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Natural Cross Ventilation for Refrigerative Cooling Reduction in a Well Insulated Apartment

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SYNOPSIS

In this paper the energy impact of natural cross ventilation is examined conducting a set of cross ventilation experiments in a well insulated apartment of a 5-storey building. The experimental results compared with simulation results derived from the combined use of the multizone air flow model COMIS and the thermal model Suncode.
A 24-hour lasting natural cross ventilation experiment was conducted, to monitor thermal comfort ventilation mainly during the day and night time cooling ventilation. A short lasting cross ventilation experiment was also conducted to monitor the impact of ventilation in midday hours. Both experiments compared with a 24-hour lasting single-sided ventilation experiment. Surface and air temperature, heat flux in building elements, ambient wind and solar conditions were monitored.
The ventilation and infiltration phenomena in the above experiments were modelled in detail using 30min / 1h time-step, taking into account landscape, wind environment, the building's shape as well as the leakage characteristics of the building's envelope.

1 INTRODUCTION

The knowledge of ventilation flow rates for all the ventilation phenomena in a building is necessary to estimate space heating and cooling loads, to determine IAQ and to make sizing calculations of air conditioning equipment (Liddament 1996). The study of cross ventilation and single-sided ventilation cooling potentials is aiming at the parallel use these techniques within the frames of ventilation strategies in order to reduce refrigerative cooling loads, and to simulate the energy impact of the user's behaviour. The ventilation phenomena and the thermal phenomena are very close related and strongly interacting and it is therefore essential to combine ventilation and thermal modelling to achieve adequate simulation of building energy performance.

The main scope of these experiments is to monitor and analyse natural cross ventilation potentials for refrigerative cooling reduction of common building types, which found to be a matter of great importance especially in the Mediterranean climates. The use of air conditioning in Greece has dramatically increased during the last decade.

2 EXPERIMENTS

2.1 Description

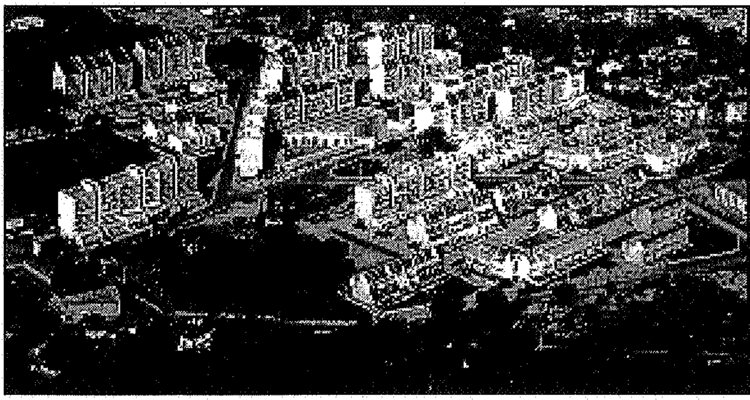
The natural cross ventilation experiments presented in this paper are:

- a 24-hour lasting, in order to combine the two aspects of passive cooling ventilation: thermal comfort ventilation mainly during the day and night time cooling ventilation.
- a short (4-hour lasting) in order to monitor the impact of midday hours ventilation on building' s thermal charge, in other words a «bad» example of summer ventilation.

A 24 hour lasting single sided ventilation experiment was also conducted to be compared with the above mentioned experiments and to examine the potentials of these two passive cooling methods for refrigerative cooling reduction.

All the experiments are focusing on the same room (bedroom) of a 60 m^2 well insulated apartment, although all the apartment rooms as well the adjacent apartments and the staircase were closely monitored.

The apartment where the experiments conducted is a reference one (not a passive solar one) and is located at the 4^{th} (top) floor of a residential building of the Solar Village, a housing project of Greek Workers' Housing Organisation completed in the early 90's in Pefki-Attica, consisting of 435 apartments distributed in 30 buildings, an energy center, a solar information center and a commercial and community center, (figures 1, 2).



