NIGHT VENTILATION EFFECTIVENESS IN VARIOUS TYPES OF OFFICE BUILDINGS

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ABSTRACT
The present paper investigates the potential of night ventilation techniques when applied to full scale office buildings, under different structure, design, ventilation, and climatic characteristics. The approach of this study includes the use of both experimental data and theoretical tools in order to determine the impact and the limitations of night ventilation regarding the thermal behavior of various types of office buildings. Real scale measurements in three buildings under free floating and air conditioning operation have been performed. The cooling potential of night ventilation techniques when applied to buildings, has been experimentally and theoretically studied.

KEYWORDS
night ventilation, passive cooling, air conditioning, free floating, natural ventilation, cooling load, overheating hours, energy conservation, thermal mass, simulation.

INTRODUCTION
Passive cooling techniques present a very important alternative to conventional air conditioning of buildings. Night ventilation techniques, when applied to massive buildings, can significantly reduce the cooling load of air conditioning buildings and increase the thermal comfort levels of non air conditioning buildings.
Night ventilation techniques are based on the use of the cool ambient air as a heat sink, to decrease the indoor air temperature as well as the temperature of the building's structure. The cooling efficiency of these techniques is mainly based on the air flow rate as well as on the thermal capacity of the building and the efficient coupling of air flow and thermal mass.

EXPERIMENTAL PROCEDURE
In order to investigate the cooling potential of night ventilation techniques, extended measurements have been carried out, during the summer of 1995 and 1996, in three real scale buildings, presenting different characteristics. In particular, the following buildings have been monitored :

- A multizone air conditioned office building located in the suburban area of Athens, named Meletitiki hereafter. Measurements have been performed during the summers of 1995 and 1996. The building is mainly composed by seven zones (Figure 1). It has a heavy structure and it is ventilated during the night period by mechanical and natural means by using two exhaust fans and opening windows. The capacity of each fan is close to 25000 m^3/hour.
- An air conditioned office building located in the central area of Athens, named University hereafter. Measurements were performed during the summer of 1996. The experiments have been performed in a zone (Figure 1), located on the third floor of a six storey building. The building has a light structure while the internal gains of the specified zone are very high. During the experiments night ventilation was achieved by natural means (single sided ventilation).
- A free floating office building, located in a low density built area in central Athens, named "National Observatory of Athens" or NOA hereafter. Experiments have been carried out during the summer of 1996. The experiments have been performed in a zone which occupies the half of this single storey building. The building has a very heavy structure and medium internal gains. During the experiments night ventilation was achieved by natural means by opening the windows of the zone (cross ventilation).

In all buildings, continuous measurements of the indoor temperature distribution as well as of the air flow rates, when night ventilation is applied, have been performed. Constant injection tracer gas techniques have been used. In both air conditioned buildings, free floating and air conditioning operational schedules have been studied.

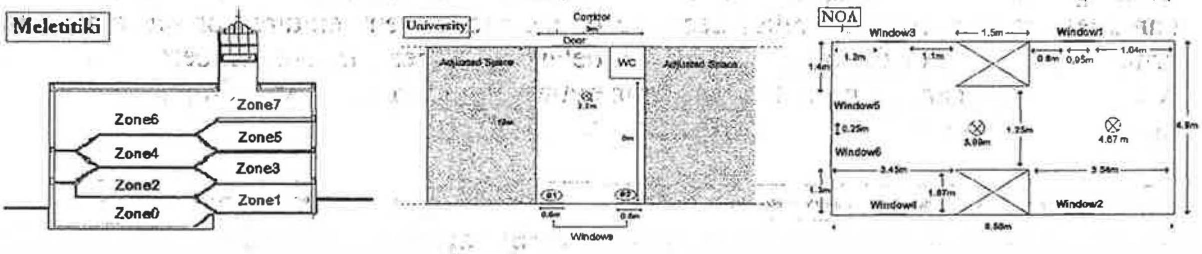

Figure 1: The three buildings where the experiments have been performed (Meletitiki, University, NOA).

