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Effects of Heating Patterns on Internal Surface Temperatures and Risk of Condensation

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The paper presents the method employed in order to investigate the effects of various heating patterns and schedules on internal surface temperatures of internal partitions and external walls. It shows that the dew point temperatures in dwellings are usually lower in cold weather, thus, in the more moderate zones, where dwellings are usually heated only intermittently, and thermal insulation levels are generally lower, the problem of surface condensation on walls may be more frequent. A dynamic thermal analysis was performed for various levels of thermal insulation and inertia of external walls, for intermittent heating schedules as well as for continuous heating. The most suitable heating schedules were derived for typical levels of thermal insulation. The results of the dynamic analysis indicate that, for the same heating schedules and living habits, lightweight walls require a larger thermal resistance, by 0.5 to 0.75 m² °C/W, in order to provide the same level of protection against surface condensation. The paper shows also that, for the same building, in the cool climatic zone, more heating hours are necessary on warmer days than on the regular cool days in order to cope with the problem of surface condensation.

INTRODUCTION

THERMAL insulation standards dictate minimum levels of thermal insulation, assuming that thermal comfort is ensured by active heating, and that the task of the insulation is to save energy. In "moderate" and "cool" winter areas, one can usually achieve tolerable internal conditions without continuous heating, and as a consequence the most common heating pattern in Israel and similar climatic zones is late evening heating, between 18.00 to 23.00 [1, 2]. However, analysis of the effects of different heating patterns on the efficiency of energy utilization and cost of electrical power vs. overall thermal comfort [3] has indicated that optimal schedules do not necessarily coincide with the existing habits. Moreover, for many years the problem of surface condensation, and its pathological consequences, have been attributed to factors affected by the building construction, e.g. poor thermal insulation of the building's envelope, the increased air tightness of windows, and the use of particular renderings and paints [4, 5]. User induced factors that have been usually investigated are: moisture producing activities [6], and ventilation habits [7], but the effects of different heating patterns on surface temperatures and risk of condensation have not been addressed. The present paper suggests a methodology for investigating the influence of this last factor, and presents results and conclusions that may be of general interest, indicating that existing habits of heating which are usually intended to achieve minimum thermal comfort are not necessarily adequate for prevention of surface condensation.

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SETTING THE LIMIT SURFACE TEMPERATURES

Surface temperatures below dew point are responsible for the occurrence of surface condensation in buildings. Dew point temperatures are determined by the internal absolute humidity, p_i (kg H_2O/kg dry air). For a given dwelling the value of p_i at time t can be derived quite accurately from:

$$p_i = p_0 + \frac{S}{\rho N_p V} + \frac{1}{\rho N_p V}\int_{t_1}^{t} \frac{\mathrm{d}W}{\mathrm{d}\tau}(1 - e^{-N_p(t-\tau)})\,\mathrm{d}t \quad (1)$$

where: p_0—is the external absolute humidity (kg H_2O/kg dry air).
S—is a constant humidity source (kg H_2O/h).
ρ—is the density of air (1.24 kg/m³).
V—is the net volume of air within the unit (m³).
W—is a non-constant humidity source (kg H_2O/h).
t_1—is the starting time of W.
N_p—is the equivalent rate of air change within the unit (h⁻¹), and is given by:

$$N_p = N + \frac{\Sigma P_j A_j}{\rho V} \quad (2)$$

where: P_j—is the permeance ((kg H_2O/m²h) per (kg H_2O/kg dry air)) of the j'th envelope part with area A_j (m²).
N—is the rate of air change within the unit (h⁻¹).

However, in most actual cases [8]:

Table 1. Difference between p_i and p_0 (kg H_2O/kg dry air) for various combinations of V, S, W, and N_p

Case Symbol	V (m^3)	S (kg H_2O/h)	W (kg H_2O/h)	N_p (h^{-1}) 0.5	1.0	Comments
S1	20	0.050	—	4.0×10^{-3}	2.0×10^{-3}	Single person bedroom
S2	25	0.100	—	6.4×10^{-3}	3.2×10^{-3}	Two-person bedroom
S3	30	0.150	—	8.1×10^{-3}	4.0×10^{-3}	Three-person bedroom
M1	100	0.150	0.150	3.0×10^{-3}	2.1×10^{-3}	Morning activity in small dwelling
M2	150	0.250	0.150	2.7×10^{-3}	1.9×10^{-3}	Morning activity in medium dwelling
M3	250	0.300	0.200	2.0×10^{-3}	1.4×10^{-3}	Morning activity in large dwelling
E1	100	0.150	0.200	3.6×10^{-3}	2.4×10^{-3}	Evening activity in small dwelling
E2	150	0.250	0.250	3.4×10^{-3}	2.3×10^{-3}	Evening activity in medium dwelling
E3	250	0.300	0.250	2.2×10^{-3}	1.5×10^{-3}	Evening activity in large dwelling

$$\frac{\Sigma P_i A_i}{\rho V} \ll N \qquad (3)$$

and the value of N_p almost equals N.

Formula 1 actually assumes that in winter the absolute humidity, p_0, and actual and equivalent air change rates, N and N_p, are quasistatic in comparison to the dynamics of the condensation problem.

The cooler the weather, the lower the values of p_0; thus, for similar buildings with equal human activity, internal humidities p_i will be significantly larger in warm winter areas. Dew point temperatures are also larger, and as a consequence the surface temperatures of all the building elements should be maintained at higher levels in order to prevent surface condensation. Table 1 summarizes some typical values of $p_i - p_0$ in dwellings during typical activities. Table 2 presents the dew point temperatures for these activities in different climatic zones (defined by the values of p_0). The case symbols in Table 2 are according to their definitions in Table 1. From the examples one can see that, in "very cold" weather, the dew point temperatures are so low that the need for thermal comfort will usually result in surface temperatures well above the possible dew point temperatures. In "cool" weather dew point temperatures do not usually exceed 12.5°C except in non-ventilated congested bedrooms. Ensuring at least 1 air change per hour in the latter, and maintaining surface temperatures above 12.5°C, will usually enable the prevention of surface condensation in this type of weather. In "warm" weather, surface temperatures should be maintained above 15.5°C, and a 1 h^{-1} ventilation rate of congested rooms is essential. In "warm" and very humid weather high rates of ventilation ($N \geqslant 1$ h^{-1}) are essential, and even then surface temperatures should be maintained at very high levels (> 16°C). From these brief examples it is obvious that one way of fighting surface condensation, in all climatic zones, may be lowering internal humidity by increasing ventilation rates. But since this energy-waster lowers thermal comfort and lowers surface temperatures, it has been found in many cases ineffective, and sometimes even causative to the problem of surface condensation [4]. The other way of lowering the risk of surface condensation is maintaining elevated surface temperatures by relevant heating strategies, without increasing ventilation rates. This is automatically the case in "very cold" climatic zones. It is not a relevant means in "warm and very humid" zones. However, in "cool" and "warm" zones it may be a very effective means, but an in-depth study has been required in order to investigate the effects of various heating patterns on surface temperatures of various construction types before any

Table 2. Typical values of dew point temperatures (°C) for the various typical activities

Case symbol	P_0* (kg H_2O/kg dry air) $<10^{-3}$ $N = 0.5$	$<10^{-3}$ $N = 1$	5×10^{-3} $N = 0.5$	5×10^{-3} $N = 1$	7×10^{-3} $N = 0.5$	7×10^{-3} $N = 1$	9×10^{-3} $N = 0.5$	9×10^{-3} $N = 1$
S1	0.5	<0	12.5	8.8	15.6	12.5	18.0	15.6
S2	7.5	<0	16.3	11.0	18.5	14.5	21.0	17.1
S3	11.0	0.5	18.3	12.5	20.6	15.6	22.5	18.0
M1	<0	<0	10.8	8.9	14.3	12.7	16.9	15.7
M2	<0	<0	10.0	8.5	13.8	12.3	16.5	15.3
M3	<0	<0	8.8	7.5	12.5	11.7	15.6	14.9
E1	<0	<0	11.8	9.6	15.0	13.3	17.6	16.1
E2	<0	<0	11.5	9.7	14.8	13.2	17.4	16.0
E3	<0	<0	9.2	7.7	13.0	11.8	15.9	15.0

*—0 is typical of "very cold" weather.
—5×10^{-3} stems from 90% at 5°C or 80% at 7°C, and is typical of "cool" winter weather.
—7×10^{-3} stems from 90% at 10°C, or 80% at 12°C and is typical of "warm" winter weather in the Mediterranean area.
—9×10^{-3} stems from 90% at 14°C or 70% at 18°C and is typical of very moist and warm winter zones (the tropics).

recommended strategies could be derived. The paper is devoted to investigating this topic for the "cool" and "warm" zones only.