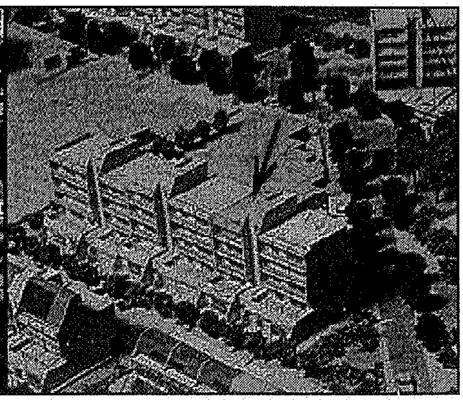
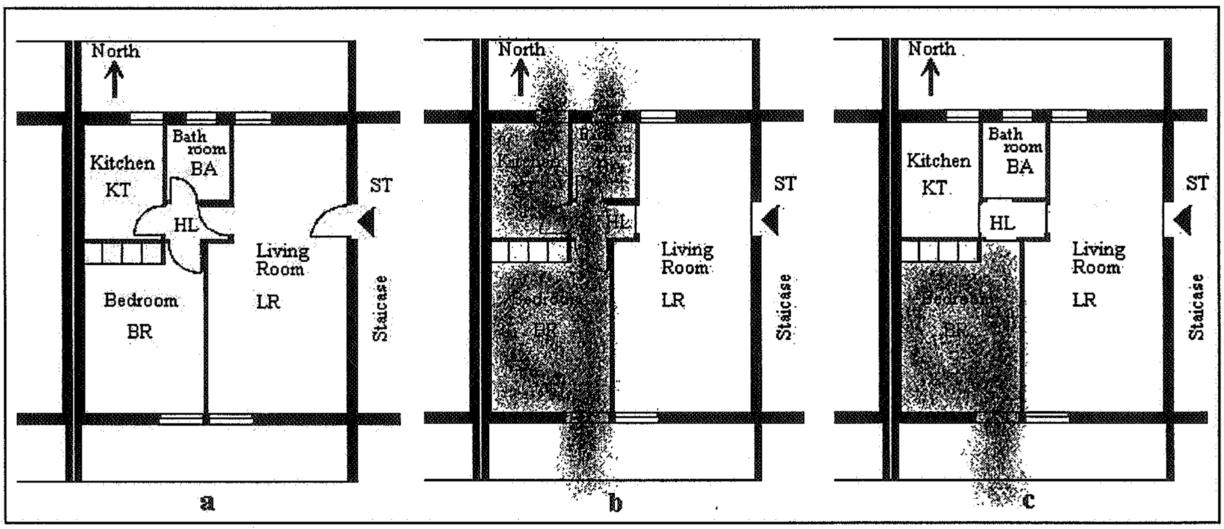


Figure 1: Aerial view of Solar Village

Figure 2: View of the building were the apartment is located

The measurements were performed implementing a the data-logger system that monitors the apartment. The sensors of the system monitored the indoor air temperature, the surface temperature of building elements (walls and roof) and the heat flux through the ceiling and the south walls (Interatom 1990, Koinakis 1992). Ambient conditions were monitored using wind velocity and wind direction sensors, temperature and related humidity sensors and a pressure sensor. Solar radiation (total horizontal and direct normal) was also monitored in order to provide the essential inputs for the thermal simulation. The ambient conditions as well the conditions inside the apartment were monitored every minute and half hour averages were produced, suitable for ventilation simulations. All the values were transformed to 1-hour averages for the simulation with the thermal model. This not very common technique was implemented to monitor closer the great variation of wind speed and direction and to validate ventilation simulation results with experimental data in a closer way.