In the Meletitiki building and during the 1995 summer experimental period, measurements have been carried out between July 26th to August 11th, when the building was empty from the occupants, while during the summer of 1996 experiments have been performed between May 24th to July 8th, during the normal operation of he building. Night ventilation has been applied between 10 pm to 6am.

In the University building, experiments have been performed between July 9th to July 23rd. The achieved air flow rate has measured by using constant injection tracer gas (Figure 2).

Experiments in the NOA building have been carried out between September 7th to September 18th. Figure 2 gives the measured air flow rate during the experiment.

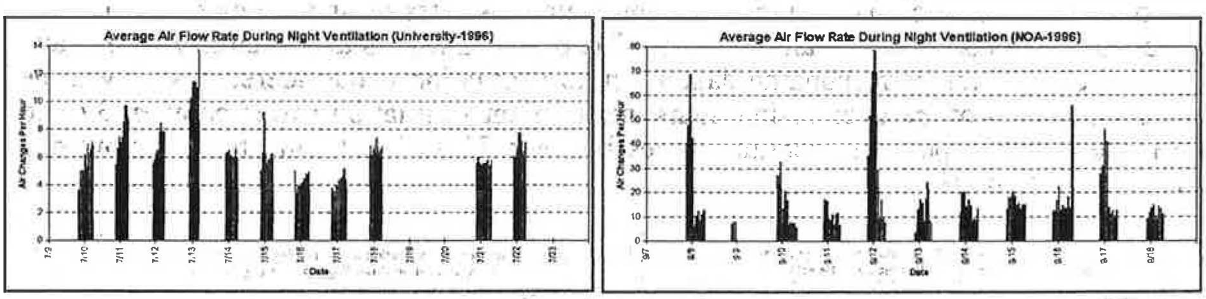

Figure 2: The measured air flow rates during the experiments in University and NOA.

THERMAL PERFORMANCE OF NIGHT VENTILATION TECHNIQUES IN THE "MELETITIKI" BUILDING

In order to study the performance of night ventilation techniques when applied to the Meletitiki building and analyze in detail the obtained experimental data, a series of simulations have been performed using the TRNSYS (Solar Energy Laboratory, 1996) simulation tool. To simulate the specific air flow processes when night ventilation is applied, an additional air flow model based on the network approach has been coupled to TRNSYS. The basics and the validation of the model are described by Bruant and al (1996) and by Dascalaki and M. Santamouris (1998).

During the first stage of the analysis the developed model has been calibrated against the collected experimental data of 1995 (Figure 3). Arrows in the figure, indicate the periods when night ventilation was applied. The mean difference between measured and simulated temperatures was found close to 0.3 C (r-squared value was higher than 0.90).

In a second step, the theoretical model has been used to simulate the thermal behavior of the building both under night ventilation and standard conditions (Figure 3). Simulation results show that under free floating conditions, night ventilation contributes to a decrease of the peak indoor temperature of the building, during the next day, up to 3 °C. Additionally, the average reduction of the temperature for the entire building is close to 2.6 °C, presenting a maximum reduction close to 6.2 °C.

Night ventilation when applied to massive buildings causes a delay in the peak indoor temperature during the day period. To illustrate time delay effects, Figure 4 presents the temperature distribution in zone 7 of the building with and without night ventilation for a specific day (8th August). As shown, night ventilation decreases the indoor temperature, in the beginning of daytime period, to about 2 °C compared to the case where no night ventilation techniques are applied. The initial decrease of the indoor temperature combined with the thermal capacitance of the building causes a delay of the peak indoor temperature to about three hours later than the peak ambient temperature, while the corresponding peak when no night ventilation is applied, is close to one hour.

