EVALUATION OF PASSIVE COOLING STRATEGIES FOR ISRAEL

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ABSTRACT

The potential of the different passive cooling strategies for popular residential buildings in Israel is evaluated using a simplified simulation program. The program, which can be run on a regular PC computer, is based on a similar one developed by the European community, but takes into account the internal mass of the building more explicitly. The passive cooling strategies considered are: natural ventilation, night cooling, ground cooling using underground pipes and combinations thereof Both air conditioned buildings and free-floating temperature buildings are considered. The basis of the study is a reference building, characteristic of popular residential homes in the coastal area of Israel. Two typical days are analyzed an average summer day and a particularly hot day in the spring (Sharav conditions). The relative merits of each strategy as well as their energy savings potential are discussed.

INTRODUCTION

Passive cooling methods for achieving comfort during the heating season are well known (See Aranovitch et al. (1990), Cook (1989)) and have been slowly but steadily reclaiming their proper place in architecture in countries where cooling problems are at least as severe as heating problems. Recently, passive cooling research was boosted by the PASCOOL program, a European Union co-operative program aimed at promoting passive methods of climatisation during the cooling season (See PASCOOL Bulletin No. 1).

In most regions in Israel (Latitude 32^{o}N), thermal comfort problems are much more important during the summer than during the winter. Although many Israeli researchers have worked in the past on the subject of passive cooling by different methods, the large effort dedicated on energy savings during the heating season contrasts with a much smaller effort dedicated to the cooling season. This makes it difficult to evaluate the different passive cooling options from the energy and the comfort point of view.

It is proposed in this work to calculate the effectiveness of different passive cooling strategies in a typical Israeli detached residential building. The calculation will be done using a simplified design tool which can be run on a PC with very modest RAM and storage requirements.

MODEL

The model is based on a thermal balance of the air inside the building, which is considered to consist of a single thermal zone. At the absence of thermal mass, this is described by the following equation:

$$K(T_i-T_o) = Q_{sol}+Q_{int}-Q_p-Q_{ac} \qquad (1)$$

where:

- T_i is the internal air temperature
- T_o is the outside air temperature
- Q_{sol} is the solar heat gain through windows and opaque external surface elements.
- Q_{int} is the internal heat gain, due to lighting, equipment and people.
- Q_p is the ground cooling due to air flowing through buried pipes (if used)
- Q_{ac} is the cooling due to air conditioning (if used).

and K is the building load coefficient:

$$K = \Sigma U_i A_i + \frac{\rho c N V}{3600} \qquad (2)$$

U_i being the U-Value of each external building element, A_i being the surface of each element, V being the volume of the building and N being the number of hourly air changes due to infiltration and/or ventilation.

The cooling effect due to pipes is modeled in the same way as in the NORMA (Asimakopoulos and Santamouris, 1994) and COOL-C (Geros, V.,1994) programs:

$$Q_s = N_p \rho \pi r^2 v(T_i-T_p)=2\pi r L h_p(T_o-T_g) \qquad (3)$$

N_p being the number of pipes, r being the radius of each pipe, L the length of each pipe, v the mean velocity through it, T_g the ground temperature, T_p the temperature at the pipe exit and h_p a heat transfer coefficient for the pipe, a function of the pipe flow rate and the depth of the pipe in the ground.

Thermal mass is modeled by lumping into a single node and using the electrical analog of Fig. 1, in which thermal mass is connected to the node representing inside temperature.