Figures 3 a., b, c:

a. plan view of the apartment - zone names and symbols
b. configuration of the cross ventilation experiments and simulations (24h and 3h periods)
c. configuration of the single-sided ventilation experiments and simulations

The apartment where measurements took place could be considered as a typical modern apartment, been slightly more insulated than the rest modern apartments in Greece. The inner walls are of 10 cm thick brick covered with 2 cm plaster on each side and the outer envelope consists of 20 cm thick brick walls and 20 cm thick concrete frame and 15 cm thick slabs. It is heavily insulated with 10 cm of mineral wool in its external walls and with 10 cm polystyrene boards, on the roof. There is also 2 cm thick mineral wool insulation between the apartment and the adjacent spaces (the apartments at the same and the lower storey and the staircase). The apartment was uninhabited during the measurements and empty of furniture. The area of the room (bedroom) examined is 12.50 m^2 and its net volume approximately 31.88 m^3 .The balcony door on the south facade was a double glazed aluminium sliding door with a total area of 2.83 m^2 (WxH = 1.35x2.10 m) and a net opening area of 2.5 m^2. The inner doors were common not weather-stripped 0.85x2.10 m timber doors.

2.2 24-hour lasting cross ventilation

The apartment was kept closed the last four days before the experiment, with short intervals of window and door opening in order to configure and test the data-lodging system. This was intended in order to increase the thermal charge of the building elements, to intensify the thermal transfer phenomena that occurred just after the beginning of cross ventilation and to monitor the heat rejection of the building elements of the room. to monitor .

The experiment started at 09:00 of Aug 25th and completed in the same time the next day. At the beginning air temperature in to the room was 26.7 ^{0}C while outdoor temperature was significantly lower not exceeding 22.1 ^{0}C . At the same time heat flux at BR south wall was lower than 0.5 W/m^2 indicating that thermal charge has been completed during the last days (figures 4, 5). Just after the formation of the cross ventilation flow due to the strong S-SW wind (first half hour average: 227 degrees, 10.44 m/s), a rapid decrease of air temperature started for the next $1^{1/2}$ hours at a mean rate of 1.5 ^{0}C/h. Air temperatures at the two other rooms (KT & BA) were cross ventilation was formatted followed at a same time with zero time lag keeping almost steady temperature differences between them and BR: Ät$_{BR}$ -Ät$_{KT}$ ~ 2^{0}C and Ät$_{BR}$ -Ät$_{BA}$ ~ 1^{0}C. This is a result of orientation characteristics of the rooms. Heat flux at BR south wall followed immediately reaching 5.7 W/m^2 (thermal discharge) at 10:30. From that moment zone air temperatures started to increase following the ambient air temperature variations. Heat flux responded immediately to these variations forming maximums and minimums at the corresponding points.

The thermal charge/discharge was calculated based on experimental data, assuming uniform formation of thermal phenomena, implementing the equation:

$$Q_i = \int_{t}^{t+\Delta t} q_i dt$$

for 30 min time step. The results are presented in figure 5. From this analysis could be concluded that 24h excessive cross ventilation of the thermally charged room under the specific conditions lead to total thermal discharge equals to 2.08 KWh.

