

# Overall thermal performance of buildings subjected to various heating patterns

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## SUMMARY

Intermittent heating patterns, characteristic of Israel and other countries with a mild winter enable energy conservation at the expense of very high peak energy consumption; very low levels of thermal comfort; and surface condensation and mould growth problems. The paper summarizes a research project which included analysis of total daily energy consumption, partial energy during evening (peak) hours, weighted cost of total energy, improved thermal comfort, internal surface temperatures of the external envelope, and surface temperatures of partitions. The effects of thermal insulation and inertia of external walls were analysed. The results include recommendations for the preferred heating patterns and schedules from an overall point of view of efficient energy utilization, which is comfort effective and can control condensation and mould growth to a large extent.

## 1. INTRODUCTION AND SCOPE

Residential buildings in climatic zones with a mild winter are usually heated only partially. In Israel the heating habits are characterized by an afternoon period,  $\approx 18:00-23:00$ , and an additional shorter period in the morning of cold days,  $\approx 6:00-8:00$ . Accepted set-point air temperatures are  $18^{\circ}\text{C}$ . Local surveys [1,2] have indicated a growing tendency to turn to electrical heating, and that this affects the electrical power consumption on the national scale. The marginal cost of electrical power production during the evening is approximately double the cost during the night. However, the price of electrical power for the domestic sector is constant. The Ministry of Energy, and the Israel Electric Corporation, were considering the introduction of time-dependent prices. Within this scope the authors have performed the evaluation of the effects of various heating patterns and schedules on the overall thermal performance of dwellings. The analysis was performed by means of the American computer program TARP - [3,4]. The suitability of this program for the present research was first validated, by comparing its simulated results with data measured during three months in an unoccupied real building subjected to various heating patterns [5].

## 2. METHODOLOGY

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

- Heating operated during one "evening" period (18:00 - 23:00).
- Heating operated during two periods, the "morning-night" period (6:00 or earlier - 8:00) and the "afternoon-evening" period (18:00 or earlier - 23:00).
- Continuous heating around the clock (0:00-24:00).

A building of generally heavyweight construction (with various combinations of thermal insulations and thermal inertias) was analysed.

The effects of variations in heating patterns and schedules on the overall performance of a dwelling were measured by [6,7]:

- a. TE - total energy demand per day.
- b. EE - partial energy demanded during the evening (18:00-23:00).
- c. WC - weighted marginal cost of the total energy per day. Weighting is performed via the marginal costs of electrical power.
- d. APS - the daily average of the hourly predicted percentages of satisfied [8]. Five typical living patterns (Lv1 to Lv5) have been considered, characterized by schedules of presence at home, metabolic activity rate and associated thermal resistance of clothing.
- e. DAPS - the difference between the average percentage of satisfied at a given heating pattern and that without heating at all.
- f. "The Energy Criterion", TE/DAPS - the total energy demand per 1% improvement in APS.
- g. "The Cost Criterion", WC/DAPS - the weighted cost per 1% improvement in APS.
- h. "The Condensation Criterion" - internal surface temperatures.

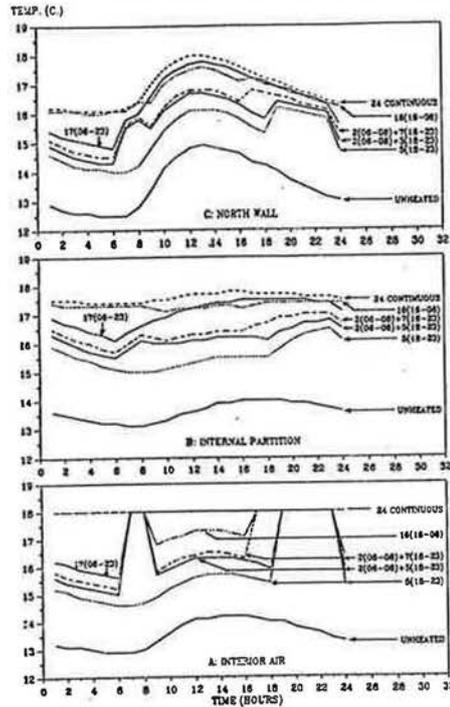
## 3. EXAMPLE OF RESULTS

The figures present some examples of results for: typical air and surface temperature variations for different heating patterns in dwellings with external walls with high thermal inertia and low thermal inertia (Fig. 1). Surface temperature vs. thermal insulation under different heating patterns (Fig. 2). Daily energy consumption and weighted cost for different heating patterns (Fig. 3). Daily average percentage of satisfied in the former case (Fig. 4). Variations of the Energy and Cost Criteria vs. the total number of heating hours (Fig. 5). Based on an extensive study of the various factors, it was possible to establish preferred heating patterns and schedules for the different weather conditions in the various climatic zones, addressing the different living stereotypes. The preferred heating schedules from the point of view of the Energy Criterion, Cost Criterion, and Condensation Criterion did not coincide. Two combinations were finally deduced, one satisfying the Condensation Criterion and Energy Criterion, and the other satisfying the Condensation Criterion and Cost Criterion. They are presented in table 1.

