International Energy Agency

Condensation and Energy

Case studies

Report Annex XIV, Volume 4

Energy Conservation in Buildings and Community Systems Programme

Energy Conservation in Buildings
and Community Systems Programme

IEA — ANNEX XIV : CONDENSATION AND ENERGY

Volume 4

Case studies

INTERNATIONAL ENERGY AGENCY — ENERGY CONSERVATION IN
BUILDING AND COMMUNITY SYSTEMS

MARCH 1991

PREFACE

THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) was established in 1975 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an International Energy programme. A basic aim of the IEA is to foster cooperation among the 21 IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D). This is achieved in part through a programme of collaborative RD&D consisting of forty-two implementing Agreements, containing a total of over eighty separate energy RD&D projects.

ENERGY CONSERVATION IN BUILDING AND COMMUNITY SYSTEMS

As one element of the Energy Programme, the IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is backing various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programmes, building monitoring, comparison of calculation methods, energy management systems, as well as air quality and inhabitants behaviour studies. Sixteen countries and the European Community,
BELGIUM, CANADA, CEC, DENMARK, FEDERAL REPUBLIC OF GERMANY, FINLAND, GREECE, ITALY, JAPAN, NETHERLANDS, NEW ZEALAND, NORWAY, SWEDEN, SWITZERLAND, TURKEY, U.K., U.S.A.,
have elected to participate and have designed contracting parties to the Implementing Agreement, covering collaborative research in this area. This designation by the government of a number of private organisations as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments alone. The importance of associating industry with government sponsored energy RD&D is recognised in the IEA, and every effort is made to encourage this trend.

THE EXECUTIVE COMMITTEE

Overall control of the programme is maintained by an Executive Commitee, which not only monitors existing projects but also identifies new area where collaborative effort may be beneficial. The Executive Committee ensures all projects to fit into a predetermined strategy without unnecessary overlap or duplication but with effective liaison and communication.
Twenty- five projects have been initiated by the Executive Committee, more than half of which have been completed:

ANNEX 1: Load energy determination of buildings (*)
ANNEX 2: Ekistics & advanced community energy systems (*)
ANNEX 3: Energy conservation in residential buildings (*)
ANNEX 4: Glasgow commercial building monitoring (*)
ANNEX 5: Air infiltration and ventilation centre (*)
ANNEX 6: Energy systems and design of communities (*)
ANNEX 7: Local government energy planning (*)

ANNEX 8: Inhabitants behaviour with regard to ventilation (*)
ANNEX 9: Minimum ventilation rates (*)
ANNEX 10: Building HVAC system simulation (*)
ANNEX 11: Energy auditing (*)
ANNEX 12: Windows and fenestration (*)
ANNEX 13: Energy management in hospitals (*)
ANNEX 14: Condensation and energy (*)
ANNEX 15: Energy efficiency of schools
ANNEX 16: BEMS 1- User interfaces and system integration
ANNEX 17: BEMS 2- Evaluation and emulation techniques
ANNEX 18: Demand controlled ventilation systems
ANNEX 19: Low slope roofs systems
ANNEX 20: Air flow patterns
ANNEX 21: Energy efficient communities
ANNEX 22: Thermal modelling
ANNEX 23: Air flow modelling
ANNEX 24: Heat- air moisture transport in new and retrofitted insulated envelope parts
ANNEX 25: Real time simulation and fault detection

ANNEX 14: CONDENSATION AND ENERGY

The idea to start an Annex on mould, surface condensation and energy grew in 1984-1985. In September 1985, a workshop was organised at the Leuven University, Belgium, focusing on the state of the art in different countries. This workshop revealed a real lack of overall knowledge and understanding, on the levels of data, modelling and measuring.

The Annex objectives were formulated as:

- providing architects, building owners and practitioners as well as researchers with a better knowledge and understanding of the physical backgrounds of mould and surface condensation, including the critical conditions for mould growth and the influencing material properties;
- to introduce better calculation models, taking into account air, heat and moisture transfer,in order to predict properly the phenomena of mould and surface condensation and to validate possible solutions;
- to develop energy conserving and cost effective strategies and complementary design methods, techniques and data for avoiding mould and surface condensation in new buildings or preventing further degradation in problem buildings.

At first 6, later 5 countries: BELGIUM, FEDERAL REPUBLIC OF GERMANY, ITALY, NETHERLANDS, U.K., joined together for 3 years of intensified research on mould and surface condensation. The shared work included case studies, common exercises and the draft of a source book, a catalogue of material properties and a guidelines booklet. Also the national research efforts were scheduled in accordance with the Annex 14 scheme and the results brought together and used as base for the Annex publications.
Seven working meetings of 3 days each were held, the first to build up a common knowledge, the last to discuss research and reports and to elaborate a common performance philosophy.

(*) completed

LIST OF EXPERTS CONTRIBUTING TO ANNEX 14

OPERATING AGENT

K.U.Leuven, Laboratory for Building Physics, represented by Prof. H. Hens, head of the lab.

NATIONAL EXPERTS

Belgium

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ir. B. Walleyn, NMH, National Housing Society, Brussels
ir. P. Wouters, WTCB- CSTC, Belgian Building Research Institute, Brussels

Federal Republic of Germany

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Italy

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Ing. G. Casetta, Consulting engineer

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ir. O. Adan, TNO-IBBC, Rijswijk
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ir. W. Lichtveld, Lichtveld, Buis en Partners, Utrecht
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National coordinator: Mr. C. Sanders,
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Dr. C. Hunter, BRE, Garston, Watford
Dr. T. Oresczyn, Bartlet School of Architecture and Planning,
University College London

CONTENTS

SYMBOLS

symbol	unit	Physical quantities
a	-	absorbivity
a	m^2/s	thermal diffusivity
a_w	-	water activity
b	$J/(m^2.K.s^{½})$	thermal effusivity
c	kg/m^3	water vapour concentration (humidity by volume)
c	$J/(kg.K)$	specific heat capacity
c'	$J/(kg.K)$	specific heat capacity of a wet material
d	m	thickness
e	-	emissivity
g_m	$kg/(m^2.s)$	density of moisture flow rate
k_a	s	air permeability
k_m	s	moisture conductivity
l	m	length
m	kg	mass
p	Pa	partial water vapour pressure
p'	Pa	partial water vapour saturation pressure
q	W/m^2	heat flow density
n	h^{-1} (s^{-1})	ventilation rate
r	-	reflectivity
t	s	time
u	%kg/kg	moisture content mass by mass
w	kg/m^3	moisture content mass by volume
x	g/kg	water vapour ratio (humidity by mass)
----------	----------	----------
A	$kg/(m^2s^{½})$	water sorption coefficient
D_w	m^2/s	moisture diffusivity
E_n		Energy consumption
G_m	kg/s	moisture flow rate , vapour production
K_a	s/m	air permeance
P	$W/m^2.K$	thermal permeance inside surface - outside
R	$m^2.K/W$	thermal resistance
S	-	degree of saturation
T	K	thermodynamic (absolute) temperature
U	$W/m^2.K$	thermal permeance
----------	----------	----------
α	K^{-1}	specific heat strain
δ_p	s	vapour permeability coupled to a vapour pressure gradient
δ_v	m^2/s	vapour permeability coupled to a vapour concentration gradient
ϵ	–	hygric strain
ρ	kg/m^3	volumic mass (density)
ρc	$J/(m^3.K)$	volumic heat capacity
φ	-	relative humidity
μ	-	vapour resistance factor
μd	m	(equivalent) vapour diffusion thickness

ψ	$\%m^3/m^3$	moisture content volume by volume
ψ_a	$\%m^3/m^3$	air content
λ	W/(mK)	thermal conductivity
θ	°C	temperature
θ_{rs}	°C	dry resulting temperature
τ	-	transmissivity
	-	temperature ratio

SUBSCRIPTS

a	ambient
c	capillary
cv	convective
e	exterior
h	hygroscopic
i	interior
m	moisture
max	maximal
r	radiation
s	surface
sat	saturation
v	vapour
w	water, liquid

ABBREVIATIONS:

CFU	colony forming units
ERH	equilibrium relative humidity
IAQ	internal air quality
RUE	rational use of energy
MGF	mean growth factor
MW	mineral wool
MPS	extruded polystyrene
RH	relative humidity
TRY	test reference year

INTRODUCTION

During 3 winters we were able to do measurements in dwellings with real mould problems, giving the opportunity to enlarge our knowledge concerning mould growth, to ameliorate the measuring techniques, and develope remedial stategies. In all the participating countries the parameters that influence mould growth were followed in problem dwellings. Some studies concern very intensive measurements in few or only one dwelling. Others collected more rough data from several similar or identical dwellings in one estate. In most of the cases remedial actions were taken and evaluated.

Aims of these case studies are:

1. to look at the present situation of the dwellings: why are there mould problems?;
2. to study the situation before the refurbishment: is it possible that there were no problems before, and if so, why?;
3. Experiment some remedial measures: what should be the solution to prevent mould in these dwellings;

Next to these aims, directly coupled to the damage case, we also like to:

1. Know whether these data fit with what is commonly assumed concerning mould problems.
2. Compare the measurements with calculation models.
3. Analyse the influence of different parameters on the hygrothermal behaviour of the dwellings.

All the case studies follow a general scheme, as dirived from previous experiences: first we OBSERVE the current situation, next we do some MEASUREMENTS, followed by an INTERPRETATION. Once we have a good knowledge of the current situation, we are ready to evaluate REMEDIAL MEASURES.
Volume 4 of Annex XIV contains summary reports of the case studies. More detailled information is availlable in the research institutes that made the study.

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E. SENAVE, H. HENS

CASE STUDY 1

"ZOLDER"

BELGIUM

International Energy Agency
ENERGY CONSERVATION IN BUILDINGS
AND COMMUNITY SYSTEMS PROGRAMME

ANNEX XIV
Condensation and Energy

FINAL REPORT

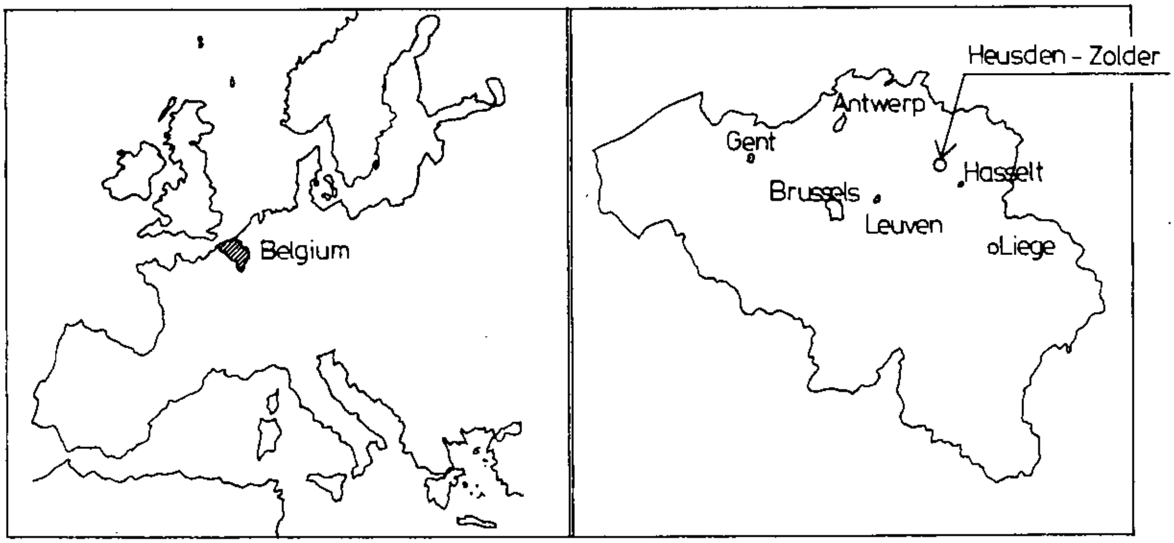
1. SITUATION

Estate "Lindeman"
Heusden-Zolder
Belgium

5°20' E
51°05' N
altitude +50m

climate

	J	F	M	A	M	J	J	A	S	O	N	D	Y
Θ	2.7	3.1	5.5	8.2	12.8	14.9	16.8	16.4	14.0	10.0	5.2	3.4	9.8
ϕ	89.6	89	84	78.5	77.8	78.9	79.9	79.8	84.2	88.3	91.2	92.7	85.2



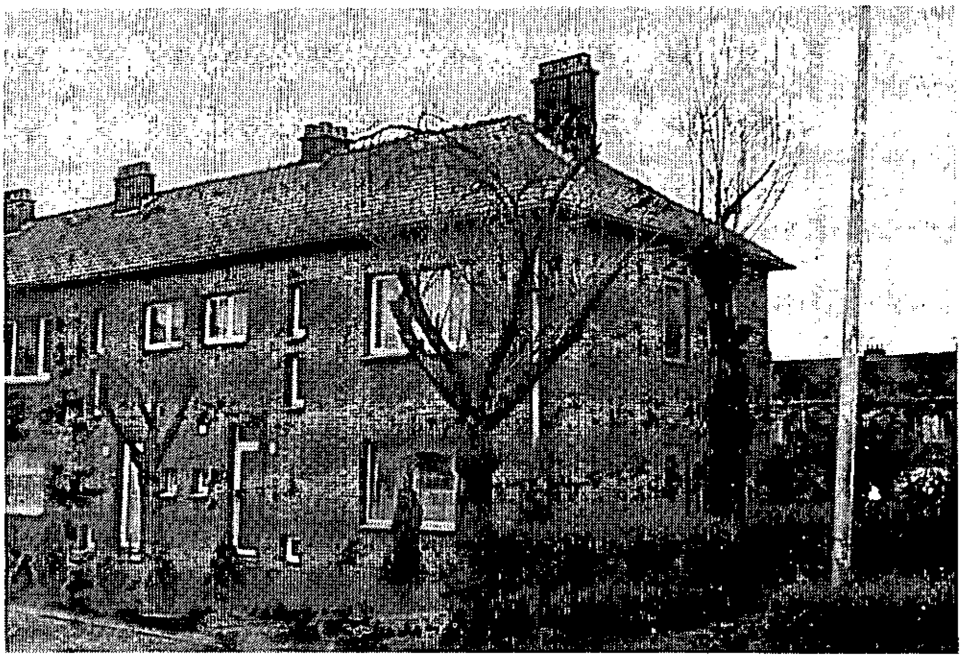
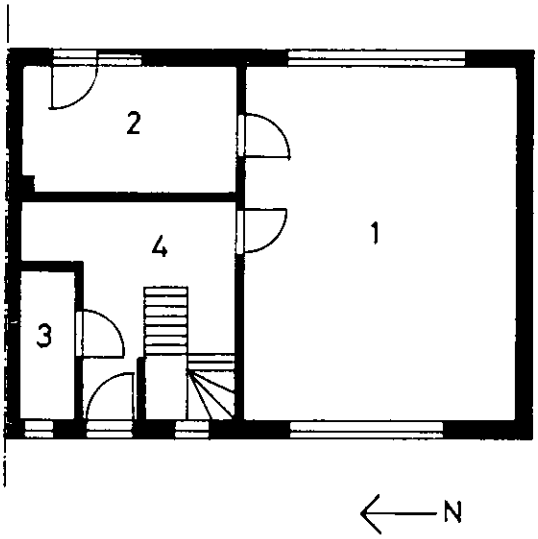


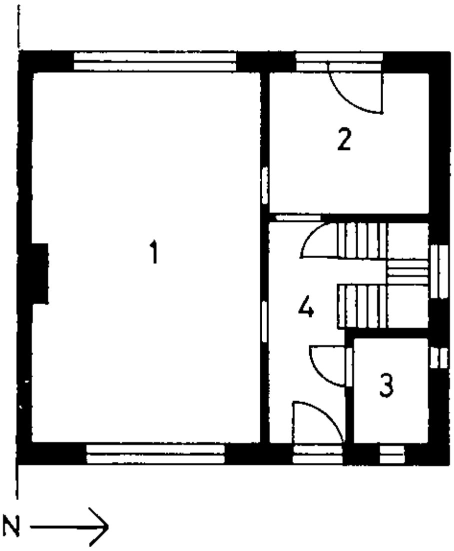
PHOTO 1.1
View of the estate
with on the foreground
dwelling 1

2. LAY OUT

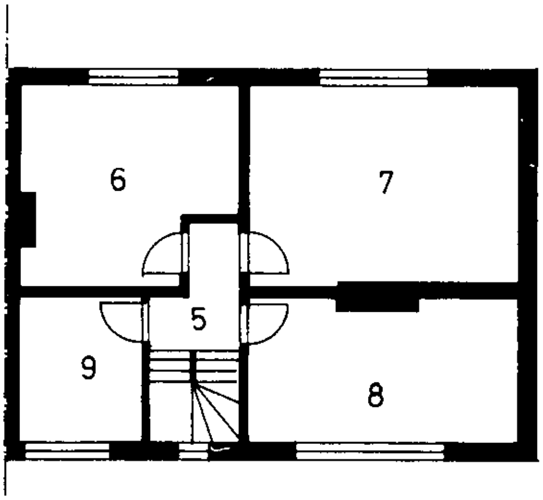
DWELLING 1, ground floor



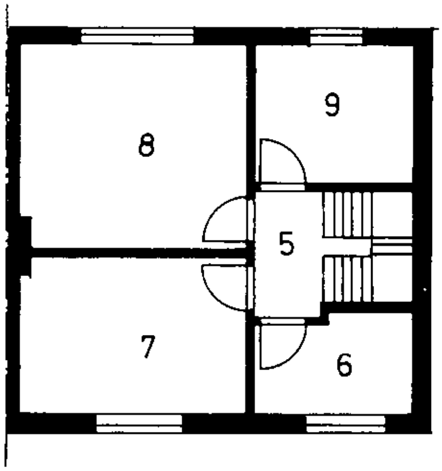
DWELLING 2, ground floor



DWELLING 1, first floor



DWELLING 2, first floor



	A [m2]	V [m3]
1. Living Room	29.6	77.4
2. Kitchen	8.9	23.3
3. Bathroom	2.8	7.3
4. Hall (down)	11.4	25.9
5. Hall (up)	5.2	12.8
6. Bedroom 1	12.1	29.8
7. Bedroom 2	16.5	40.8
8. Bedroom 3	12.2	30.2
9. Bedroom 4	5.8	14.3
Cellar	26.1	52.3
Attic		

	A [m2]	V [m3]
1. Living Room	27.6	72.5
2. Kitchen	7.6	19.9
3. Bathroom	2.9	7.5
4. Hall (down)	8.3	18.2
5. Hall (up)	5.4	14.5
6. Bedroom 1	5.4	13.7
7. Bedroom 2	11.4	29.6
8. Bedroom 3	15.7	40.9
9. Bedroom 4	7.5	19.5
Cellar	11.1	21.4
Attic		

CONSTRUCTION PARTS

WALLS: cavity walls:
outer leaf, 8 cm massive brickwork
cavity, 5 cm, ventilated: aeration openings 10 cm2/m at the bottom and upside
inner leaf, 18 cm massive brickwork; 1,5 cm plaster.

ROOF: pitched, tiled roof
loft space floor: reinforced brick floor

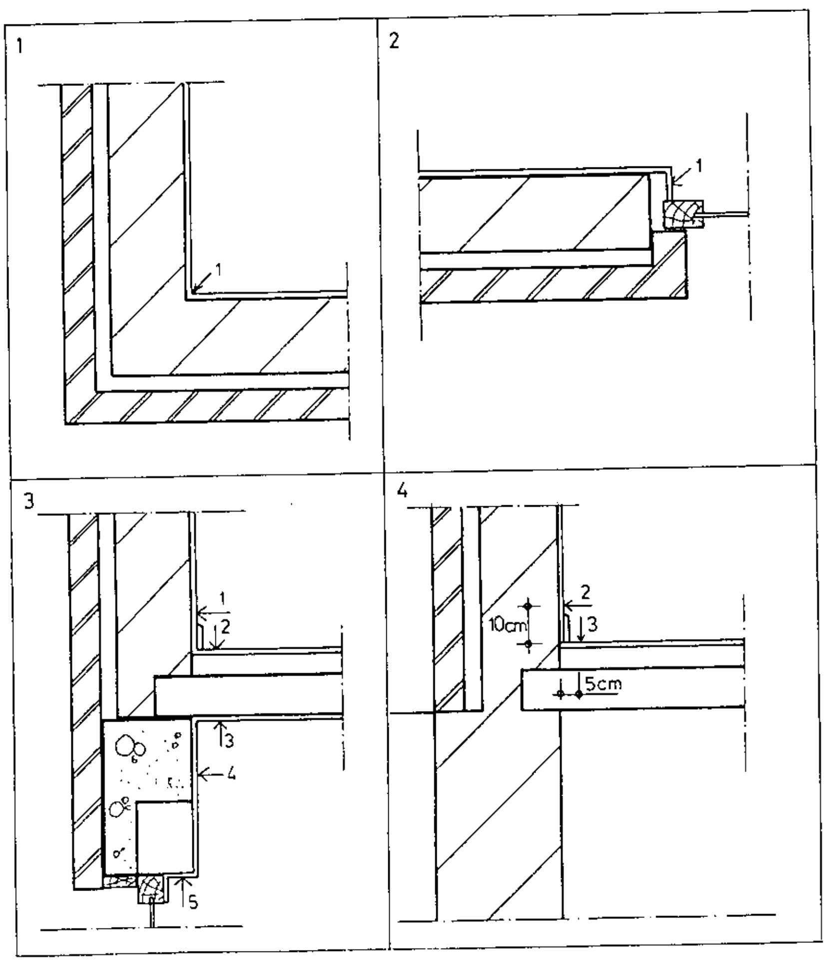
FOORS: same as loft space floor
floor above cellar partly concrete on ground, partly reinforced brick

DOORS & WINDOWS: PVC, stripped; single glazing upstairs, double downstairs (Dwelling 1, refurbished), aluminium doors, steel framed windows, single glazing (Dwelling 2, original)

CONSTRUCTION DETAILS

	figure	r [-] 1	2	3	4	5
CORNER	1	0.61				
WINDOWS	2	0.70				
LINTEL	3	0.73	0.73	0.71	0.60	0.63
BASEMENT	4	0.65	0.70	0.67		

The values presented are calculated, using $h_i = 4.5$ and $h_e = 23\ W/m^2K$



4. THE MOISTURE PROBLEM

MOISTURE PRODUCTION & REMOVAL

Estate: the dwellings are intended for maximum 5-6 persons.
Dwelling n°1 2 persons (pensioners), but much visitors
n°2 5 persons (2 adults + 3 children)
Extract fan in the kitchen of both the dwellings.
No previsions for laundry drying; the inhabitants dry it in the cellar when it is raining.