Thermal mass is set equal to the amount of energy stored in the building when the heating (or cooling) rate increases by 1 W, the outside temperature being kept constant :

$$C = \sum U_i A_i \tau_i + \sum M_j A_j \quad (4)$$

where i denotes an external element and j an internal element, A is the area of the element, M is the thermal mass of an internal element (partition, structure etc) and τ is the external thermal time constant of an external element.

$$M = \sum c_{pl} \rho_l d_l \quad (5)$$

$$\tau = \sum c_l \rho_l d_l \left(\frac{r_l}{2} + \sum_{k=1}^{l-1} r_k \right) \quad (6)$$

In Eqs. (5) and (6), d is the thickness of each layer of wall, c_p is the specific heat of the layer, ρ is the density of the layer and r is the resistance of the layer. In Eq. (6), layers are counted from outside towards the inside, the first layer being the outside film resistance. The node representing internal mass is connected to the node representing internal temperature by an additional resistance, taken from the NORMA program:

$$R_{in} = 1/(h_i \sum A_{in}) \quad (7)$$

$$C \frac{dT_m}{dt} + K''T_m = K'T_o + K'''T_p + Q_{sol} + Q_{int} \quad (8)$$

where:

$$K' = K/(1+K\,R_{in}) \quad (9)$$

$$K''' = N_p \pi \rho v r^2/(1+K\,R_{in}) \quad (10)$$

$$K'' = K' + K''' \quad (11)$$

Equation (8) can be integrated using a time step Δt=1 hour:

$$T_m(t) - T_m(t-\Delta t) e^{-\Delta t/\tau'} = \left(\frac{K'T_o + K'''T_p + Q_{sol} + Q_{in}}{K''} \right) (1 - e^{-\Delta t/\tau'}) \quad (12)$$

$$\tau' = C/K'' \quad (13)$$

When, on the other hand, air conditioning is used to prevent the internal temperature from falling below a set-point T_d, a different form of Eq. (12) should be used:

$$T_m(t) - T_m(t-\Delta t) e^{-\Delta t/\tau''} = T_d (1 - e^{-\Delta t/\tau''}) \quad (14)$$

$$\tau'' = C\,R_{in} \quad (15)$$

The internal temperature (or the air conditioning load, depending on the mode of operation) can then be calculated from a heat balance:

$$K(T_i - T_o) + (T_i - T_m)/R_{in} = Q_{sol} + Q_{int} - Q_p - Q_{ac} \quad (16)$$

BUILDING AND PASSIVE COOLING CONFIGURATIONS

The analysis of the thermal behavior of a passively cooled Israeli residential building is based on a 10m x 5 m rectangular apartment, having a 4 m^2 single glazed window on the southern elevation and 2.5 m^2 on the northern elevation. The external envelope was assumed to consist of 20 cm thick white Ytung walls and a 15 cm concrete flat roof with 4 cm insulation over it. The house is built on a 15 cm slab on the ground. Internal loads were assumed to consist of three people during the whole of the 16 hours and 200 W lighting during the evening hours. Infiltration was taken to be equal to 0.6 air change per hour. The climate assumed is the one of the relatively humid coastal area. The climatic data are based on the "average" year of Schweitzer (1976) for the coastal area and emphasis is on two typical days: the 15th of August, a typical average summer date and the 21st of May, on which particularly hot "Sharav" conditions prevail, which are considered by many as the most uncomfortable days in Israel. Three passive cooling strategies were considered:

a. Natural Ventilation, i.e. a ventilation of 2 air changes per hour (ACH) when the outside temperature is lower than the internal temperature, but internal temperature is higher or equal to the set-point.

b. Night Ventilation, i.e. a ventilation rate of 3-10 ACH during night hours only.

c. Ground cooling through buried pipes. One and three pipes of 10 cm radius and 10 m. length, with an air velocity of 4 m/s were considered. Air flow through the pipes is thermostatically controlled and is discontinued if the pipe outlet temperature is higher than the building internal temperature or the cooling set-point temperature.

d. Combinations of Night Ventilation and Ground Cooling. In every case, both air-conditioned buildings (cooling set-point temperature 25°C) and non-air conditioned buildings (free-floating temperature) were considered.