Heating systems, however, are set according to overall air temperature and not according to local surface temperatures. There are small variations in set-point temperatures which stem from individual differences, but in general their values have been determined since the 1973 energy crisis on a national basis (21.1°C in the U.S.A., 20°C in many European countries, and 18°C in Israel). We thus assume that, during heating periods, the internal air temperature is constant, and the daily variations of surface temperatures of all the elements follow from it.

ANALYSIS OF TYPICAL CASES

In order to investigate the effects of various heating patterns on the hourly variations of internal surface temperatures, a dynamic thermal analysis must be performed by a computer program that can simulate these effects with reasonable accuracy. It was found that the American TARP [9, 10, 11] is fit for this purpose. The program consistently overestimates the thermal inertia of the external walls, and underestimates the overall inertia of the whole building, but this is only of minor significance since its predictions of internal surface temperatures in a real building, subjected to various heating patterns over a period of three months, were excellent (within ±0.5°C of measured data for the internal partitions, ±0.4°C for the eastern walls, and ±0.7°C for the northern walls).

Field surveys have shown [4] that surface condensation does not occur on southern walls in dwellings with an obvious southern orientation and significant solar gains. We have thus limited the investigation to non-southern dwellings, and performed the analysis on the north-eastern block of dwellings presented in Fig. 1.

Three heating patterns, with varying schedules, have been considered:

—Heating operated during one period that starts at 18.00 or earlier and ends at 23.00. The number of heating hours varies between 5 to 23. This pattern is denoted by "One Period Intermittent Heating".
—Heating operated during two periods, one of them, the "morning–night period", starts at 6.00 or earlier and ends at 8.00. The "afternoon–evening period" starts at 18.00 or earlier, up to 15.00, and ends at 23.00. Each period consists of mostly 8 hours of heating. This pattern is denoted by "Two Period Intermittent Heating".
—Continuous heating around the clock, denoted by "Continuous Heating".

The analysis was performed for two types of winter weather, a "moderate" winter, as presented by the data of Tel Aviv, and a "cool" winter, as presented by the data of Jerusalem. Typical external air temperatures are given in Fig. 2.

A building of generally heavyweight construction, with different types of external walls, was considered. The combinations of thermal insulations and thermal inertias are given in Table 3. Symbols for walls and floors are S and D which denote symmetric and non-symmetric elements respectively. The first number to the right of the letter is 100 times the face-to-face thermal resistance, *r* (m^2°C/W), of the elements. The second number is the face-to-face thermal time constant, TTC, from the outside towards the inside (hrs). For the D type elements the third number is the face-to-face thermal time constant from inside towards outside. All external wall elements were "sandwich" elements composed of a thermal insulation layer of expanded polystyrene (with a thickness relevant to the *r*-values) enclosed between two layers of concrete, whose thickness varied between 10 to 100 mm to provide the relevant TTC-values. Bottom floors were composed of a 200 mm concrete slab with thermal insulation underneath. Roof ceiling was composed of the

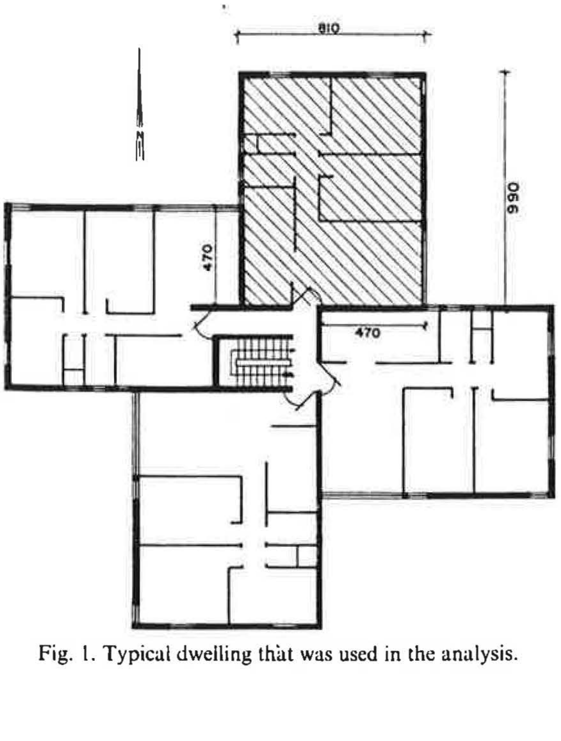

Fig. 1. Typical dwelling that was used in the analysis.

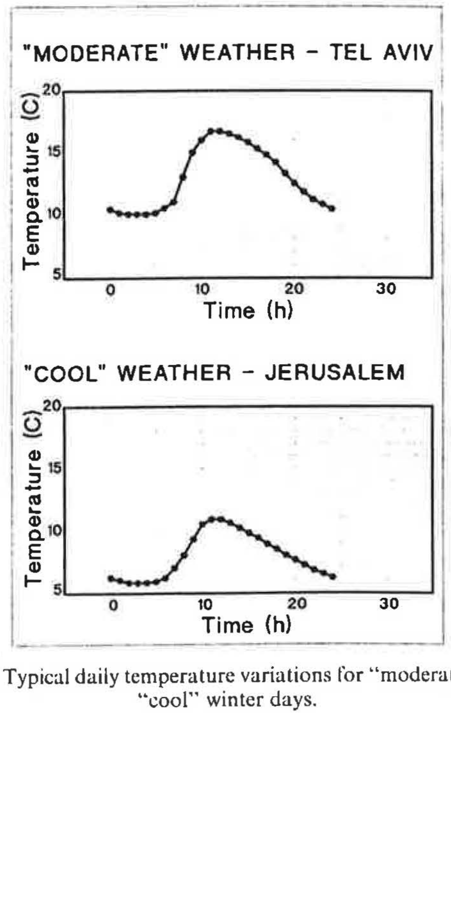

Fig. 2. Typical daily temperature variations for "moderate" and "cool" winter days.

Table 3. Definition of building types and combinations of analyzed factors

Symbol of Building Types	Type of Building Elements			Climatic Conditions*
	External Walls	Roof	Bottom Floor	
HH 26-19	S 16-29	D 51-56-10	S 10-10	TV
HH 51-33	S 51-33	D 51-56-10	D 51-56-10	TV, Jer
HH 76-47	S 76-47	D 76-65-07	D 76-61-10	TV, Jer
HH 101-43	S 101-43	D 101-58-04	D 101-58-04	Jer
LH 51-03	S 51-03	D 51-56-10	D 51-56-10	TV, Jer
LH 76-05	S 76-05	D 76-65-07	D 76-61-10	Jer
LH 126-08	S 126-08	D 51-56-10	D 51-56-10	TV, Jer
LH 151-10	S 151-10	D 76-65-07	D 76-61-10	TV, Jer

* TV—denotes Tel Aviv.
Jer—denotes Jerusalem.

same slab, but with the insulation on top. Internal partitions were composed of plastered block walls, and intermediate floors were composed of 200 mm concrete slabs.