DAMAGE

* Water penetration seems to be a problem in cellar of all dwellings
* Mould: 77% of the dwellings visited (110), 68% of those with mould damage (75)

		number	%
bedroom	lintels, entire ceiling, especially near the corners	64	85
kitchen	ext. wall / ceiling	26	35
bathroom	ext. wall / ceiling	27	36
living room	ext. wall / corners	22	29
hall	ceiling / walls	25	33

Dwelling 1: all of the above problems.
Dwelling 2: only mould on the bedroom ceiling and 3-dimensional corner in the bathroom.

THE MOULD SPECIES

in x % of the samples present (out of 10)

Ulocladium Consortiale	70
Aspergillus Fumigatus	60
Cladesporium Cladesporoides	60
Penicillium Cyclopium	40
Mucor sp.	40

Some 16 species were found, the composition being different from one dwelling to another, from one room to another and even from one finishing layer to another

CONSEQUENCES FOR THE INHABITANTS

Complaints about health problems: 26 out of 75 questioned (34%)
Legal actions against local building company, after 3 year still without any result.

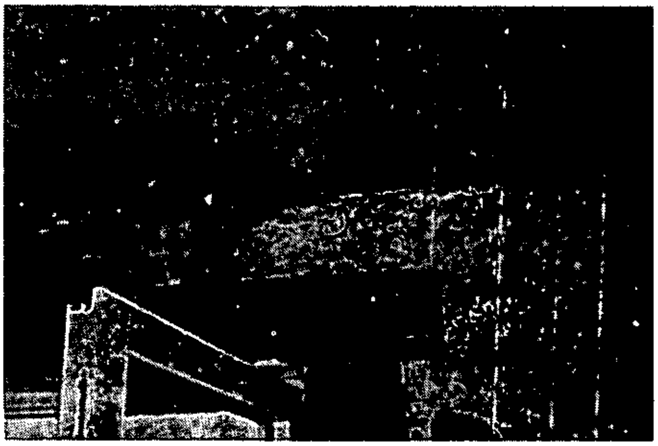


PHOTO 4.1
Intensive mould growth in a bedroom

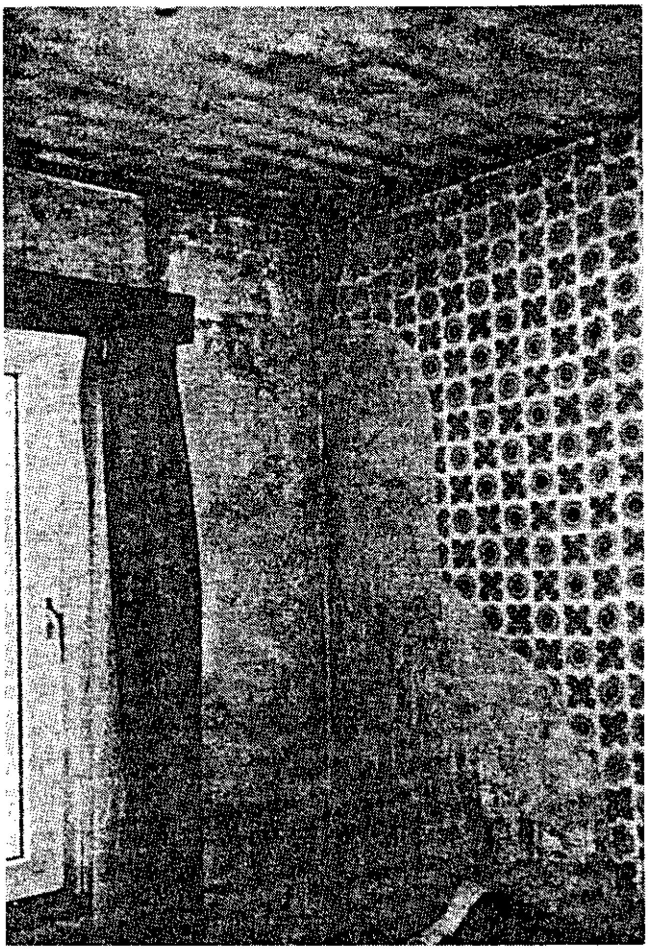


PHOTO 4.2
mould growth in a bedroom corner

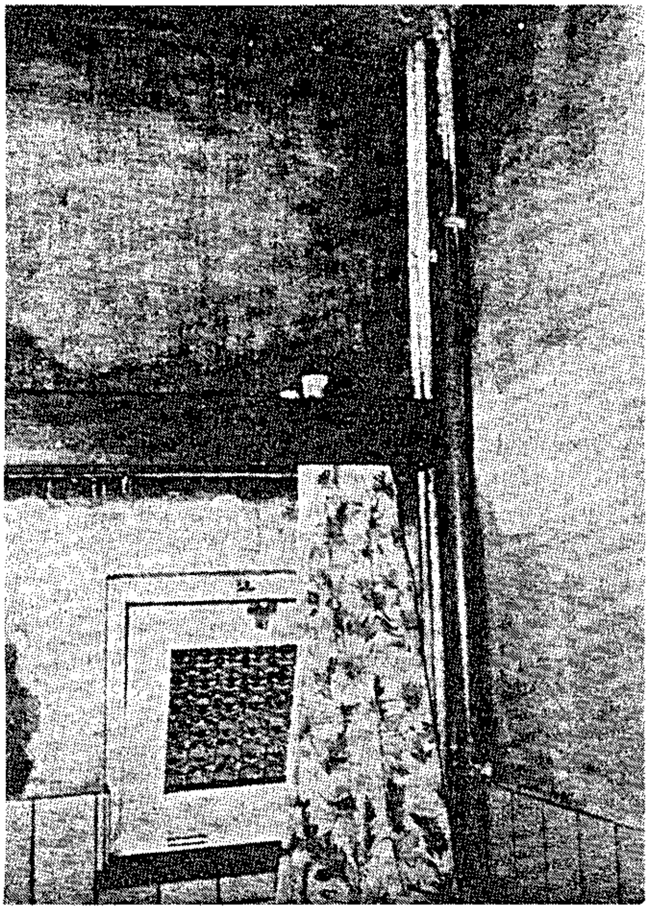


PHOTO 4.3
Moulds on the bathroom walls (Dwelling 1)

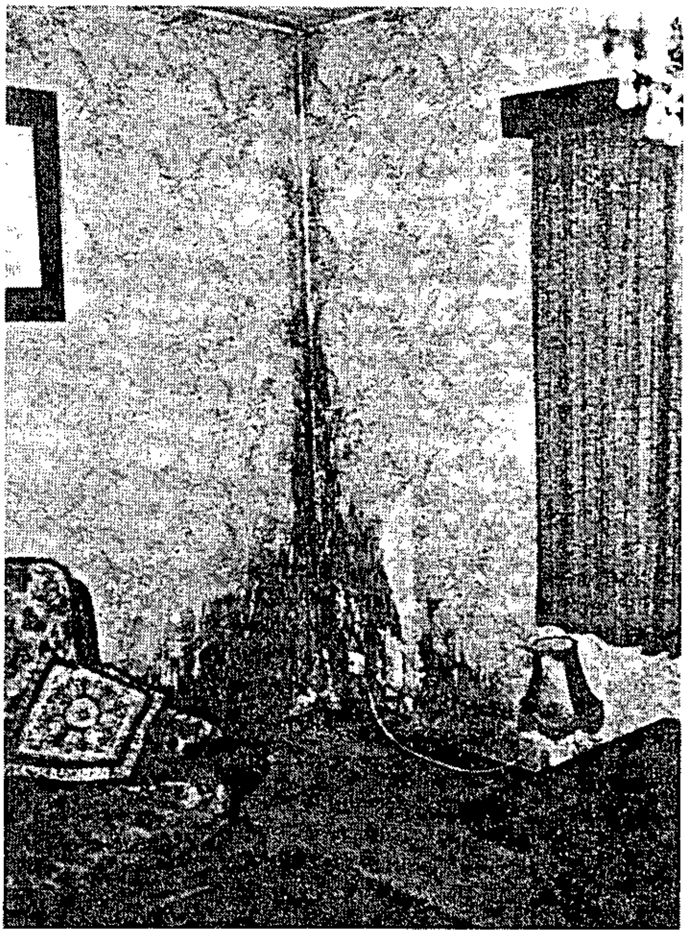
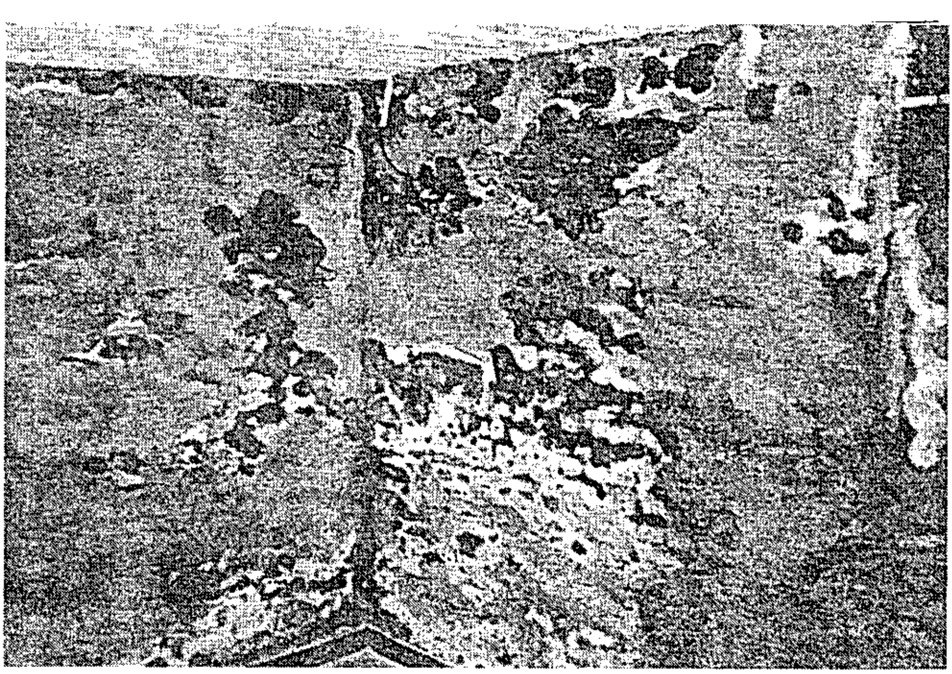


PHOTO 4.4
Mould in a 3-dimensional corner of the living room (Dwelling 1)

PHOTO 4.5
Rain penetration in the cellar.



5. MEASUREMENTS

	WHAT	EQUIPMENT
1	SURFACE TEMPERATURE	Cu-Co thermocouples
2	AIR TEMPERATURES	Hygrothermograph (Bimetal) or
3		Pt100 in humidity meter
4	RESULTING TEMPERATURE	Cu-Co thermocouples in ping pong ball
5	RELATIVE HUMIDITY	Hygrothermograph or
6		Humidity meter: Rotronic Hygromer
7	HEAT FLUXES	Fluxmeter TNO-W531
8	AIR TIGHTNESS	Pressurisation Door
9	MOULD SAMPLING & DETERMINATION	

MANAGEMENT(*)

'86 - '87:	Estate:	2+5 and 9 in several dwellings
	Dwelling 1:	4 in all rooms; 8 for the whole dwelling
		1,7 and 2+5 in living room and 1 bedroom
'87 - '88:	Estate:	2+5 in several dwellings
	Dwelling 1:	4 in all rooms; 1 and 7 in living room and 1 bedroom
		2+5 in living room, 1 bedroom, bathroom and cellar
'88 - '89:	Dwelling 1:	3+6 in all rooms; 1 in living room and 1 bedroom
	Dwelling 2:	3+6 in all rooms; 1 and 7 in living room and 1 bedroom

Data Acquisition unit: hp85 (hp vectra) + hp8087 datalogger

(*) the numbers refer to the ones above

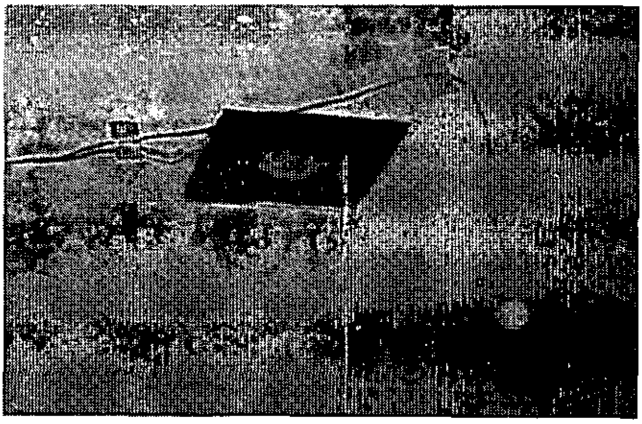


PHOTO 5.1
(ceiling bedoom 4, Dwelling 2)
Measurement of:
- heat flow
- surface temperature
  (thermocouple behind heat flow meter)
- dry resultant temperature
  (thermocouple in a ping pong bal

PHOTO 5.2
(Upper part of the hall in dwelling 2;
remark the intensive mould growth on the ceiling!)
measurement of the relative humidity
and air temperature

6. *THE INSIDE CLIMATE (original situation)*

TEMPERATURE	$\Theta i = f(\Theta e)$	r^2	$\Theta_e = 5°C$
living room	17.8 - 0.08 Θe	0.17	17.4
kitchen	19.2 - 0.09 Θe	0.19	19.6
bathroom	13.6 - 0.01 Θe	0.00	13.7
Hall down	13.7 + 0.16 Θe	0.39	14.5
Hall up	12.2 + 0.15 Θe	0.10	13.0
bedroom 1	11.5 + 0.16 Θe	0.32	12.3
bedroom 2	10.2 + 0.29 Θe	0.68	11.7
bedroom 3	10.4 + 0.42 Θe	0.41	12.5
bedroom 4	8.1 + 0.38 Θe	0.70	10.0
cellar	10.3 + 0.31 Θe	0.55	11.9

HUMIDITY	$Pi-Pe = f(\Theta e)$	r^2	$\Theta_e = 5°C$
living room	562 - 4.7 Θe	0.25	539
kitchen	506 - 3.8 Θe	0.14	487
bathroom	478 - 4.0 Θe	0.20	458
Hall down	327 - 6.3 Θe	0.29	296
Hall up	374 - 4.2 Θe	0.25	353
bedroom 1	356 - 9.7 Θe	0.35	308
bedroom 2	401 - 1.0 Θe	0.10	396
bedroom 3	373 - 3.3 Θe	0.43	357
bedroom 4	399 - 8.6 Θe	0.39	356
cellar	217 - 15 Θe	0.29	142

(*) = value measured 1988-1989, after insulation of loft space floor. It is assumed that the value is not imfluenced by the measure.

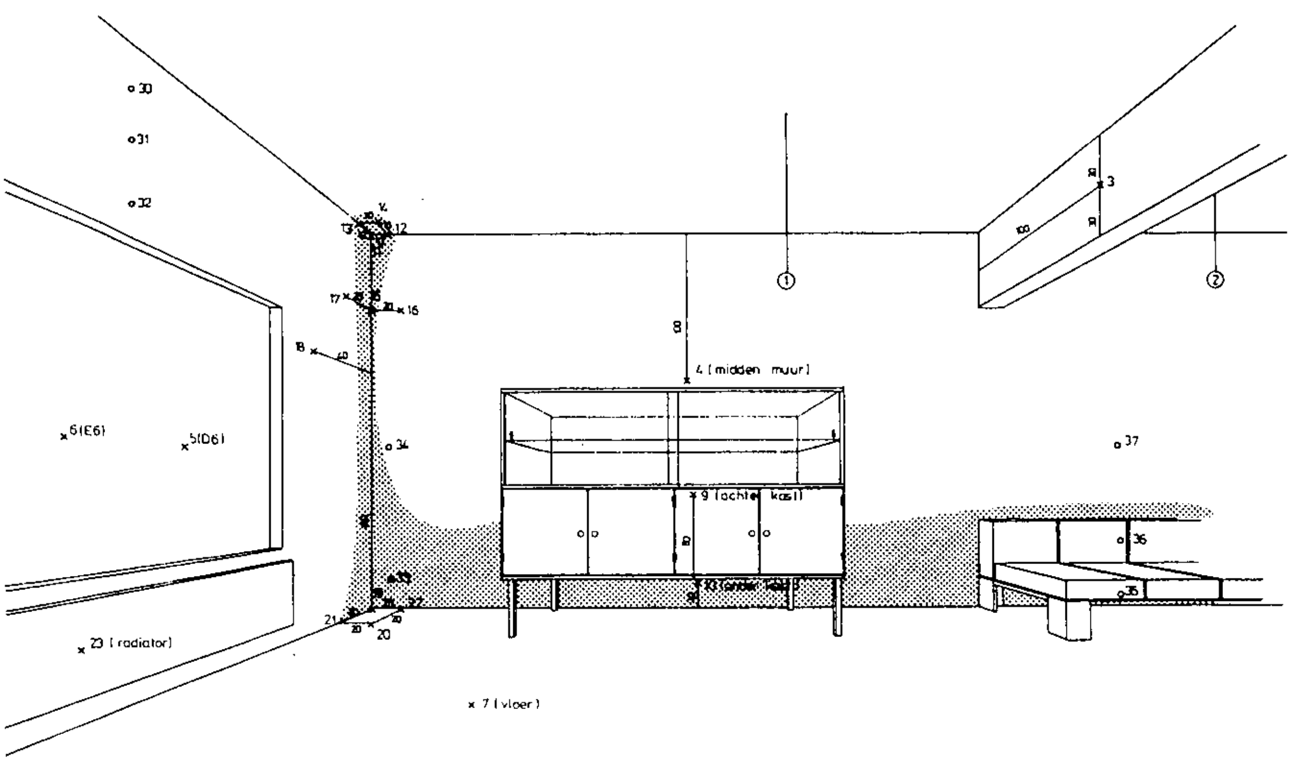
BUILDING FABRIC

Thermal resistance: case 7.1
Wall: living room 0,47 m^2K/W, bedroom 0,66 m^2K/W.
Ceiling bedroom: 0,66 m^2K/W
τ-values: case 7.2, see tabel 7.2.2
Ventilation: case 7.3
Air tightness: n_{50} $[h^{-1}]$ = 5,1 (Dwelling 1 at present)
Ventilation rate (calculated):
whole building 0,2 to 0,4 h^{-1}
living room: 0,18 h^{-1}
Heating cost:
natural gas consumption: 94.1 - 3.91 x Θe [m^3 gas/week]
percentage of the dwelling heated: 0,42%

SURFACE CONDITIONS

measuring point		finishing material	mould (Y/N)	% of time =100%	>95%	>90%	>80%	>70%	>70%
Dwelling 1	living room								
9	wall behind cupboard	wallpaper	Y_*	30	42	61	82	98	
19	3D-corner floor	stone	Y	11	18	33	71	79	
11	3D-corner ceiling	plaster	(Y)	0	1	4	22	65	
15	2D-corner wall	wallpaper	(Y)	0	1	5	21	62	
10	wall under cupboard	wallpaper	(Y)	0	1	3	19	59	
13	2D-corner wall-ceiling	plaster	(Y)	0	0	2	12	48	
12	2D-corner wall-ceiling	plaster	(Y)	0	0	1	10	44	
7	floor	stone	N	0	0	1	10	31	
17	wall near 2D	wallpaper	N	0	0	1	7	31	
16	wall near 2D	wallpaper	N	0	0	0	4	20	
14	ceiling near 3D	plaster	N	0	0	0	3	20	
4	wall	wallpaper	N	0	0	0	2	18	
18	wall	wallpaper	N	0	0	0	4	21	

(Y) = visible mould from the past. It is not clear wether this mould is still active
Y_* = present mould growth
Y = no mould, but surface condensation observed during measuring period



8. *SPECIAL TOPICS*

8.1 SITUATION BEFORE RETROFITTING

The effect of placing airtight windows and double glazing in the original dwellings and removing the stove in the living room was analysed.
The situation in the living room before refurbishing was less comfortable (draughts when stormy weather, only pleasant near the stove), and the climate was dryer (higher ventilation rate, drying effect of single glazing), but very probably there were no moulds!
In the bedroom on the other hand, mould growth occurred probably in many dwellings, especially when these places were not heated. This could be seen in dwellings where the original windows are still present.

8.2 INFLUENCE OF THE CELLAR ON THE MOISTURE PROBLEM

Measurements show that the cellar has no or minor influence on the humidity level in the rest of the dwelling. Reason is the underpressure in the cellar, caused by the boiler.

8.3 MOISTURE DISTRIBUTION

Perfect mixing is acceptable when speaking about the moisture distribution in one zone, because moisture transport is coupled to air transport, and, by that, is a very quick reaction, as far as there are no barriers for convective air flow.

8.4 HYGROSCOPICITY

Some examples of hygroscopic effects in dwellings show that rooms lead their own lives, based on the mean humidity level in that room over a longer period.
Combined with moisture distribution, it is concluded that it is very important to have significant and permanent ventilation with outside air.

