#4384

Surface Condensation and Molds:
A Case Study

C. Lombardi C. Aghemo, Ph.D.

ABSTRACT

Within the concern of IEA Annex 14, "Condensation and Energy," an experimental measurement campaign was conducted, examining a tower building owned by the Istituto Autonomo Case Popolari in Turin, showing decay problems due to surface condensation and molds.

Two flats in the whole building were studied and monitored during winter 1987-1988, showing opposite exposure - one northeast-northwest (with condensation problems) and southeast-southwest (without condensation problems).

The quantities, which were measured and recorded hourly on a magnetic cassette, were the following: outside air temperature and relative humidity, horizontal total solar radiation, wind direction and velocity, inside relative humidity and air temperature in every room, and surface temperatures.

Air exchange measurements employing the tracer gas technique were made from time to time. Data about annual fuel consumption (natural gas) and electric energy were obtained by the respective distributing societies.

With the collected information some elaborations were possible which gave an evaluation of the relative importance among the possible causes of the observed decay in the first flat.

A parallel analysis was made concerning the variety of molds and the number of colonies found on the different surface measuring points in order to correlate their presence to the collected climate data and to the quantity of spores in the air.

INTRODUCTION

Within the concern of IEA Annex 14, "Condensation and Energy," the problems of concern were connected with humidity by surface condensation and mold growth inside residential buildings.

The surface condensation phenomenon and/or microorganism growth on building walls is mainly due, in mild and cold climates, to two related phenomena:

- high moisture content in inside air, a consequence of the moisture production without an adequate ventilation rate; and
- low inside surface temperature on the envelope as a consequence of a poor thermal insulation or of the presence of thermal bridges.

C. Aghemo, C. Lombardi, Dipartimento di Energetica - Politecnico di Torino,
c.so Duca degli Abruzzi 24 - 10129, Torino, Italy

RH = 70%	spores germination threshold
RH = 80%	new spores growth threshold

For that reason, the time percentages were calculated at which relative humidity (inside air and surface) was higher or equal to these threshold values or reached the condensation condition (100% RH). In Table 3, the values are listed concerning one of the dwellings under consideration. In the IACP 2 dwelling (with neither condensation problems nor mold growth) the limit value *RHi* and *RHsi* = 70% was never exceeded.

($Xi - Xe$) Values vs. ϑe

From the measured physical quantities, the mean weekly values of the difference between inside and outside air humidity ratio ($Xi - Xe$) were calculated and put into a graph vs. the outside air dry-bulb temperature ϑe (Figure 4). In the same figure a line is drawn under which, according to a statistical analysis made by a research group at Centre Scientifique et Technique de la Contruction, Belgium (1984), 95% of the weekly mean differences were found. Significantly, the values concerning dwelling IACP 1 (with condensation problems) are over the line, showing the exceptional character of relative humidity in that dwelling.

Linear Regression of ($\vartheta si - \vartheta e$), vs. ($\vartheta i - \vartheta e$)

By using the mean daily values of ϑsi, ϑi, and ϑe, the points ($\vartheta si - \vartheta e$, $\vartheta i - \vartheta e$) were found (Figure 5). The graph shows that the points are quite close to the regression line. Moreover, if the regression lines are drawn for the same point but for three different periods of 15 days each (Figure 6), it can be seen that any measuring time lasting two weeks is sufficient for identifying the daily mean thermal behavior at that point.

Temperature Ratio Values

By using mean daily values of ϑsi, ϑi, and ϑe, the temperature ratio values (τ) have been calculated according to the following expression:

$$\tau = \frac{\vartheta si - \vartheta e}{\vartheta i - \vartheta e} \qquad (1)$$

The τ values have been found for the main thermal bridges in order to check how much below the threshold value of 0.7 they were. The 0.7 value is provided by the literature as the minimum suggested one (Centre Scientifique et Technique de la Construction, Belgium 1984).

In such a way it was verified that in the bathroom (Figure 7) and in bedroom 1 in the IACP 1 dwelling the thermal bridge remained around the τ value.