Graphs of temperatures vs. time can be used for the analysis of behavioural effects. Figure 3 presents some typical results for the interior air temperature, internal partitions' surface temperature and northern wall's internal surface temperature for a building with heavyweight external walls ($r = 0.51$ m^2°C/W, TTC = 33 hrs) in the "moderate" winter of Tel Aviv. Figure 4 presents the results for lightweight walls (TTC = 3 hrs) with the same thermal resistance. Figures 5 and 6 present the results for the same cases in the "cool" climatic zone of Jerusalem.

Between the unheated situation and the "continuous" heating are encapsulated all the other heating schedules. In order to avoid ambiguity, we have presented in the graphs only two "one period" schedules (the late evening schedule of 5 heating hours, from 18.00 to 23.00, and the afternoon-night schedule of 16 hours, from 16.00 to 8.00) and two "two period" schedules (both with 2 hours of morning heating, from 6.00 to 8.00, one of them with only late evening heating, and the other with earlier afternoon heating). A comparative study of the results indicates that:

—The general variation of the internal air temperature, and mainly the amplitude of passive air temperature fluctuations, depend strongly on the overall thermal inertia of the building, and only to a minor extent on the thermal inertia of the external walls. It is evident that the walls' inertia affects only the absolute values of the amplitude, but does not affect at all the phase difference between external and internal extreme temperatures. For all cases, when early morning or night heating are not applied, minimum internal air temperatures occur at 5.00 to 7.00 in the morning.

—The effect of the thermal inertia of the internal partitions is manifested by their surface temperatures not coinciding with the air temperature, mainly for the various intermittent heating patterns. In addition, for the unheated case, it is obvious that there is a very slight (approximately 1 hour) phase difference between their temperature and the internal air temperature (this is not affected at all by the thermal inertia of the external walls). At the beginning and end of the heating periods, despite the abrupt changes in the air temperature, the partitions do not follow suit, and their surface temperature changes very moderately (approximately 0.25°C/h). As a result, their temperature is higher than the air temperature during non-heated periods and lower than the air temperature during the heated periods.

—As mentioned above, the thermal inertia of the external walls hardly affects the phase and magnitude of the internal air temperature and surface temperature of the internal partitions, but it has a strong effect on the temperature of the wall's internal surface itself. From Figs 3B and 3C, or 5B and 5C, one can see that the variation of the surface temperature of the heavyweight walls is very similar to that of the internal partitions, except that the rise during heating periods is somewhat more moderate. Comparison of Figs 3C and 4C, or 5C and 6C, indicates clearly that the surface temperatures of the lightweight walls are strongly influenced by the changes in external air temperature, and are hardly affected by the large overall thermal inertia of the building. This is manifested, for the unheated case, mainly by the lack of a phase difference in comparison to the external air temperature, and for the heated cases—by the significant temperature increase during the non-heated period of 8.00 to 13.00. Moreover, during the afternoon and evening heating hours, there is an immediate response (within 1–2 hours) to the application of heating, but afterwards the decreasing external temperature manifests itself, and the dynamic balance between internal power supply and drop in external temperature result in decreasing surface temperatures in the "moderate" climatic zone, and a constant, or even somewhat increasing surface temperature in the "cool" climatic zone. This is explained by the fact that the external air temperature drop in the "cool" zone is less than 0.4°C/h, whereas in the "moderate" zone it is approximately 1°C/h.

—Addition of all the graphs for the various heating patterns and schedules on the figures will only obscure the information, and prevent any clear observations. We thus assume that, for any practical analysis, the surface temperatures at 7.00 and 20.00 can represent the risk of condensation on walls in the living quarters during the morning and evening activity periods, and that the minimum night-time temperatures—the risk of condensation on bedroom walls at night.

The effects of the various heating patterns on the 7.00 and 20.00 temperatures are summarized in Figs 7, 8, 9

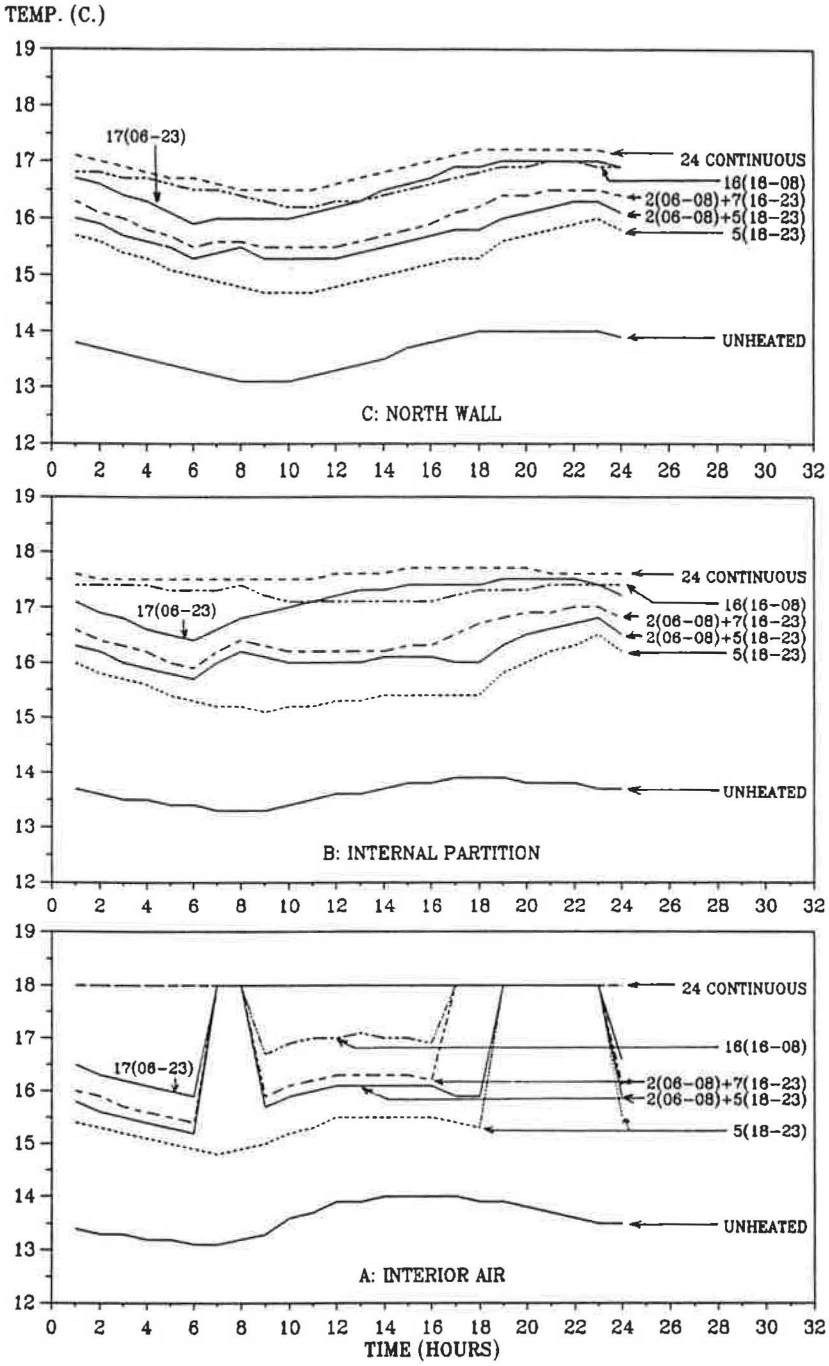

Fig. 3. Temperature variations for a building with heavyweight walls (HH 51-53) in "moderate" weather (Tel Aviv).