8.5 DEHUMIDIFIERS

A dehumidifier, apart from being a very effective machine, is not regarded as a remedial measure, because people in Belgium do not like it to be in their homes.
It may be used as an instrument to determine the vapour production in the dwelling (it is a "negative" moisture source)

9. *INSULATION OF LOFT SPACE FLOOR*

Placing of 12 cm mineral wool on the loft space floor

EFFECTS:

Increase of the thermal resistance of the ceiling:

before : R = 0.26 m2K/W
after : R = 3.34 m2K/W

Increase of the surface temperature of the ceiling:

before : r = 0.67 $\Theta si = 0.88\ \Theta i + 0.16\ \Theta e - 1.43$
after : r = 0.85 $\Theta si = 0.92\ \Theta i + 0.08\ \Theta e - 0.05$

Increase of the room air temperature in non heated rooms:

TABEL 9.1	BEFORE	r^2	$\Theta e = 5^\circ C$	AFTER	r^2	$\Theta e = 5^\circ C$
BEDROOM 1	$11.5 + 0.16\ \Theta e$	0.32	12.3	$13.2 + 0.12\ \Theta e$	0.68	13.8
BEDROOM 2	$10.2 + 0.29\ \Theta e$	0.68	11.6	$13.3 + 0.16\ \Theta e$	0.69	14.1
BEDROOM 3	$10.4 + 0.42\ \Theta e$	0.41	12.5	$13.0 + 0.36\ \Theta e$	0.70	14.8
BEDROOM 4	$8.1 + 0.38\ \Theta e$	0.70	10.0	$13.3 + 0.07\ \Theta e$	0.50	13.7

Increase of the air temperature in the heated rooms, caused by fewer heat losses to the non heated rooms, espeecially at night:

TABEL 9.2	BEFORE	r^2	AFTER	r^2
LIVING ROOM	$17.9 - 0.08\ \Theta e$	17.4	$17.7 + 0.09\ \Theta e$	0.14
KITCHEN	$19.2 - 0.09\ \Theta e$	18.7	$18.7 + 0.00\ \Theta e$	0.01
BATHROOM	$10.4 + 0.42\ \Theta e$	0.41	$16.1 - 0.07\ \Theta e$	0.07
HALL	$8.1 + 0.38\ \Theta e$	0.70	$14.0 + 0.05\ \Theta e$	0.16

Decrease of surface coefficient on the (insulated) ceiling, increase on the other surfaces

TABEL 9.3 : h_i [w/m^{2}K]	BEFORE	AFTER
CEILING	5.81	1.59
WALL	3.86	3.82

No influence on the difference in vapour pressure, decrease of the relative humidity in the bedrooms

TABEL 9.4	LIVING ROOM		BEDROOM 2	
	Pi-Pe	R.V.	Pi-Pe	R.V.
BEFORE	587 (± 134)	64,6%	392 (±45)	79,2%
AFTER	562 (± 118)	58,4%	401 (±52)	68,3%

Improvement of the surface conditions, both on the insulated and on the non insulated walls (*)

Energy savings, caused by putting of heating in the bedrooms : total energy demand at $\Theta e = 5^\circ C$, using the measured temperatures as input for a stationary multizone model:

Before: 4257 W
After: 3780 W

EVALUATION:

FROM intensive mould growth (photo 4.1) TO no more mould on the ceiling of the bedrooms
Amelioration on all the other bedroom walls,as well as in the heated rooms
Energy savings, low cost, easy handling
FIRST THING TO DO IN THIS ESTATE

10. INTERNAL INSULATION

Placing 3 cm PS + plasterboard against the walls of the living room

EFFECTS:

Increase of the thermal resistance of the wall:
before : R = 0.43 m2K/W
after : R = 1.23 m2K/W

Increase of the surface temperature of the wall:
before : τ = 0.75
after : τ = 0.82

No significant difference of the surface temperatures of the non insulated construction parts.

TABEL 10.1 MEASURING POINT	BEFORE τ	MEASURING POINT	AFTER τ
9	0.36		
33	0.39		
19	0.45		
21	0.52		
36	0.52		
22	0.54		
35	0.57		
34	0.58		
11	0.60		
15	0.61		
20	0.61	19	0.45
10	0.62	21	0.52
5	0.66	5	0.56
13	0.66	20	0.57
12	0.66	13	0.67
17	0.70	17	0.70
16	0.73	18	0.73
18	0.73	14	0.74
31	0.73	28	0.75
14	0.74	29	0.80
37	0.74	4	0.82
4	0.75		
30	0.76		
32	0.83		

No significant difference in air temperature / resulting temperatures

No influence on the difference in vapour pressure inside - outside

Improvement of the surface conditions on the insulated walls, but not on the non insulated ones.

Energy savings: total energy demand at $\Theta e = 5^{\circ}C$, using the measured temperatures as input for a stationary multizone model:
Before: 3703 W
After: 3285 W

EVALUATION:

NO MORE MOULD ON THE INSULATED WALLS
REMAINING PROBLEMS at the corners: floor/ceiling
DIFFUCULT to mount on walls with radiators, electricity, windows,..
LIMITED POSSIBLE APPLICATIONS

11. DOUBLE GLAZING

Replacement of single glasing by double glasing. In the heated zone only a few square metres (mostly double glasing before the renovation); in the bedrooms all the windows.

EFFECTS

Higher surface temperature of the glased surfaces, so practically no more condensation on the glasing.

Before: $\tau = 0.38$
After: $\tau = 0.68$

Increase of the temperature in all living rooms:

TABEL 12.1 $\Theta i = f(\Theta e)$

	before	r2	after	r2
Living room	17.7 + 0.09 Θe	0.14	18.5 + 0.01 Θe	0.00
Kitchen	18.7 + 0.00 Θe	0.01	19.1 + 0.07 Θe	0.14
Bathroom	16.1 - 0.07 Θe	0.07	18.8 - 0.37 Θe	0.87
Hall down	14.4 + 0.05 Θe	0.16	14.2 + 0.08 Θe	0.50
Hall up	13.7 + 0.05 Θe	0.10	14.2 + 0.15 Θe	0.66
Bedroom 1	13.2 + 0.12 Θe	0.68	14.7 + 0.11 Θe	0.82
Bedroom 2	13.3 + 0.16 Θe	0.69	14.9 + 0.07 Θe	0.73
Bedroom 3	13.0 + 0.36 Θe	0.70	14.6 + 0.23 Θe	0.76
Bedroom 4	13.3 + 0.07 Θe	0.50	14.5 + 0.23 Θe	0.23
Cellar	13.2 + 0.02 Θe	0.63	12.3 + 0.11 Θe	0.94

No significant influence on the difference in vapour pressure in all the rooms, the occupied bedroom excepted!

TABEL 12.2 $Pi\text{-}Pe = f(\Theta e)$

	voor:	r^2	na:	r^2
Living room	562 - 4.7 Θe	0.25	522 - 2.9 Θe	0.21
Kitchen	506 - 3.8 Θe	0.14	521 - 1.8 Θe	0.36
Bathroom	478 - 4.0 Θe	0.20	455 - 3.5 Θe	0.03
Hall down	327 - 6.3 Θe	0.29	337 - 4.0 Θe	0.07
Hall up	374 - 4.2 Θe	0.25	421 - 4.0 Θe	0.11
Bedroom 1	356 - 9.7 Θe	0.35	386 - 4.3 Θe	0.03
Bedroom 2	401 - 1.0 Θe	0.10	505 - 4.2 Θe	0.17
Bedroom 3	373 - 3.3 Θe	0.43	368 - 3.6 Θe	0.12
Bedroom 4	399 - 8.6 Θe	0.39	411 - 3.9 Θe	0.21
Cellar	217 - 15 Θe	0.29	184 - 2.9 Θe	0.35

Consequences for the surface conditions:
The chance for mould growth remains the same or a small amelioation is seen, the occupied bedroom excepted, where we see a higher risk .

TABEL 12.3: Mean relative humidity on a thermal bridge with temperature factor $\tau = 0{,}7$

	BEFORE	AFTER
Living room	73	70
Kitchen	69	68
Bathroom	76	71
Hall down	67	67
Hall up	71	72
Bedroom 1	72	71
Bedroom 2	78	80
Bedroom 3	73	69
Bedroom 4	76	72

Almost no energy savings, because the remedial measure was limited to the not heated bedrooms: total energy demand at $\Theta e = 5^{\circ}$ C, using the measured temperatures as input for a stationary multizone model:

Before: 3780 W
After: 3703 W

EVALUATION

Placing double glazing is excellent from the point of view of energy savings, and quite harmless in most of the cases. Only when there is much condensation on the existing single glasing, as it normally occurs in occupied bedrooms, caution must be made.

Ventilation grids in doors and windows

EFFECTS

No significant influence on the air temperature:

TABEL 13.1 Θi = f(Θe)

	before		after:	
Woonkamer	18.48 + 0.01 Θe	0.00	18.73 - 0.19 Θe	0.21
Keuken	19.09 + 0.07 Θe	0.14	20.95 - 0.30 Θe	0.41
Badkamer	18.81 - 0.37 Θe	0.87	14.42 + 0.38 Θe	0.38
Hall beneden	14.24 + 0.08 Θe	0.50	13.13 + 0.33 Θe	0.17
Hall up	14.20 + 0.15 Θe	0.66	12.66 + 0.36 Θe	0.16
Bedroom 1	14.71 + 0.11 Θe	0.82	11.14 + 0.45 Θe	0.48
Bedroom 2	14.94 + 0.07 Θe	0.73	12.37 + 0.33 Θe	0.39
Bedroom 3	14.55 + 0.23 Θe	0.76	13.53 + 0.22 Θe	0.63
Bedroom 4	14.54 + 0.23 Θe	0.23	12.79 + 0.34 Θe	0.17
Cellar	12.25 + 0.11 Θe	0.94	12.73 + 0.13 Θe	0.21

Strong decrease of the difference in vapour pressure between the inside and outside

TABEL 13.2 Pi-Pe = f(Θe)

	before:		after:	
Living room	562 - 4.7 Θe	0.25	525 - 35 Θe	0.21
Kitchen	506 - 3.8 Θe	0.14	539 - 41 Θe	0.36
Bathroom	478 - 4.0 Θe	0.20	279 + 5 Θe	0.07
Hall down	327 - 6.3 Θe	0.29	142 + 1 Θe	0.23
Hall up	374 - 4.2 Θe	0.25	189 + 5 Θe	0.38
Bedroom 1	356 - 9.7 Θe	0.35	118 + 16 Θe	0.13
Bedroom 2	401 - 1.0 Θe	0.10	322 + 17 Θe	0.17
Bedroom 3	373 - 3.3 Θe	0.43	187 -5 Θe	0.30
Bedroom 4	399 - 8.6 Θe	0.39	131 + 16 Θe	0.02
Cellar	217 - 15 Θe	0.29	187 -1 Θe	0.00

Amelioration of the surface conditions

TABEL 13.3: Mean relative humidity on a thermal bridge with temperature factor τ = 0,7

	before	after:
Living room	70	60
Kitchen	68	57
Bathroom	71	64
Hall down	67	55
Hall up	72	60
Bedroom 1	71	65
Bedroom 2	80	79
Bedroom 3	69	59
Bedroom 4	72	64

Almost no energy savings, because the remedial measure was limited to the not heated bedrooms: total energy demand at Θe = 5° C, using the measured temperatures as input for a stationary multizone model:

Before: 3780 W
After: 3703 W

EVALUATION

Placing double glazing is excellent from the point of view of energy savings, and quite harmless in most of the cases. Only when there is much condensation on the existing single glasing, as it normally occurs in occupied bedrooms, caution must be made.

13. CONCLUSIONS

The cause of the problems in these dwellings is quite obvious, and may be summarised in one sentence: "The cause of the problems is a combination of poor thermal quality and limited ventilation possibilities, leading to mould growth in dwellings where people can not afford to heat well".

The solution can be found in two ways: increasing the surface temperature of the walls or lowering the inside humidity.
Increasing the surface temperature can be achieved by heating more, a very costly and inefficient way (surely in low income housing), or by increasing the thermal quality of the dwellings. The most straightforward measure in this regard is insulating the loft space floor, followed by placing double glazing and (external) insulation.
Lowering the inside humidity level can be achieved by removing the humidity near the sources (kitchen hood, bathroom ventilator) and by making natural ventilation possible and more efficient (by placing ventilation grids in the windows and inside doors).
In order to be sure to have dwellings without moisture problems all the remedial measures above (thermal insulation and increased ventilation and moisture removal) must be taken.

Out of tne measuring results two important aspects were analysed:

1. MOISTURE DISTRIBUTION
   Perfect mixing is acceptable when speaking about the moisture distribution in one zone, because moisture transport is coupled to air transport, and, by that, is a very quick reaction, as far as there are no barriers for convective air flow.
2. HYGROSCOPICITY
   Some examples of hygroscopic effects in dwellings show that rooms lead their own lives, based on the mean humidity level in that room over a longer period.
   Combined with moisture distribution, it is concluded that it is very important to have significant and permanent ventilation with outside air.

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CASE STUDY 2

"RUHRGEBIET"

GERMANY

International Energy Agency
ENERGY CONSERVATION IN BUILDINGS
AND COMMUNITY SYSTEMS PROGRAMME

ANNEX XIV
Condensation and Energy

IEA EC ANNEX XIV
CASE STUDY "RUHRGEBIET"

Germany

1.0 Introduction

In the spring of 1988, an investigation of 67 flats affected by mould growth was carried out by The Fraunhofer Institute of Building Physics. It was to provide information about the extent and the cause of the damage encountered in those flats.

Due to the large number of dwellings which had to be visited, it was not possible to carry out measurements which yield reliable results only after a sustained period. Therefore, methods were selected which, after a single visit, give conclusive data useable for statistics. The main points of the investigation were:

- Observation of the building stock

- Collection and analysis of surface samples affected by mould

- Collection of building component samples from the affected surface areas and determination of the moisture content (with the occupants' consent only)

- Air change rate measurements (with the occupants' consent only)

- Photographic documentation

2.0 Building stock

2.1 Geographic location/climate

The investigation was carried out in North Rhine-Westphalia in the northern and southern Ruhr (Fig. 1). The area is situated at 152 m above sea-level.

Geographic location: Longitude: 6,7° East
Latitude: 51,4° North

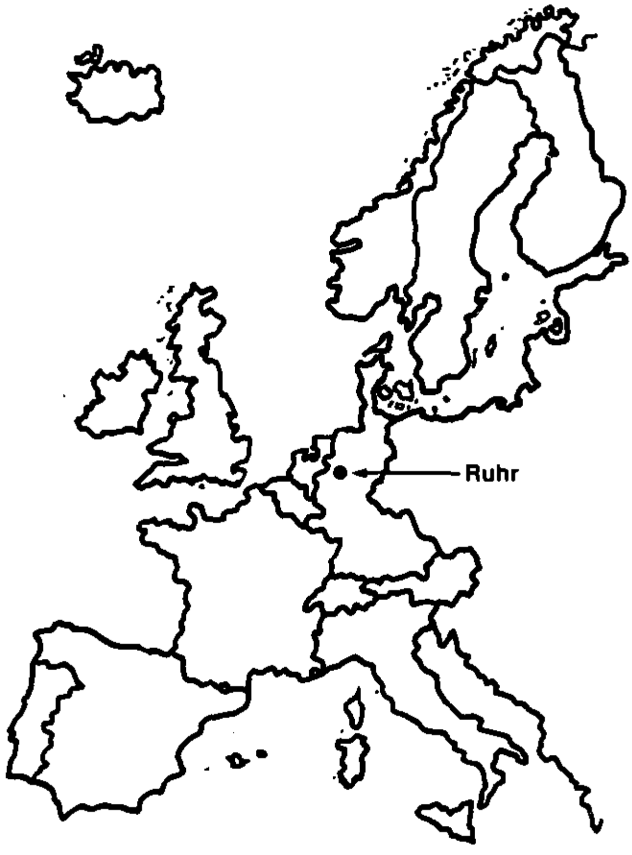


Fig. 1: Location of the Ruhr in Germany.

The mean climate conditions of the test area are compiled in Table 1. All through the year, a relative outside air humidity of more than 70 % prevails. For this reason, the outside air is heavily loaded with moisture, particularly in the mild season.

Table 1: Mean climate conditions in the test area.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Mean value
Outside air temperature [°C]	1.87	1.85	5.29	8.04	13.38	15.02	17.11	17.75	14.58	10.12	6.00	1.89	9.45
Relative outside air humidity [%]	83	82	75	69	68	75	74	70	78	81	81	87	76

2.2 General description of dwellings

The 67 buildings examined were mostly constructed in the years from 1940 to 1970, a time when there existed no energetic requirements for external walls. For this reason, the exterior walls were only equipped with the minimum level of thermal insulation which was required then. From 1978 to 1986, the windows that had originally been installed were replaced in almost every flat by new ones with improved thermal insulation and higher airtightness. One or two years later, mould growth set in in most dwellings, which were mainly equipped with composite windows having plastic frames with aluminium cores. 17 % of the dwellings, however, were equipped with single-glazed windows. There is a theory according to which it is precisely the installation of windows with improved thermal insulation which results in the occurrence of damage, because it is claimed that single-glasing, as a "natural condensator", has a moisture-regulating effect. Statements of that kind, which are frequently heard in discussions and which are often meant as a lecture, are certainly refuted by the above result. The amount of surface condensation which occurs at glasings is much lower than the moisture produced within dwellings. It is therefore through ventilation that humidity must be extracted. Increased heat losses through insufficient thermal insulation of windows are however to be avoided.

Table 2: The types of windows (in per cent) installed in the test flats.

Frame material	Type		
	Single glasing	Thermopane glasing	Composite windows
Wood	11	1	-
Aluminium	6	2	5
Plastic	-	6	69

3.0 Boundary conditions

3.1 Occupation density

The tested dwellings were occupied by a relatively large number of people. In Fig. 2, the living space of each occupant is compared as frequency curves to the values characteristic of the FRG. The curves represent the percentage of people included in the survey occupying a living space which is below the corresponding value on the curve. From Fig. 2 it can be concluded that in the tested dwellings, the living space related to the number of occupants is visibly inferior to West-German average values. The mean living space of rented flats is known to be inferior to the living space of flats occupied by their

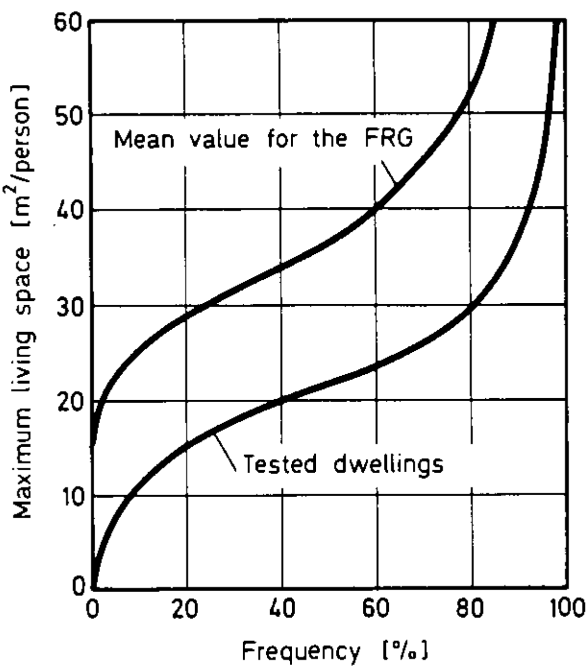


Fig. 2: Comparison between the frequency curves of the living spaces in the tested flats related to the number of occupants and the mean values characteristic for the FRG, acc. to [1]. The frequency curves indicate the percentage of people included in the survey who occupy a living space which is inferior to the resp. value on the curve.

owners. The size of rented flats is approximately 20 % below the mean value characteristic of the West-German building stock. In some of the flats examined the living-space is more than 50 % below average. In 50 % of the dwellings the space related to the number of occupants is less than 21 m^2 (compared to an average of 46 m^2). For dwellings with such a high occupation density, a higher moisture load is therefore to be expected.

3.2 Moisture production

The moisture loads recorded in the tested flats are presented in Fig. 3 in the form of a frequency distribution curve. A mean moisture production of app. 3 $g/(h \cdot m^3)$ prevailed in most flats. In some, however, values of up to 6 $g/(h \cdot m^3)$ were reached. Given a mean dwelling size of 64 m^2 resp. 160 m^3, this corresponds to a mean daily moisture production of app. 12/l of water vapour, which is the amount generated by an average family. For this reason, it can be concluded that the quantity of water vapour emitted by the occupants mostly corresponds to mean empirical values, and that in most cases it did not exceed average.

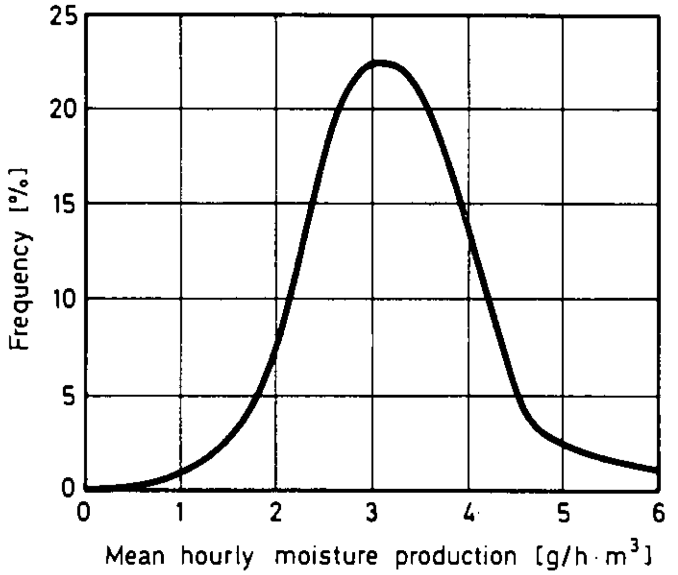


Fig. 3: Frequency distribution of the mean hourly moisture production in the tested flats.

3.3 Rent and heating

The tested flats are objects with average building equipment. The monthly costs of rent and heating related to living space are presented in Fig. 4.

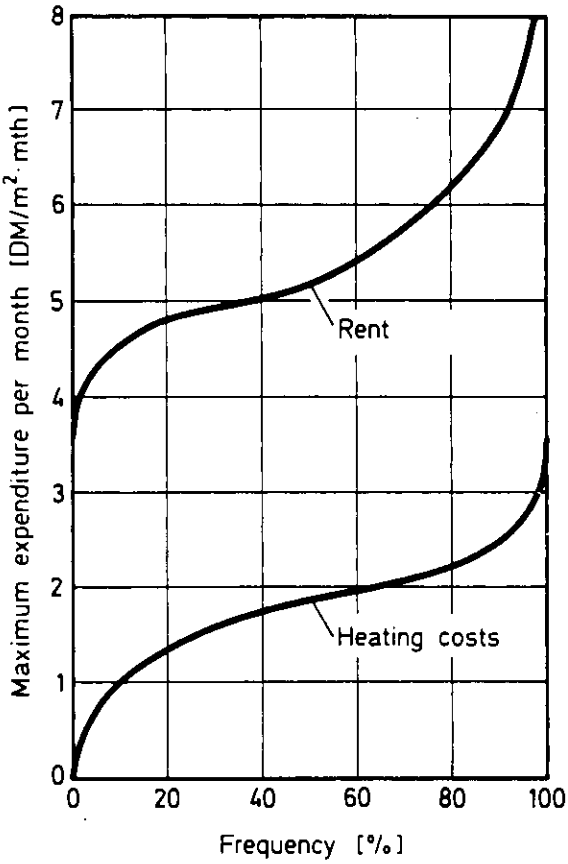


Fig. 4: Frequency curves of rent and heating costs related to living space (1987/1988 heating period). The frequency curves indicate the percentage of people included in the survey incurring expenses which are superior to the resp. value on the curve.

