Night-time Ventilation for Passive Cooling of Dwellings: A case study for Cyprus

Koukkouli A.[1], Panayiotou G.[2], Gelegenis J.[3] and Kalogirou S.[2]

1. SW Solarwatt Ltd, P.O.Box 27797, 2433 Nicosia, Cyprus,

2. Department of Mechanical Engineering and Materials Science and Engineering, Cyprus University of Technology, P.O. Box 50329, 3603 Limassol, Cyprus, Tel.: +357 25002381, Fax: +357 25002637, E-mail: soteris.kalogirou@cut.ac.cy

3. Department of Energy Technology, Technological Educational Institution of Athens Ag. Spyridona 17, 12210 Egaleo, Greece

Abstract

The objective of this work is to investigate the effectiveness of night ventilation (NV) system that could cover at least a part of the cooling load of domestic buildings in an environmental friendly way in areas with a hot and humid climate. In this framework, a case study is conducted for the island of Cyprus where the Climatic Cooling Potential for NV is estimated for representative areas of the island namely for the cities of Nicosia, Limassol, Larnaca, Paphos and Paralimni. Subsequently the applicability of NV is further evaluated according to synthetic and analytical weather data. A detailed model has been used for the calculation of the mean and maximum inside temperature decrease and also for the percentage of the cooling coverage when NV is applied. The outcome of the case study is the evaluation of the effectiveness of NV systems for typical domestic buildings. It is found that the Climatic Cooling Potential is rather low for the cities of Nicosia and Paralimni during the summer months when the need for cooling is imperative.

1. Introduction

Night ventilation (NV) is a well established technique for passive cooling. Lower external temperatures that usually prevail at summer nights may assist to the release of heat that is stored in the building mass during the day, and decrease accordingly the internal temperatures, provided however that sufficient air change rate, heat exchange area and thermal storage capacity are available in the building [1]. NV can be applied either naturally or forced. For the natural application there should be provision for openings of appropriate size, orientation and sides of the building; natural ventilation can be further investigated with several techniques as wind stimulated ventilation, stack effect ventilation and operation of a solar chimney [2].

Pfafferott et al. [3] noticed that for effective NV, the cooling load should not exceed the value of 150 Wh/m^2, if the temperature difference between the day and night is less than 5 K, and 250 Wh/m^2 if the temperature difference is higher than 10 K. The same researchers noticed, that a critical parameter is the heat transfer coefficient for which the various building simulation models present a standard deviation of 20-40%, a fact that raises a significant uncertainty in the modelling of the process.

Santamouris and Asimakopoulos [4] have noted that the cooling load can be reduced when NV is used to an air conditioned or non-air-conditioned building. On the other hand, Givoni [5] noted that NV can be applied in regions where daytime ventilation is not enough to sustain the appropriate comfortable indoor conditions. Also NV can be used in regions where night time temperatures are about 20^{o}C.

Kolokotroni and Aronis [6] investigated the potential energy savings by applying a night-ventilation strategy for a typical air conditioned office. Energy consumption decreased by mechanical NV and energy saving increased further by integrating NV with a 'low energy' design.

Florides et al. [7] used TRNSYS software to simulate a typical house in Cyprus (square shape with 196 m^2 floor area) in order to investigate measures to reduce energy consumption in modern houses. The measures examined were natural and controlled ventilation, solar shading, type of glazing, orientation, shape of buildings, and thermal mass. They found that indoor temperature may even reach 46°C in the city of Nicosia, Cyprus. This day maximum temperature was reduced by 7°C if NV was applied at a rate of 11 air changes per hour.

Although the meteorological data needed for this purpose are usually available in relevant data bases this was not valid for the case of Cyprus. For instance, Meteonorm database [8] includes meteorological data from 7400 stations all over the world, but for Cyprus it only includes data for Larnaca. Nevertheless, NV can be preliminary studied for representative cities of Cyprus by using meteorological data from Cyprus Meteorological Service by applying suitable models to generate detailed weather data from their mean values. The models used were those suggested by Erbs et al. [9] for the generation of hourly temperature data and that of Knight et al. [10] for the generation of hourly humidity data.