and 10, for building types HH 51-33 and LH 51-03 in the "moderate" and "cool" climatic zones. The dashed lines are for the 7.00 temperatures and the full lines graphs are for the 20.00 temperatures. The lines with asterisks are for the "one period" heating pattern, with the last point on these lines being for the "continuous" heating pattern. The "two period" heating patterns are denoted by rhomboids for the evening period starting at 18.00, by circles for 17.00, by squares for 16.00, and by triangles for 15.00. The effects of the heating patterns on the minimum night time temperature are presented in Fig. 11. It was observed that all the graphs of the minima for the HH type buildings, and the graphs of minima for internal partitions in the LH type buildings, are actually very similar to those of 7.00 temperatures, and no additional information or conclusions are expressed by them. Figure 11 thus includes only the results for the external north wall of building LH 51-03. The following observations are of general interest:

—For the HH type building—the general variations along the graphs for external walls and internal partitions are very similar.

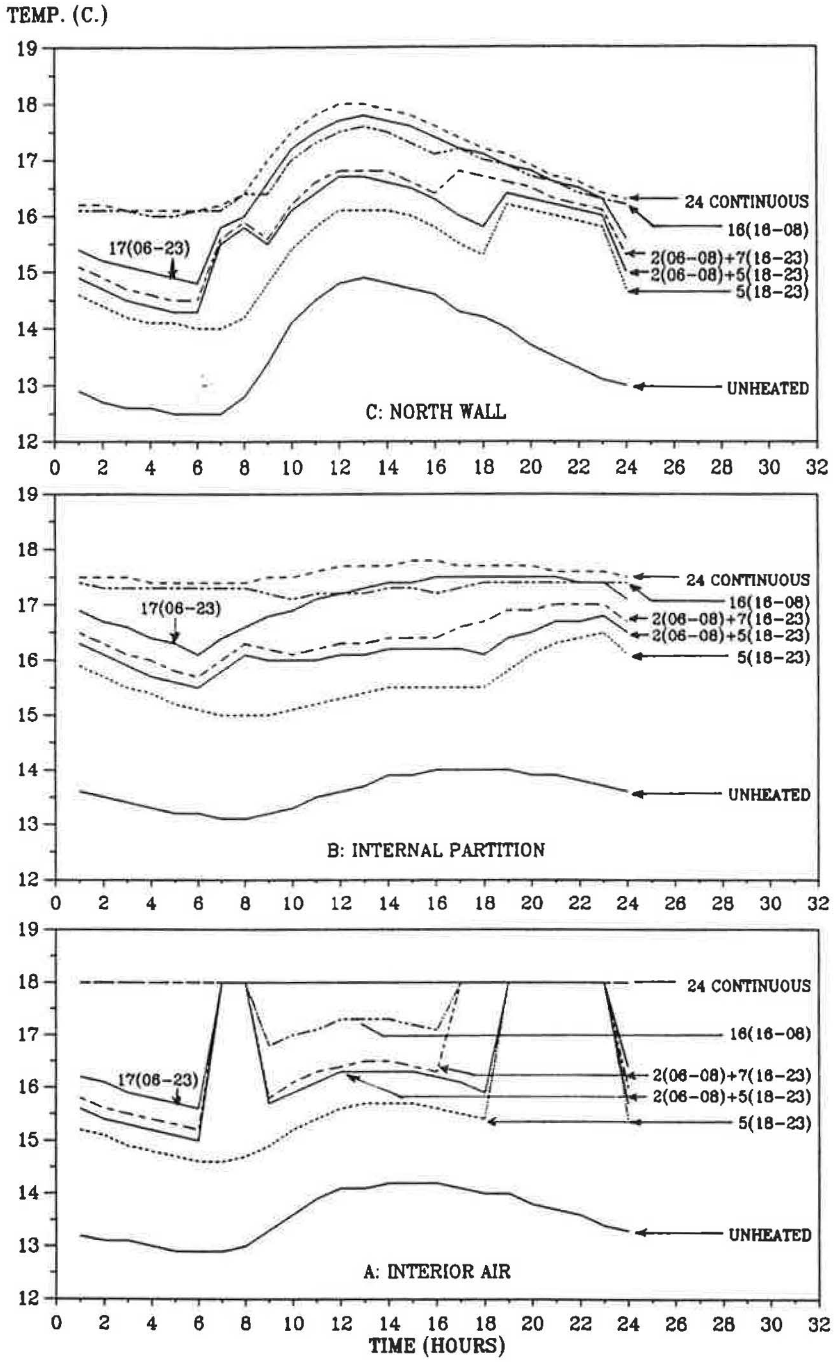

Fig. 4. Temperature variations for a building with lightweight walls (LH 51-03) in "moderate" weather (Tel Aviv).

—The graphs for internal partitions of LH type buildings are almost identical to those of HH type buildings.
—For the "one period" heating—the morning temperatures of the lightweight walls are significantly lower than those of the heavyweight walls with the same level of thermal insulation. The evening temperatures, on the other hand, are higher when heating is during less than 12 hours, and lower when longer heating periods are applied.
—In both types of weather, the "two period" heating is obviously more effective in raising the minimum and morning temperatures, than the "one period" heating, and this is even much more significant for the lightweight walls of the LH type building.
—In "moderate" weather the evening temperature is mainly affected by the total number of heating hours, and not so much by the type of heating pattern. This is true for all walls in all buildings.
—In "cool" weather the "one period" heating pattern is obviously more effective in raising the evening tem-