RESULTS

In Figures 2-4, the variation of the the air temperature for a building cooled using natural or night ventilation and/or air going through the ground is shown for different amounts of ventilation and for different numbers of pipes, for the average summer day both in Beit-Dagan and for Sharav conditions. The results are summarized in Table 1, both for air-conditioned and non-air conditioned buildings: In the former case, the effect of passive cooling is quantified using the daily cooling load required to prevent the temperature from increasing above 25°C, whereas in the latter case the daily cooling degree hours (Centigrade above 28°C).

In Figure 1, the effect of using natural ventilation or different amounts of natural ventilation in Beit-Dagan is shown. For the regular summer day, it is seen that even a modest amount of night ventilation is capable of eliminating the cooling load for almost all the day. For the Sharav day, a much larger amount of night ventilation cannot eliminate the cooling load completely, but reduces it by almost 80%.

In Figure 3, the effect of using ground cooling by circulating air in buried pipes is shown. For the regular summer day, it is seen that one pipe is sufficient to eliminate all the cooling load for a non-air conditioned building. For the Sharav day, the cooling degree hours are reduced by 80% by using one buried pipe and are almost reduced to zero when three buried pipes are used, for an outside temperature of above 40°C.

In Figure 4, the combined effect of ground cooling and night ventilation is shown to be relatively small for the regular day, in comparison to using each of the two methods separately. For the Sharav day, on the other hand, it is shown that to completely eliminate the cooling load, simultaneous use of both night ventilation and ground cooling is necessary.

For air conditioned buildings, the effect of using passive cooling techniques is shown in Table 1 to be much less spectacular, especially in the very hot day, when using a high amount of night ventilation and buried pipes only reduces cooling load by 50%. The main reason is that in an air-conditioned building, the comfort requirements are much higher and usually one strives to a maximum temperature of 25°C or lower. In a naturally cooled house, a 28°C temperature combined with some moderate air movement is considered sufficiently comfortable.

DISCUSSIONS AND CONCLUSIONS

A simplified, one zone model has been developed, which is capable of assessing the thermal behaviors of both air conditioned and non-air conditioned buildings when passive cooling methods are used. The computer program based on the method has very small computer resource requirements and can run on a 286 PC compatible with an almost immediate response. The method is based to a large extent on the NORMA and COOL-C programs, but contains some changes which account for the thermal storage properties of a building.

Similar results were obtained using the ESP program for a similar building (Hassid, 1994). This gives us confidence in using the computer program described in this work.

The thermal performance of a passively cooled typical Israeli building is shown for several cooling strategies. It is shown that in most cases, summer comfort during the cooling season can be reached using passive methods, which can reduce the internal temperature by 2-3°C and thus bring it into the comfort region. This is particularly so on the Sharav day when comfort can be achieved in spite of very difficult conditions outside. In many cases comfort can be further improved by using ventilation (natural or mechanical) to increase comfort at the same temperature, due to a higher air velocity.

Although evaporative cooling is not treated in this particular work, it can easily be incorporated in the algorithm: in fact, its treatment should be very similar to the one of buried pipes, with the wet bulb temperature taking the place of the ground temperature. A treatment of evaporative cooling should be complemented with a moisture balance, in addition to the thermal balance, so that the operation of the evaporative cooler is discontinued when the relative humidity becomes uncomfortably high.

Of course, it should be stated that the potential of passive cooling cannot always be realized cost-effectively. The estimated ground cooling is also based on a rather large pipe area and it can be expected that the effect will be rather smaller. On the other hand, it can be seen that a combination of the above methods can be used to significantly improve comfort during the hot season.

It can therefore be concluded that one is justified to further investigate the potential of passive cooling methods in Israel, both as add-on methods to conventional systems but especially as methods standing by themselves, given the lower comfort requirements in such a case.

ACKNOWLEDGEMENT

The author is indebted to Profs. M. Santamouris and Prof. D. Asimakopouos for letting him use NORMA and COOL-C, developed in the frame-work of the PASCOOL project.