1.1 Evaluation criteria for Night Ventilation

Various criteria are applicable for the evaluation of a NV system, depending on the operation of the building, the presence or not of air conditioning in the building, and the priorities set by the user e.g. energetic, environmental and economic.

Criterion 1: Effect of ventilation rate on the reduction of the maximum indoor-temperature (expressed in °C). This criterion is useful to check if NV can be used instead of air conditioning (AC) and the results can be presented in the form of the indoor temperature variation during a typical summer day.

Criterion 2: Annual cooling reduction due to the use of NV (expressed in kWh/year), for maintaining the temperature in the building between 21 and 25°C. This criterion should be used in cases where by applying criterion 1 it is observed that in spite of the fact that NV was applied the maximum indoor temperature still exceeds 26°C, for more than an acceptable time period.

Criterion 3: Reduction in required peak plant capacity [6]. In the same context, the time that power is required, distinguishing between the times that peak power, usual power and low power occurs, is useful when comparing normal AC with combined NV and AC [11].

Criterion 4: Indoor temperature just after night cooling was applied by Thomas et al.[12] to determine a suitable night cooling schedule. This criterion however is quite similar to criterion 1.

1.2 Climate of Cyprus

The island of Cyprus is located on the eastern Mediterranean Sea on an average north longitude of 35° and east latitude of 33°. The climate of Cyprus is characterized as a standard Mediterranean climate and it is mainly affected by the fact that it is surrounded by the Mediterranean Sea. The main characteristics of this kind of climate is that it has a hot, with low rainfall but high humidity summer from the mid-May until mid-September, while winter is mild and lasts from the mid-November until mid-March. During the summer period Cyprus and in general the whole eastern Mediterranean territory is affected by the fact that it is under the effect of a seasonal low barometric which has its center at the northwest Asia and causes high level of temperatures.

The climatic data that are used in this work were taken from the Meteorological Service of Cyprus [13]. More specifically, the weather data used were the monthly statistical values of temperature, relative humidity (RH) and global radiation for the time period of 2002-2007. Detailed hourly values of temperature and relative humidity for the various months are calculated according to appropriate models, [9] and [10] respectively.

In Fig. 1 we can observe that the actual and theoretical values of both relative humidity (RH) and temperature are in good agreement so it can be concluded that this model gives reliable results and it can be used for the calculation of hourly daily temperatures and RH.