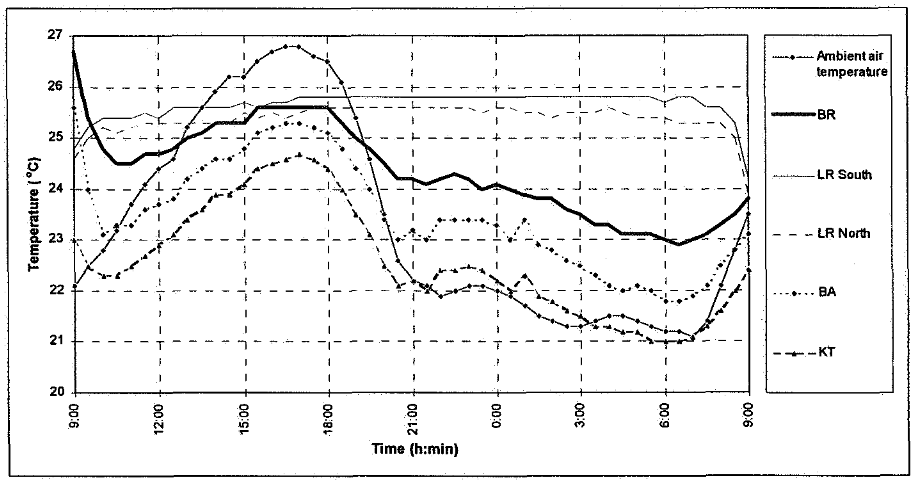


Figure 4: Air temperature variation during the 24h cross ventilation experiment

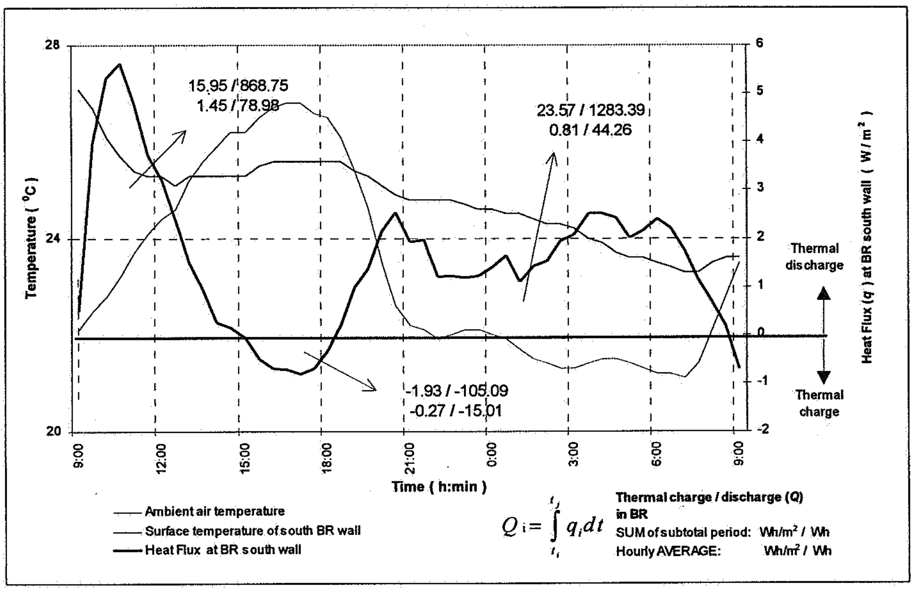


Figure 5: Heat flux and surface temperature variations during the 24h cross ventilation experiment

2.3 Short lasting cross ventilation

This 4-hour midday cross ventilation experiment was conducted between 10:00 and 14:00 in a hot summer day (July 31th). It is a «bad» example of ventilation not rare in Mediterranean climates, where airing could cause undesirable thermal charge. The aim of this experiment is to monitor the effect on inner temperatures and the role of thermal mass to prevent from excessive temperature variations.
As it is derived from figures 6 and 7, this 4-hout lasting noon ventilation leads to 0.5 ^{0}C temperature increase and to 214 Wh thermal charge. It should be mentioned that thermal charge was not too significant because of the heat capacity of the building elements as well as of the increased thermal charge of the room which remained closed the day before.