This research was supported by the Fund for the Promotion of Research at the Technion.

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Table 1

Daily Energy Consumption (for buildings air conditioned to 25°C) and Daily Cooling Degree Hours above 28°C (for non-air conditioned buildings in Beit-Dagan for different passive cooling methods

	kWh(A/C)		CDHs(Non-A/C)	
	Regular	Hot	Regular	Hot
Base Case	18	41	11	115
Natural Ventilation	17	40	7	80
Night Ventilation, 3 ACH	14	35	0	64
Night Ventilation, 10 ACH	9	29	0	22
Buried Pipes - 1	8	35	0	31
Buried Pipes - 3	0	28	0	5
Night Ventilation (3 ACH) & Buried Pipes(1)	0	30	0	21
Night Ventilation (10 ACH) & Buried Pipes(3)	0	21	0	2

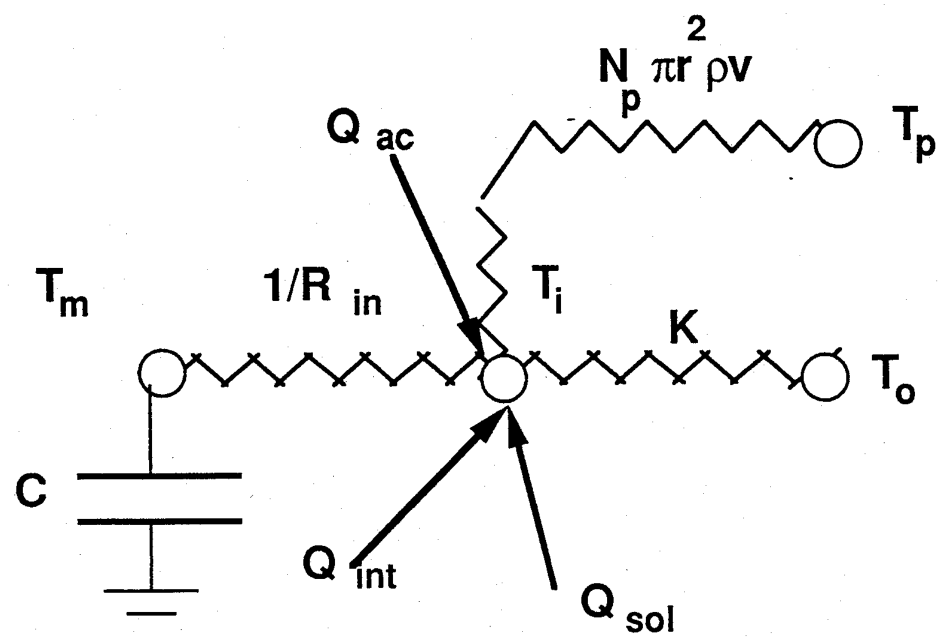
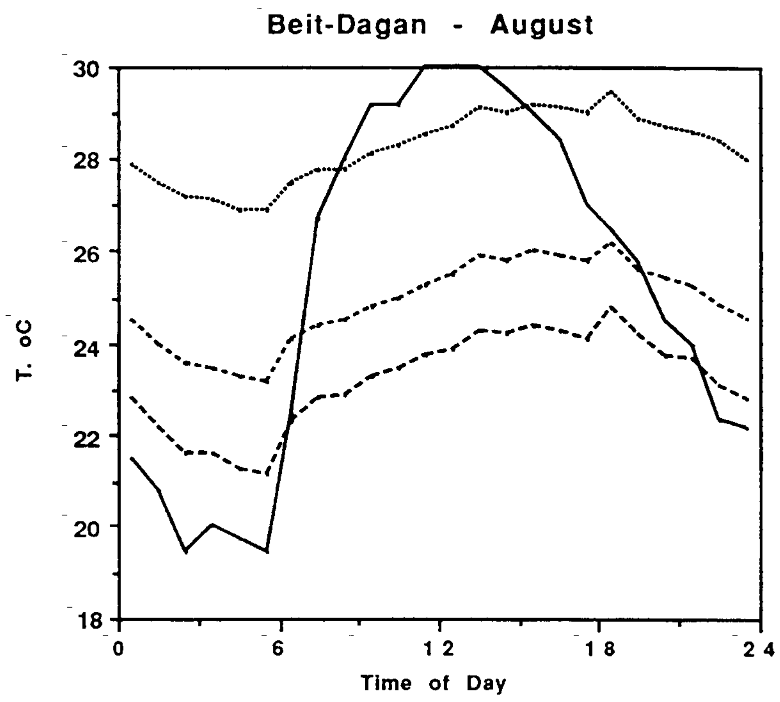