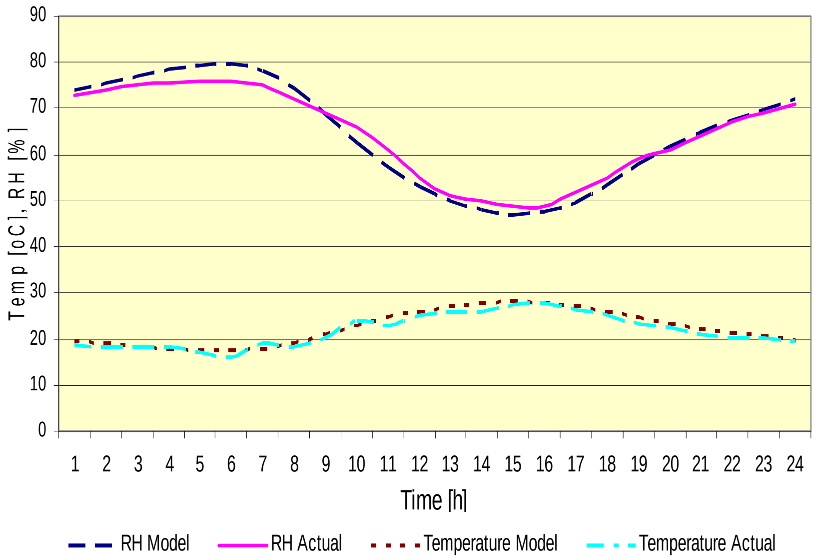

Fig. 1 Comparison of actual and theoretical temperature and RH values

2. Data and assumptions for the case study

The case study is conducted for a typical dwelling in Cyprus according to the data published by Florides et al. [7]. The building plan and orientation is illustrated in Fig. 2. The typical house has a floor area of 196m^2 and consists of four identical external walls, 14 m in length by 3 m in high, with a total window opening of 5.2 m on each wall. It is considered that four people live in the house which is used for 16 hours a day. The typical house is further divided into four identical zones and the partition walls are considered as walls separating the four zones. Each partition wall has a window opening with a total area equal to the area of all actual window openings of each zone.

In this study two separate cases are going to be examined. In both cases the basic dimensions of the house are identical with the difference being that in Case 1 the house is assumed to be non-insulated, while in Case 2 the house will be constructed from higher quality materials with good insulating properties.

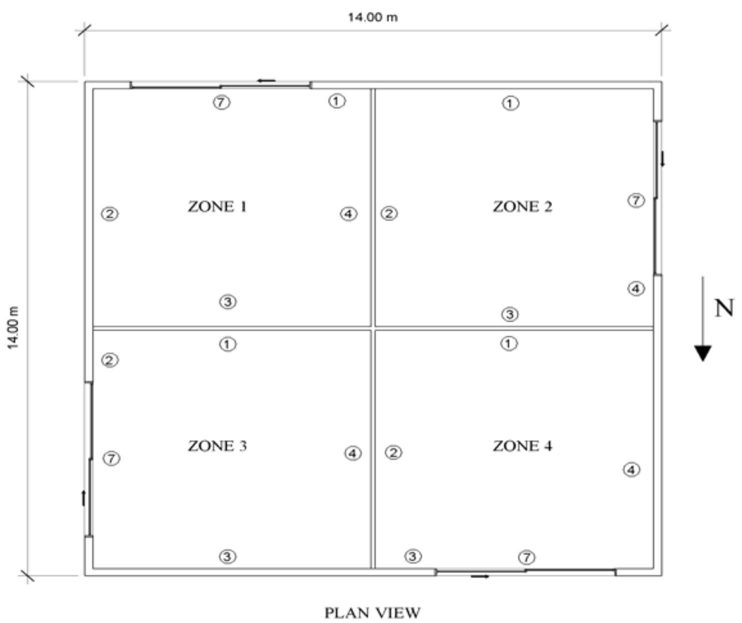

Fig. 2 Typical dwelling plan [7]

3. Estimation of Climatic Cooling Potential (CCP)

Artmann et al. [14] define the Climatic Cooling Potential (CCP) during a time period of N nights as the summation of products between building/external air temperature-difference, T_b-T_e, and time interval:

$$CCP = \frac{1}{N}\sum_{n=1}^{N}\sum_{h=hi}^{hf} m_{n,h}\left(T_{b,n,h} - T_{e,n,h}\right) \quad \begin{Bmatrix} m = 1h & if & T_b - T_e \geq \Delta T_{crit} \\ m = 0 & if & T_b - T_e < \Delta T_{crit} \end{Bmatrix} \qquad (1)$$

Where parameter h stands for the time of the day, $h \in \{0,\ldots,24h\}$, h_i and h_f denote the initial and the final time of night-time ventilation, and ΔT_{crit} is the threshold value of the temperature difference when night-time ventilation is applied. In the numerical analysis, it was assumed that night-time ventilation starts at h_i = 19h and ends at h_f = 7h. The units of CCP are Kelvin hours per day (Kh/day). As a certain temperature-difference is needed for effective convection, NV is only applied if the difference between building and ambient temperature is greater than ΔT_{crit}= 3K [14]. The present method is valuable in order to estimate the CCP for a given climate and might be rather helpful in the initial design phase of a building at a given location. In Figs. 3 and 4 the CCP data, calculated in the present work, according to the hourly temperature of a typical day of each month for the worst and best case of the five locations examined are presented. It should be noted that due to space limitations only the worst (Nicosia) and best (Paphos) cases are presented.