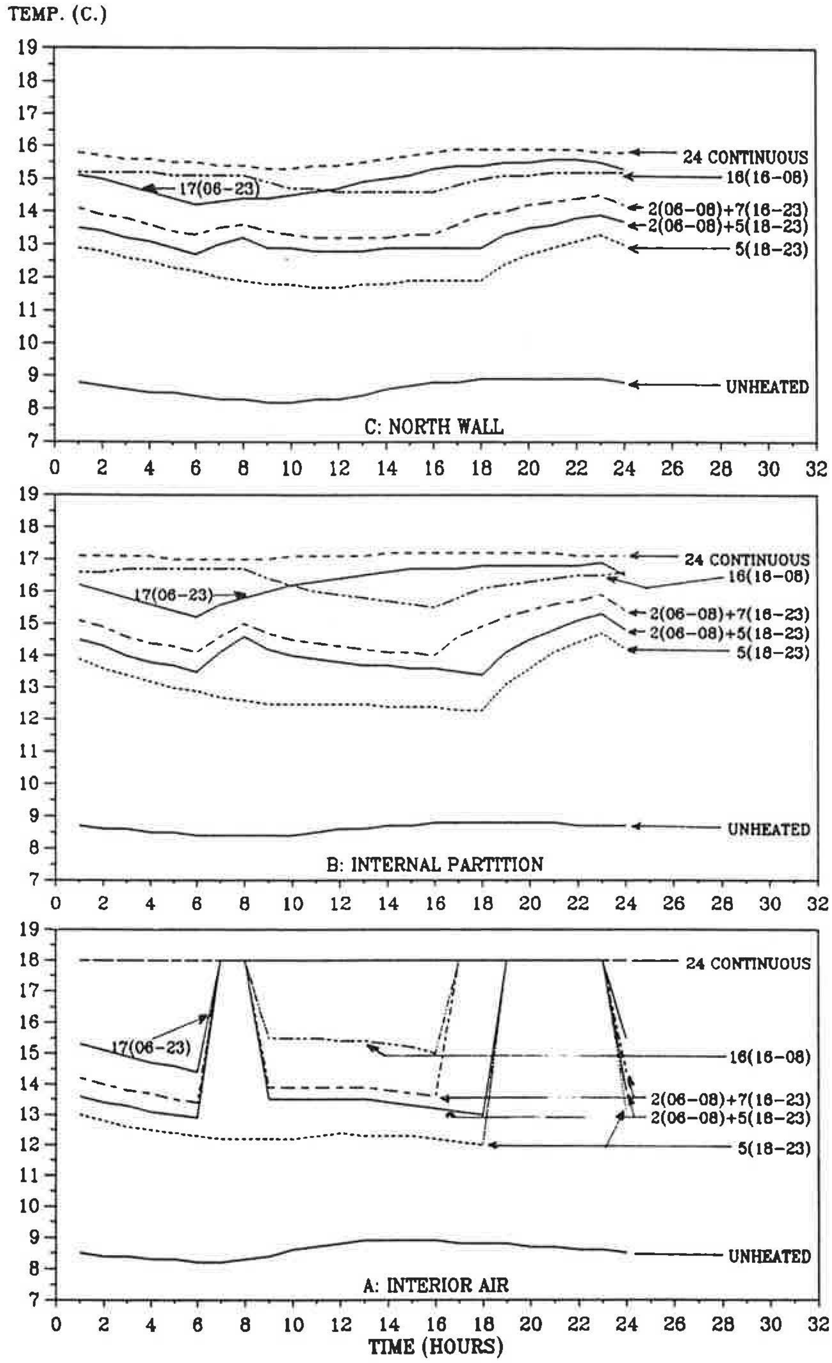

Fig. 5. Temperature variations for a building with heavyweight walls (HH 51-33) in "cool" weather (Jerusalem).

peratures, than the "two period" heating, with the difference somewhat more pronounced for the heavyweight walls than for the lightweight walls.

—The minimum and morning temperatures achieved with the maximum heating hours of the "two period" heating patterns are almost equal to those achieved with "continuous" heating. The graphs of evening temperature for "one period" heating almost level off after 20 hours of heating in HH type buildings, and after 18 hours in LH type buildings. These two observations indicate that, from the point of view of surface condensation prevention, it is hardly ever necessary to apply "continuous" heating.

—For "one period" heating, morning temperatures are much lower than evening temperatures. For "two period" heating with a total of 10 heating hours or more, the difference between morning and evening temperatures decreases significantly.

For different levels of thermal insulation all the observed trends were exactly the same as listed above except, of course, that the absolute values of the various

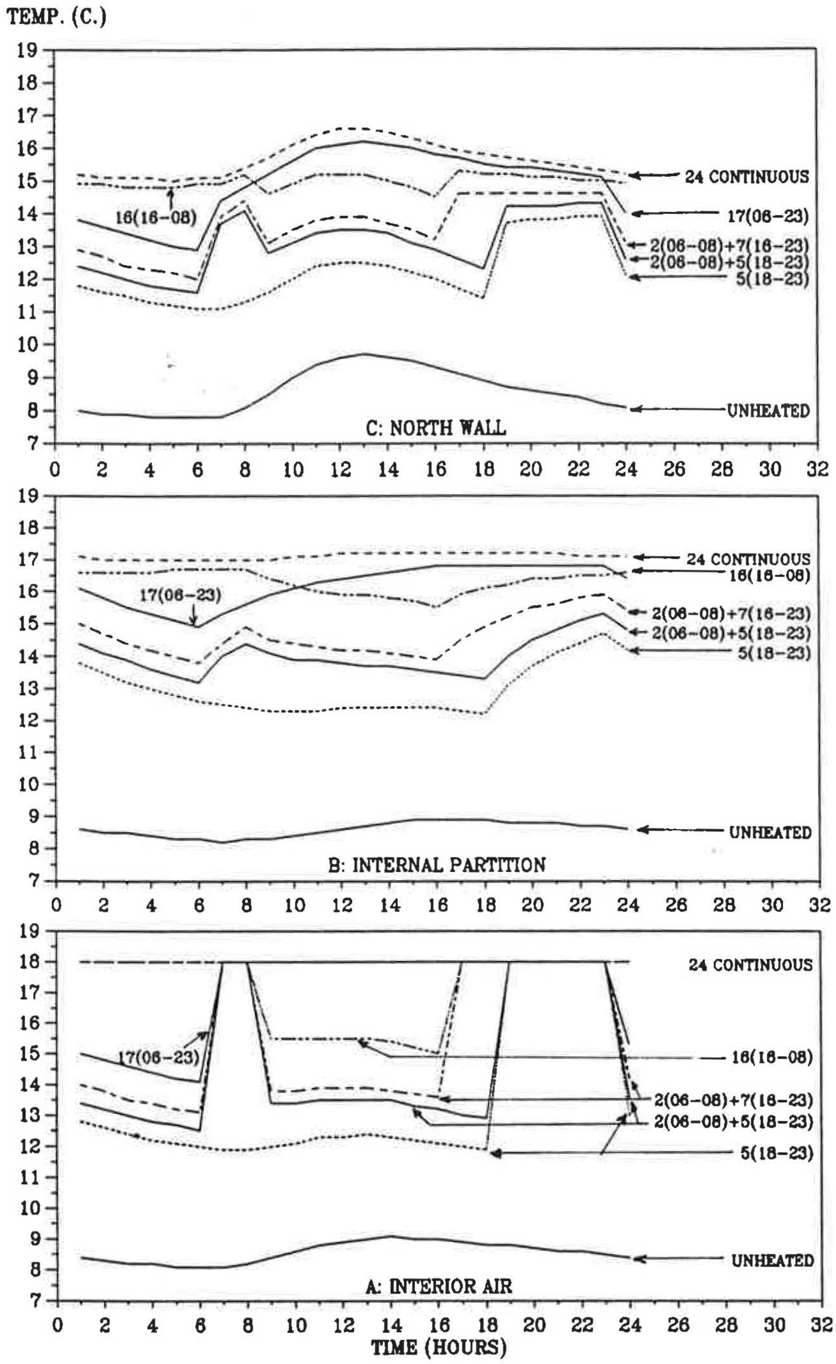

Fig. 6. Temperature variations for a building with lightweight walls (LH 51-03) in "cool" weather (Jerusalem).

temperatures are larger. An example of the effect of the thermal insulation levels on the internal surface temperatures of external walls is given in Fig. 12. Values are given at 4.00, 7.00 and 20.00 for the unheated, continuously heated, and 5 hour evening heating between 18.00 to 23.00. Full lines are for the heavyweight north wall of HH buildings, and dashed lines for the lightweight north wall of LH buildings. All data are for the "cool" climatic zone. The main observations are:

—Night and morning surface temperatures of heavyweight walls are usually higher (by up to 1°C) than those of lightweight walls. Evening temperatures are almost indifferent to inertia for the unheated and continuously heated cases. But for intermittent heating patterns, evening surface temperatures of lightweight walls are higher (by up to 1°C) than those of heavyweight walls.

—In an unheated dwelling, surface temperatures are almost indifferent to the thermal insulation of the external walls, with the heavy walls being usually warmer (by up to 0.75°C) than the light walls.