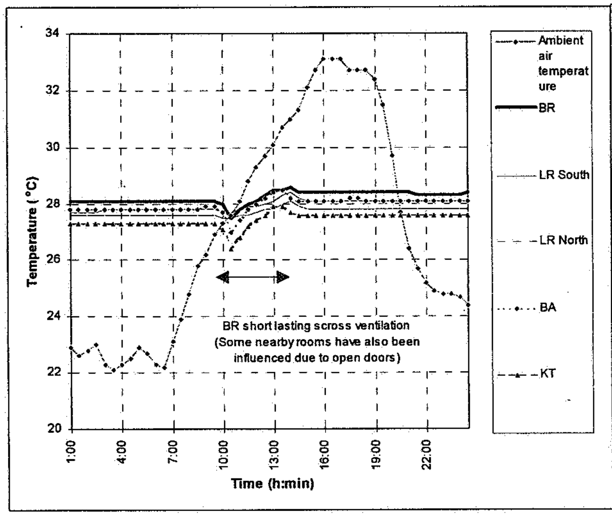


Figure 6: Air temperature variations during the 4h cross ventilation experiment

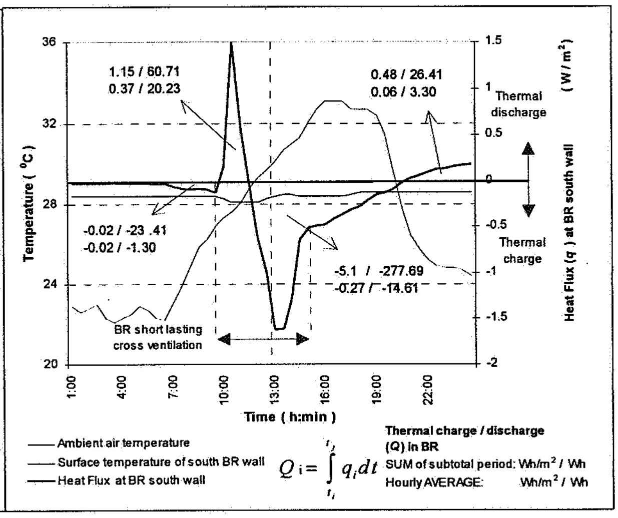


Figure 7: Heat flux and surface temperature variations during the 4h cross ventilation experiment

2.4 24-hour lasting single sided ventilation

The 24 hour lasting single sided ventilation experiment was conducted to be compared with the above mentioned experiments and to examine the potentials of these two passive cooling methods for refrigerative cooling reduction. An extra reason is to evaluate the single-sided ventilation modelling (presented in paragraph 3), as the other two ventilation experiments.

In figures 8 and 9 the variations of air and surface temperatures and the heat flux at BR south wall are presented for a 3 days period, including the preceding day and the next day of the 24-hour single-sided ventilation, in order to monitor the disturbance caused to the thermal figures of the room. It can be seen that heat flux is significantly lower than cross ventilation heat flux, having maximum value 2 times smaller than the corresponding cross ventilation value. As a result room air temperature decreased about 1 ^{0}C after being almost steady for more than a day.

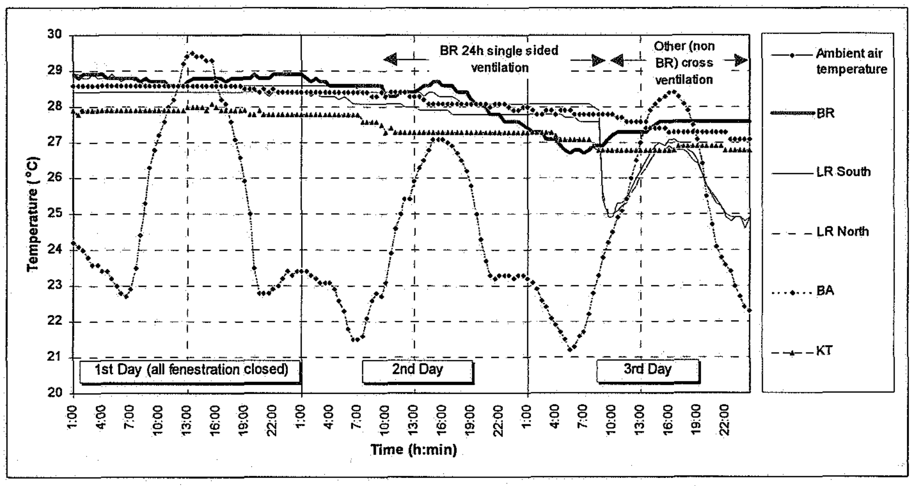


Figure 8: Air temperature variation during the 24h single-sided ventilation experiment