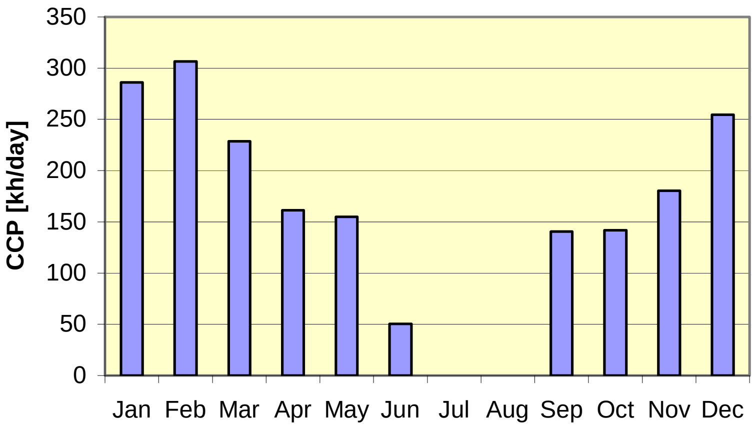

Fig. 3 Monthly mean CCP per night for Nicosia

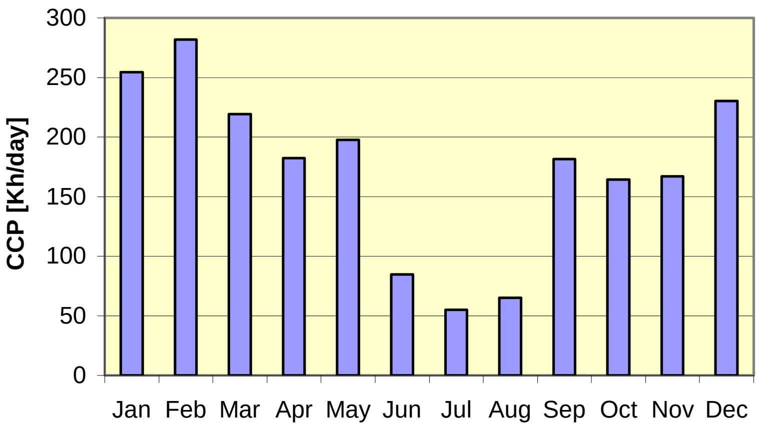

Fig. 4 Monthly mean CCP per night for Pafos

As can be observed in Fig.3 the CCP for the city of Nicosia has its maximum value (306 Kh/day) in February and minimum value (0 Kh/day) in July and August, as expected. As for the city of Paralimni, according to the calculation results, the CCP value is 0 Kh/day during July and August. The results for the cities of Limassol, Larnaca and Pafos are more promising since for the city of Limassol the CCP is zero only during August while in Pafos and Larnaca the CCP is positive for all summer months.

Consequently, it can be concluded that the most appropriate areas to apply NV is Larnaca and Paphos. In these areas the CCP during the summer months reaches rather high levels. On the other hand at Paralimni, Limassol and Nicosia the application of a NV system is not excluded but it needs a specific strategic plan of use in order to be efficient.

In spite of the fact that during the preliminary calculations the CCP was found to be zero, this is not completely correct or representative due to the fact that mean monthly values of temperature were used for a typical hour of the day of each month and not actual hourly values.

4. Detailed calculations

4.1 Operation strategy

Various operation strategies have been studied for the NV system in order to choose the one with optimum results. Among the parameters examined were the desired inside temperature (for the air-conditioned buildings), the air change rate during NV and the hours of operation of the NV system or alternatively the minimum difference between inside/outside temperatures to set the NV system into operation.