Ventilation Rate

By means of the following mass balance equation, obtained for steady-state conditions without condensation:

$$Xi' = Xe + 825\ D\ /\ n\ V \qquad (2)$$

and by means of the more complex expression in the presence of condensation (Centre Scientifique et Technique de la Construction, Belgium 1984),

$$Xi = \frac{Xi' + 10.48\ Xsa\ \Sigma A/nV}{1 + 10.48\ \Sigma A/nV} \qquad (3)$$

where

D = hourly moisture production (kg/h)
n = hourly air ventilation rates (1/h)
V = net heated volume (m^3)

Xi' = inside air humidity ratio in case of no condensation (g/kg)
Xsa = saturated air humidity ratio at the temperature of the condensation surface A (g/kg)

The needed ventilation rates have been calculated in order to avoid condensation.

An example of the results is shown in Figure 8. The processing procedure was as follows:

- from the measured Xi and Xe, D/nV values have been found for the periods of no surface condensation for every room (Cali' et al. 1978);
- by evaluating surface condensation areas, by IEA (1988) the Xi' were found that reached the maximum value of 1.3 Xi, and consequently the ratio D/nV was also evaluated during condensation;
- by using air exchange measurements ($n = 0.32$ and $n = 0.47$, respectively) a mean value of $n = 0.4$ was considered, and the D (kg/h) value was found for each room;
- the maximum value of the ratio D/V for each room multiplied by the whole volume of the dwelling gave as a result total values of D in the range between 0.936 and 1.06 kg/h; therefore, the maximum $Dtot$ value for dwelling IACP 1 was assumed to be 1 kg/h;
- by using the calculated RHs values, the periods for which $RHs > 95\%$ were found and, for these periods, assuming the inside air humidity by mass X'' such as to obtain $RHs = 95\%$, the necessary ventilation rates were carried out.

Such rates have been shown in histograms (see Figure 8), where "zero" values mean that the actual ventilation is sufficient in order to prevent the dwelling from condensation, and the threshold value of 83.5 (grey dashed area) represents the ventilation rate corresponding to $n = 0.4$.

From the histogram analysis we notice that an air exchange of 170 m^3/h (corresponding to $n = 0.8$) with the maximum probable steam production also ensures no condensation in the coldest points of the walls.

Thermal Bridges Analysis

Another analysis was made on thermal bridges. By assuming maintainance of the relative humidity on the inside air within comfort limits by means of ventilation, that is to say less than 60%, the $RHsi$ values around thermal bridges have been carried out again. The time percentages at which surface relative humidity might exceed 70, 80, and 100% were found (see Table 4).

As for condensation, Table 4 shows that some problem could arise only in the bathroom, while as for mold growth, the critical thermal bridges are in bedroom 1, in the bathroom, and in the kitchen. For these thermal bridges the isotherm trends, in steady-state conditions, have been analyzed by a calculation program using finite elements. Some improvement hypotheses were checked and compared. Examples are given in Figures 2 and 9.

MOLD AND COLONIES ANALYSIS

Sampling was carried out by a naturalist in dwelling 1 during November 1987. In each room moldy walls were usually sampled on the paint near windows; that was done by using both sterile cotton swabs, which were carefully rubbed into an area of 80 cm^2 within a plastic template, and by pressing strips of transparent adhesive tape on several parts of the walls. The strips were then mounted with lactic acid directly on slides for observation on microscopes.

This method allows a direct analysis of the surface and points out the possible interactions among microorganisms present on the wall. In bedroom 2, where mold growth was mainly found, five cotton swab samplings were taken corresponding to five different situations: whitewash roof, wall paint, enamel paint on the window post, and wallpaper with and without mold.

Moreover, two petri dishes (15 cm Ø) containing malt agar have been exposed to the air for 15 minutes, 50 cm above the floor (air gravity sampling) in each room.