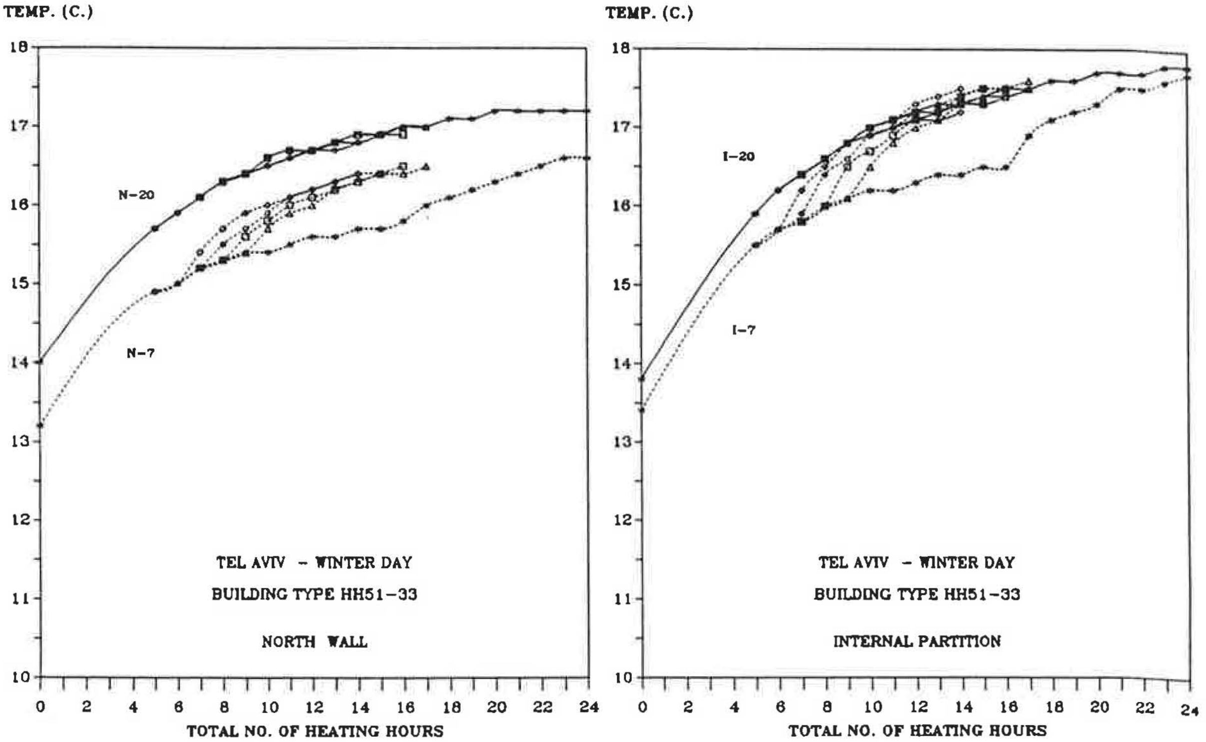

Fig. 7. Effects of heating patterns on 7.00 and 20.00 temperatures for a building with heavyweight walls in "moderate" weather.

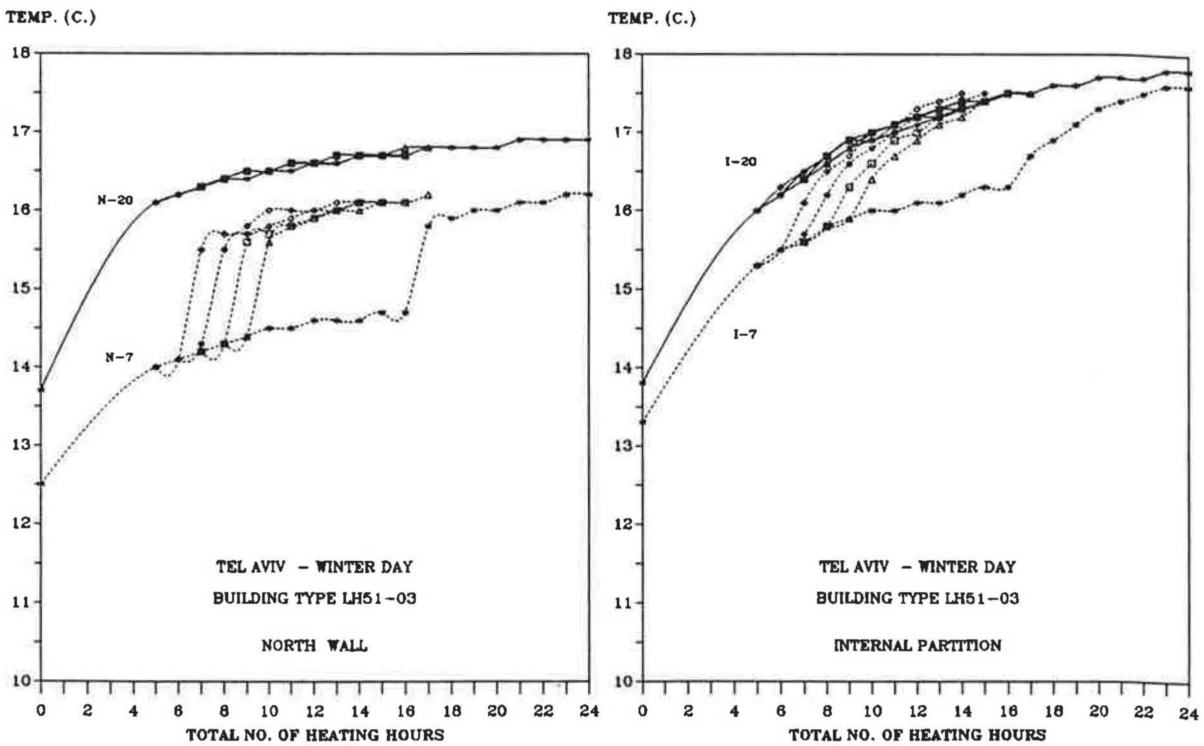

Fig. 8. Effects of heating patterns on 7.00 and 20.00 temperatures for a building with lightweight walls in "moderate" weather.