In this frame several cases were examined, according to the inside temperature, ranging from 26 to 28°C, NV air change rates from 1 up to 20 ACH and temperature difference to start NV from 0°C up to 5°C. Two main categories of buildings were distinguished, namely buildings with air-conditioning system and without air-conditioning system. In the first category the percentage of the cooling load that is covered with the NV system (decrease of mechanical cooling needs) and the coefficient of performance of the NV system in comparison with the COP of the competing AC system were estimated. It should be noted that the coefficient of performance of NV system should exceed the mean value that is achieved by typical AC units, e.g. $COP_{NV} > 3$. In the second category the decrease of the maximum day temperature and the decrease of the mean temperature within the building, were calculated.

From the results of the calculation process it is clear that at 26°C and by altering the ACH the COP is much lower than the typical COP of an air conditioning unit. Additionally, the percentage of cooling load coverage is low. The results for 27°C proved to be better both for the COP and the percentage of cooling load coverage. At 28°C the percentage of cooling load coverage is relatively high while COP is also quite higher. It could be noticed that the most advantageous scenario would be at 28°C with 3 ACH. Such a scenario however is not suggested due to the fact that 28°C is not within the comfort criteria zone. So, a first conclusion is that the more detailed calculations should be made for 27°C and 5 ACH.

4.2 Simulation for non-conditioned building

In non air conditioned dwellings it is important to estimate how much NV can reduce the mean temperature, the maximum temperature and the overheating hours (temperature floating case). Taking the most important energy fluxes into account, and assuming that all boundary conditions oscillate regularly, Keller et al. [15] developed a model to estimate the variation of temperature with time.

Calculations were carried out for 5 ACH and 10 ACH during night-time for four successive days in the mid July and the results for the city of Limassol are shown in Figs. 5 and 6 respectively. From these figures we observe that for both building cases the maximum inside temperature without NV is around 31°C. Then by applying NV with 5 ACH the maximum inside temperature is decreased by 1°C while when having 10 ACH it decreases by 1.5°C. From this fact it becomes obvious that the effectiveness of NV decreases with the increase of the ACH value, as it is expected.

Also, another interesting fact that can be observed is that in the case of the insulated building the fluctuation of the inside temperature follows more closely the fluctuation of the ambient temperature when compared with the non-insulated building due to the existence of insulation. In the non-insulated building a large amount of heat is stored in the building elements during the day which is later on slowly released into the building and this result to a slower response of the building to the lower night temperature.

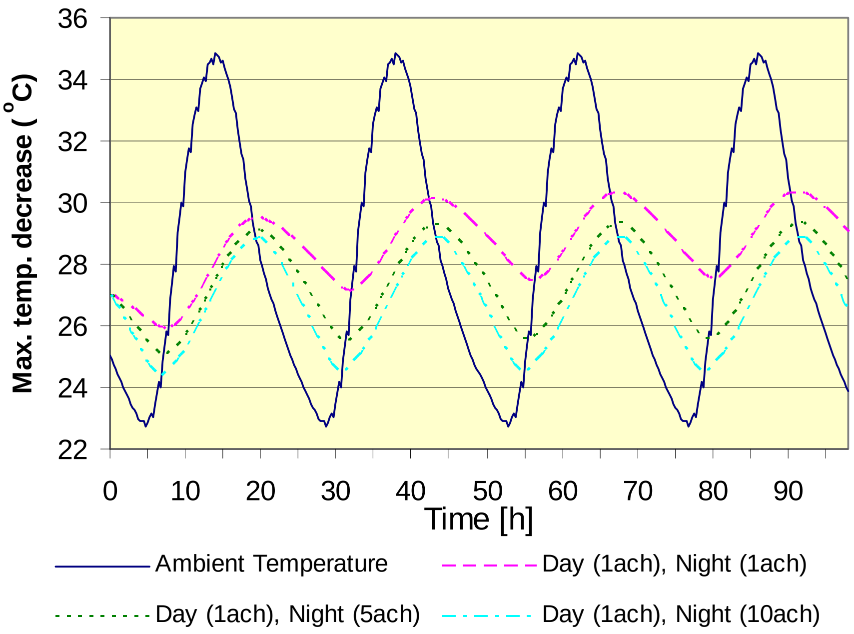

Fig. 5 Temperature behavior with and without NV for non-insulated building in Limassol