The CFU (colony-forming units) that developed from petri dishes of the air gravity sampling were counted and for each different presumed species two culture tube insulations were made in malt agar or in Czapek agar (a substrate normally used to identify *Aspergilli* and *Penicillia*).

Table 5 shows the fungal CFU obtained for the different room both by air gravity (A) and cotton bud sampling (B). The highest counts were found in the bathroom and in bedroom 2. Bathroom counts agree well with physical data, whereas the counts for bedroom 2 do not correspond to high relative humidity. Perhaps the low relative humidity and the large CFU may be explained by the fact that this room is no longer inhabited: molds developed in the past and now they are still growing.

On the contrary, most of the percentages with highest RH were found in bedroom 1, without a corresponding high CFU. This bedroom had been recently cleaned.

It is interesting to note that wallpaper samplings from bedroom 2 supplied a low CFU count; this substrate does not therefore seem the best for fungal growth (perhaps for cellulosolytic species only).

The species obtained by air gravity and cotton bud samplings were identified and their frequency (CFU x 100/total NFU) for different rooms and different substrates in bedroom 2 were estimated (Sampo' and Mosca 1988). Altogether, 50 species were identified.

The fungal flora obtained from air gravity sampling were qualitatively rich, whereas only a few species developed on the walls, at times only one, and that is *Cladosporium sphaerospermum*. This is probably due to nutritional and environmental factors, to biocides, mycostatics, and UV resistance and, in general, to a greater competitive saprophytic ability such as rapid spore germination, rapid growth, efficient production of depolymerase enzymes, ability to use available mineral nutrients, parasitism or other forms of antagonism, antibiotics tolerance or production, etc.

Ecological data for single species obtained from literature indicate for most of them the possibility to grow (or at least to survive as) conidia or spores, even without optimum environmental conditions.

CONCLUSIONS

Data logging and subsequent processing allow an understanding of the relative significance of the different causes of the decay phenomena and improvement hypothesis. The analysis in particular shows that the main cause of condensation and mold growth is a lack of ventilation, as hypothetical moisture production of 1 kg/h is very close to the usual value (846 g/h), according to data (BSI 1988) related to the average moisture production for six inhabitants; the measured inside temperatures are not so bad, since they reach the lowest value of 16°C; only some thermal bridges are at a dangerous temperature level.

On the other hand, the assumed hourly ventilation rate of 170 m^3/h in order to avoid condensation corresponds to an air exchange of 28 m^3/h/person, a value close to that recommended for comfort and health. Thermal bridge improvements can then be analyzed by means of the aforesaid calculation program using finite elements.

The detailed mold analysis gives very useful information, when related to other case studies, in order to relate the molds present to observed climate data and to different substrates.

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TABLE 1

Number of persons during different times

Dwelling	Inhabitants	Time (hours)	Number of occupants
IACP 1	6	from 9 to 12	3
		" 12 to 14	6
		" 14 to 18	3
		" 18 to 9	6
IACP 2	6	from 9 to 12	1
		" 12 to 14	6
		" 14 to 18	2
		" 18 to 9	6
Venaria	5	from 9 to 12	3
		" 12 to 14	4
		" 14 to 18	4
		" 18 to 9	5

TABLE 2

Damage

Dwelling	Bedroom 1	Bedroom 2	Living room	Kitchen	Bath-room 1	Bath-room 2
IACP 1	A/F/M	A/F/M	F	A	F/S	-
IACP 2	/	/	/	/	/	-
Venaria	A/M	A/M	A	/	A/S	A/S

A	Mold growth in the corners of external walls
F	Mold growth around windows
M	Mold growth behind furniture
S	Mold growth on the ceiling

TABLE 3

Relative humidity time percentages over threshold values, dwelling IACP 1

Room	Percent of time					
	>70%		>80%		100%	
	RHi	*RHsi*	*RHi*	*RHsi*	*RHi*	*RHsi*
Bedroom 1	37,0	86,5	2,6	68,4	0	12,8
Bedroom 2	26,5		1,8		0	
On white wash (ceiling)		53,9		18,6		0
On wall paper (outside wall)		44,6		9,1		0
On wall paper (partition)[a]		2,5		0		0
Plaster along side of wardrobe		54,1		2,1		0
Bathroom	32,1		1		0	
Corner[b]		81		60		3
Over rolling Shutter box		65,7		36,4		0,5
Kitchen[a]	0,1	18,3	0	5	0	0
Living room	1,5	66,1	0	47,6	0	1,8
Outside	51,2		38,9		0	

[a] Data of the third measuring period only.