Figure 1. Building Electric equivalent



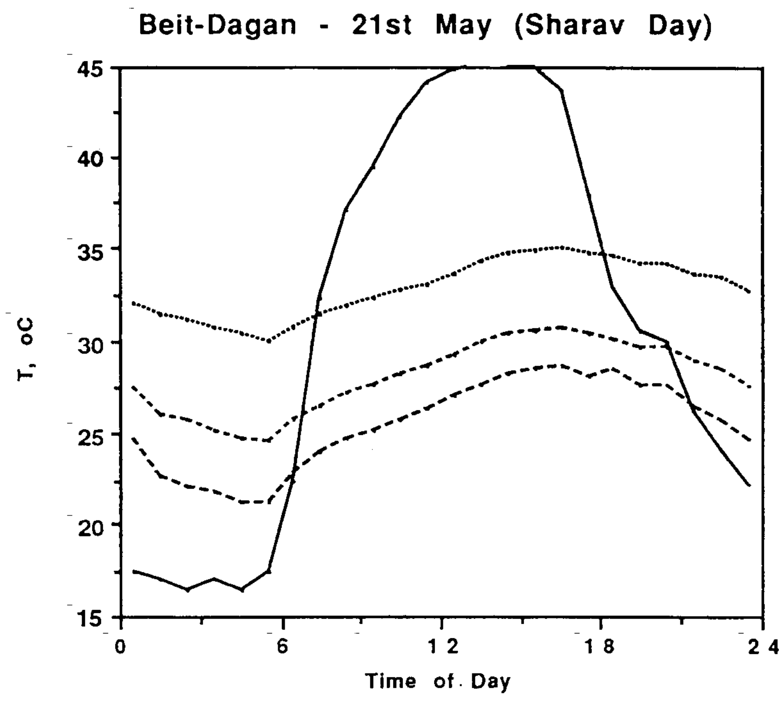


Fig.4. Effectiveness of Combined Night Cooling and Ground Cooling through Burried Pipes in Beit-Dagan (Coastal Area) on a. an average day b. A very hot date. ———— Outside Temperature. ······ Internal Temperature, No Ground Cooling
- - - - Internal Temperature, 3 ACH and 1 pipe. – – – –, Internal Temperature, 10 ACH and 3 Pipes.