Rents are between 4 and 8 DM/m^2, the average being 5 DM/m^2. In 1988, the price of energy was low. When the new windows were installed it was twice as high as before, thus amounting to some kind of second rent. As rents also include heating, and given the rising price of energy, the only way to prevent them from further increasing is reduced heating. In order to achieve an energetic improvement of the dwelling stock from the point of view of the building industry (with or without state subsidies), a revision of the method for rent calculation will be necessary. With the present calculations, damage increases through insufficient heating are to be expected in case the price of energy rises.

4.0 Damage analysis

4.1 Frequency of occurrence of mould damage

In the investigation it was found that the extent of damage caused by mould growth was not identical for all rooms. The frequencies of occurrence of mould damage related to the different types of rooms are presented in Table 3. Most often, it were bedrooms which were affected. In living-rooms and child's rooms the values were only half as high. Kitchens accounted for only 10 % of the contaminated rooms, and bathrooms for only 2 %. Both kitchens and bathrooms were exclusively ventilated by windows. In many flats it was observed that the doors between living-room(s) and bedroom(s) were almost continuously open, thus increasing the risk of surface condensation because of the lower bedroom temperatures and the almost equal moisture distribution in all rooms. Therefore, it has to be examined which room conditions the boundary conditions which are used to determine, whether the building component surfaces are free of condensation, are to be assigned to.

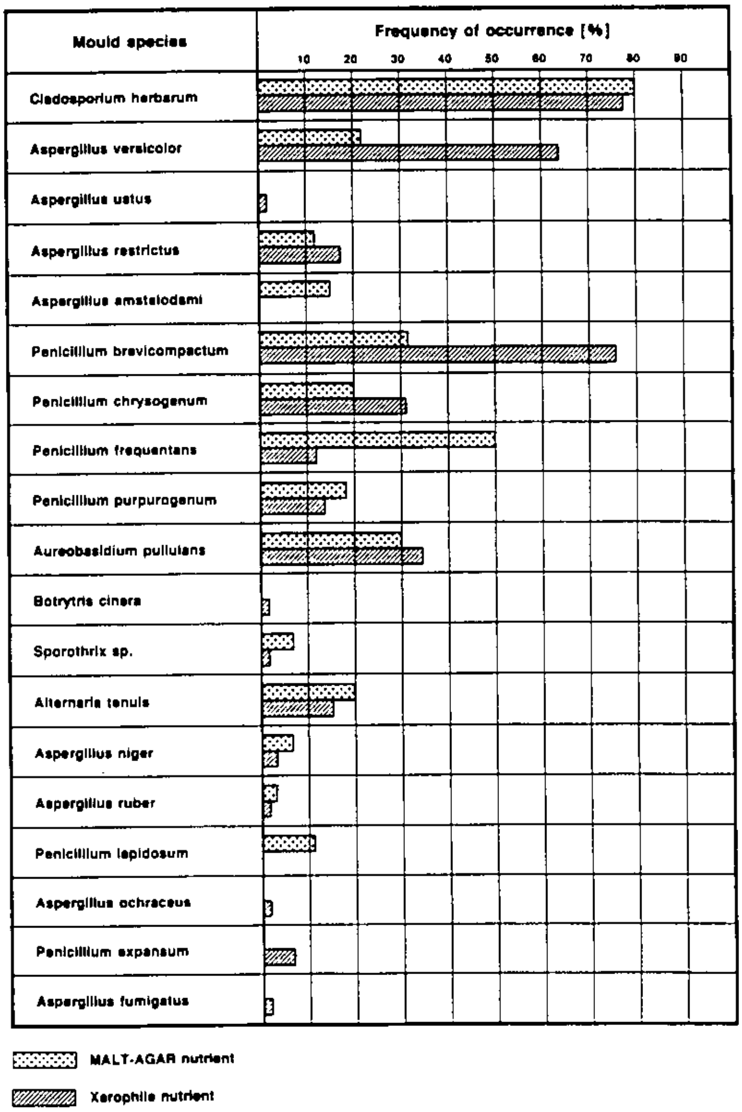
Table 3: The types of rooms most frequently affected by mould.

Room	Frequency [%]
Bedroom	42
Living-room	22
Child's room	21
Kitchen	11
Bathroom	2
Other rooms	2

4.2 Analysis of species of fungi identified

An analysis was conducted to determine the causes for damage and identify the genera encountered. Table 4 gives an overview of the fungi and their frequencies of occurrence on some 200 test specimen. Pure cultures were provided by subculturing the mixed populations on to fresh malt-agar and xerophile nutrients. Cladosporium herbarum was isolated from app. 80 % of the samples (see Table 4). Aspergillus versicolor and Penicillium brevicompactum were identified from 50 % of the samples. Penicillium chrysogenium, Penicillium frequentans and Aureobasidium pollulans appeared on one sample in four. The remaining species accounted for less than 20 % of the samples. However, there was no sample with a pure culture consisting of a single species. In general, each sample included 3 to 8 different genera. It is therefore necessary to know the microbiology of the most frequent species to draw conclusions about the boundary conditions for their growth in terms of building physics.

Table 4: Compilation of the species of fungi identified from the samples.



4.3 Occupancy patterns

A metrological determination of occupancy patterns was not possible, because only spot samples were taken. Data on the occupants' behaviour with regard to heating and ventilation was exclusivley obtained by way of a survey. Although there may exist considerable differences between estimated occupancy patterns and measurement results, surveys are nevertheless a means of identifying certain tendencies. The occupants were asked about the mean temperature level in their homes, and how long the mean daily ventilation period was. The results are compiled in Table 5.

Table 5: Result of the survey on the occupants' behaviour during the heating period.

Survey question		Occupants' behaviour		Number [%]
What is the mean temperature inside your dwelling?	< 19 °C	Readiness to heat	Low	22
	19 - 21 °C		Average	66
	> 21 °C		Strong	1
	No answer			11
How long is your mean daily ventilation period?	< 15 min	Ventilation activity	Low	31
	15 - 45 min		Average	16
	> 45 min		Strong	22
	Now answer			31

Most occupants estimated the temperatures within their dwellings to be normal, while some inhabitants were deliberately keeping them at a low level. With respect to ventilation, a larger variety of patterns could be observed. One third of the inhabitants opened their windows less than 15 min./day. In a brochure distributed by the house management, the inhabitants were provided with comprehensive information about mould problems and asked to open their windows at least 3 times a day for 5 to 10 minutes of intensive ventilation. Some 20 % of those surveyed declared that they opened their windows longer than recommended. It could not be established whether the answer was influenced by the brochure, which was in particular destined for the inhabitants of mouldy homes.

4.4 Influential factors

The investigation analysed the parameters which might be the cause for mould growth. In this context, influences relating to construction and to user behaviour were examined. Excessive values of indoor air humidity were obviously attributable to user behaviour, when mould was not only growing on building component surfaces but also on furnishings. A compilation of the factors and their frequencies is presented in Table 6. Structural deficiencies included thermal bridges, defective rain protection devices and rising moisture . Among structural deficiencies it was defective rain protection that ranked first: large cracks were frequently observed in exterior plaster. Thermal bridges came second, namely feathered building components, gravel stops and window joints. To avoid building damage, the same close monitoring is required for modernising old dwellings as for constructing new ones.

Damage due to rising moisture was of minor importance in the investigation. Instead, in one third of the dwellings, mould was observed not only on exterior building components but also on furnishings, furniture and interior building components. This phenomenon indicates an excessive level of indoor air humidity in all rooms, since mould growth will set in at 80 % r.h.. By adding up the frequencies in Table 6, it becomes clear that the damage is often caused by more than just one factor. For this reason, all possible parameters should be included in the damage evaluation. The building substance and its construction as well as occupancy patterns should be taken into account.

Table 6: Compilation of the most frequent parameters for mould growth. Since damage is often due to more than a single factor, the addition of the parameters results in a value above 100 %.

<table>
<tr><th colspan="3">Influential factors for moisture damage</th><th>Frequency [%]</th></tr>
<tr><td rowspan="6">Building</td><td rowspan="3">Thermal bridges</td><td>Parapet</td><td>21</td></tr>
<tr><td>Window reveal</td><td>18</td></tr>
<tr><td>Others</td><td>5</td></tr>
<tr><td rowspan="2">Rain protection device</td><td>Small cracks</td><td>37</td></tr>
<tr><td>Large cracks</td><td>15</td></tr>
<tr><td colspan="2">Rising moisture</td><td>9</td></tr>
<tr><td>Occupant</td><td colspan="2">Indoor air humidity (mould growth on furniture)</td><td>31</td></tr>
</table>

5.0 Literature

Erhorn, H.: Schäden durch Schimmelpilzbildung im modernisierten Mietwohnungsbau. Umfang, Analyse und Abhilfemaßnahmen. Bauphysik 10 (1988), H.5, S. 129 - 134.

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CASE STUDY 3

"IACP TORINO"

ITALY

International Energy Agency
ENERGY CONSERVATION IN BUILDINGS
AND COMMUNITY SYSTEMS PROGRAMME

ANNEX XIV
Condensation and Energy

CASE STUDY IACP **ITALY**

FINAL REPORT

OBSERVATIONS

MEASUREMENTS

RESULTS

REMEDIAL MEASURES

CONCLUSIONS

1. SITUATION

Torino Caselle

45° 11' N
7° 39' E
altitude ≈ 282 m

climate

	J	F	M	A	M	J	J	A	S	O	N	D
Θ	O.1	1.6	7.2	11.0	15.5	19.2	22.0	20.4	17.2	11.6	5.6	1.6
ϕ	82.4	82.6	53.5	56.6	68.1	77.9	74.6	85.3	75.6	82.5	87.9	82.8

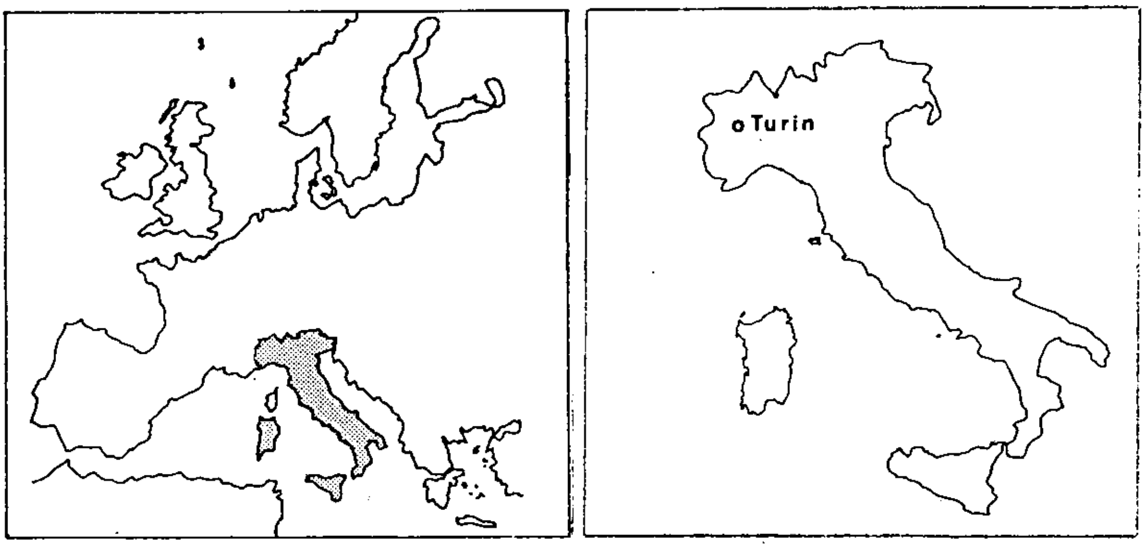
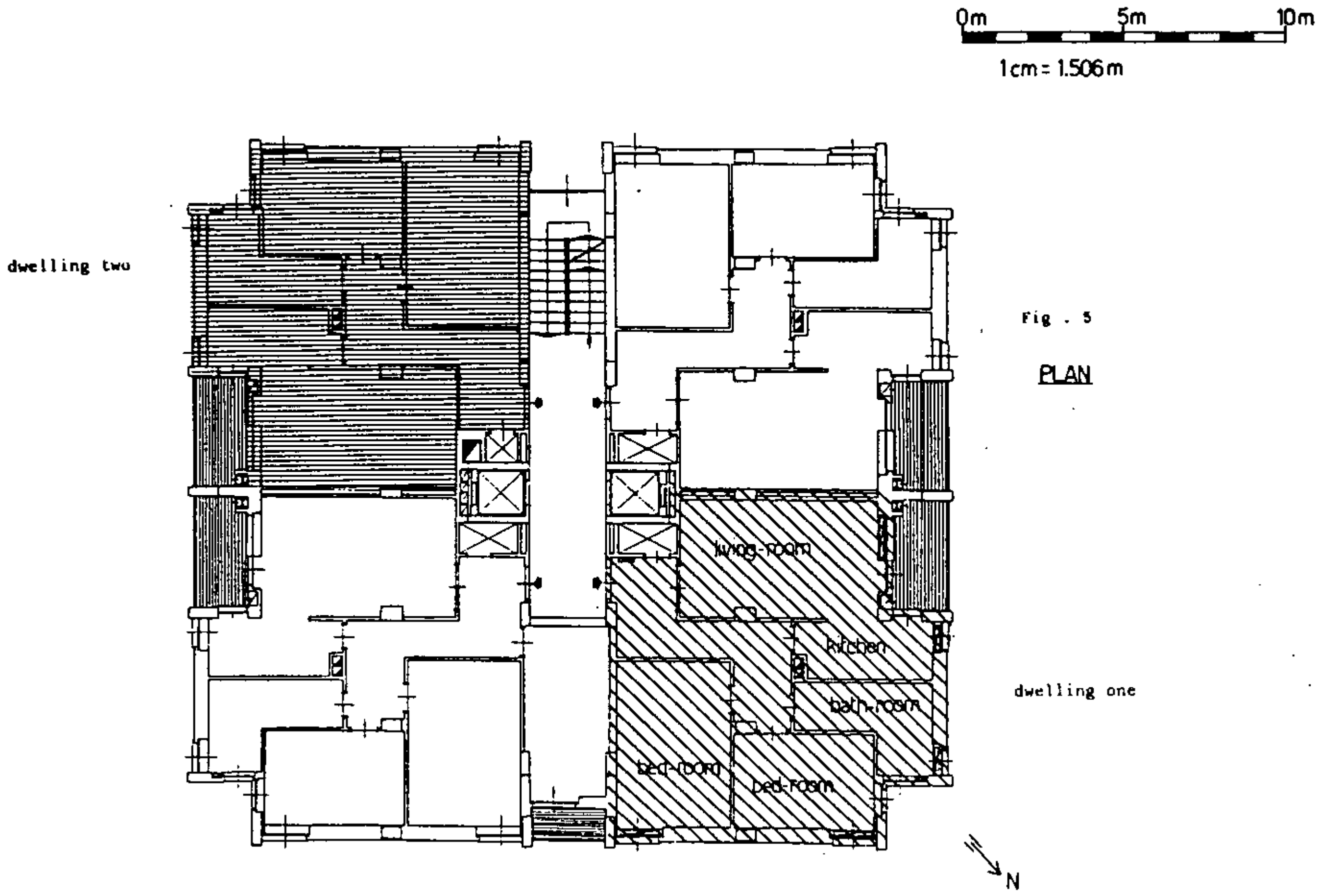


Fig. 1 - Photo of the settlement

2. LAY OUT



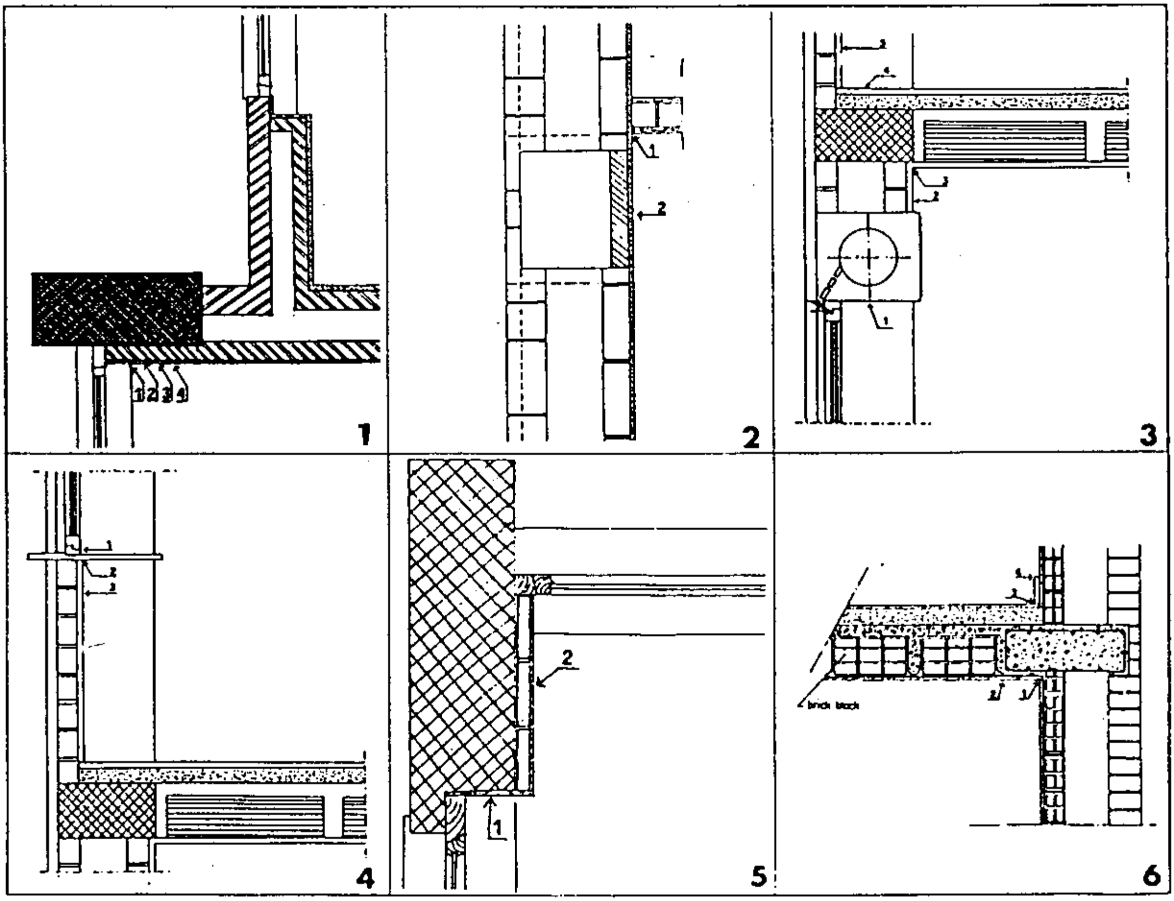
	A [m²]	V [m³]
1. Living Room	19.7	59.0
2. Kitchen	6.5	19.6
3. Bathroom	7.2	21.6
4. Hall	12.4	37.1
5. Bedroom 1	15.9	47.6
6. Bedroom 2	10.8	32.5

3. BUILDING FABRIC

CONSTRUCTION PARTS		R [m^2K/W] Calculated
WALLS:	cavity walls (10/18/12)	0.73
	concrete curtain and air brick walls	0.36
ROOF:	pitched, tiled roof loft soace floor	
	reinforced brick floor	0.67
FLOORS:	same as loft space floor	0.67
	the first floor is on pilings	0.62
DOORS AND WINDOWS:	metal frames, simple glazing	0.17

CONSTRUCTION DETAILS	figure	τ [-] 1	2	3	4	5
CORNER 1	1	0.26	0.64	0.67	0.68	
PILLAR	2	0.82	0.72			
WINDOW LINTEL	3	0.91	0.50	0.83	0.70	0.62
SILL WINDOW	4	0.45	0.50	0.63		
CORNER 2	5	0.66	0.73			
FLOORS	6	0.71	0.87	0.74	0.78	

The value presented are calculated using hi = 8 and he = 23 W/m^2K



4. THE MOISTURE PROBLEM

MOISTURE PRODUCTION & REMOVAL

Dwellings: n 1 6 persons
n 2 6 persons

There is no mechanical nor natural ventilation system, there is a individual heating system. People dry cloths in the bathroom when it is raining.

Dwelling n 1: window sealing and rolling shutter box insulation

Dwelling n 2: frequent windows opening

DAMAGE

	Mould damage	photo
bedroom 1	on outside walls corners, around windows, behind wardrobes	
bedroom 2	on outside walls corners,around windows, behind wardrobes	2
living room	around windows	
kitchen	on outside walls corners	
bathroom	around windows, on ceiling surface	1

Dwelling n 1: all of the above problems

Dwelling n 2: no problems

THE MOULD SPECIES in x % of the samples present

	AIR GRAVITY out of 12 samples	SWABBING out of 9 samples
Cladosporium sphaerospermum	83	100
Cladosporium cladosporioides	75	-
Aspergillus versicolor	58	44
Penicilium brevi-compactum	50	-
Acremonium strictum	17	33
Penicillium chrysogenum	41	22
Acremonium kiliense	8	22
Phoma herbarum	8	22
Penicillium diversum	33	-
Stachybotrys chartarum	33	-
Ulocladium alternariae	33	11
Alternaria alternata	33	-
Penicillium aurantio-griseum	25	11
Penicillium corylophilum	17	11
Aspergillus sulphureus	17	-
Aureobasidium pullulans	17	-
Chaetomium globosum	17	-
Penicillium implicatum	17	-
Penicillium viridicatum	17	-
Mycelium sterile moniliaceum (5)	17	-
Asdpergillus sydowi	-	11
Phoma pomorum	-	11
Mycelium fibulatum moniliaceum	-	11
Mycelium arthroconidicum moniliaceum (3)	-	11
Mycelium arthroconidicum moniliaceum (4)	-	11
Mycelium arthroconidicum moniliaceum (5)	-	11
Mycelium sterile moniliaceum (7)	-	11
Mycelium sterile dematiaceum	-	11

Some 50 species were found, being different from one room to another and from one finishing layer to another.