[b] Data of the first two measuring periods only.

TABLE 4

RHsi trend when *Rhi* is equal to 60%, dwelling IACP 1

Room	*RHsi*				Time % of condensation on the window (calculated surface temperature)
	Mean value	>70%	>80%	100%	
Bedroom 1[a]	77	96,4	15	0	67.7
Bedroom 2					66.6
On white wash (ceiling)	67	13,5	0	0	
On wall paper (outside wall)	64	0,3	0	0	
On wall paper (partition)[a]	59	0	0	0	
Plaster along wardrobe side	67	16	0	0	
Bathroom					73.6
Corner[b]	78	100	33,6	0,2	
Over rolling Shutter box	68	11,8	0	0	
Kitchen[a]	70	46,7	0,83	0	74.3
Living room	72	38,8	24,5	0	74.5

[a] Data of the third measuring period only.
[b] Data of the first two measuring periods only.

TABLE 5

Fungal colony-forming units in the different rooms and on different substrates, dwelling IACP 1

Room	Substrates	A	B
Hall		55	-
Living room	Paint of window post	49	7435
Kitchen	Painted wall near window	58	9544
Bathroom	Painted wall near window	147	13784
Bedroom 1	Paint of window post	76	5421
Bedroom 2	Painted wall near window	205	12782
	Whitewash of ceiling		5304
	Enamel paint of window post		10745
	Moldy wallpaper		96
	Not moldy wallpaper		15

A - air gravity samplings (colony-forming units in 350 cm^2 malt agar)
B - cotton swab samplings (colony-forming units in 6 ml suspension)