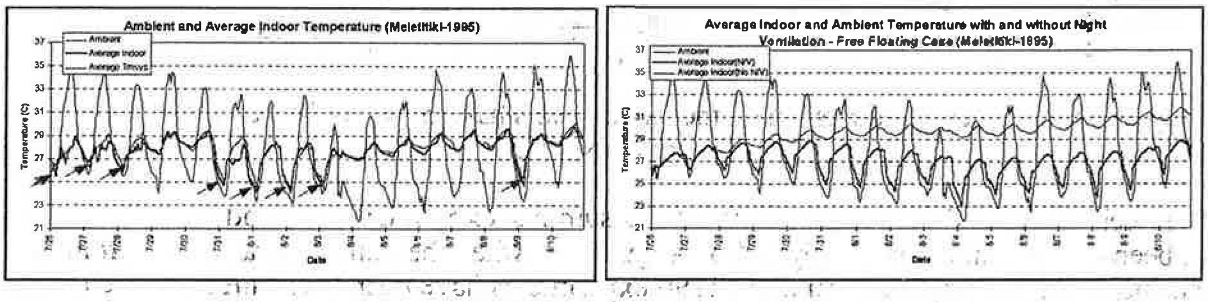

Figure 3: Comparison between simulated and measured data. - Average Indoor temp rature with and without night ventilation. (Meletitiki-1995).

An index to characterize the contribution of night ventilation techniques to the indoor thermal comfort conditions, the number of overheating hours during the whole summer period, may be used. Three base temperatures, 25, 27 and 29 °C, to calculate the overheating hours have been considered. For each base temperature three air flow rates during the night period have been taken into account, 10, 20 and 30 ACH. The obtained results are given in Figure 4 and are compared with the corresponding data when no ventilation is considered. As shown, the achieved reduction of the overheating hours due to night ventilation varies between 39.3 to 95.7% when the set point temperature varies between 25 to 29 °C and the are flow rate between 10 to 30 ACH.

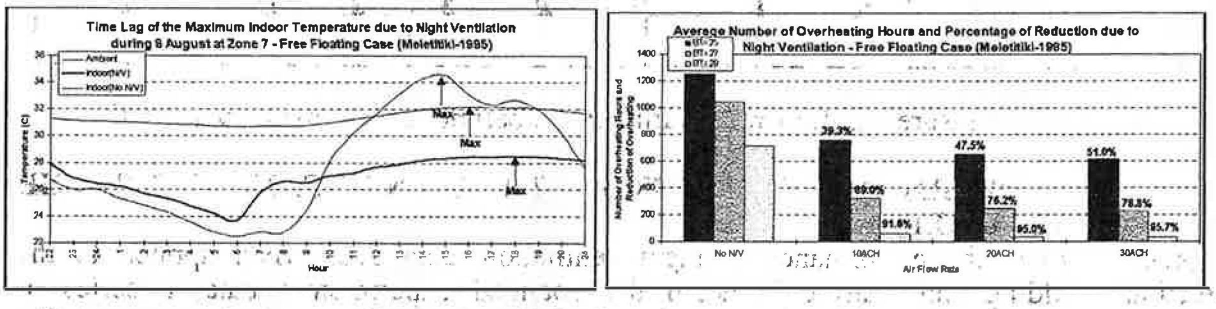

Figure 4: Time delay of the maximum indoor temperature.-Average number and reduction of overheating hours for 10 to 30 ACH and 25,27 and 29 °C base temperatures. (Meletitiki-1996)

During the second experimental period, summer of 1996, the building was air conditioned. Also, it was occupied and the internal loads were important.

Firstly, the model developed in TRNSYS was calibrated against the collected experimental data for A/C conditions. The obtained simulation results were compared with the corresponding measurements of the indoor temperature (Figure 5). In figure 5 the arrows indicate the nights when night ventilation was applied by mechanical means. For all the other days, night ventilation was achieved through natural means. The mean difference between measured and simulated temperatures was close to 0.3 °C (r-squared value was close to 0.94).