CONSEQUENCES FOR THE INHABITANTS

Complaints about health problems of people sleeping in bedroom 2

fig. 1

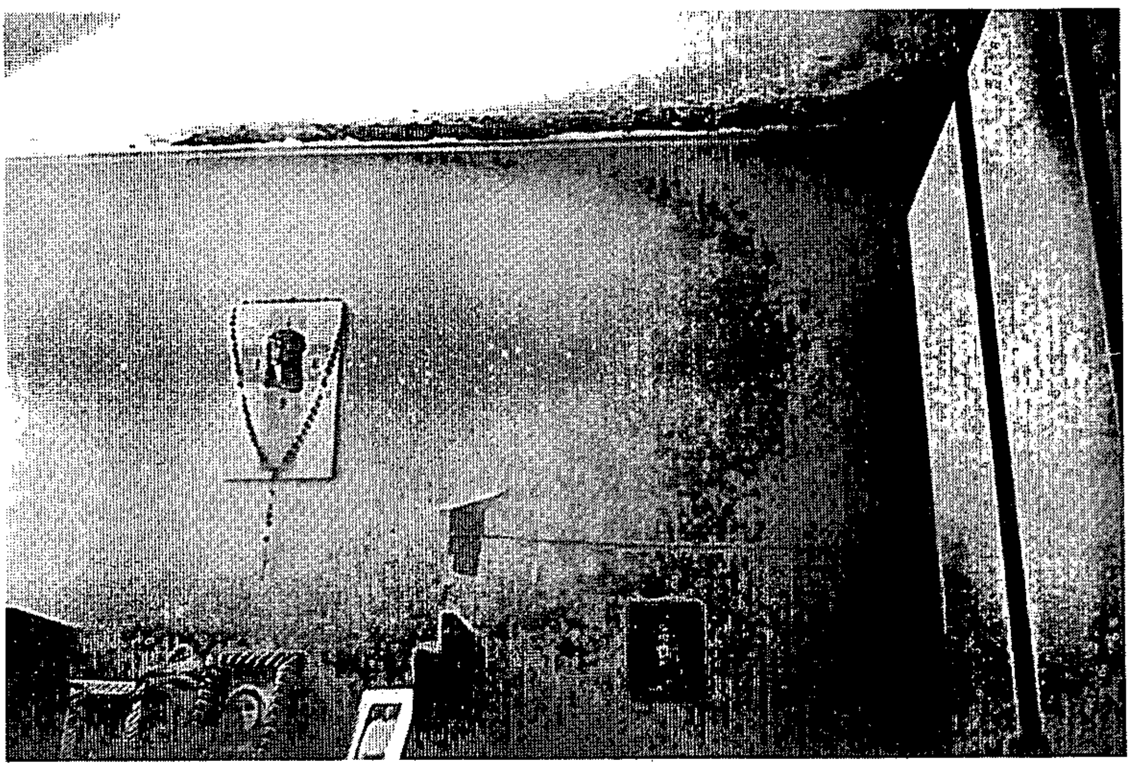


fig. 2

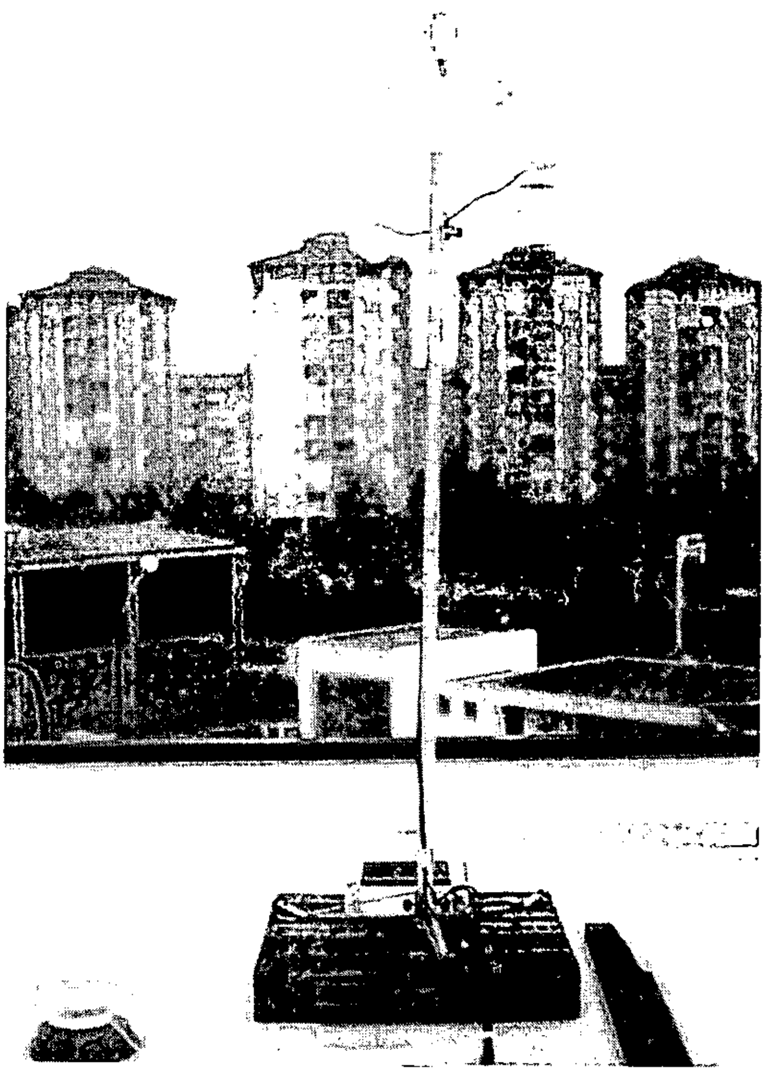


fig. 1

fig. 2

5. MEASUREMENTS

	WHAT	EQUIPMENT	Photo
1	SURFACE TEMPERATURE	Pt100 thermoohmresistance	
2	AIR TEMPERATURES	Pt100 thermoohmresistance	
3	RESULTING TEMPERATURE	Pt100 in ping pong ball	
4	RELATIVE HUMIDITY	Capacitive probes	
5	AIR TIGHTNESS	Tracer-gas devices	
6	MOULD SAMPLING & DETERMINATION	Air gravity and swabbing with sterile buds samples (Petri dishes) Insulation in tubes with malt or Czapek's agar and identification by key books for species.	
7	OUTSIDE CLIMATE	Meteo System LSI	
	• TEMPERATURE	Pt100 thermoohmresistance	
	• RELATIVE HUMIDITY	Resistance probe	
	• TOTAL SOLAR RADIATION	Solarimeter	1
	• WIND SPEED AND DIRECTION		

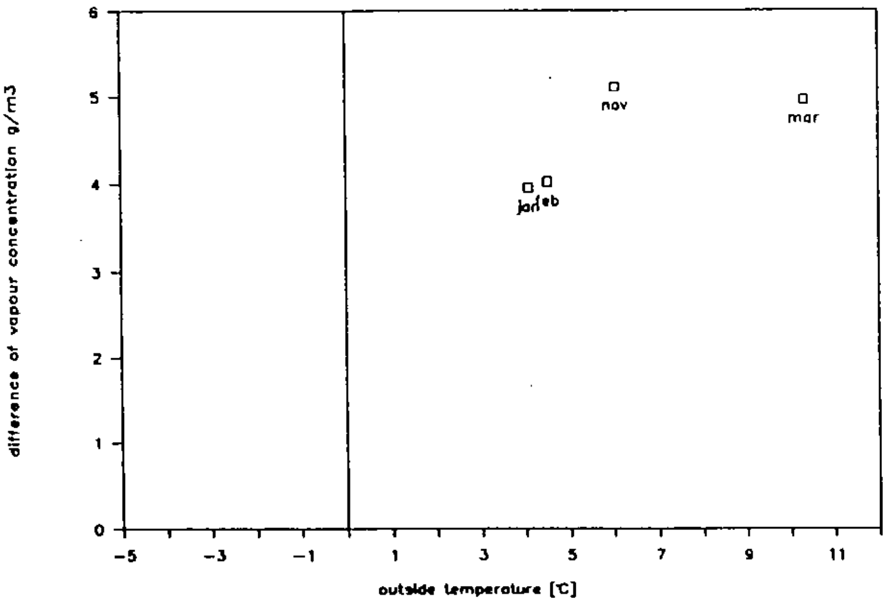
MANAGEMENT

13-30 November 1987	Dwelling n 1	2+4 in all rooms 1 in some significant points of bedrooms 1 and 2, living room and bathroom	
13 January-14 February 1988	Dwelling n 1	2+4 in all rooms 1 in some significant points of bedroms 1 and 2, living room and bathroom	
17 January-26 February 1988	Dwelling n 2	2+4 in all rooms 1 in the symmetric points of dwelling 1	
19-23 March 1988	Dwelling n 1	2+4 in all rooms 1 in some significant points of bedrooms 1 and 2, living room anf bathroom	
Data Acquisition Unit:	data logger on magnetic tape (LSI- Laboratori di Strumentazione Industriale S.p.a)		2

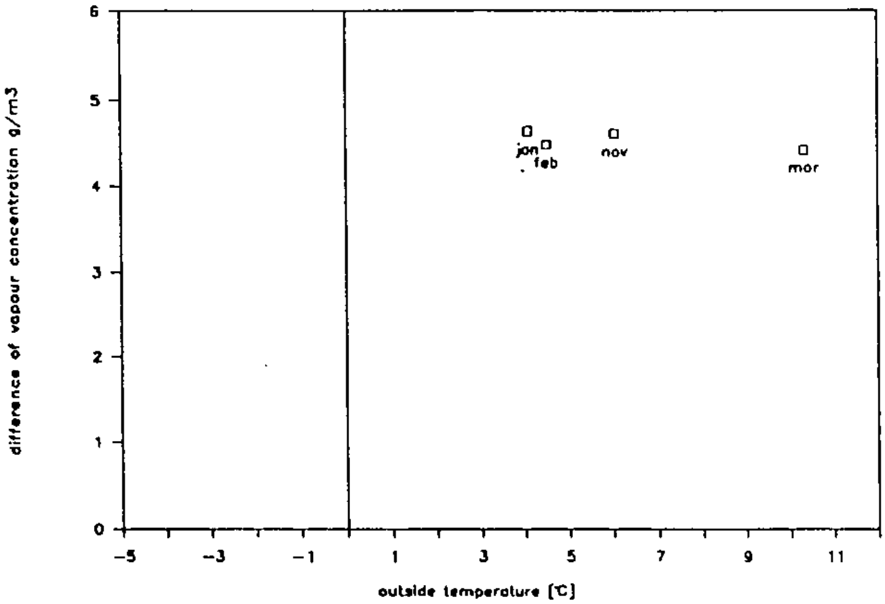
6. THE INSIDE CLIMATE (original situation)

TEMPERATURE	$\Theta i = f(\Theta e)$ Dwelling 1	r^2
bedroom 2	$16.3 + 0.26\Theta e$	0.27
bedroom 1	$18.2 + 0.02\Theta e$	0.016
livingroom	$16.8 + 0.15\Theta e$	0.16
bathroom	$18.3 + 0.12\Theta e$	0.10
kitchen	$20.2 + 0.07\Theta e$	0.04

HUMIDITY	$Pi - Pe = f(\Theta e)$ Dwelling 1	r^2
bedroom 2	$745 - 9.6\ \Theta e$	0.03
bedroom 1	$681 + 2.19\ \Theta e$	0.00
living room	$505 - 5.6\ \Theta e$	0.02
bathroom	$841 - 17.0\ \Theta e$	0.09
kitchen	$586 + 8.1\ \Theta e$	0.02



KITCHEN



BEDROOM 1

7. THE BUILDING PERFORMANCE

BUILDING FABRIC

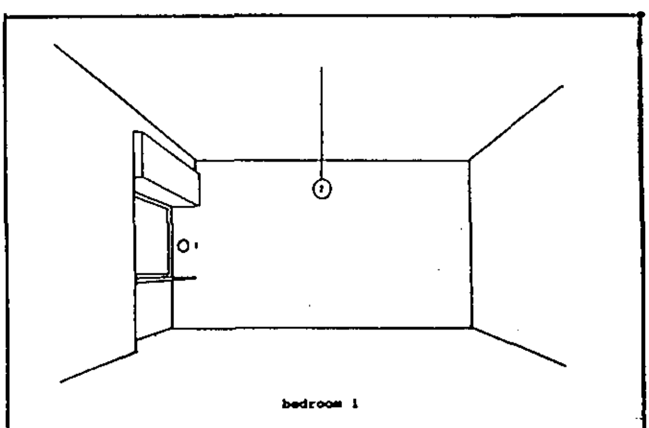
	Dwelling 1	Dwelling 2
Thermal resistance and τ-values		see 3
Ventilation rate (measured) [h^{-1}]		0.4
Heating cost		

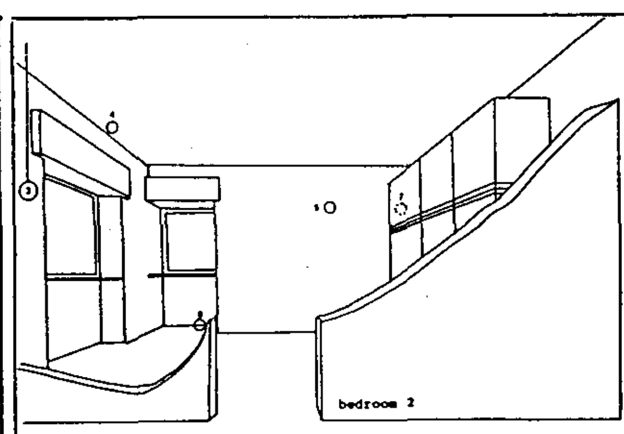
SURFACE CONDITIONS

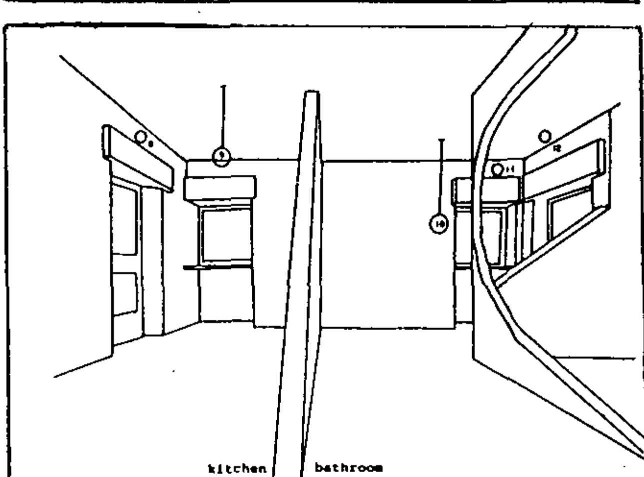
measuring point — **% of time**

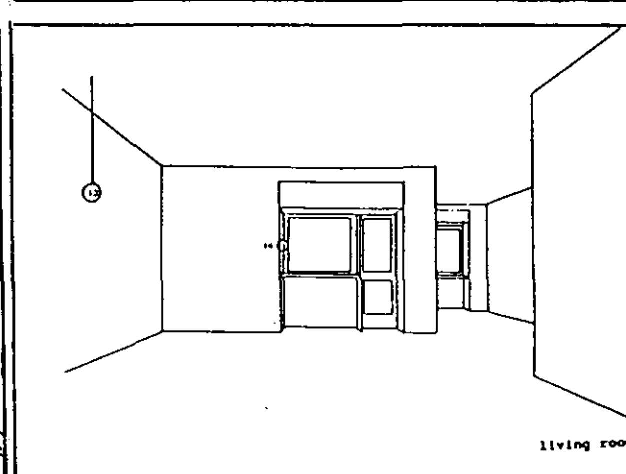
	finishing material	mould (Y/N)	$\phi > 70\%$	$\phi > 80\%$	$\phi = 100\%$
Dwelling 1					
2 bedroom 1 air			37.0	2.6	0
1 window sash	enamel paint	Y	86.5	68.4	12.8
3 bedroom 2 air			26.5	1.8	0
4 ceiling	white wash	Y	53.9	18.6	0
5 outside wall	wall paper	Y	44.6	9.1	0
6 partition	wall paper	N	2.5	0	0
7 wall along side of wardrobe	plaster	Y	54.1	2.1	0
10 bathroom air			32.1	1	0
12 corner	white wash	Y	81	60	3
11 shutter box	enamel paint	Y	65.7	36.4	0.5
9 kitchen air			0.1	0	0
8 lintel		(Y)	18.3	5	0
13 living room air			1.5	0	0
14 window sash		Y	66.1	47.6	1.8

(Y) = visible mould from the past. It is not clear wether this mould is still active
Y = present mould growth
* = no mould, but surface condensation observed during measuring period









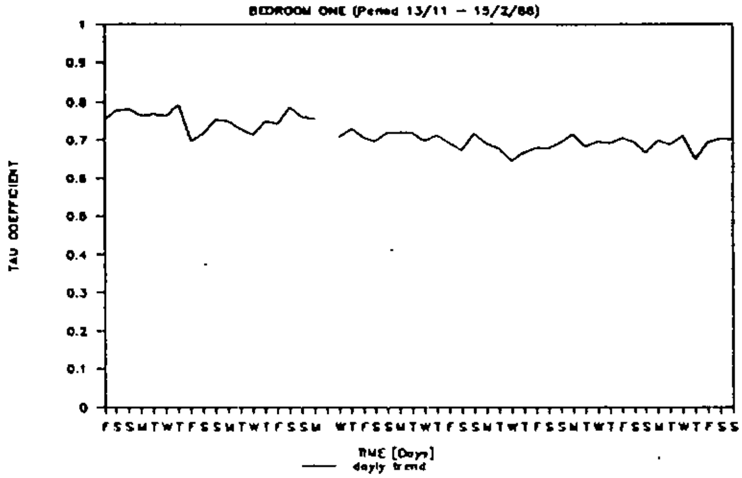
8. SPECIAL TOPICS

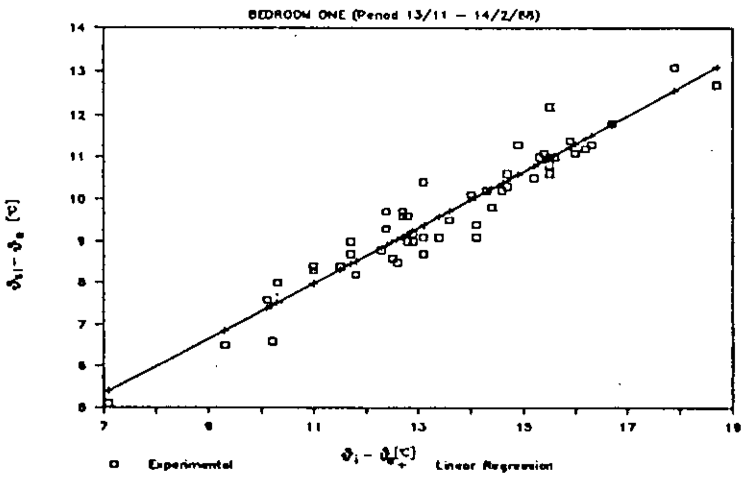
8.1 TEMPERATURE FACTOR τ

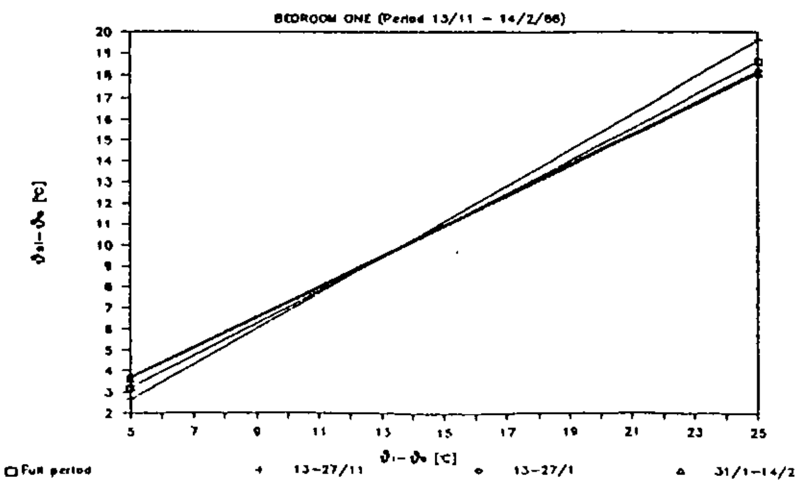
τ varies in space and time for a number of reasons, such as the presence of two ot three dimensional heat fluxes in the building structure, or time varying boundary conditions within the wall and at the wall boundaries.

Nevertheless a regression line can be plotted of (Θ_{si}-Θ_e) against (Θ_i-Θ_e); the slope of the regression line gives a mean estimate of the temperature factor at that point.

The measuring period requested to obtain a reliable regression line is of 15 days.







8.2 HUMIDITY ON THE WALL

Assuming to mantain the relative humidity in the inside air within the comfort limits (60% RH) by means of ventilation, the time percentages at which surface relative humidity might exceed 70%, 80%, =100% were found.

EVALUATION

- The critical thermal bridges are in bedroom 1, in the bathroom and in the kitchen.
- For all the other thermal bridges the high RH in the room seems to be the main cause of molds growth and surface condensation.