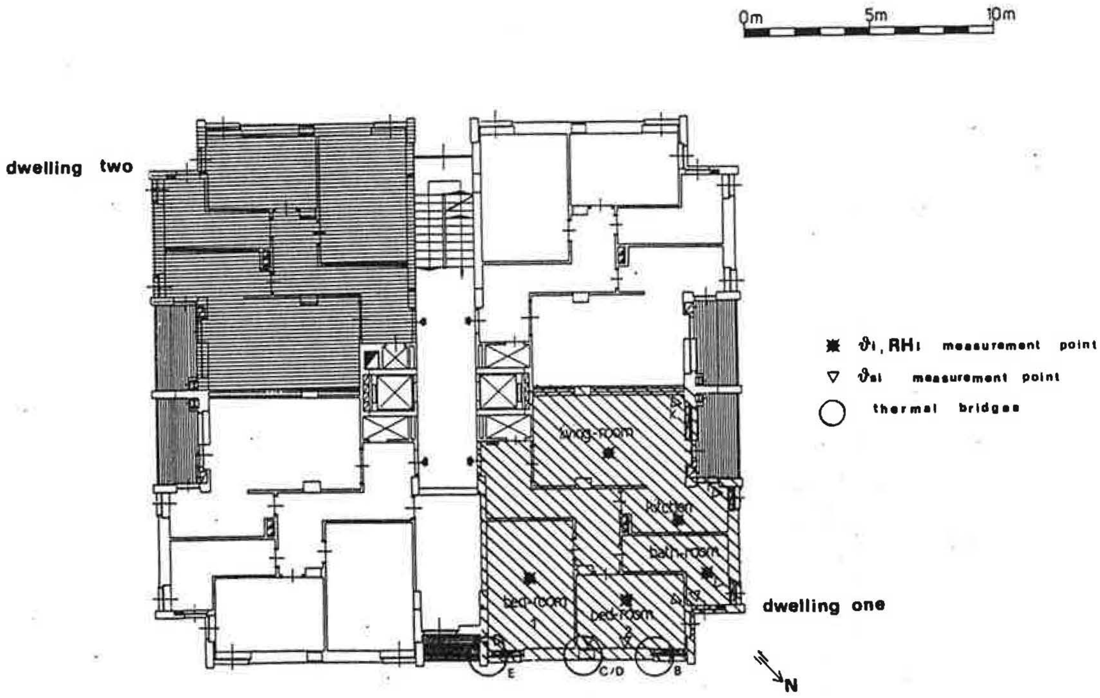


Figure 1. IACP dwellings plan

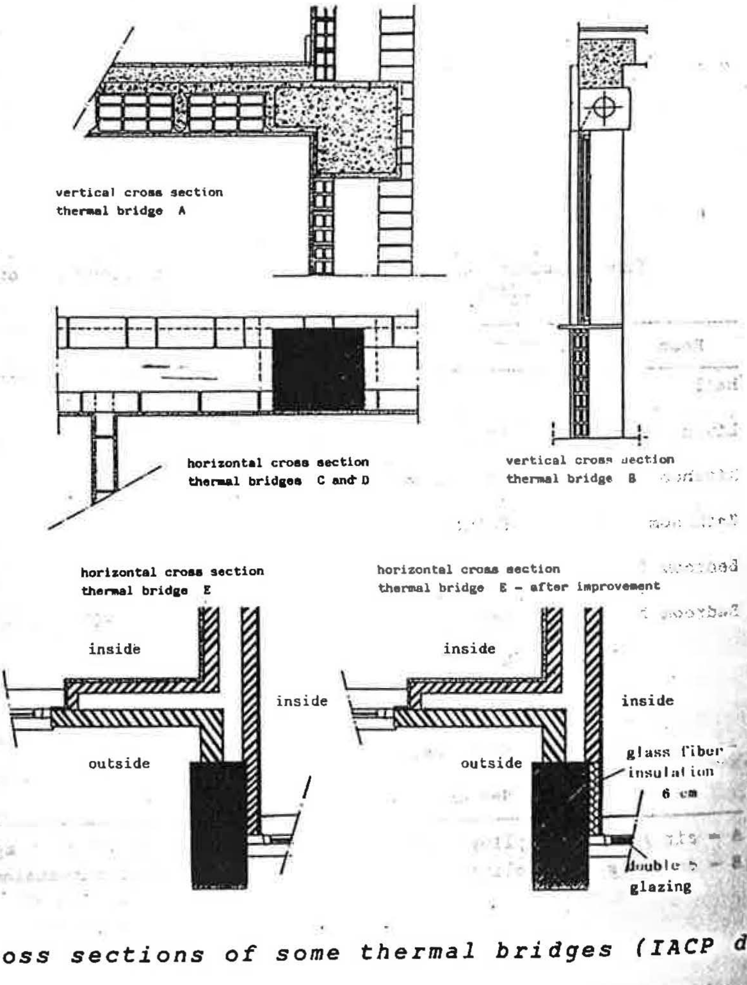
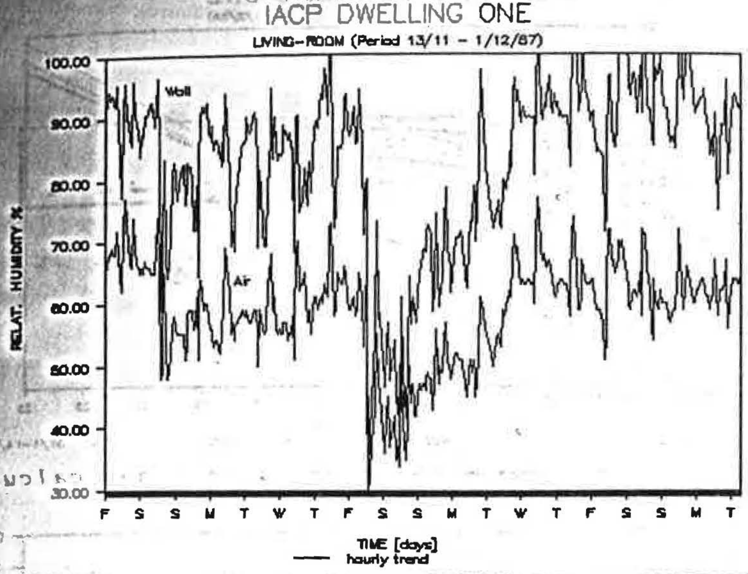