To evaluate the cooling potential of night ventilation techniques when applied to A/C buildings, a series of comparative simulations has been performed. Real climatic data collected during the experiments have been used. In the first series the building was considered as a conventional one while in the second series the building is treated as a night ventilated one. Night ventilation techniques were considered for every night of the studied period and between 11pm to 7am of the next day. The cooling capacity of the air conditioning system was supposed to be high enough to meet the building's cooling requirements. Three different set point temperatures were considered : 25, 27 and 29 °C, to investigate the impact of night ventilation with various indoor temperature profiles. The results of this analysis show that the smaller the set point temperature, the smaller the initial indoor temperature when night ventilation starts and consequently the smaller the indoor air temperature during night ventilation. Furthermore, the lower the set point temperature, the lower the increasing rate of the indoor temperature after the end of night ventilation. The high thermal mass of "Meletitiki" reduces the increasing rate of the indoor temperature. The average indoor temperature reduction, during night ventilation, has been calculated in order to evaluate the influence of night ventilation on the indoor temperature profiles. For set point temperature 25, 27 and 29 °C the average indoor temperature reduction is 1, 1.8 and 2.8 °C respectively.

Energy gains due to night ventilation are mainly a function of the potential reduction of the indoor air temperature, compared to the case of a non night ventilated building, during the early morning hours and before the A/C system is switched on. While the temperature reduction is high, the peak cooling demand is delayed and decreased, and thus the total cooling load of the building is lower. The overall analysis has shown that the set point temperature affects seriously the temperature reduction in the early morning hours. In particular for set point temperatures equal to 25, 27 and 29 °C the average early morning indoor temperature reduction is close to 0.8, 1.5 and 2.5 °C respectively.

To determine the potential for energy conservation due to night ventilation, a series of simulations have been performed to calculate the corresponding cooling load of the building under three set point temperatures (25, 27 and 29 °C) and for 10, 20 and 30 ACH during the night period. Figure 5 gives the calculated cooling load and the corresponding energy conservation during the whole cooling season (May-September). As shown, when the set point temperature varies from 25 to 29 °C and the air changes per hour between 10 to 30 the corresponding energy conservation due to night ventilation varies from 48.5 to 93.7%. Thus, as expected it is found that, the higher the air flow rate, the higher the energy conservation, however, the relative gains for higher air flows are not considerable. Also, the higher the set point temperature, the higher the energy conservation, as the difference between the operational temperature of the building and the night ambient temperature is higher and thus the cooling potential increases.

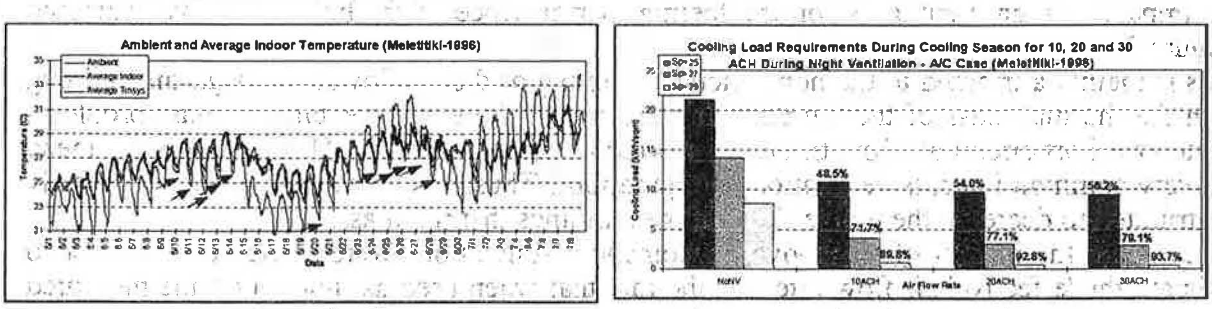

Figure 5: Mean measured and simulated indoor temperatures - Cooling load and corresponding energy conservation during the cooling season (Meletitiki- 1996).