RHsi trend when RHi is equal to 60% (% time)
Dwelling IACP 1

room / time %	RHsi Mean value	RHsi >70%	RHsi >80%	RHsi =100%
bedroom 1	77	96,4	15	0
bedroom 2				
on white wash (ceiling)	67	13,5	0	0
on wall paper (outside wall)	64	0,3	0	0
on wall paper (partition) **	59	0	0	0
plaster along wardrobe side	67	16	0	0
bathroom				
corner **	78	100	33,6	0,2
over rolling shutter box	68	11,8	0	0
kitchen*	70	46,7	0,83	0
living room	72	38,8	24,5	0

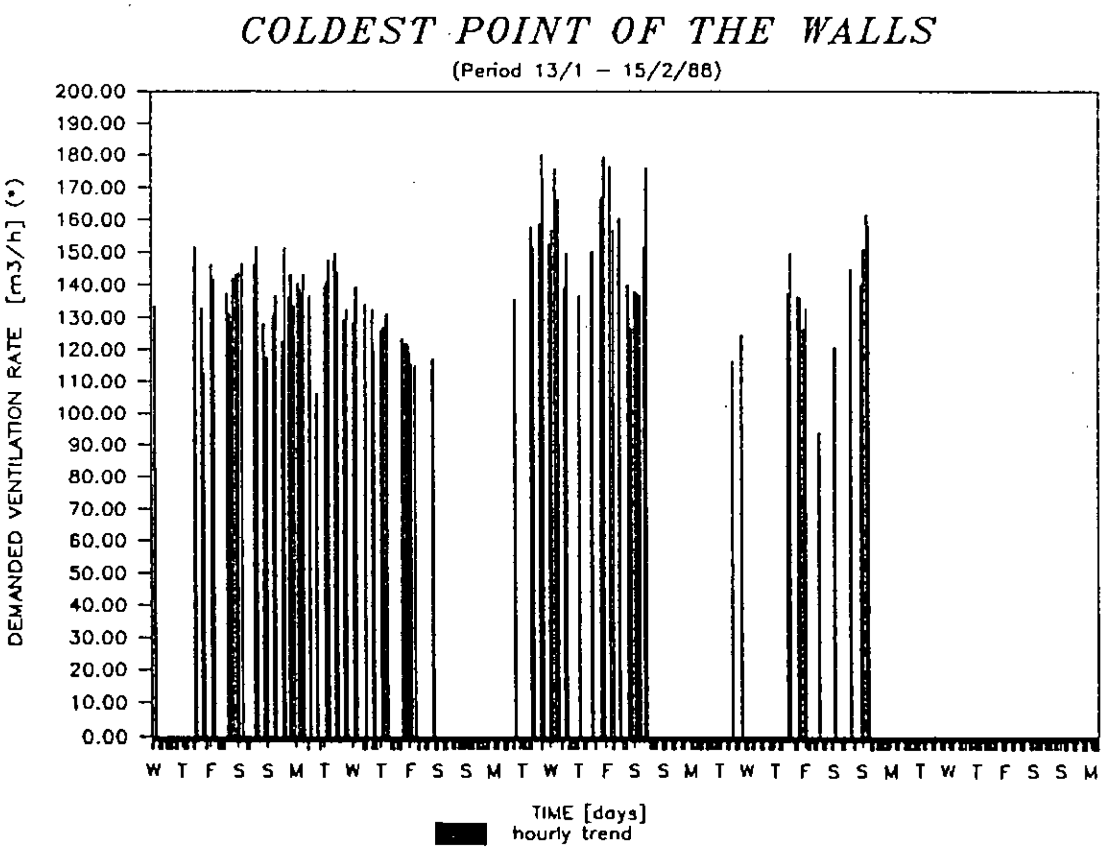
* data of the third measuring period only
** data of the first two measuring periods only

8.3 MOISTURE GENERATION AND VENTILATION

Using the mean ventilation rate and, as first approximation, the steady - state mass balance equations, the hourly moisture generation in each room and then the maximum steam production in all the flat (1kg/h) were derived.
To contrast moisture generation and prevent surface condensation a minimum ventilation rate was plotted.

EVALUATIONS

- The estimated everage steam production (1kg/h) is an acceptable value for six people living in the dwelling.
- A value of 170 m^3/h (n = 0.8) prevents from condensation also on the coldest point of the walls.



(*) When no ventilation rate is requested it means that the mean natural ventilation with n = 0.4 is enough.

REMEDIAL MEASURES
9. THERMAL BRIDGES IMPROVEMENT

Some easy to be done thermal bridges improvements were tested using the finite elements calculation method.

CONSTRUCTION DETAILS

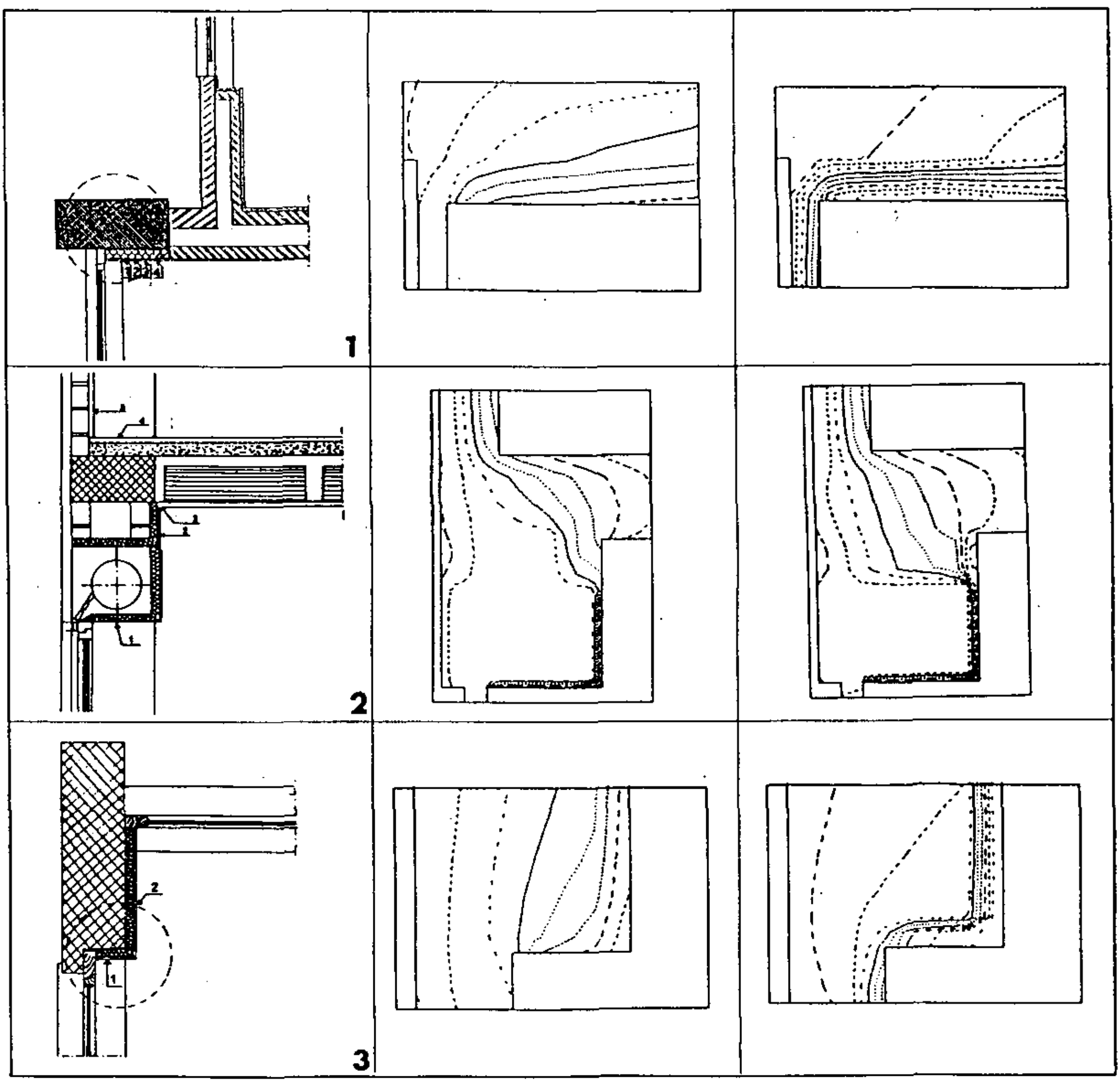
		τ[-]				
	figure	1	2	3	4	5
CORNER 1	1	0.58	0.93	0.94	0.97	
WINDOW LINTEL	2	0.90	0.91	0.89	0.77	0.63
CORNER 2	3	0.89	0.92			

The value presented are calculated using hi = 8 and he = 23 W/m^{2}K

EFFECTS
Higher surface temperatures

THERMAL BRIDGE **ISOTHERMS**

Before **After**

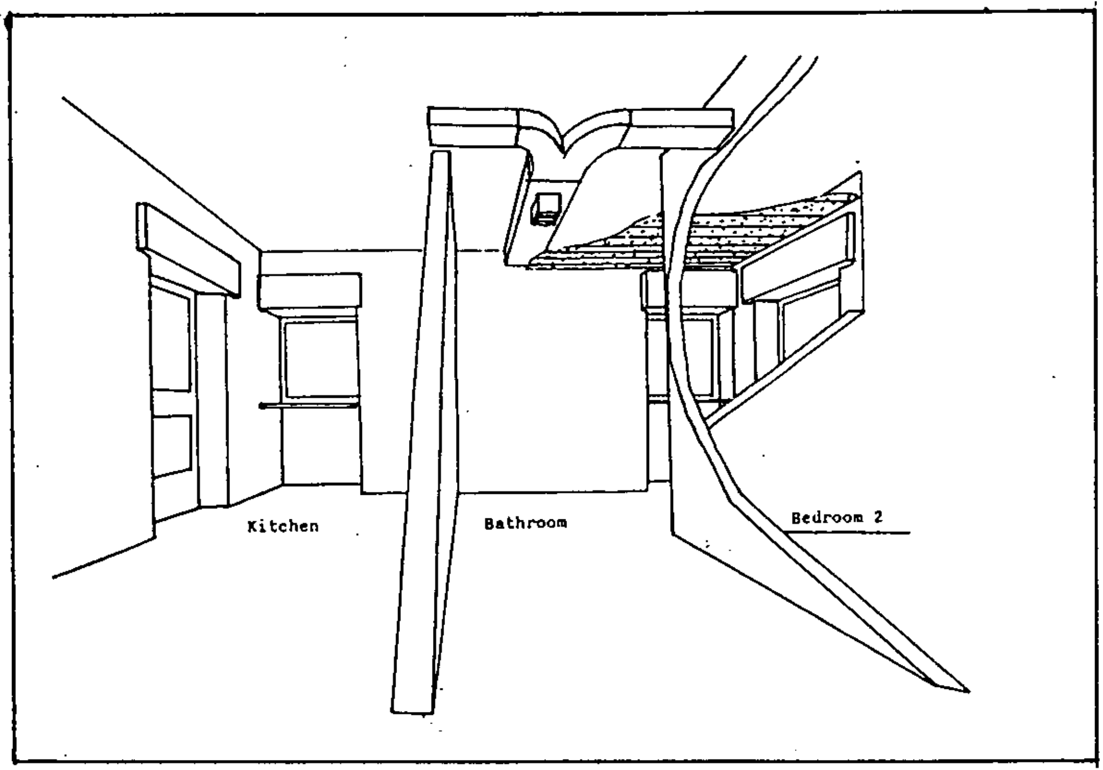


10. MECHANICAL VENTILATION

The installation of a humidity controlled ventilation system was recommended putting an extract fan over a suspended ceiling in the bathroom, and supply air devices in the kitchen, in the bathroom and in bedroom 2.

EVALUATION

To be done



CONCLUSIONS

The measurements done in the present case - study allowed to show the thermal insulation lack in some points of the building envelope due to the wrong design of some thermal bridges.
Besides this structural failing the insufficient ventilation toghether with an heavy occupancy of the dwelling appears as the main cause of mould growth and surface condensation.

Netherlands organization for applied scientific research

TNO-report

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CASE STUDY 4

"PIJNACKER"

THE NETHERLANDS

International Energy Agency
ENERGY CONSERVATION IN BUILDINGS
AND COMMUNITY SYSTEMS PROGRAMME

ANNEX XIV
Condensation and Energy

1. SUMMARY

Within the frame of IEA-Annex XIV "Condensation and Energy" a case study has been carried out in a dwelling in the village Pijnacker.
In this dwelling mould and discoloration problems occured at the inner surface of the end-wall in the livingroom and at the plastered surfaces in the bathroom. From January 1988 till May 1988 measurements have been carried out in the dwelling and remedial measures were proposed to prevent mould growth in the future (see report BI-88-124).
After measures had been carried out the effects on the indoor climate in relation to mould growth as well as the behaviour of the building elements were determined.
As a special feature mould samples were taken from the surfaces as well as from the air at three different moments during the measuring period, which started in Frebruary 1989 and lasted till september 1989.
The aims of objectives of measuring and sampling were:

- evaluation of the measures i.e. their effects on indoor climate, thermal quality of the envelope and mould growth circumstances;
- contribution to the inventory of damage causing moulds in dutch dwellings;
- gaining more insight in the usefulness of biological analyses in solving fungal problems.

As far as the biological analyses are concerned, main conclusions are:

- microscopic survey of a sample of plaster from the affected spot in the livingroom showed that discoloration had been caused by fungal attack. However, cultivation of fungal parts (spores, hyphen) on agar plates did not result in any mould growth. Therefore, it is reasonable to conclude that fungal activity or vitality is very small. In other words, the discoloration is not related to the indoor climate registered in 1989; in fact, while measuring the fungal problem did not exist anymore in the livingroom.
  This result emphasizes the importance of simple biological analyses in advance of more complex and expensive measuring of indoor climate.

- sampling from the walls and ceilings have been carried out 3 times, in february, june and september 1989. The results showed that evaluation of the effect of (remedial) measures on mould growth circumstances takes at least a time period of 6 months.
- from sampling and cultivation it was obvious that the yellow discoloration in the bathroom was not a consequence of biodeterioration. This is in contrast with the assumptions that fungi and yeasts were main causes.

  The results emphasize the importance of biological research to focuss further investigations. In case of the Pijnacker dwelling one may think of studying chemical processes in the bathroom plaster.

Conclusions on the several measures are:

- refilling the lacks in the cavity wall-insulation in the end wall of the livingroom resulted in a significant better temperature ratio τ during the winter period.
- the indoor climate in the livingroom showed a lower moisture content of the indoor air (kitchen was moved to the barn at the rear side of the dwelling).
- an important conclusion can be drawn on the measure concerning the ventilation of the bathroom. The indoor humidity was originally (1988) acceptable because of the frequent window-opening by the inhabitants. The system of natural ventilation as such was inadequate.

  After installing a mechanical ventilation the indoor humidity (climate class, measured in 1989) increased, due to changes in behaviour of the occupants. While originally the window was kept open for several hours, now the new system appears only to be used during the showering period. Although in the past no problems due to mould occured, biological analyses in september 1989 showed that now indeed moulds are growing and that problems are to be expected.

  The relation between the now measured indoor climate and the development of mould will be subject of a future internal TNO-study.

2. SITUATION

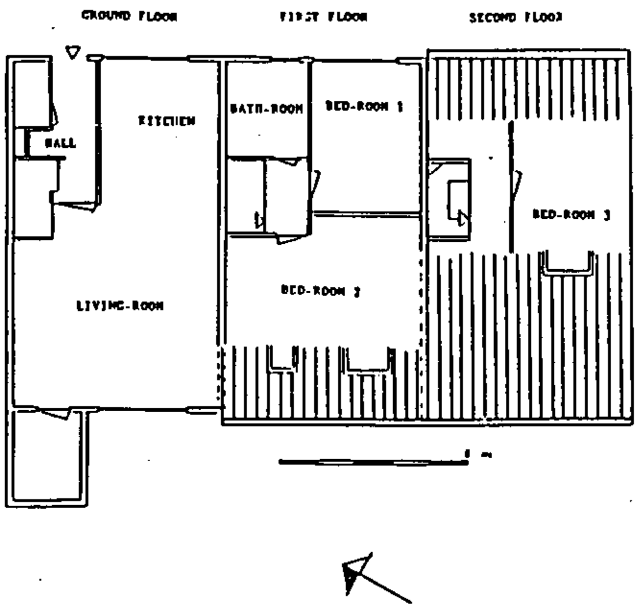
Single family dwelling
Peizerdiep 27 — 4°26'OL
Pijnacker — 52°01'NB
Netherlands — altitude - 5 m

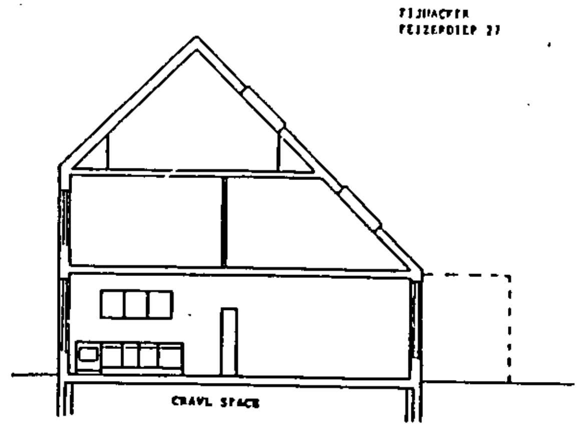
climate

	J	F	M	A	M	J	J	A	S	O	N	D
θ	1.3	2.4	4.3	8.1	12.1	15.3	16.1	16.1	14.2	10.7	5.5	1.2
φ	92	87	80	78	74	73	77	79	81	86	89	92

Photo 2.1 Front side of the dwelling

3. LAY-OUT





In december 1988 the kitchen has been moved to the barn at the rear side.

	original situation		'new' situation	
	A (m^2)	V (m^3)	A (m^2)	V (m^3)
Livingroom	26.9	70.0	36.2	94.3
Kitchen	9.3	24.3	4.3	11.1
Hall	3.6	9.4		
Bathroom	4.0	9.6		
Bedroom 1	11.3	27.2		
Bedroom 2	20.5	37.3		
Bedroom 3	13.6	26.4		

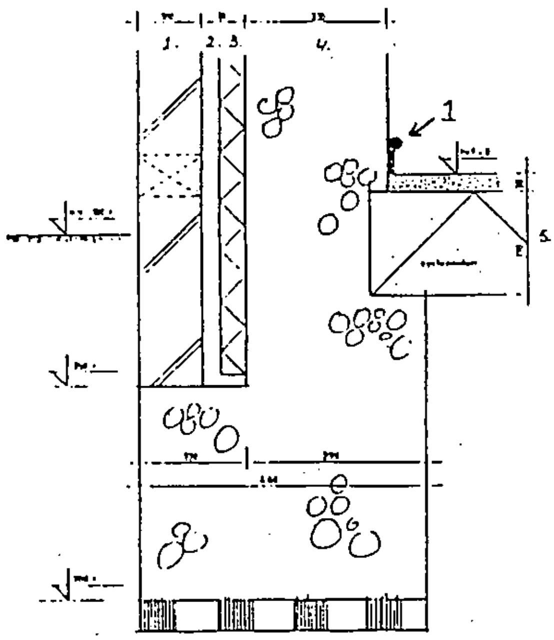
4. BUILDING FABRIC

CONSTRUCTION PARTS	R ($m^2.K/W$) Calculated
WALLS : end wall, cavity wall (10/7/23 cm) concrete innerleaf	1.3
front and rear wall, cavity wall (10/7/10 cm) cellular concrete innerleaf	1.6
ROOF : tiled roof, insulated	1.5
FLOORS : reinforced concrete	
floor above crawl space, reinforced concrete + woodfiber concrete	0.6
WINDOWS: wood, single glazing upstairs, double downstairs	

CONSTRUCTION DETAILS

	figure	$\tau = f(\theta_e)$	r^2
End wall livingroom	3.1		
measuring period			
09-01-88 / 19-04-88		$0.733 - 0.013\ \theta_e$	0.23

The τ value has been measured (see figure 4.1)
The temperature ratio τ increases at decreasing outside temperature due to the influence of the temperature in the crawl space (figure 4.2).
The indoor air temperature was measured at 1.1 m height above the floor.



1. masonry
2. air split
3. mineral wool insulation
4. reinforced concrete
5. composition floor
o measuring point 1

Figure 4.1 : Cross section of the end wall

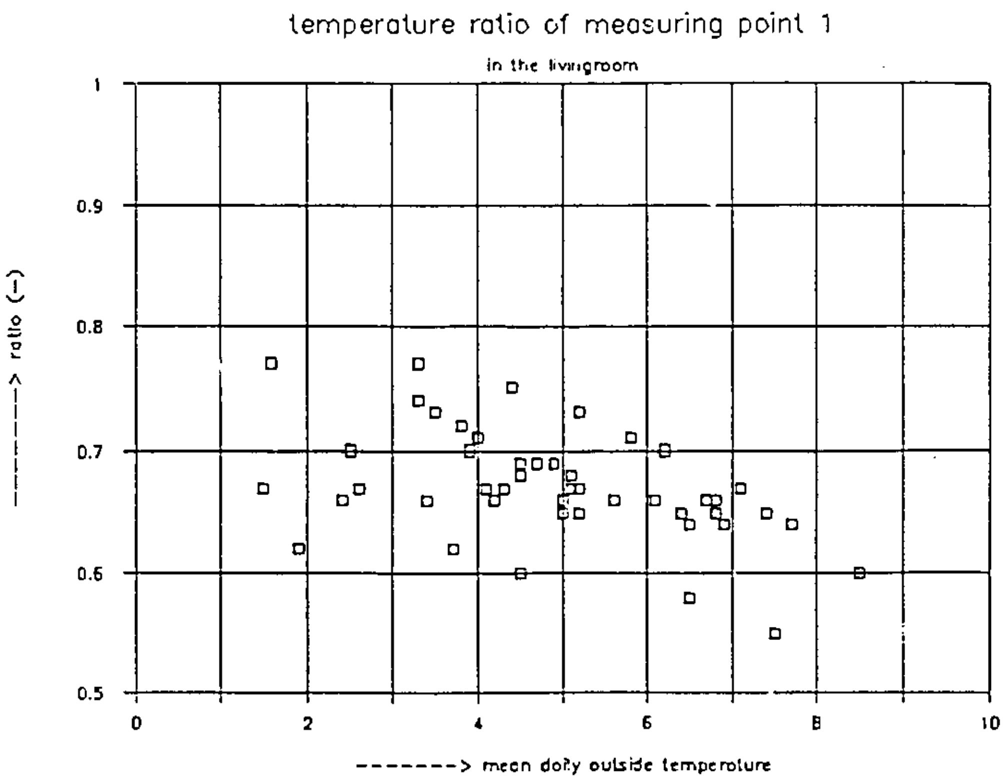


Figure 4.2 : Temperature ratio at 0.05 m above floor

5. THE MOISTURE PROBLEM

MOISTURE PRODUCTION & REMOVAL

Dwelling 4 persons (2 adults + 2 children)
Extract fan in the kitchen (not used)
No previsions for laundry drying; the inhabitants dry it in the loft

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DAMAGE		photo
livingroom	: discoloration of the end wall	5.1
bathroom	: discoloration of walls and ceiling	5.2

THE MOULD SPECIES (tape samples)

Livingroom (original present)
- Cladosporium
- Alternaria
- until september 1989 no moulds were determined.