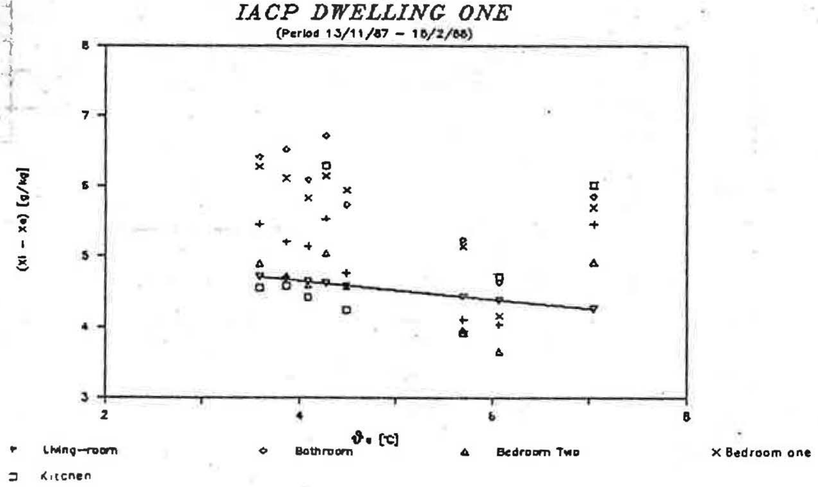
Figure 2. Cross sections of some thermal bridges (IACP dwellings)



IACP DWELLING ONE

LIVING-ROOM (Period 13/11 - 1/12/87)

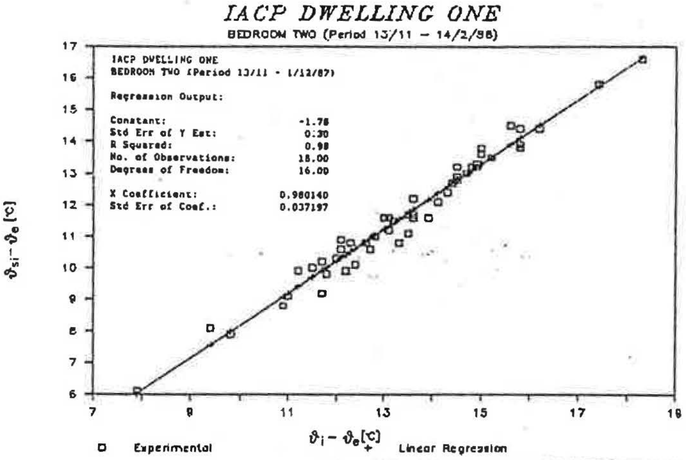
Figure 3. *RH trends in inside air and on the wall (K position in Fig.1)*



IACP DWELLING ONE

(Period 13/11/87 - 16/2/88)

Figure 4. *Mean weekly values of (Xi - Xe) versus ϑ_e compared to the line obtained from [1]. Under that line lay 95% of the weekly mean difference measured in Belgium.*



IACP DWELLING ONE

BEDROOM TWO (Period 13/11 - 14/2/88)

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IACP DWELLING ONE
BEDROOM TWO (Period 13/11 - 1/12/87)

Regression Output:

Constant:                      -1.78
Std Err of Y Est:               0:30
R Squared:                      0.98
No. of Observations:           18.00
Degrees of Freedom:            16.00

X Coefficient:              0.980140
Std Err of Coef.:           0.037197
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Figure 5. *Linear regression between mean daily values of (ϑ_{si} - ϑ_e) and of (ϑ_i - ϑ_e)*

