13351

A SIMPLE DESIGN TOOL FOR DETERMINING THE EFFECTIVENESS OF THERMAL MASS AND NIGHT VENTILATION AS PASSIVE COOLING DESIGN STRATEGY

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ABSTRACT

We calculate the influence of thermal mass and night ventilation on the maximum indoor temperature in summer. The results for different locations in the hot humid climate of Israel are presented and analyzed. We find that the maximum obtained indoor temperature depends linearly on the temperature difference between day and night at the site. The fit can be applied as a tool to predict from the temperature swing of the location the maximum indoor temperature decrease due to the thermal mass and night ventilation. Consequently, the fit can be implemented as a simple design tool to present the reduction in indoor temperature due to the amount of the thermal mass and the rate of night ventilation, without using an hourly simulation model. Moreover, this design tool is able to present the designer already in the early design stages the conditions when night ventilation and thermal mass are effective as passive cooling design strategy.

KEYWORDS

Thermal mass, Night ventilation, Passive cooling, Design strategies, Design tools, Hot humid climate.

INTRODUCTION

It is well known that thermal mass with night ventilation can reduce the maximum indoor temperature in the building in summer (Kammerud et al., 1983). Hence, comfort temperatures may be achieved by proper application of the above means. In addition, energy can be saved if air conditioning unit is used (Shaviv, 1989). The reason being that in summer, heavy external walls delay the heat transfer from the outside into the inside spaces. Moreover, if the building posses a lot of internal mass the increase in the air temperature is slow. This is because the penetrating heat raises the air temperature as well as the temperature of the heavy thermal mass. The consequence is a slow heating of the building in summer and the maximal inside temperature is reached only during the late

hours when the outside air temperature is already low. The heat that flows from the heavy walls inside can be removed with good ventilation in the evening and night. The capability to store energy also helps in winter, since energy can be stored in walls from one sunny winter day to the next cloudy one. But, it is also widely believed that in a hot humid climate, like Florida, it is not recommended to use thermal mass with night ventilation as a passive cooling design strategy. On the other hand, in the hot-humid climate of Israel, traditional architecture is to build with heavy thermal mass, and experience shows that better thermal comfort conditions exist in heavy structures than in light buildings.

The questions therefore, addressed in this work are:
I.   "Under what conditions night ventilation and thermal mass are effective as passive cooling strategy? "
II. "Can a simple design tool to predict the reduction of the maximum indoor temperature due to the rate of night ventilation and the amount of the thermal mass be developed?"

A thorough analysis was carried out with the purpose to provide a complete answer to the above questions. In this analysis, we used the hourly simulation model ENERGY (Shaviv and Shaviv, 1978) to calculate the maximum summer indoor temperature. This time dependent model solves simultaneously the heat transfer equation through all exterior walls, taking into account the thermal mass in each external wall and in the internal partitions as well (Shaviv, 1989). The model allows the calculation of the inside temperatures without operating an air conditioning unit, as well as the required energy for keeping a pre-determined inside air temperature, once an air conditioning unit operates.

THE SIMULATION STUDY

The above questions were examined on a typical Israeli apartment building.
We define four levels of night ventilation as follows:
I.   No night ventilation (2 air changes/hour)
II. Natural night ventilation (5 air changes/hour)
III. Forced night ventilation (20 air changes/hour)
IV. Forced night ventilation (30 air changes/hour).

We define four levels of thermal mass as follows:
I.   Light building: no thermal mass, like a mobile home.
II. Medium-light building: Light walls, but heavy floor, like cement tiles on concrete floor, and concrete ceiling.
III. Semi-heavy building: Heavy floor, ceiling and external walls (20cm concrete blocks) but light internal partitions (Gibsum boards).
IV. Heavy building: Heavy floor, ceiling, external and internal walls (10cm concrete blocks, with plaster on both sides).