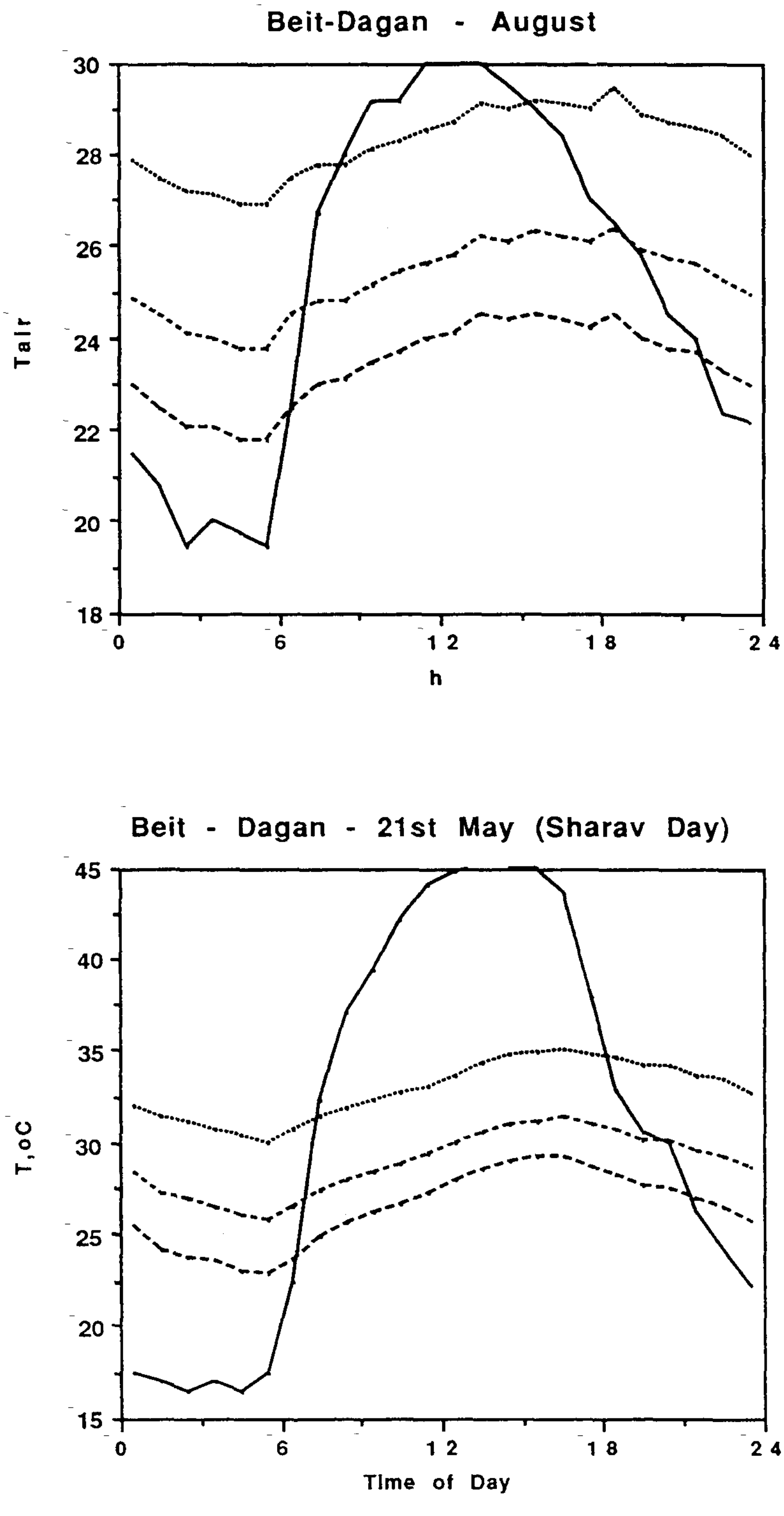


Fig.3. Effectiveness of Ground Cooling through Burried Pipes in Beit-Dagan (Coastal Area) on a. an average day b. A very hot date. ——— Outside Temperature. ······ Internal Temperature, No Ground Cooling - - - - Internal Temperature, 1 pipe. – – – –, Internal Temperature, 3 Pipes. 10 cm radius, 20 m long pipe buried at a depth of 4 m. under the ground.