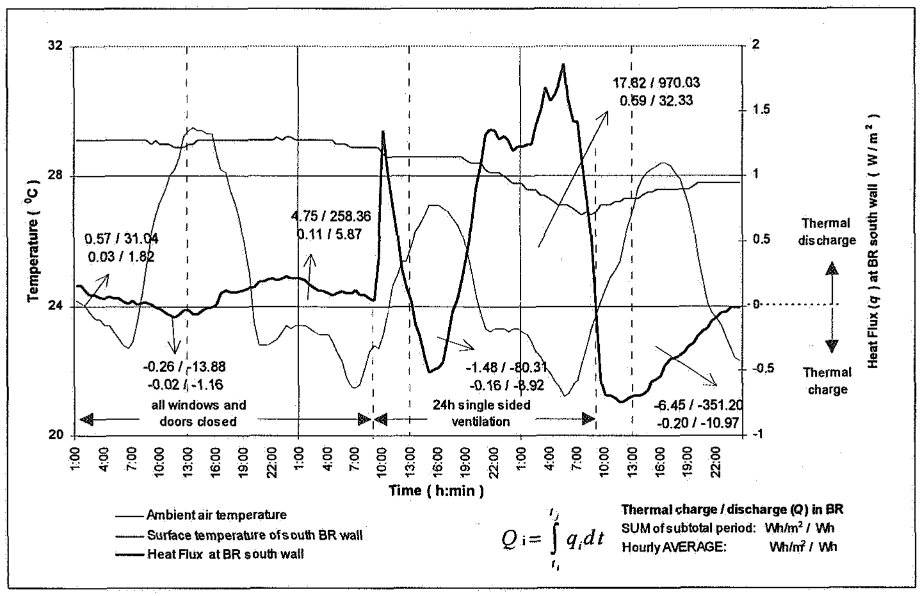


Figure 9: Heat flux and surface temperature variations during the 24-hour single-sided ventilation. experiment

3 SIMULATIONS

3.1 Integration of ventilation and thermal simulations

Energy flow due to infiltration and natural (cross and single-sided) ventilation is calculated separately for each zone of the apartment following the configuration of the experiments mentioned in paragraph 2 and only the values for the room tested above are presented. Energy flow is calculated in two ways:

- for incoming air flow from the ambient, due to infiltration and cross and single-sided ventilation
- for total incoming air flow (ambient and interzonal), due to infiltration and ventilation

Both air flows resulted from simulations implementing the air flow nodal model COMIS and the thermal nodal model Suncode (Feustel 1990 & 1995, Grosso 1992 and Weeling 1985).

The variation of meteorological parameters, especially wind speed and direction and ambient temperature cause systematic variation in infiltration and ventilation rates in building (ASHRAE 1985 & 1993, Blomsterberg 1990, Grosso 1992, Roulet 1991). Moreover the interaction of these parameters with user's behaviour expressed as the opening and closing of windows and doors using any possible combination, adds considerably on the complexity of the phenomena. From the one moment to the other completely different phenomena could take place in a common room starting for example with infiltration in a room closed for hours or days and overheated -as the one at the experiments- and then suddenly experiences massive air flow due to cross ventilation under strong 8-12 m/s wind. Soon after this would be followed by lower ventilation rates as a result of single-sided ventilation, possibly as a result of user's need for privacy or rest. It is therefore essential to examine in situ the ventilation phenomena and conditions in order to monitor every day's complexity and validate the capabilities of ventilation and thermal modelling.

For the purpose of ventilation and thermal simulations the apartment has been divided in five zones as presented in figure 3. An extra zone has been used for the staircase because it has found that significant interzonal air flow could occur between the living room (LR-zone) of the apartment and the staircase (Koinakis 1992). Although only the bedroom is examined in detail in this paper, it is preferable to produce a detailed ventilation model because the combination of the closed and opened doors and windows, could lead to various kinds of interzonal flows. On the contrary thermal modelling is a matter of less importance in this case study, because of the prevailing importance of the thermal phenomena. Air change rates in cross ventilation under strong wind often found to reach or exceed 100 ach and air flow velocity in selected points inside the apartment reached 1.8-2m/s making papers to blow. Although this seems excessive at first sight , it is a very common phenomenon in mild summer Mediterranean climate, where people find excessive air flow desirable and refreshing even at hot noon hours.
The adjacent spaces (the two adjacent apartment on the same and the lower storey were modelled as an extra zone using the temperature data of the data logger system. The building is assumed to be non conditioned and uninhabited as it was at the time of the measurements.