Bathroom
- original no moulds
- in september 1989 Cladosporium was determined.

CONSEQUENCES FOR THE INHABITANTS

No complaints about health; only aesthetical problems

Photo 5.1 : Discoloration of the end wall in the livingroom

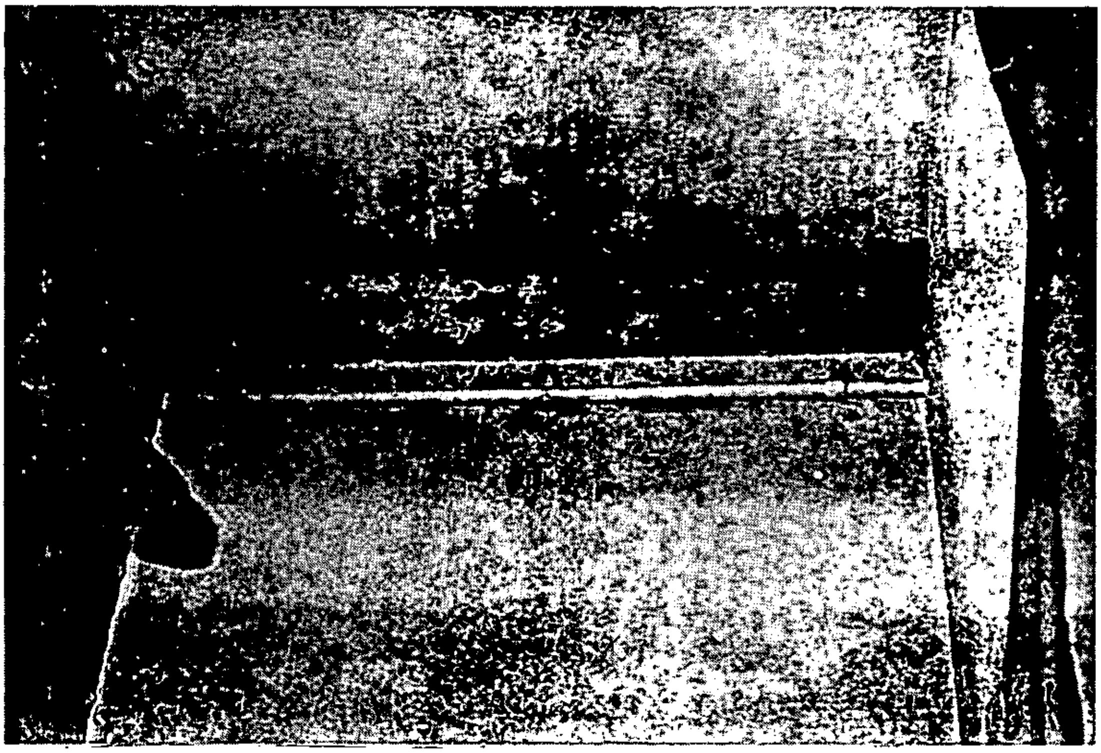


Photo 5.2 : Discoloration of walls and ceiling in the bathroom

6. MEASUREMENTS

WHAT		EQUIPMENT
1	SURFACE TEMPERATURE	Cu-Co couples, Pt100
2	AIR TEMPERATURE	Vaisala HMP 112Y
3	RELATIVE HUMIDITY	Vaisala HMP 112Y
	ABSOLUTE HUMIDITY	Dewpoint meter
4	AIR TIGHTNESS	
5	MOULD SAMPLING & DETERMINATION	

MANAGEMENT

1988 : 1 + 2 + 3 in livingroom and bathroom
4 for the whole dwelling
2 + 3 in hall + bedroom 2 + bedroom 3

1989 : 1 + 2 + 3 + 5 in livingroom and bathroom

Data Acquisition unit : hp3497A datalogger

7. THE INSIDE CLIMATE (original situation)
(measuring period 09-01-88 / 19-04-88)

TEMPERATURE (weekly average)		$\theta_i = f(\theta_e)$	r^2
livingroom	:	$16.1 + 0.11\theta_e$	0.20
bathroom	:	$14.4 + 0.11\theta_e$	0.05
bedroom 2	:	$16.1 + 0.17\theta_e$	0.25
bedroom 3	:	$15.0 + 0.25\theta_e$	0.40
hall	:	$13.2 + 0.18\theta_e$	0.21

HUMIDITY (weekly average)		$p_i - p_e = f(\theta_e)$	r^2	figure
livingroom	:	$393 - 23.9\theta_e$	0.38	7.1
bathroom	:	$386 - 12.7\theta_e$	0.12	7.2
bedroom 2	:	$203 - 22.9\theta_e$	0.59	
bedroom 3	:	$190 - 22.3\theta_e$	0.56	
hall	:	$182 - 16.5\theta_e$	0.48	

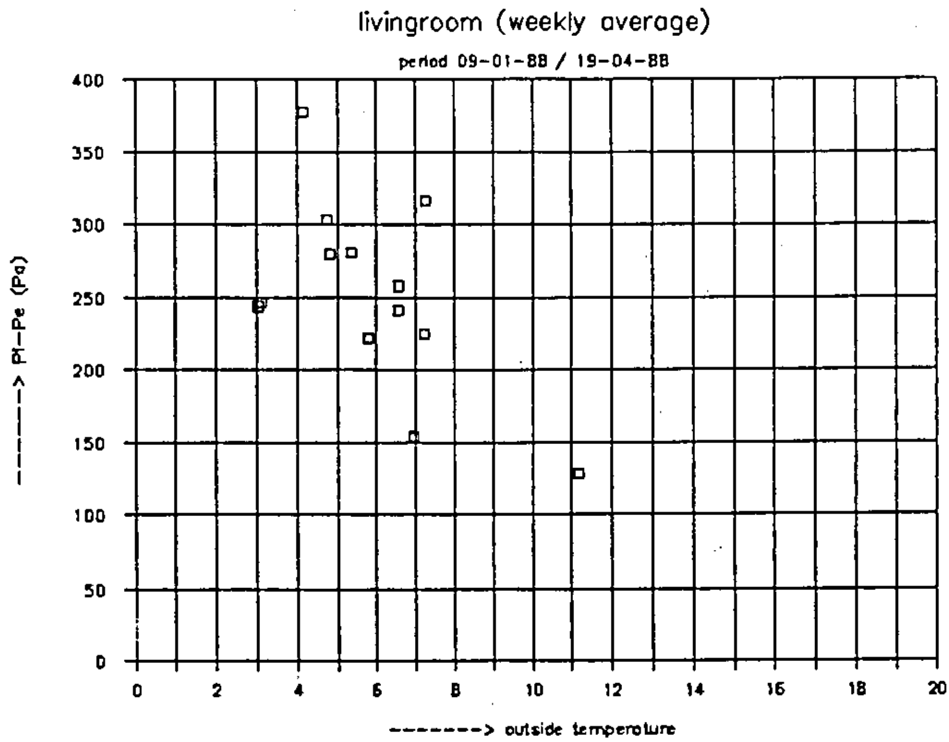


Figure 7.1 : Vapour pressure difference between inside and outside

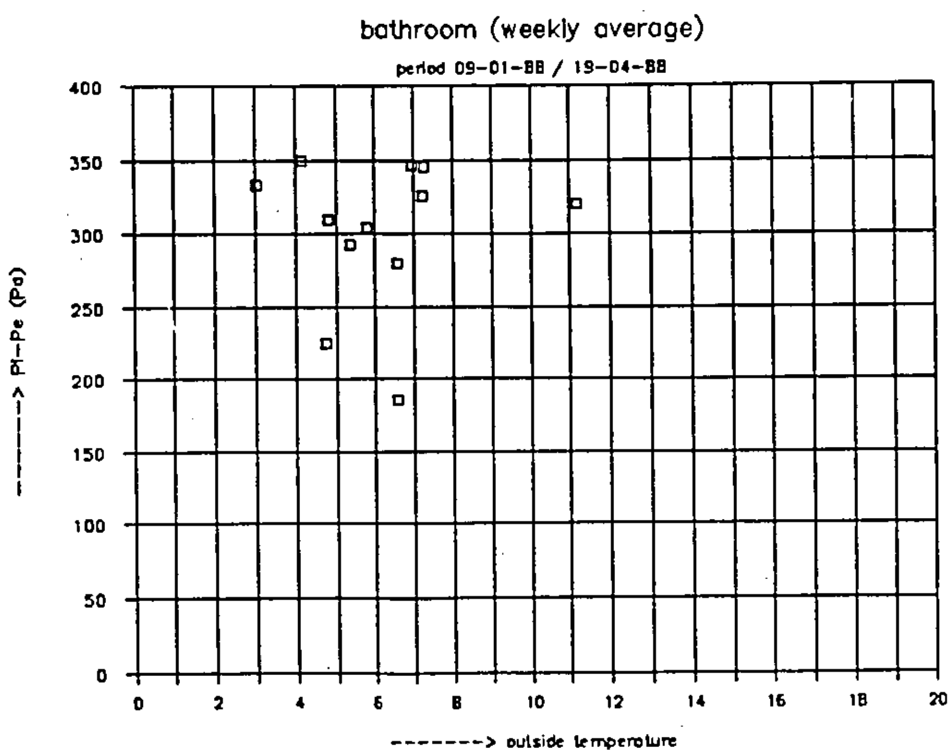


Figure 7.2 : Vapour pressure difference between inside and outside

8. THE BUILDING PERFORMANCE

BUILDING FABRIC

Thermal resistance and r-values	see 3
Air tightness: $n_{50}[h^{-1}]$	1.3
Ventilation rate $[h^{-1}]$	1.0
Heating cost (m^3 gas/year)	2050

SURFACE CONDITIONS (measuring period 09-01-88 / 19-04-88)

measuring point % of time

		finishing material	mould	RH=100%	>95%	>90%	>80%	>70%
livingroom	1	plaster	(Y)	0	0	2	8	38
	2	plaster	(Y)	0	0	0	3	24
	3	plaster	(Y)	0	0	0	0	3
	4	plaster	(Y)	0	0	0	0	3
bathroom	5	plaster	(?)	3	5	7	12	24

(Y) = visible mould from the past.

(?) = discoloration not caused by moulds

9. SPECIAL TOPICS

9.1 THERMOGRAPHIC

Photo 9.1.1 shows an infra red thermographic picture of the part of the end wall as shown in photo 4.1.
Furthermore a thermography survey of the outside surface of the end wall showed that in the cavity parts of the insulation layer were missing.
This was confirmed by checking with an endoscope.

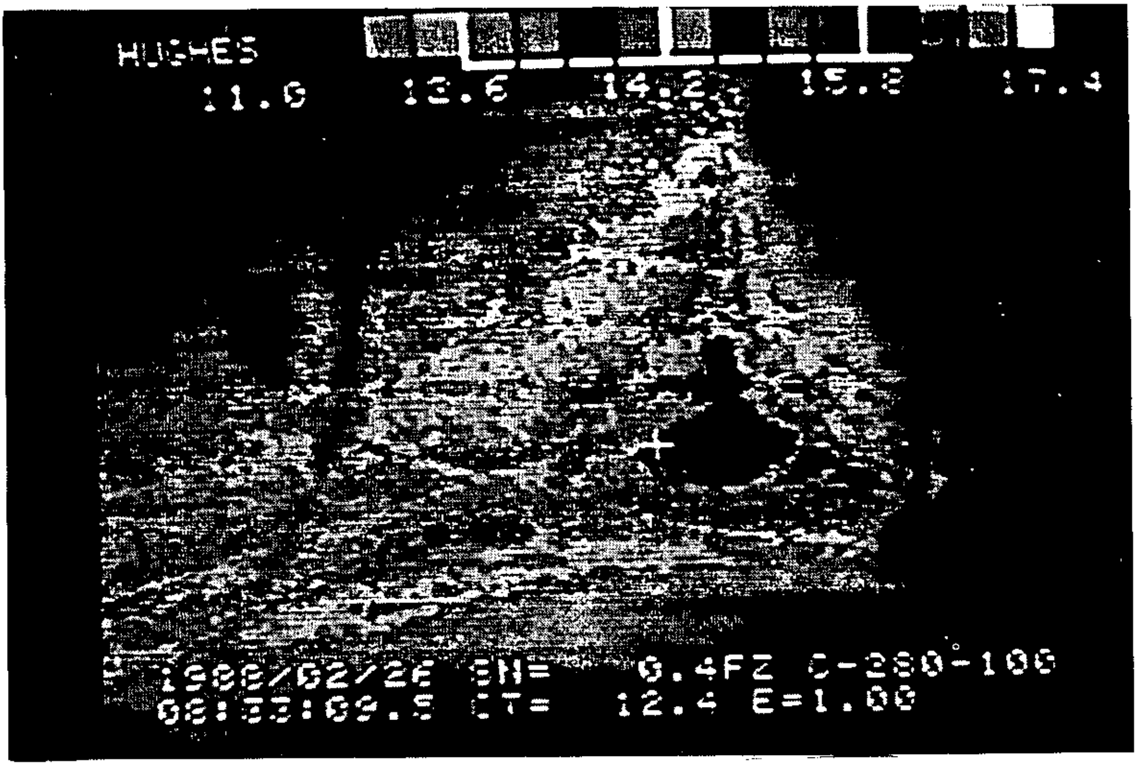


Photo 9.1.1 : Infra red picture of the inner surface of the end wall in the livingroom

9.2 VENTILATION OF THE DWELLING

During the measuring period of three months (1988) the pressure difference over a number of permeable elements as well as the position of doors and windows were continuously measured.
An overview of the use of the windows during this measuring period is shown in table 8.2.1. In this table the percentage of time the windows were opened is mentioned. Furthermore a short explanation is given concerning the use of the windows.
With the MT-TNO ventilation model calculations have been made on the ventilation and the ventilation pattern of the dwelling.
Three periods of the day have been distinguished, from 8 to 17 h, from 17 to 20 h and from 20 to 8 h.
Specific for the period from 8 to 17 h is that the ventilation light in the bathroom is continuously opened.
Specific for the period 17 to 20 h is that the ventilation light in the livingroom (front) is opened.
For the period of 20 to 8 h is that in all bedrooms windows are opened ajar.

The calculated air change rate of the dwelling by use of the windows for the different periods is given in table 9.2.2; the results are depending on the wind direction. The air change rate is in average about 1 per hour (assumed wind speed 5 m/s and an outdoor temperature of 5 °C).
The behaviour of the occupants (opening windows) proves to be an important factor.

Table 9.2.1 : Overview of the use of the windows

	% opened during measuring period	illustration
vent. light livingroom (rear)	2	no clear tendency
casement window living-room (rear)	13	a few times the window during a long time stands ajar (several days)
vent. light livingroom (front)	14	mostly in the afternoon (during cooking)
casement window living-room (front)	33	mostly the window stands ajar for a long time (several days)
vent. light toilet	15	no clear tendency
vent. light bathroom	42	mostly opened from 8-17h; window is also opened at other times for shorter periods (1-3h)
vent .light bedroom 1	27	opened frequently at night
casement window bedrooml	78	for long periods ajar
large pivoting window bedroom 2	4	no clear tendency
small pivoting window bedroom 2	32	at night often ajar
large pivoting window bedroom 3	60	often during long periods ajar (nights)

Table 9.2.1 : Calculated air change rate of the dwelling as a whole at a windspeed of 5 m/s and a temperature outside of 5 °C

	winddirection			
	north	east	south	west
period 8 to 17 h	1.0	0.9	1.1	1.2
period 17 to 20 h	1.0	1.0	1.1	1.2
period 20 to 8 h	1.0	1.0	0.9	0.9
average over 24 h	1.0	1.0	1.0	1.0

9.3 MOISTURE PRODUCTION; MOISTURE DISTRIBUTION

The moisture production in the dwelling seems to be normal; no other sources then natural human production seem to play a role.
The figures 9.3.1 and 9.3.2 are showing moisture distribution effects throughout the dwelling:

- moisture production in the kitchen can be traced in the livingroom (figure 9.3.1)
- moisture production in the bathroom can sometimes but not always be traced in the bedrooms (figure 9.3.2)

From calculations with the ventilation model results that there will exist a rather large air flow through the staircase to the loft. This is mainly caused by the ventilation provisions for the heating installation, which are placed at the ridge.

For moisture distributions consequences are that moisture produced in the loft space (drying of laundry) will mostly be extracted directly from the dwelling. Moisture produced in the bathroom will, dependent on the wind direction, also often be extracted directly. Moisture from the kitchen however could be spread over various rooms.

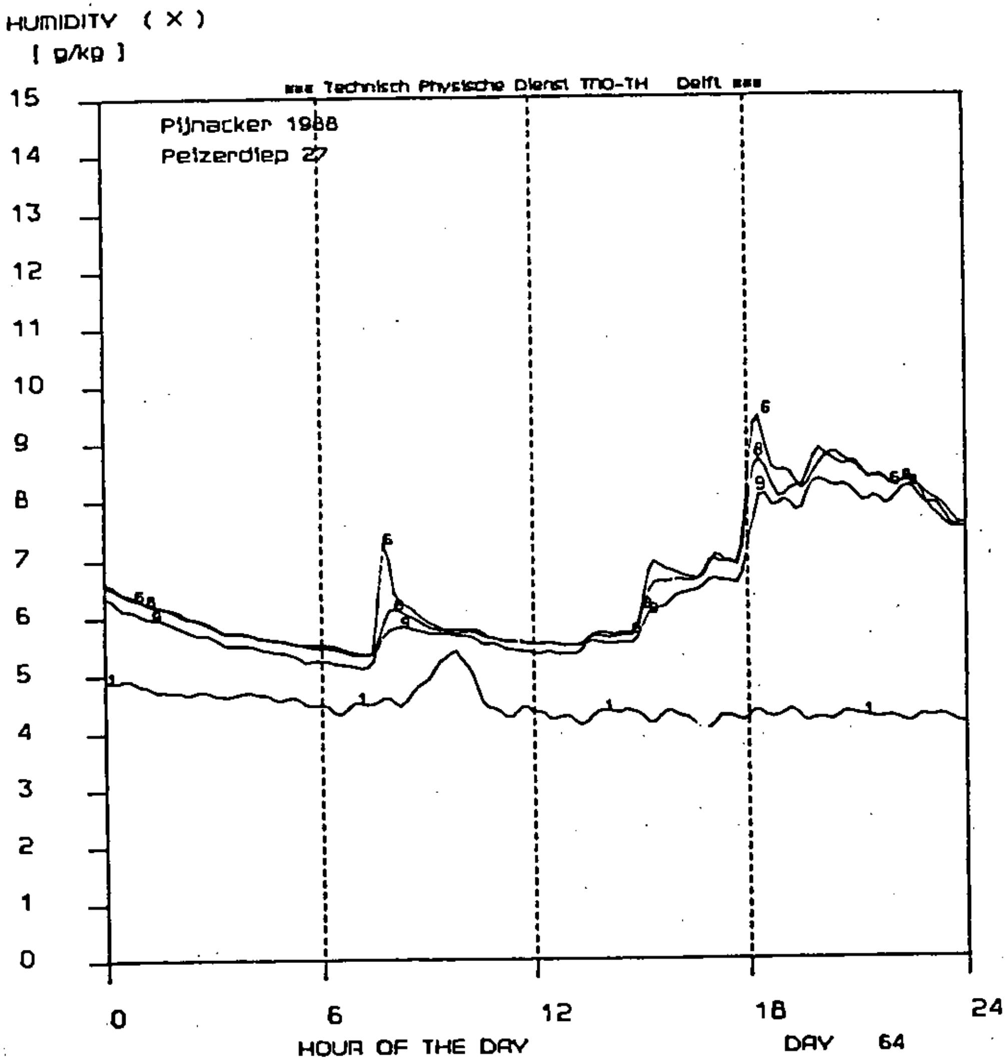
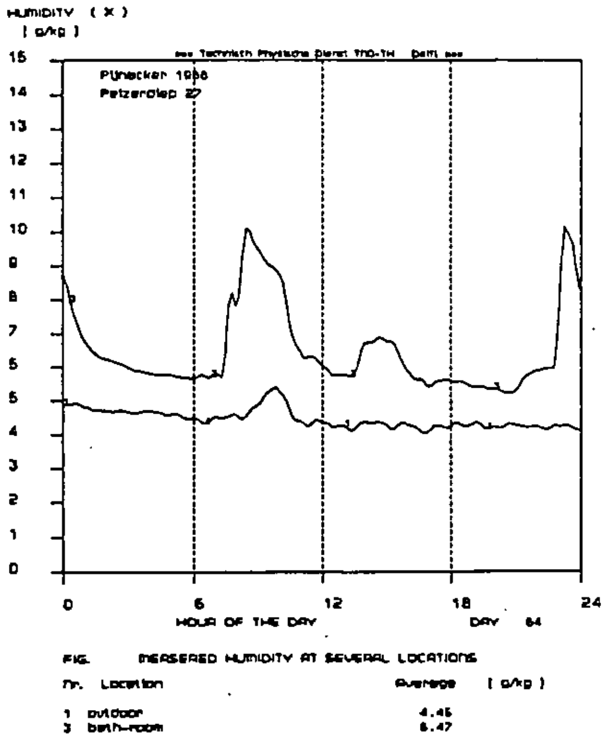


FIG. MEASERED HUMIDITY AT SEVERAL LOCATIONS

nr.	Location	Average [g/kg]
1	outdoor	4.45
6	kitchen	6.53
8	living-room	6.46
9	living-room (corner)	6.23

Figure 9.3.1 : Course of water vapour content in the kitchen, livingroom and outdoors on 4th of march 1988



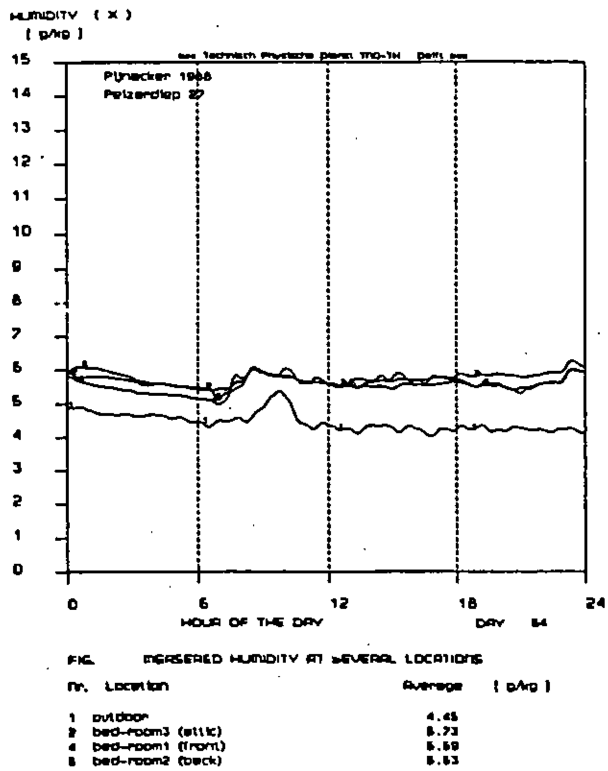


Figure 9.3.2 : Course of water vapour content in the bathroom and outdoors on 4th of march 1988

REMEDIAL MEASURES

10.1 AMELIORATION OF THE THERMAL QUALITY

10.2 MOVING THE KITCHEN

10.3 AMELIORATION OF THE VENTILATION

10.1 AMELIORATION OF THE THERMAL QUALITY

Refilling the missing parts of the cavity insulation of the end wall. This was done by blowing in mineral wool flocks.
Furthermore the inner surface of the end wall was replastered (gypsum) and painted (white acrylic dispersion paint).