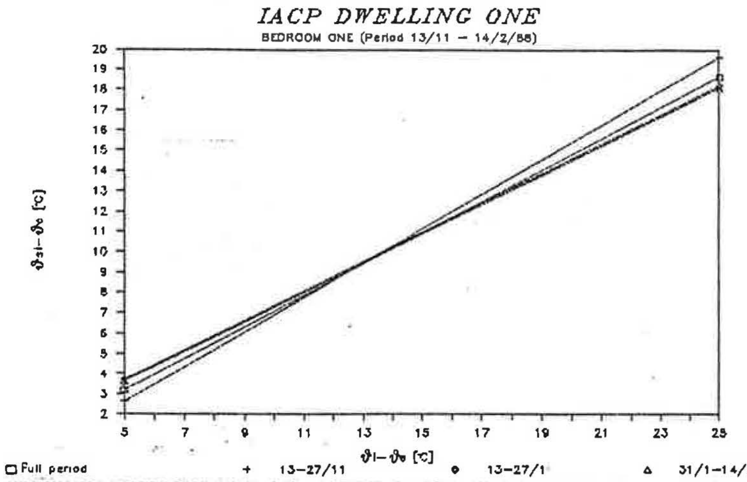

Figure 6. Comparison between the regression lines calculated from data of different periods

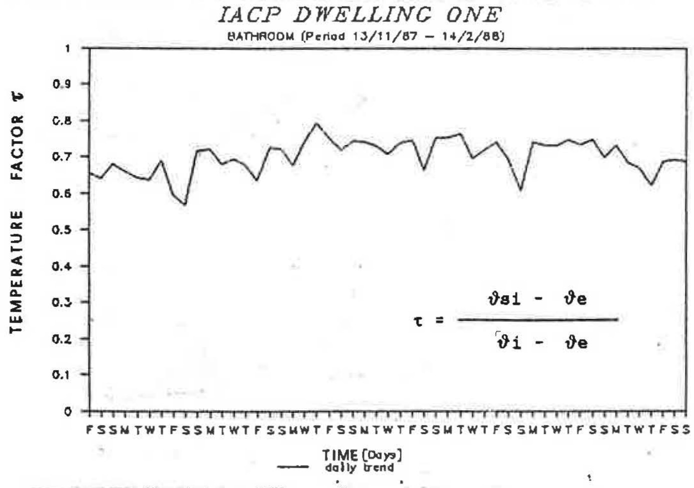

Figure 7. Mean daily values of the temperature factor τ vs. time (days)