Assuming specific values for zone air temperature, the air change rate is calculated for each zone for the specific door and window configuration. This is used as an input for thermal simulation where new zone air temperature values are calculated. The air change rate is then recalculated using these new temperatures. This iterative procedure is repeated till convergence is less than the desired threshold (preferably from 0.01 to 0.05 ^{0}C).
The results derived from simulations were detailed including complete interzonal air flows, but only the results related to the examined room (bedroom) are presented in this paper.
The contribution of a special ventilation model as the COMIS model proved to be essential in modelling summer conditions where excessive ventilation is the main cause of heat transfer phenomena and adds considerably on the dynamic character of the phenomena. Therefore it is strongly recommended to implement an integrated calculation method for thermal simulation incorporated the estimation of ventilation and infiltration providing the essential wind and leakage data.

3.2 Simulation results compared with experimental data

The simulation results (figures 10, 11 and 12) were modified in order to show the energy flow per m^2 inner BR surface, following the guidelines mentioned in the previous paragraph. It derives that energy flow due to ventilation follows almost exactly the heat flux variation, proving that ventilation is by far the main cause of heat transfer phenomena.

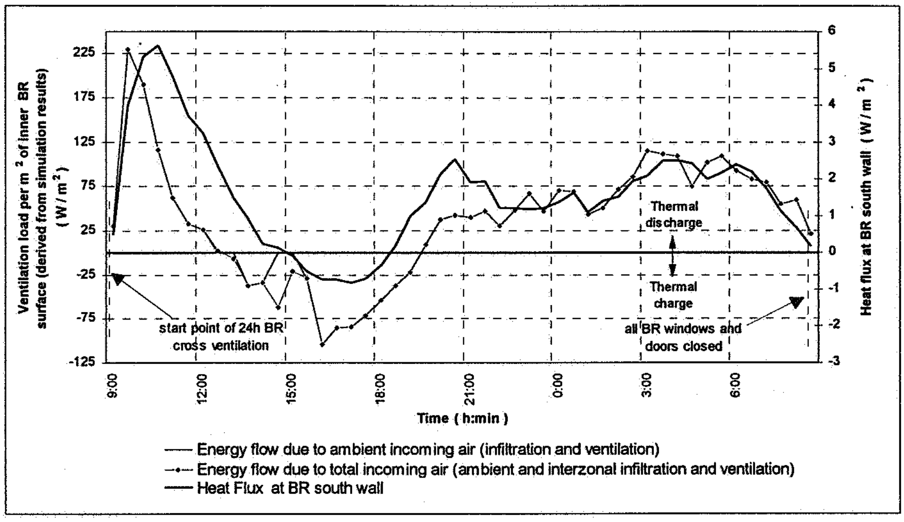


Figure 10: 24-hour lasting cross ventilation experiment: energy flow due to ambient air and total incoming air derived from simulation, versus heat flux experimental data in south BR wall.