We run the simulation using the data of four locations along the coastal plane. The data is taken from the climatological data given in the Climatic Atlas of Israel (Bitan and Rubin, 1991). The places are presented from North to South:
I.   Nahariya: Temperature swing from day to night: 9.5 degC. Ave RH in August: 76%.
II. Geva Carmel: Temperature swing from day to night: 8.8 degC. Ave RH in August: 71%.
III. Tel Aviv: Temperature swing from day to night: 6.9 degC. Ave RH in August: 71%.
IV. Gaza: Temperature swing from day to night: 7.9 degC. Ave RH in August: 73%.

The prediction for the maximum temperature obtained in the hottest month in this region, August, is presented in Figure 1 for the different case studies.
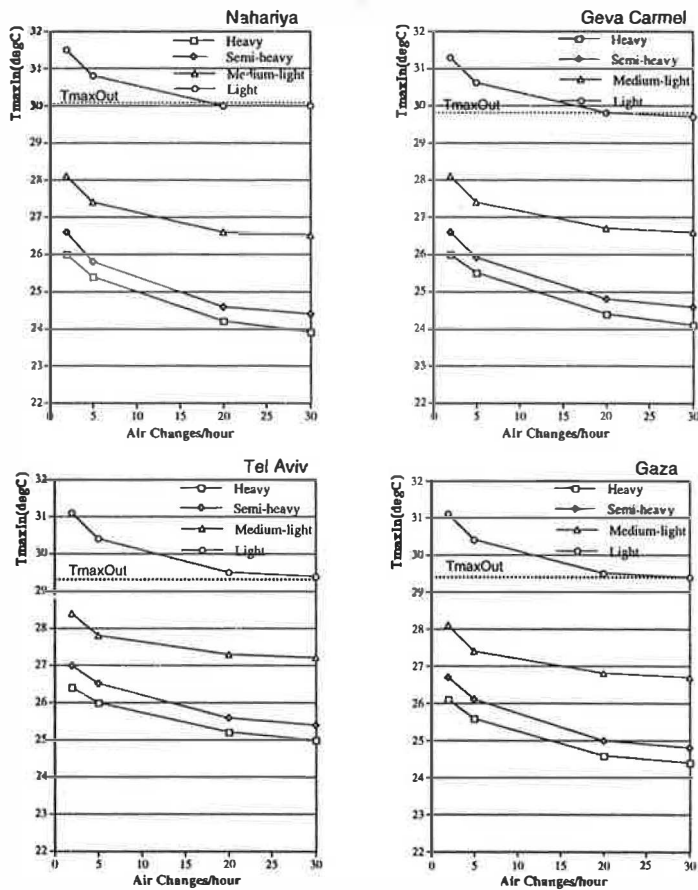

Figure 1. The prediction of the maximum indoor temperature (TmaxIn) in August in a residential building along the Mediterranean coastal plane, as a function of the thermal mass and night ventilation.

The analysis of the results yields that the reduction in the maximum indoor temperature as a function of the rate of night ventilation (dTmaxIn/dach, where ach is the number of air changes per hour, and TmaxIn is the maximum indoor temperature) is vanishing towards the value of 30ach (see Figure 1). An effective plateau is reached by the time the air changes reach 20ach. This means that there is no need for a very powerful vent for the forced night ventilation. However, achieving 20ach is important. If 20ach are not achievable by natural means, forced night ventilation is recommended.

Comparing the performance of the different heavy and light structures, we observe that the light structure behaves like a heat trap. The temperature obtained in such buildings is even higher than the maximum outside temperature. The medium light structure improved significantly the thermal behavior of the building, by reducing TmaxIn. The semi-heavy structure further improved significantly the performance of the building and the improvement proceeds with the heavy structure, although this improvement is less significant.

A SIMPLE DESIGN TOOL

The above results show that a comfortable T_{maxIn} can be obtained in heavy structures in hot humid areas by proper application of night ventilation. However, to reply to both questions raised above, additional analysis is required. To this goal we summarized the results obtained for ΔT_{max} (reduction in maximum indoor temperature compared with the maximum outside temperature $\Delta T_{max}=T_{maxOut}-T_{maxIn}$). The results for heavy and medium light structures are presented in Table 1 along with the climatic data of T_{swing} (the temperature swing from day to night at the site) and the relative humidity in August.