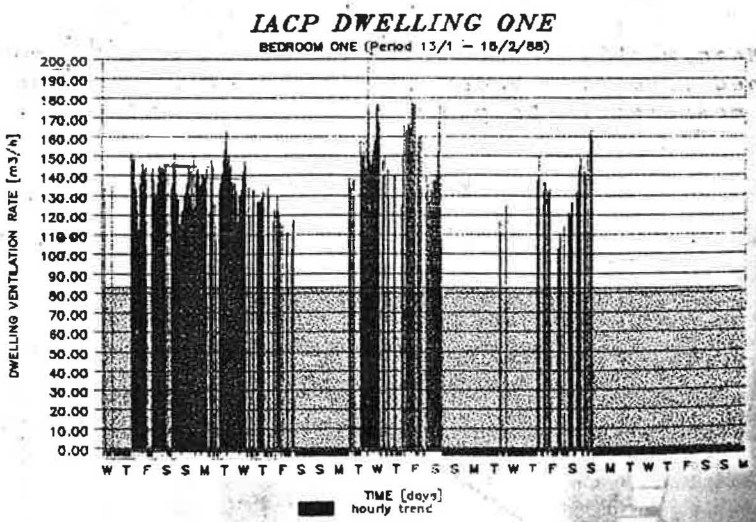

Figure 8. Ventilation rates in order to avoid surface condensation

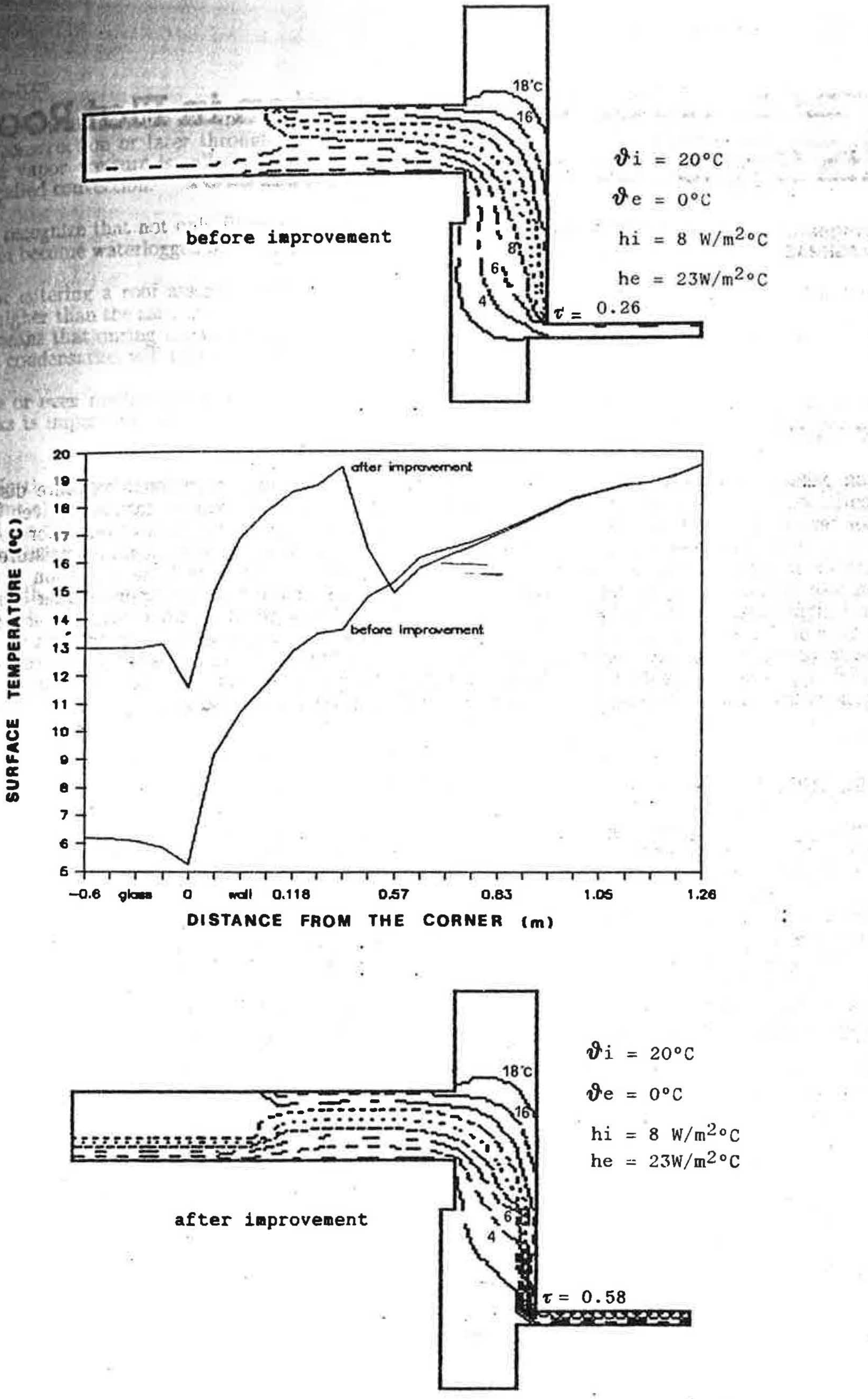

Figure 9. Surface temperature trend and isotherms within thermal bridge E in Fig. 2, drawn by a calculation program using the finite elements method