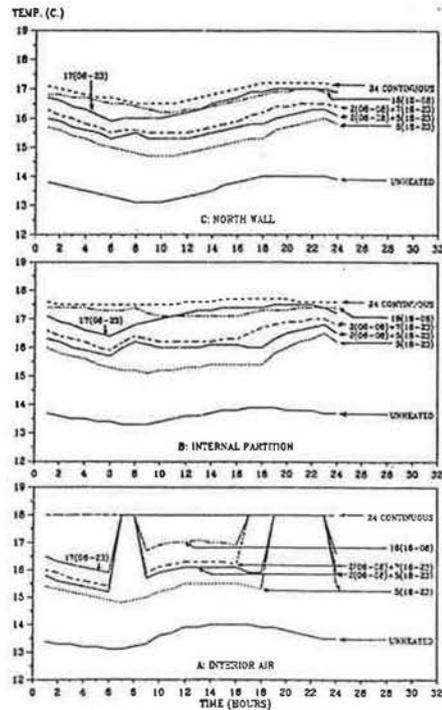
**Table 1: Recommended Heating Schedules for Condensation Control Satisfying Energy or Cost Criteria**

Climatic Zone	Required $r$ ( $m^2 \cdot C/W$ )	Energy Criterion		Cost Criterion
		0.4 (High-Inertia)	1.25 (Low-Inertia)	0.40 (High-Inertia) 1.25 (Low-Inertia)
"Moderate" (Tel-Aviv)	On Regular Days	LVI (11:00 to 23:00)	(4:00 to 8:00) + (18:00 to 23:00)	(4:00 to 8:00) + (18:00 to 23:00)
		LIV (11:00 to 23:00)	(6:00 to 23:00)	2:00 to 8:00 + (18:00 to 23:00)
	On Cold Days	LVI (6:00 to 8:00) + (16:00 to 23:00)	(6:00 to 8:00) + (16:00 to 23:00)	(4:00 to 8:00) + (16:00 to 23:00)
		LIV (6:00 to 23:00)	(6:00 to 23:00)	(15:00 to 8:00)
"Cool" (Zaruzhin)	On Regular Days	LVI (6:00 to 8:00) + (16:00 to 23:00)	(6:00 to 8:00) + (16:00 to 23:00)	(16:00 to 8:00)
		LIV (6:00 to 23:00)	(6:00 to 23:00)	(0:00 to 24:00)
	On Warm Days	LVI (6:00 to 8:00) + (16:00 to 23:00)	(5:00 to 8:00) + (16:00 to 23:00)	(4:00 to 8:00) + (16:00 to 23:00)
		LIV (6:00 to 23:00)	(6:00 to 23:00)	(15:00 to 8:00)