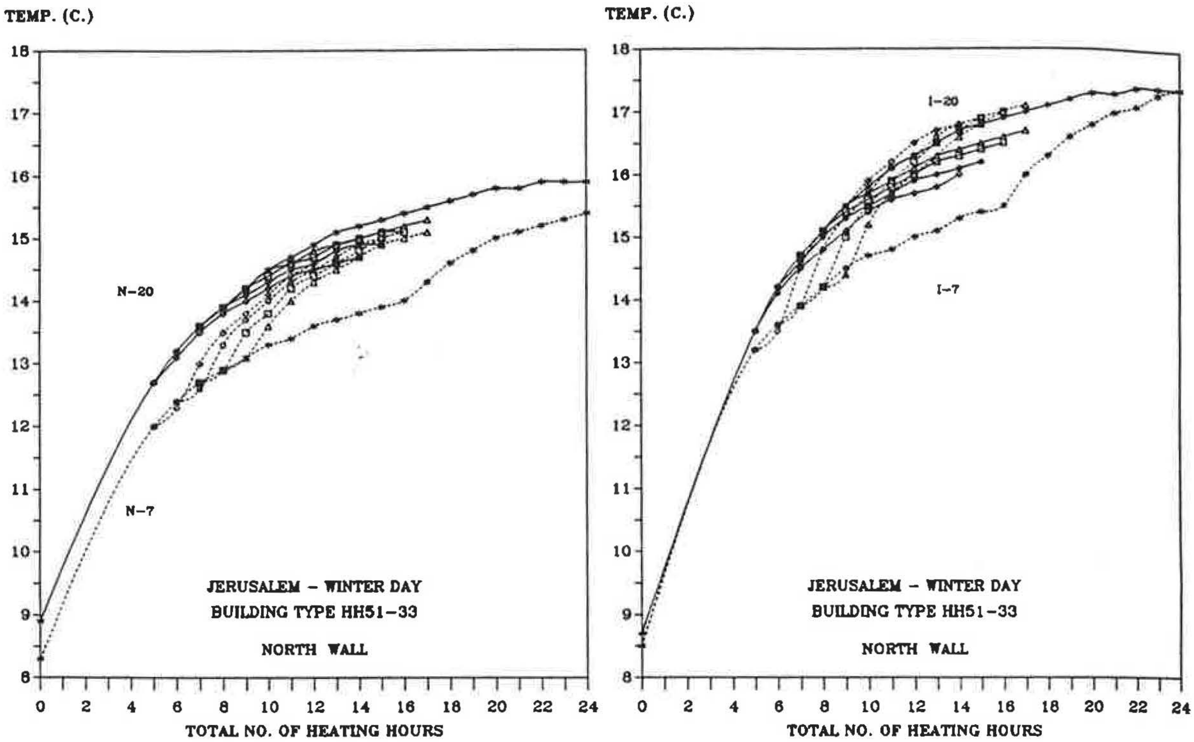

Fig. 9. Effects of heating patterns on 7.00 and 20.00 temperatures for a building with heavyweight walls in "cool" weather.

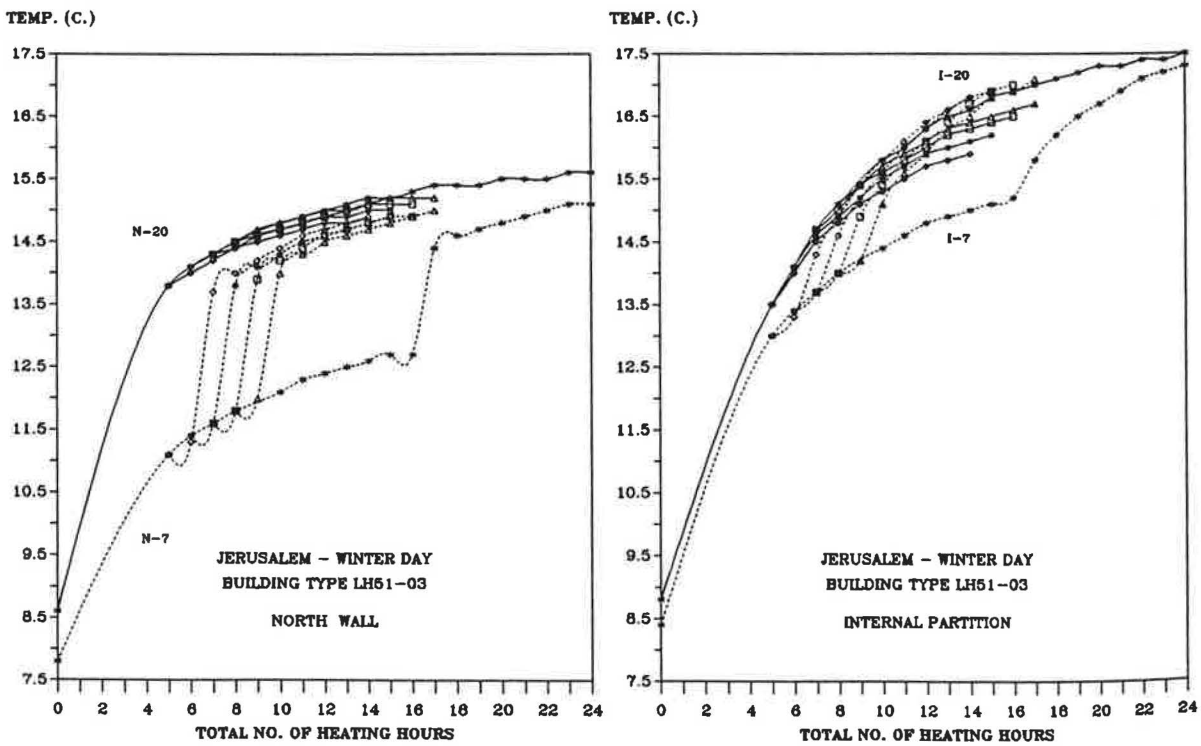

Fig. 10. Effects of heating patterns on 7.00 and 20.00 temperatures for a building with lightweight walls in "cool" weather.

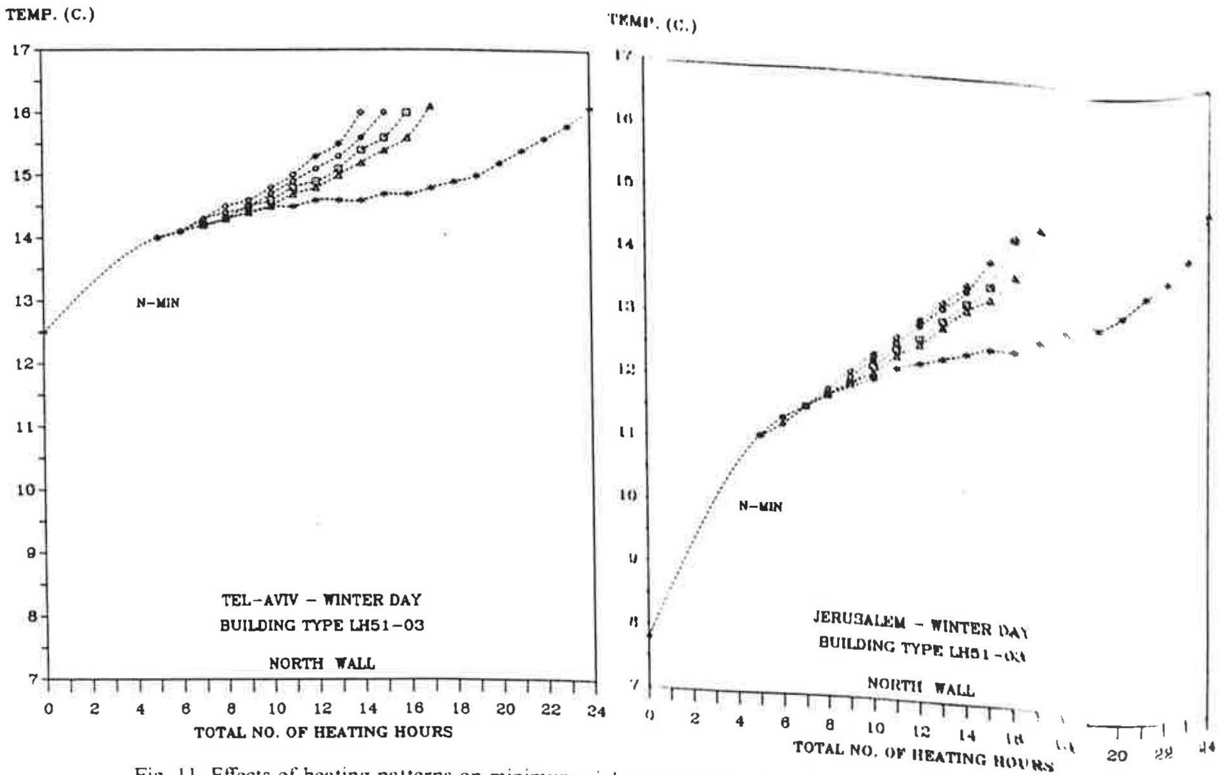

Fig. 11. Effects of heating patterns on minimum night-time temperatures for a building with lightweight walls in both types of weather.