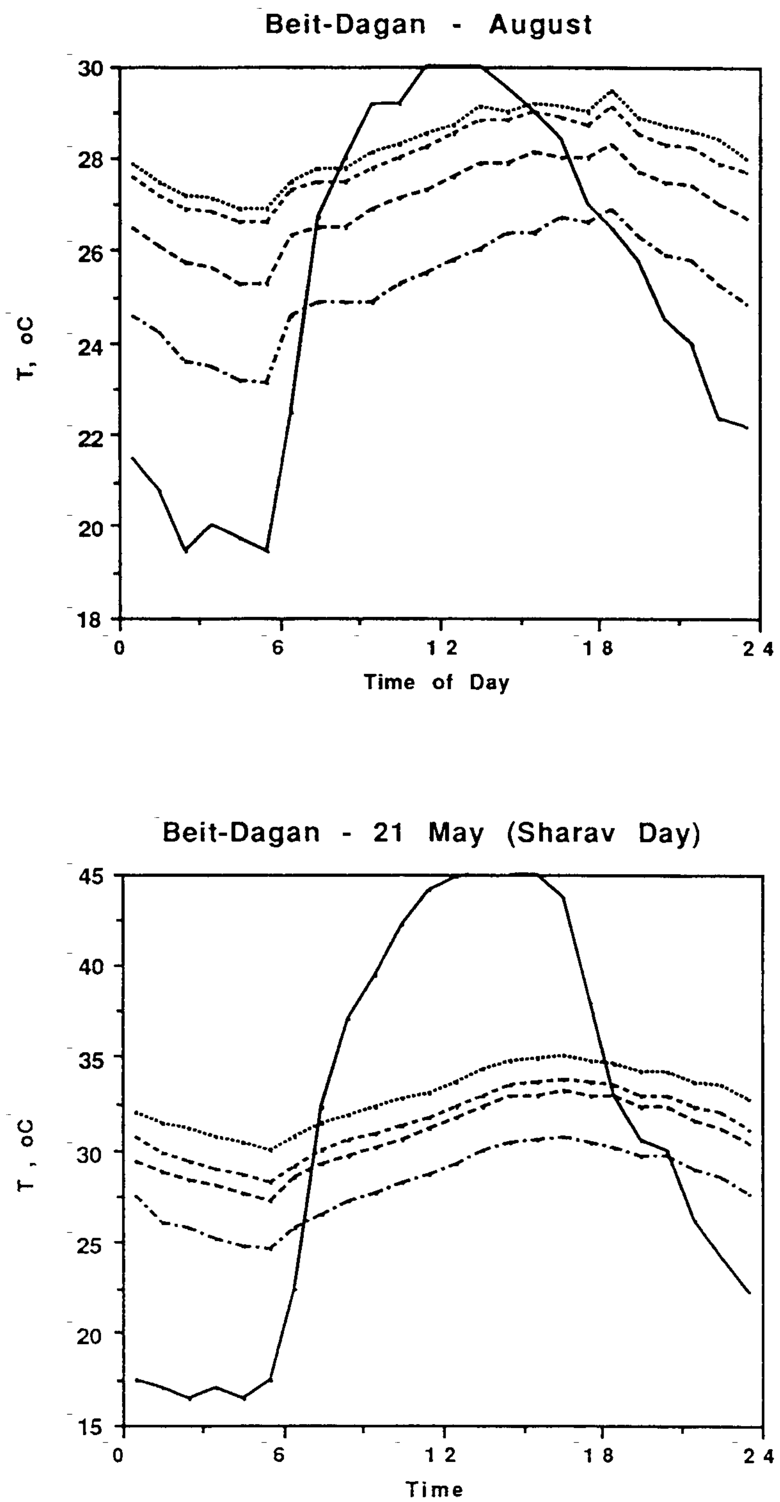


Fig.2. Effectiveness of Natural and Night Ventilation in Beit-Dagan (Coastal Area) on a. an average day b. A very hot date. ——— Outside Temperature. ······ Internal Temperature, No Natural or Night Ventilation - - - - Internal Temperature, Natural ventilation (2ACH). Internal Temperature– – – –, Night Ventilation (3 ACH). -·-·-·-·. Internal Temperature, Night Ventilation (10 ACH).