THERMAL PERFORMANCE OF NIGHT VENTILATION TECHNIQUES IN THE "UNIVERSITY" BUILDING

In order to evaluate the efficiency of night ventilation techniques when applied in low to medium thermal mass buildings like the "University", a series of simulations have been carried out using TRNSYS. The zone where experiments were carried out was simulated using as inputs the measured air flow rate (Figure 2). At a first step, the model has been calibrated against the collected experimental data (Figure 6). The mean difference between the two sets of data was close to 0.3 °C (the r-squared value was close to 0.88).

The evaluate the impact of night ventilation techniques, when applied in free floating buildings of low to medium thermal capacity, a series of comparative simulations were performed with and without considering ventilation during the night period. The impact of night ventilation is not important and the calculated decrease of the next day peak indoor temperature is close to 0.2 °C, while the average temperature decrease during the whole day and night was close to 0.4 and the maximum one close to 2.4 °C.

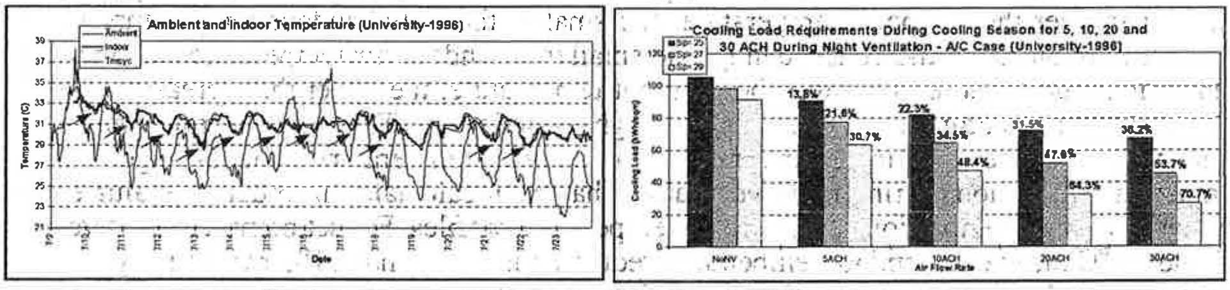

Figure 6: Measured and simulated indoor temperatures. - Cooling load and corresponding energy conservation during the cooling season. (University - 1996)

The possible energy conservation due to the application of night ventilation was also evaluated considering that the building is thermostatically controlled. Three set point temperatures, 25, 27 and 29 °C as well as four air flow rates, 5, 10, 20 and 30, have been considered (Figure 6). As shown when the set point temperature varies between 25 to 29 °C and the air flow during night ventilation between 5 to 30 ACH the corresponding energy conservation varies between 13.8 % and 70.7%.

THERMAL PERFORMANCE OF NIGHT VENTILATION TECHNIQUES IN THE "NOA" BUILDING

NOA building is a very heavy massive and free floating building where night ventilation was applied by natural cross ventilation. Experiments were carried out using and not night ventilation. As for the previous buildings, a thermal model using TRNSYS has been developed. The results given by the theoretical model has been compared with the corresponding experimental data and a good agreement has been achieved when ventilation techniques are not used. However, when the measured air flow rate was used (Figure 2) as an input to calculate the thermal performance of the building when night ventilation is applied, the impact of night ventilation on the thermal performance of the building is overestimated (Figure 7).

This is mainly attributed to the non efficient coupling of the air flowing through the building with the thermal mass of the building. In fact, during the experimental procedure problems related to short circuit air flow through the windows were observed. This type of phenomena are very common in cross ventilation configurations. Thus, only a part of the flow has really contributed to decrease the temperature of the buildings thermal mass.

To evaluate the impact of the above phenomenon, simulations were carried out in order to estimate the 'effective' air flow rate, i.e. the rate that when used as input gives the measured temperature profile. The simulation results are given in Figure 7. The curve named Trnsys (Measured ACH), represents the calculated indoor air temperature when the measured values of the air flow rates have been considered, while the curve named Trnsys (Fixed ACH), gives the temperature distribution calculated by trying to calibrate the air flow rate to the measured temperature data. As shown, almost a perfect agreement with the experimental data has been achieved.

