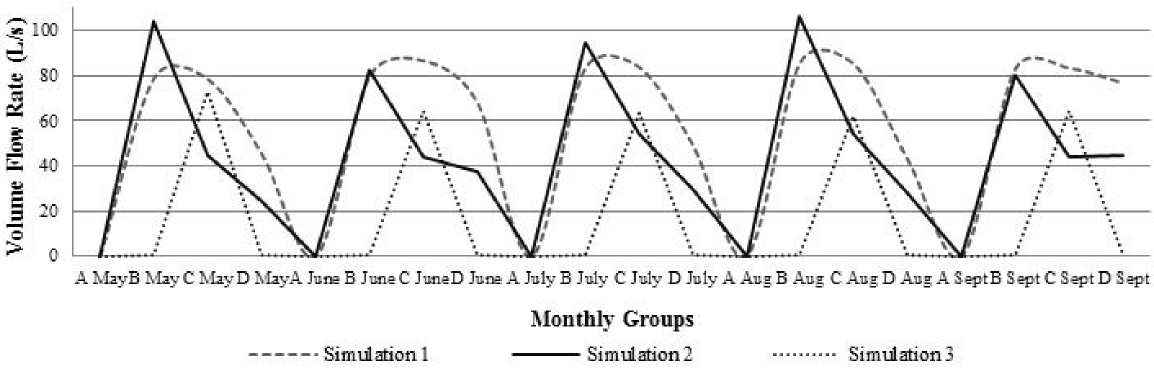

Figure 6 Mean volume flow rate through the openings on the external wall subdivided by group of time for the different simulations results

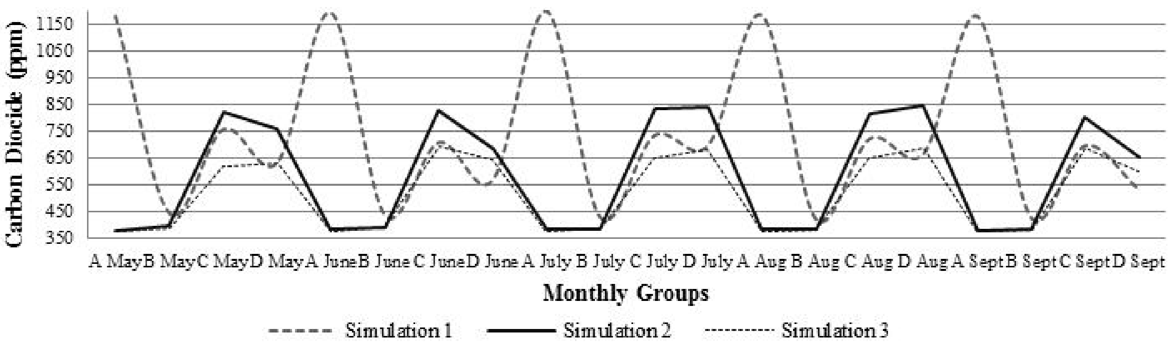

Figure 7 Mean value of the carbon dioxide concentration in ppm of the 2 bedrooms for the examined period, subdivided by group of time for the different simulations results

are periods of the day with the highest temperatures and CO_2 levels due to high internal heat gains and the fact that the main windows remain closed due to the high external air temperatures.

It was anticipated that the cooling strategy in simulation 3 would be more efficient, but possibly due to the shafts' inefficient design (the shafts' top outlet is an opening in the horizontal plane of the flat roof surrounded by two sides from the penthouse walls), it had only a small contribution. It was therefore thought that the design could be improved by replacing the top outlet of the shaft with a wind catcher at a height above the penthouse roof in order to capture the wind from both north and northeast. Simulations of this configuration did not give the expected increase of the ventilation rates in the airshaft and the spaces. Future work will use computational fluid dynamics (CFD) to investigate the optimal design of both the wind catcher and the airshaft.

CONCLUSIONS

In this paper, the application and performance of natural cooling strategies in the living spaces of an apartment building in the typical Mediterranean climate of Greece (based on the Köppen Climate Classification System (Gialamas, 2011)) were explored. The influence on the thermal comfort levels by utilising passive techniques was calculated using dynamic thermal simulation. Simulation results demonstrate that passive ventilation through the re-arrangement of the opening profile of the windows (windows were open throughout the day at all times when the internal temperature exceeded the external) as well as the implementation of an airshaft, is able to improve the IAQ levels and is feasible in existing multi-storey apartment buildings. A significant reduction of about 2°C in the internal air temperature and of up to the 66% of the initial CO_2 levels was observed. It is furthermore anticipated that the passive techniques employed in this study could be efficiently implemented in similar cases of building in Mediterranean climates.

Thermal responses in real-world projects are linked to the climate and to the way in which the internal spaces are experienced and controlled by the occupants. This work has shown that passive cooling systems can effectively reduce reliance on mechanical systems whilst ensuring thermal comfort for occupants. The findings of this work demonstrate that, during the warm season, the proposed passive ventilation strategy of the residential unit studied, can successfully increase ventilation rates, extend occupants' thermal comfort period and successfully enhance the previously single-sided ventilation strategy.

Future work will investigate the performance of a single shaft assisting the passive cooling process of a number of apartments and spaces over different floors of the building and evaluate airflow movement using CFD simulations in order to define the optimal design.

NOMENCLATURE

Tc = comfort temperature (^{o}C)

T_{rm} = running mean outdoor temperature (^{o}C)

T_{RM80} = T_{rm} for index 0.80 (^{o}C)

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