Table 4. Local standard requirements for r Values and the corresponding most suitable heating schedules for prevention of surface condensation

			Type of External Walls	
			Heavyweight	Lightweight
"Moderate" Zone (Tel Aviv)	Required r (m^2°C/W)		0.40	1.25
	Suitable Heating Schedule	On Regular Days	(11.00 to 23.00) or (4.00 to 8.00) + (18.00 to 23.00)	(6.00 to 23.00) or (4.00 to 8.00) + (18.00 to 23.00)
		On Cold Days	(16.00 to 23.00) or (6.00 to 8.00) + (18.00 to 23.00)	(16.00 to 23.00) or (6.00 to 8.00) + (18.00 to 23.00)
"Cool" Zone (Jerusalem)	Required r (m^2°C/W)		0.70	1.50
	Suitable Heating Schedule	On Regular Days	(18.00 to 23.00)	(17.00 to 23.00) or (7.00 to 8.00) + (18.00 to 23.00)
		On Warm Days	(16.00 to 23.00) or (6.00 to 8.00) + (18.00 to 23.00)	(8.00 to 23.00) or (5.00 to 8.00) + (18.00 to 23.00)

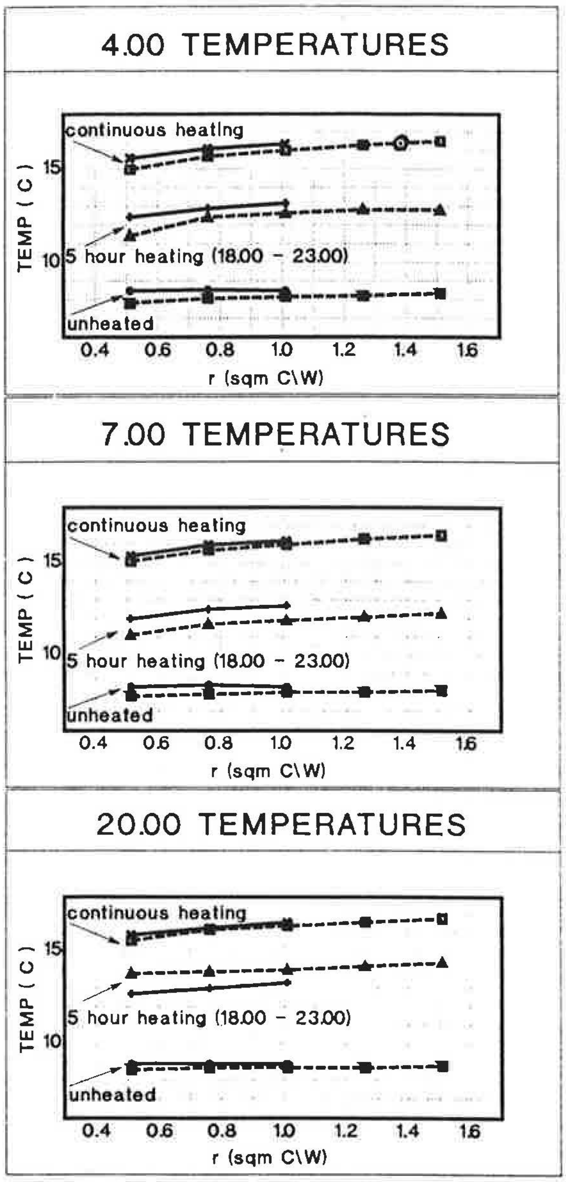

Fig. 12. Effects of thermal insulation and thermal inertia of external walls on surface temperature of northern wall.

—In heated dwellings, the beneficial effect of thermal insulation is clearly indicated, with the insulation increment from 0.51 m^{2}°C/W to 1.51 m^{2}°C/W causing a temperature increment of up to 1.5°C.

—Short periods of intermittent heating cause much lower surface temperatures than "continuous" heating. Even for lightweight walls, which respond quite fast to the external and internal changes, the 20.00 temperature, that occurs during the hours of heating, is lower by more than 2°C than the temperature at the same hour when continuous heating is applied For the heavier walls this difference increases to more than 3°C.

—A comparison of the dynamic results with steady-state computations showed that steady-state values of the internal surface temperature (for a constant internal air temperature of 18°C, and external air temperature varying according to Fig. 2) are larger by 0.5°C to 1.0°C than those obtained by the dynamic analysis of the continuous heating to 18°C. The differences between steady-state values during the heated periods of intermittent heating patterns, and the actual values in these highly dynamic situations, are in the order of magnitude of several degrees (up to 5°C). Steady-state computation of surface temperatures during non-heated periods is actually impossible. It is thus clear that the use of steady-state computations, without due consideration to the dynamic behaviour associated with the prevailing heating patterns, yields a very poor simulation, and consequently wrong design decisions with regard to required insulation levels.

—For the particular cases considered (with the limit surface temperatures of 15.5°C and 12.5°C in "moderate" and "cool" climatic zones respectively) continuous heating can prevent surface condensation, even in a poorly insulated building. However, for the prevailing intermittent heating patterns, the night and morning temperatures may be critical, and determination of the required thermal resistance should be accomplished by means of the graph of morning temperature (7.00) versus *r*.

—In order to obtain the same level of protection against surface condensation, with the same heating patterns, thermal resistance of lightweight walls should be by 0.5 to 0.75 m^{2}°C/W larger than that of heavyweight walls.

As specific results for the specific local conditions, we have obtained the most suitable heating patterns (and schedules) for prevention of surface condensation in dwellings constructed with thermal insulation levels required by the local standards. The required *r* values and corresponding most suitable heating schedules are given in Table 4. Obviously, with the given levels of thermal insulation, the most common heating pattern, "one period" late evening heating (18.00 to 23.00), is usually not sufficient in order to prevent surface condensation, except on the regular "cool" days of the "cool" climatic zone. On warmer days in this zone, additional heating hours are required, despite the natural tendency to reduce heating on warmer days. In the "moderate" zone the addition of 4 hours of night and morning heating, or alternatively full day heating, are necessary on the regular "moderate" days. On cold days in this zone (which is similar, but not identical, to the regular days in the "cool" zone) the addition of two heating hours, either in the morning, or in the afternoon, are usually sufficient in order to prevent surface condensation.

In order to obtain the actually most suitable heating patterns and schedules for every type of weather in each climatic zone, these particular results should, of course, be combined with the conclusions about preferred heating patterns and schedules derived from other points of view (such as thermal comfort, energy cost, etc.).

CONCLUSIONS

Determination of thermal resistance of the building envelope by means of steady-state analysis of surface temperature causes an underestimate of the required insulation, even when continuous heating is concerned. When intermittent heating is the dominant pattern, the use of steady-state analysis is too misleading to be of any practical application.

Dynamic analysis of the effects of various heating patterns on surface temperatures of walls in dwellings has shown that the thermal inertia and insulation of the external walls hardly affect the temperatures of the internal partitions, but have a strong influence on the surface temperature of the external walls themselves. Heavyweight walls behave in a similar manner to the internal walls, and their temperature fluctuations are relatively moderate, with intermittent heating patterns causing only a small rise in their temperature. Lightweight walls are strongly affected by the changes in external air response. Their surface temperature drops to lower levels at night, if heating is not applied then, and rises to much higher levels during daytime hours, even when heating is not applied. In order to obtain the same level of protection against surface condensation, and maintain the same heating habits, the lightweight walls require larger values of thermal insulation (by 0.5 to 0.75 $m^2 {}^\circ C/W$). In moderate climatic zones the general level of thermal insulation required by standards is usually smaller than that required in cooler climatic zones, but internal absolute humidity levels and dew point temperatures are usually higher. This may result, as is the case in Israel, in a need for more heating hours in the more moderate zones in order to fight surface condensation. Thus, existing heating habits, which stem mainly from trying to achieve some minimum level of thermal comfort while saving energy and costs, may, in moderate climatic zones, be insufficient for ensuring surface temperatures larger than the relevant dew point temperatures.

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