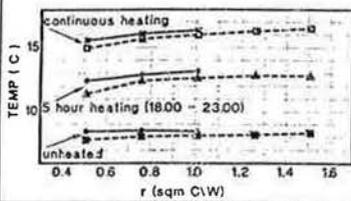
**A. Low-Inertia Walls**



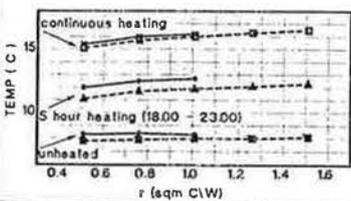
**B. High-Inertia Walls**



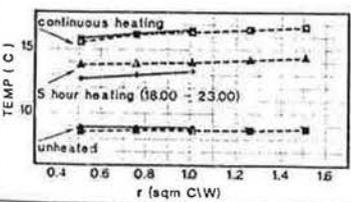
**4.00 TEMPERATURES**



**7.00 TEMPERATURES**



**20.00 TEMPERATURES**



**Figure 2: Surface Temp. vs. r**

**Figure 1: Temperature vs. Time**

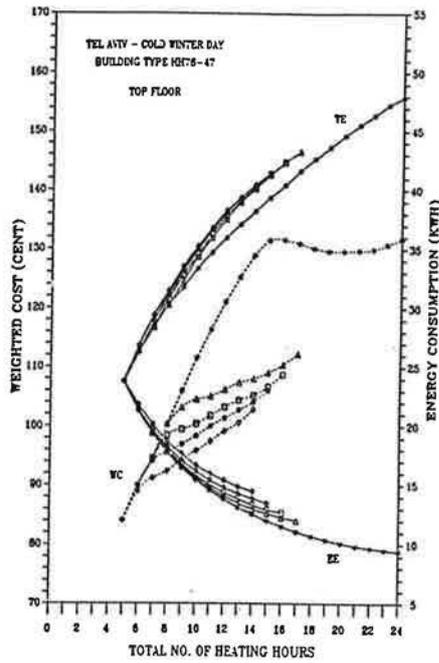


Figure 3: Energy & Cost vs. Heating Hours

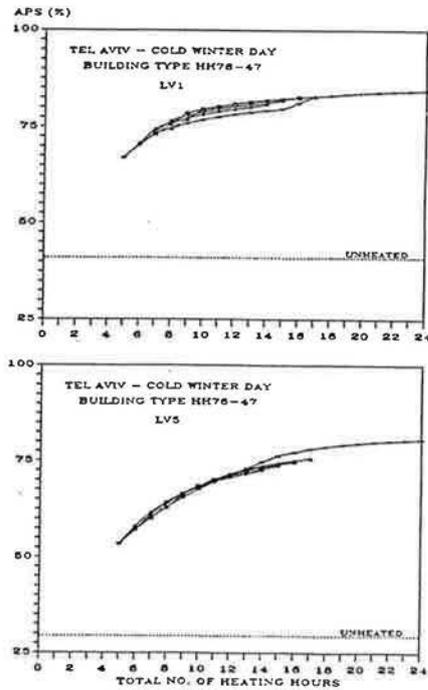


Figure 4: APS vs. Heating Hours

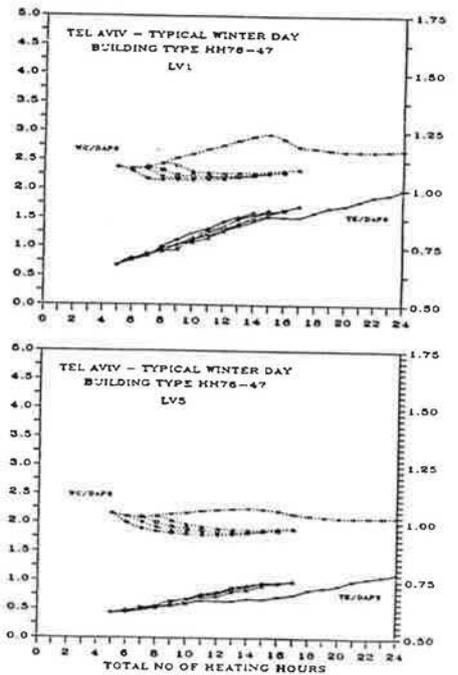
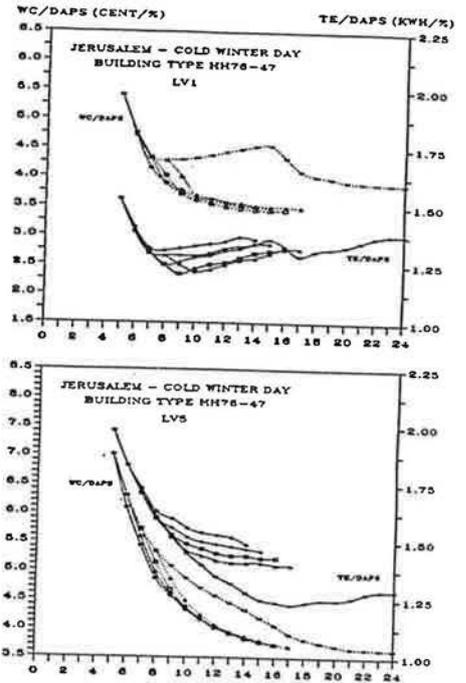


Figure 5: Energy & Cost Crit. vs. Heating Hours

#### 4. CONCLUSIONS

A thorough analysis of the various factors [6,7] yielded the following general conclusions, that may be of general interest:

##### 4.1. For Energy and Cost Criteria

- a. In general, all the optimal heating patterns enable similar thermal comfort levels (with APS = 68%-80% for the energy based schedules, and 71%-84% for the weighted cost based schedules), with the energy based schedules requiring less total energy, more evening energy but generally higher weighted costs.
- b. Storage of night and early morning heating is cost-effective only if prices of energy are considerably lower during these hours than during the main activity hours. In this event it is an effective replacement to daytime heating, mainly in "cool" and "cold" weather, and for families whose members are at home for many hours.
- c. For generally heavyweight construction, independent of walls' and roof's thermal insulation level, or on thermal inertia of external walls:
  - Families who stay out of home most of the day in "moderate" climates would prefer, from the energy criterion point of view, the late evening heating starting at 18:00, but if weighted prices are made available the addition of 2 hours of morning heating (6:00-8:00) is recommended.
  - For cooler, and even colder weather, as long as energy prices are constant, the addition of heating hours may be restricted to two hours advancement of afternoon heating and two hours of morning heating. When weighted prices are available it is also valuable to advance afternoon heating to 16:00, but in addition to add early morning heating in "cool" weather (starting at 4:00), and all night heating in "cold" weather.
  - For more "domestic" families in "moderate" climates it is valid to add the two hours of morning heating (6:00-8:00) to the late evening heating (from 18:00) even when energy prices are constant, and if weighted prices are available, to add very early morning heating (from 2:00). In cooler and colder weather, all-day heating in one period (6:00-23:00) is preferred when constant prices are considered, but afternoon and night heating (15:00-8:00) for "cool" weather, and around-the-clock continuous heating for "cold" weather, should be preferred when weighted prices are made available.

##### 4.2. For Surface Temperature Criteria

- a. 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. High-inertia 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. Low-inertia walls are

strongly affected by the changes in external air temperature. 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 low-inertia walls require larger values of thermal insulation (by 0.5 to 0.75 m<sup>2</sup>°C/W).

- b. 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.

## 5. REFERENCES

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