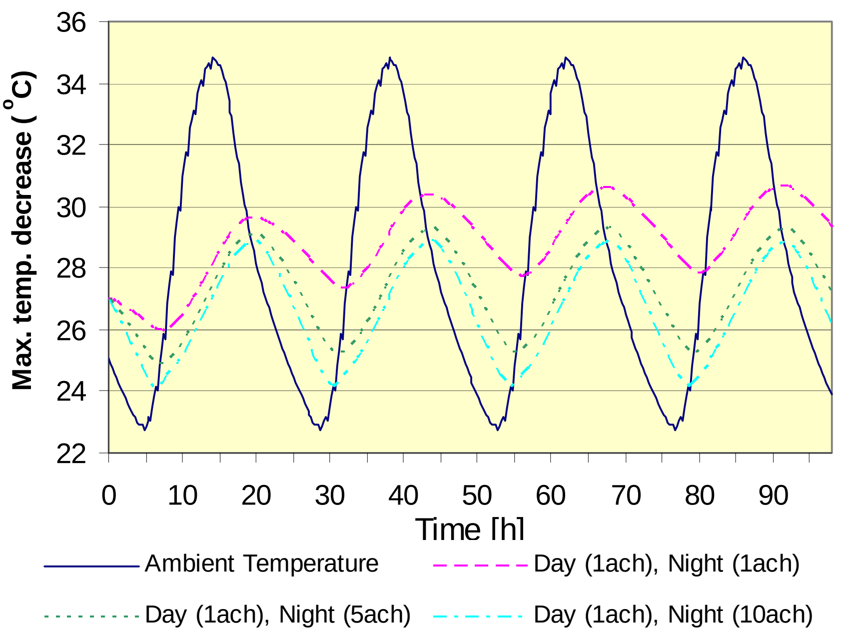

Fig. 6 Temperature behavior with and without NV for insulated building in Limassol

The decrease of the mean inside temperature for the non-insulated building ranges between 1.3°C-1.9°C for the five cities examined, while for the insulated building ranges between 1°C-1.3°C. The highest decrease of the mean inside temperature is observed at Larnaca and the lowest at Paralimni.

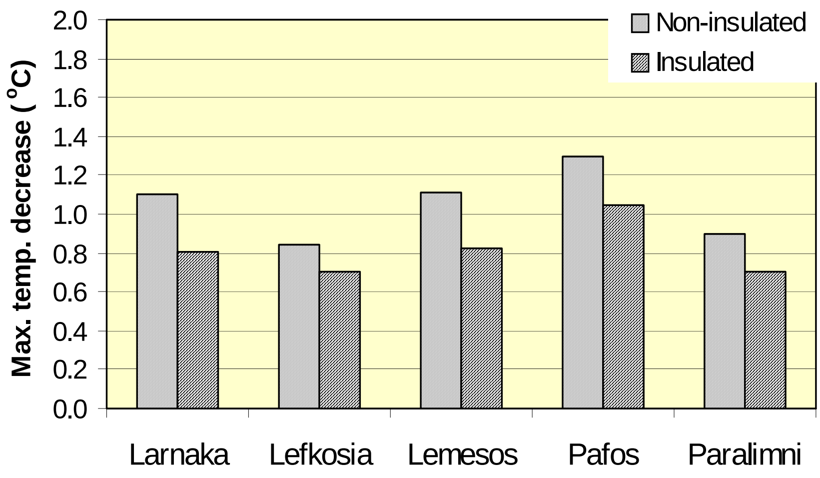

Fig. 7 Maximum temperature decrease for insulated and non-insulated building in the five cities of Cyprus examined

The decrease of the maximum inside temperature for the non-insulated building ranges between 0.85°C to 1.3°C while for the insulated building ranges between 0.7°C-1.05°C. The highest decrease is observed at Paphos and the lowest at Nicosia.