TABLE 1

MAXIMUM REDUCTION IN INDOOR TEMPERATURE IN AUGUST IN HOT HUMID ZONE
FOR HEAVY STRUCTURES (H) AND MEDIUM LIGHT STRUCTURES (M)

City	T_{swing} degC	ΔT_{max} degC 20ach H M	ΔT_{max} degC 5ach H M	ΔT_{max} degC 2ach H M	RH_{ave} %	RH_{max} %	RH_{min} %	ΔRH %
Nahariya	9.5	5.9 3.5	4.7 2.7	4.1 2.0	76	93	60	33
Geva Carmel	8.8	5.4 3.1	4.3 2.4	3.8 1.7	71			
Tel Aviv	6.9	4.1 2.0	3.3 1.5	2.9 0.9	71	82	60	22
Gaza	7.9	4.8 2.6	3.8 2.0	3.3 1.3	73	85	63	22

Figure 2 presents ΔT_{max} as a function of T_{swing}. There are two groups of three lines each in the figure. The upper group is for heavy thermal mass and the lower group is for medium light thermal mass. The lines in each group represent the different rates of air changes per hour. We see that the relation between ΔT_{max} and T_{swing} is linear. This relation allows us to predict the influence of the thermal mass and night ventilation in locations for which we do not have simulation results.
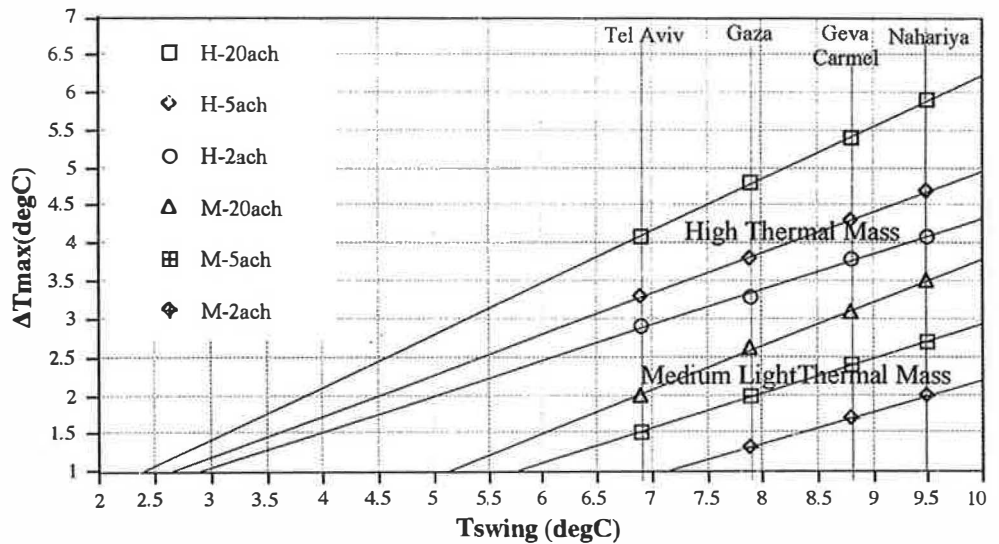

Figure 2. The reduction in the maximum indoor temperature compared with the maximum outside temperature (ΔT_{max}) in the hot-humid climate of Israel, as a function of the temperature swing at the site (T_{swing})

We have tried to presents ΔT_{max} as a function of the relative humidity. However, no simple relation was found, whether it was the maximum, minimum or average relative humidity.

We conclude that the answer to the first question is: Thermal mass with night ventilation is effective as passive cooling strategy depending on the temperature swing at the site (T_{swing}). Moreover, it is not directly related to the relative humidity of the site. Although in most cases, when the relative humidity is high, T_{swing} is small. Yet, exceptions are known (cf. the climatic data of Nahariya).

So far we found the linear relation for the range of T_{swing} = 7-10 degC. It is interesting to see to what extent the linear relation is preserved for still higher T_{swing} when the relative humidity is low. We added two more locations, Jerusalem and Sede Boker, which are located in another climatic zone, the mountain. In the mountain zone the average relative humidity is lower, and especially the relative humidity during daytime is much lower (see Table 2).