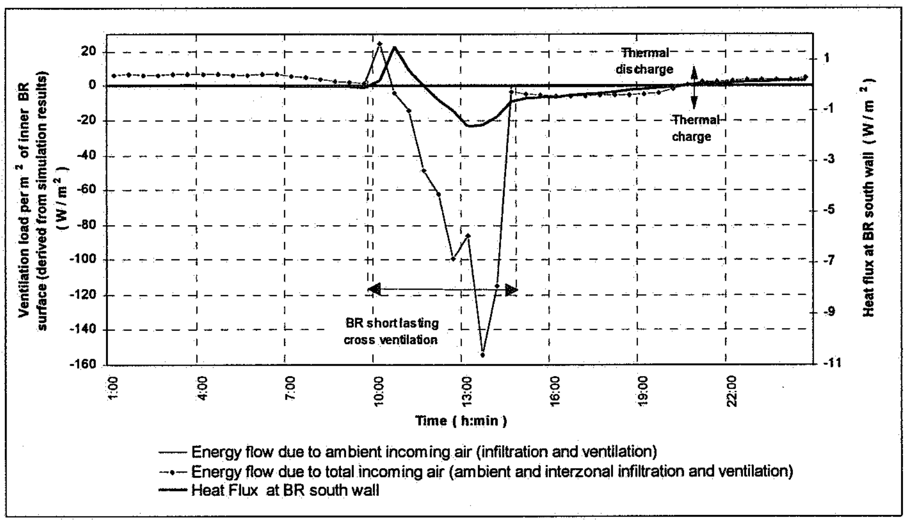


Figure 11: Short lasting cross ventilation: energy flow due to ambient air and total incoming air derived from simulation, versus heat flux experimental data in south BR wall.

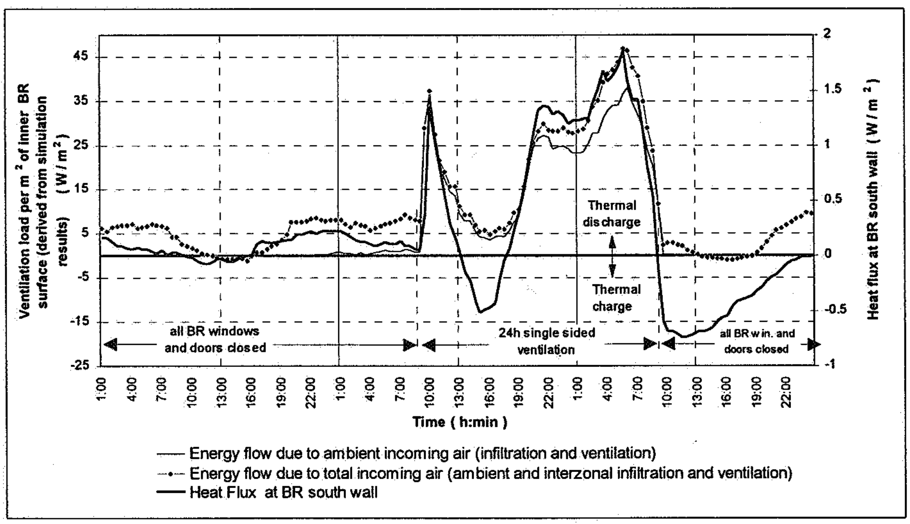


Figure 12: 24-hour lasting single-sided ventilation: energy flow due to ambient air and total incoming air derived from simulation, versus heat flux experimental data in south BR wall.

4 CONCLUSIONS

As it derived from the three experiments and the corresponding simulations, air flow inside buildings is strongly influenced by (in order of importance):

- the configuration and the combination of opened and closed external and internal windows and doors and the time of the day they occurred,
- the outdoor wind conditions, mainly wind speed and direction,
- the thermal charge of the building elements and the ventilation period.

Air infiltration and leakage of the building's envelope tend to be negligible for buildings like the one examined in this paper in cases of summertime ventilation, because:

- increased ventilation combined with increased thermal mass placed in the inner building's surfaces proved to keep almost steady surface temperatures and heat flux. Only excessive air flow for more than a 4-hour period results significant temperature and heat flux change.
- the way that common Mediterranean buildings where built restricts infiltration flow paths only through the cracks of the external windows. The rest of the external building envelope is rather solid and airtight (Papamanolis 1996).

Heat flux in external building elements appear to form a sinus-like curve which was kept almost undisturbed by infiltration flow rates regardless the wind magnitude. As soon as ventilation begins, heat flux follows step by step and in zero time lag the ventilation heat flow which resulted from the simulations.

Taking into consideration the total incoming flows (ambient and interzonal) proved to be quite important in cases of excessive ventilation rates . Ventilation heat flow due to total incoming air (ambient and interzonal) follows heat flux in building's envelope more accurate than ventilation heat flow due to ambient incoming flow only.

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