4.3 Simulation for air-conditioned buildings

For an air-conditioned building (cooling energy floating case) it is important to calculate how much NV can reduce the mechanical cooling load. Santamouris et al. [16] developed an integrated method to calculate the energy contribution of NV techniques to cover the cooling load of a building. The basic assumptions of this model are:

- Maximum energy that can be removed from the fabric during the night should be greater than the NV cooling capacity
- NV cooling capacity should not exceed the daily cooling needs.

In a thermostatically controlled building the inside temperature is assumed to be constant at 27°C for 5 ACH, according to the operation strategy suggested earlier. The calculations concerning the ability of the system to cover the entire cooling load in order to maintain the inside temperature constant are shown in Fig. 8.

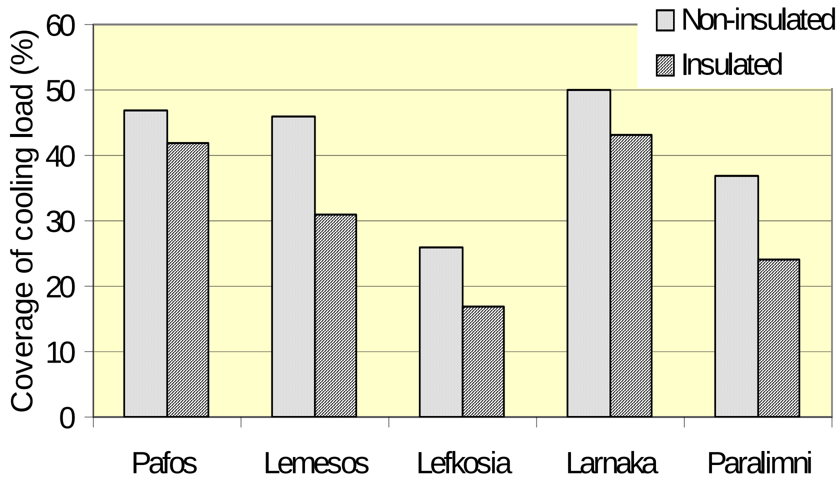

Fig. 8 Coverage of cooling load for insulated and non-insulated building in the five cities of Cyprus examined the five selected cities of Cyprus

From this we can observe that the percentage of cooling load coverage for non-insulated building is in the range of 25-50% and for insulated building around 17-43%. Therefore, the system can cover only a part of the cooling load.

5. Conclusions

In this paper the effectiveness of a NV system that could cover at least a part of the cooling loads of domestic buildings in an environmental friendly way in Cyprus is investigated. The demand for cooling during the summer period in Cyprus is very high due to the high levels of temperature.

The CCP was found to be very low and in several areas in Cyprus was even zero. The most appropriate areas to apply NV are Larnaca and Paphos. In these areas the CCP during the summer months reaches rather high levels. On the other hand, at Paralimni, Limassol and Nicosia the application of a NV system is not found to be efficient. In these cases, by using a specific strategic plan of operation the efficiency could be satisfactorily improved.

The percentage decrease of the cooling load due to the application of NV does not in any occasion exceed 50% while the coefficient of performance of the NV system does not exceed the coefficient of the air conditioning units in any of the cities examined at summer. The models used to study the applicability and effectiveness of the application of NV for these specific areas lead to similarly discouraging results.

Therefore, NV systems can only be used during spring and autumn period and only as part of another system and not as an autonomous solution. The case study was focused on dwellings with relatively low thermal gains. In buildings with larger thermal mass, greater exchange surfaces and higher heat gains (and consequently cooling loads) the advantages of an NV system could be more important.

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