The two data sets of the experimental and active air flow rates have been compared in order to evaluate the ventilation efficiency during the experiment. An index, Q (ventilation efficiency) has been calculated and the results are given in Figure 7. The parameter, Q is defined as the ratio of the estimated to the calculated air changes per hour. As shown, Q varies between 0 and 1.72. The 96% of the ventilation efficiency values are less than one, while its average value is close to 0.3. Therefore the 'active' air exchange rates that really contribute to decrease the temperature of the building's mass are much lower than the measured ones for almost the entire experimental period.

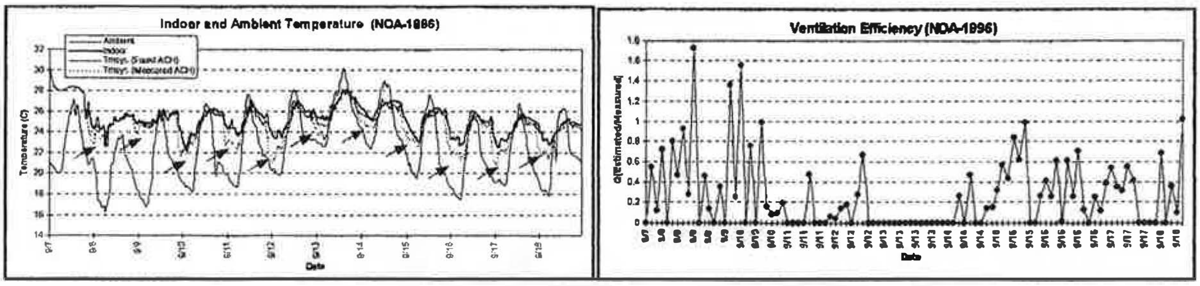

Figure 7: Measured and simulated indoor temperatures.-Ventilation efficiency. (NOA - 1996)

CONCLUSIONS

The efficiency of night ventilation is strongly related to three main parameters. The relative difference between indoor and outdoor temperature mainly during the night period, the useful air flow rate applied during the night period and the thermal capacity of the building.

As shown from the whole experimental procedure, the lower the outdoor temperature during night and the higher the fresh air supply, the higher is the efficiency of night ventilation. Additionally, the existence of important thermal-structural mass increases the efficiency of the technique since the inertia of the building is increased and the effect of the night ventilation can clearly be observed in the next day's indoor temperature profiles (lower and delayed peak indoor temperature). Additionally, the interior planning of the building plays a very important role, determining the flow and the "paths" of the air flowing through the building. Finally, another important climatic parameter is the daily amplitude of the ambient temperature. When the amplitude is high, night ventilation techniques can be very effective (especially if the minimum ambient temperature is low).

In the present paper, night ventilation techniques have been applied in three real scale buildings, of different structure, ventilation, layout and regional characteristics. "Meletitiki" building has important thermal mass and the first set of experiments (during 1995) has been performed during a period of very low internal gains, and without any operation of the air conditioning system. On the contrary, the "University" building has a light structure and was monitored when internal gains were important and the air conditioning system was in use. The two case studies are extreme conditions and in a way they indicate the limits of the cooling potential of night ventilation techniques.

The problem of efficient coupling of the air flow with the thermal mass of the building has been presented in the NOA building. Because of the short circuit air flow, convective exchanges between the fresh air and the building walls were very poor.

In conclusion, night ventilation techniques can contribute to decrease significantly the cooling load of A/C and improve the comfort levels of free floating buildings. The exact contribution of night ventilation for a specific building is a function of the building structural and design characteristics, the climatic conditions and the building's site layout, the applied air flow rate, the efficient coupling of air flow with the thermal mass of the building and the assumed operational conditions. Appropriate design of night ventilation systems requires exact consideration of all the above parameters and optimization of the whole procedure by using exact thermal and air flow simulation codes.

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