TABLE 2
MAXIMUM REDUCTION IN INDOOR TEMPERATURE IN AUGUST IN COOL DRY ZONE FOR HEAVY
STRUCTURES

City	T_{swing} degC	ΔT_{max} degC 20ach	ΔT_{max} degC 5ach	ΔT_{max} degC 2ach	RH_{ave} %	RH_{max} %	RH_{min} %	ΔRH %
Jerusalem	11.7	7.9	6.4	5.4	63			
Sede Boker	14.8	10.4	8.7	7.6	60	90	30	60

The corresponding graph with the two additional location data is presented in Figure 3. One can see that the assumption of linear relation between ΔT_{max} and T_{swing} holds over (r = 0.996 - 0.999). When a new linear regression is carried out including the new points, only negligible changes in the fits constants occur.
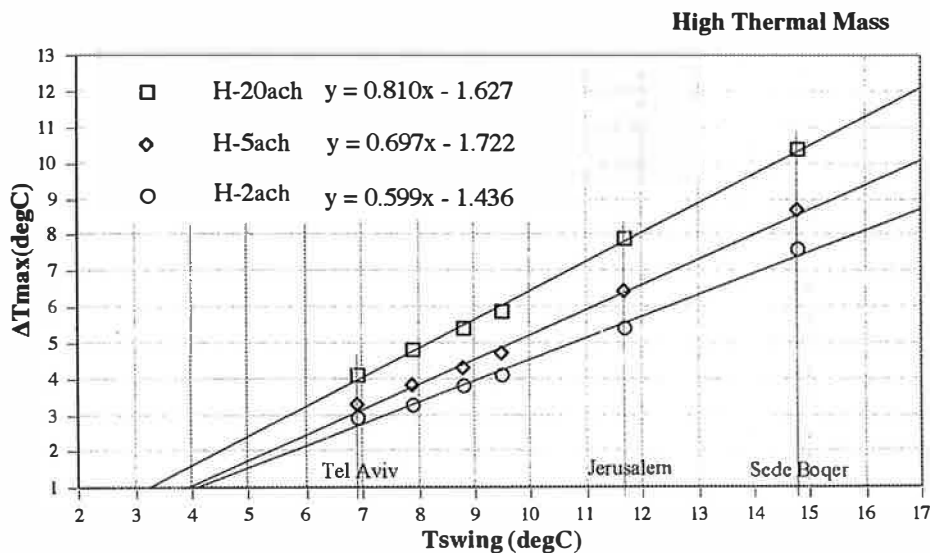
High Thermal Mass

Figure 3. The reduction in the maximum indoor temperature compared with the maximum outside temperature (ΔT_{max}) in different climatic zones in Israel, as a function of the temperature swing at the site (T_{swing})

The fitting lines in Figure 3 can serve as a simple design tool for determining the effectiveness of the thermal mass and night ventilation as passive cooling design strategy. From Figure 3 one can see that for heavy thermal mass and night ventilation of 20ach, T_{swing} should be greater than 6 degC, in order to achieve an effective ΔT_{max} of about 3 degC. This design is not effective for lower values of T_{swing}. When the rate of the night ventilation is smaller, or the building is lighter, even a higher value of T_{swing} is required for this design strategy to be effective.

SUMMARY AND CONCLUSIONS

An analysis for the determination of the reduction in the maximum indoor temperature compared with the maximum outside temperature (ΔT_{max}) was carried out using an hourly simulation model ENERGY to predict the thermal performance of the building. The results obtained show that in the hot humid climate of Israel it is possible to achieve a reduction of 3 to 6 degrees Centigrade in a heavy constructed building without operating an air conditioning unit. The exact reduction achieved depends on the amount of the thermal mass, the rate of night ventilation, and the temperature swing of the site between day and night. In addition, we have found a simple design tool to predict the reduction in indoor temperature as a function of the above three mentioned parameters. The simple design tool provides the conditions under which night ventilation and thermal mass are effective.

ACKNOWLEDGEMENT

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