EFFECTS

measuring point	τ	r^2	figure
End wall livingroom 1			
(measuring period)			
before (09-01-88 / 19-04-88):	$0.733 - 0.013\,\theta_e$	0.23	4.2
after (09-03-89 / 07-05-89):	$0.845 - 0.021\,\theta_e$	0.70	10.1.1

Moulds
- no discoloration appeared (last observation sep. 1989).
- no new mould growth could be determined.

EVALUATION

Moulds on the inner surface are probably an inheritance from the past. Refilling the lacks in the cavity wall-insulation results in a significant better temperature ratio τ during the winter period.

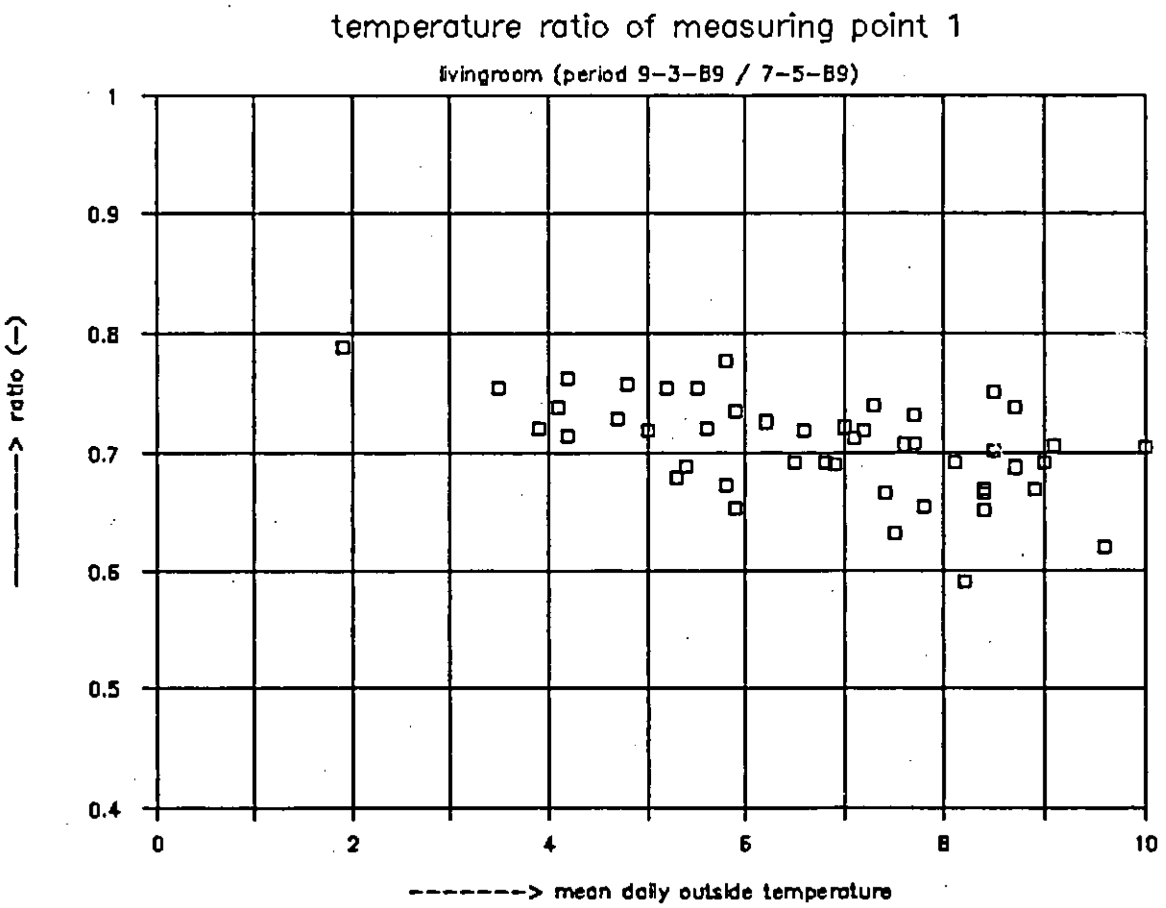


Figure 10.1.1 : Temperature ratio at 0.05 m above floor after refilling missing insulation

10.2 MOVING THE KITCHEN

The kitchen was moved to the barn at the rear side in december 1988. (as planned by the inhabitants).

EFFECTS

The inside climate (weekly average):

- indoor temperature :
  (measuring period)
  before (09-01-88 / 19-04-88): $\theta_i = 16.1 + 0.11\ \theta_e$ $r^2 = 0.20$
  after (09-03-89 / 07-05-89): $\theta_i = 17.2 + 0.04\ \theta_e$ $r^2 = 0.02$
- moisture content in the livingroom (weekly average):
  (measuring period)
  before (09-01-88 / 19-04-88): $p_i - p_e = 393 - 23.9\ \theta_e$ $r^2 = 0.38$
  after (09-03-89 / 07-05-89): $p_i - p_e = 370 - 24.1\ \theta_e$ $r^2 = 0.31$
  (figure 10.2.1)

EVALUATION

Moving the kitchen results in a lower moisture content of the indoor air in the livingroom.
Not a measure that should be generally advised.

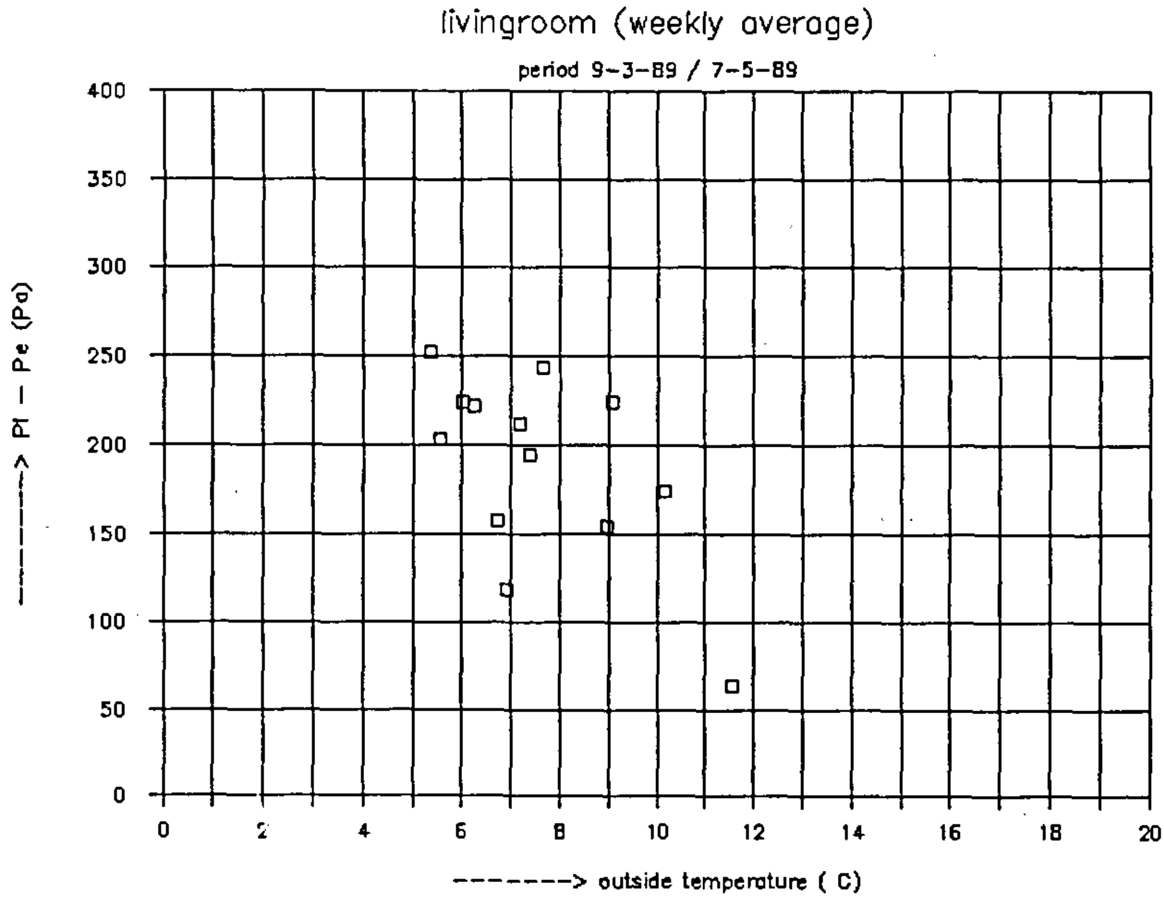


Figure 10.2.1 : Vapour pressure difference between inside and outside

10.3 AMELIORATION OF THE VENTILATION

An electric fan was installed in the bathroom

The walls and ceiling were repainted (acrylic dispersion paint)

EFFECTS

The inside climate:

- indoor temperature (weekly average)

(measuring period)		
before (09-01-88 / 19-04-88):	$\theta_i = 14.4 + 0.11\ \theta_e$	$r^2 = 0.05$
after (09-03-89 / 07-05-89):	$\theta_i = 15.8 + 0.23\ \theta_e$	$r^2 = 0.21$

- moisture content in the bathroom (weekly average)

before (09-01-88 / 19-04-88):	$p_i - p_e = 386 - 12.7\ \theta_e$	$r^2 = 0.12$
after (09-03-89 / 07-05-89):	$p_i - p_e = 536 - 8.6\ \theta_e$	$r^2 = 0.05$

(figure 10.3.1)

- frequency of high RH's at the surface increased as well.

	% of time					
	RH = 100 %	> 95%	> 90%	> 80%	> 70 %	
before :	3	5	7	12	24	figure 9.3.2
after :	5	7	10	18	41	figure 9.3.2

Moulds

- walls and ceiling show no discoloration (last observation sep. 1989)
- mould (Cladosporium) was determined on the surface in september 1989

EVALUATION

Installing an electric fan gave here a negative result concerning the indoor air humidity. The inhabitants are using the fan probably only during showering.

Proper information must be given to the inhabitants how to use this kinds of provisions, hence the effects could be negative and could lead to (increase of) problems. In this case the increase of the indoor air humidity did not lead until now to visible new mould growth on the surface, although Cladosporium was determined in september 1989.

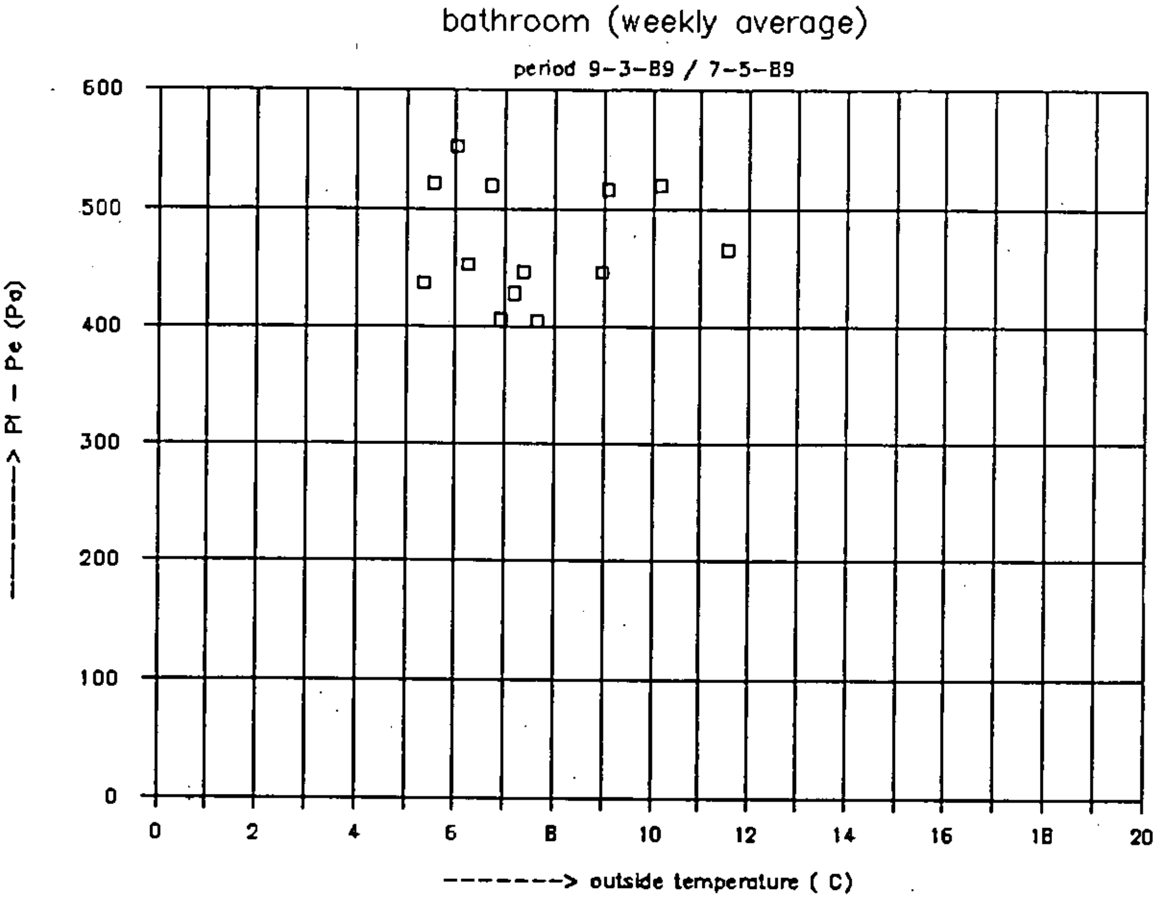


Figure 10.3.1 : Vapour pressure difference between inside and outside

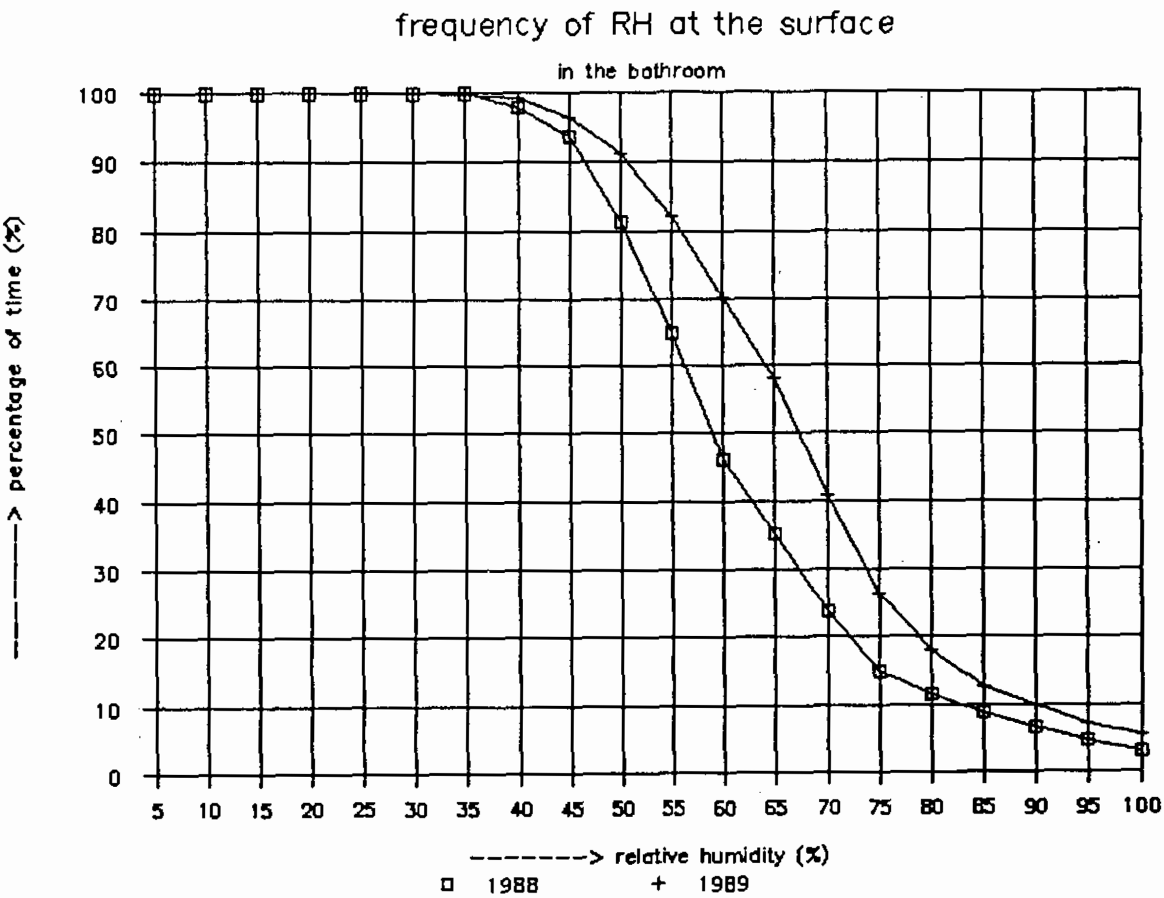


Figure 10.3.2 : Frequency of RH at the surface in the bathroom

dgmr
raadgevende ingenieurs bv
akoestiek
lawaaibeheersing
trillingstechniek
milieufysica
energiebeheersing
bouwfysica

G. MEERDINK, A.M.S. WEERSINK

CASE STUDY 5

"ALEXANDERPOLDER"

THE NETHERLANDS

International Energy Agency
ENERGY CONSERVATION IN BUILDINGS
AND COMMUNITY SYSTEMS PROGRAMME

ANNEX XIV
Condensation and Energy

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6814 bd arnhem
tel. 085 - 51 21 41

's gravenhage
surinamestraat 23
2585 gg 's gravenhage
tel. 070 - 61 43 31

maastricht
oranjeplein 98
6224 kv maastricht
tel. 043 - 62 36 54

drachten
zuidkade 24
9203 cl drachten
tel. 05120 - 2 23 24

Contents: Page:

1 Introduction

In the scope of IEA Annex XIV "Condensation and Energy" case-studies dealing with moisture and mould problems in dwellings had been carried out.
In order of NOVEM BV the dutch case-study "Alexanderpolder Rotterdam" (executed by Cauberg Huygen consulting engineers BV) is summarized by DGMR consulting engineers BV.
This report contains a summary of the case study "Alexanderpolder Rotterdam" according to the format of Annex XIV report B-T7-34/1989.

Additional information of "Rotterdam-Alexanderpolder" is obtainable.
IEA Annex XIV reports dealing with this case study are:
- NL-T7-18/1988
- NL-T7-24/1988
- NL-T7-33/1989

2 Observations

2.1 Situation

Europe - The Netherlands

The Netherlands - Rotterdam

2.1.1 Estate

Estate: Vignolastraat 14 (dwelling 1) - Alexanderpolder Rotterdam
3 rooms / corner
mould growth problems (in the livingroom and bedroom)

Vignolastraat 22 (dwelling 2) - Alexanderpolder Rotterdam
4 rooms / middle
no mould damage

2.1.2 Climate

The climate of The Netherlands is presented in next table.

Meteorological Data of The Netherlands

user : 1280UWFYSICA programma : KLITOT 10:50 2 JUN 88 - 1 -

KLIMAATJAREN 1961-1970

	Temp max [C.]	Temp min [C.]	Temp gem [C.]	RV Tmax [g/kg]	RV Tmin [g/kg]	RV max [g/kg]	RV min [g/kg]	RV gem [g/kg]
MAAND: 1	11.9	-17.8	1.3	6.9	0.7	7.6	0.7	3.8
MAAND: 2	16.2	-16.2	2.4	5.5	0.9	8.0	0.9	3.9
MAAND: 3	23.8	-10.0	4.3	6.5	1.6	7.9	1.2	4.1
MAAND: 4	27.0	-4.8	8.1	6.8	2.4	10.3	1.4	5.2
MAAND: 5	28.5	-2.5	12.1	12.4	3.1	13.1	2.9	6.5
MAAND: 6	31.2	1.5	15.3	12.3	4.0	14.9	3.4	7.9
MAAND: 7	31.7	3.6	16.1	10.6	4.6	16.0	4.4	8.8
MAAND: 8	31.1	4.6	16.1	11.2	4.8	15.6	4.5	9.0
MAAND: 9	28.0	1.8	14.2	12.8	4.3	17.1	3.9	8.2
MAAND: 10	23.3	-1.1	10.7	10.2	3.3	12.4	0.3	6.9
MAAND: 11	19.9	-7.9	5.5	9.0	2.0	9.9	0.5	5.0
MAAND: 12	13.8	-12.6	1.2	8.9	-	9.0	0.8	3.8

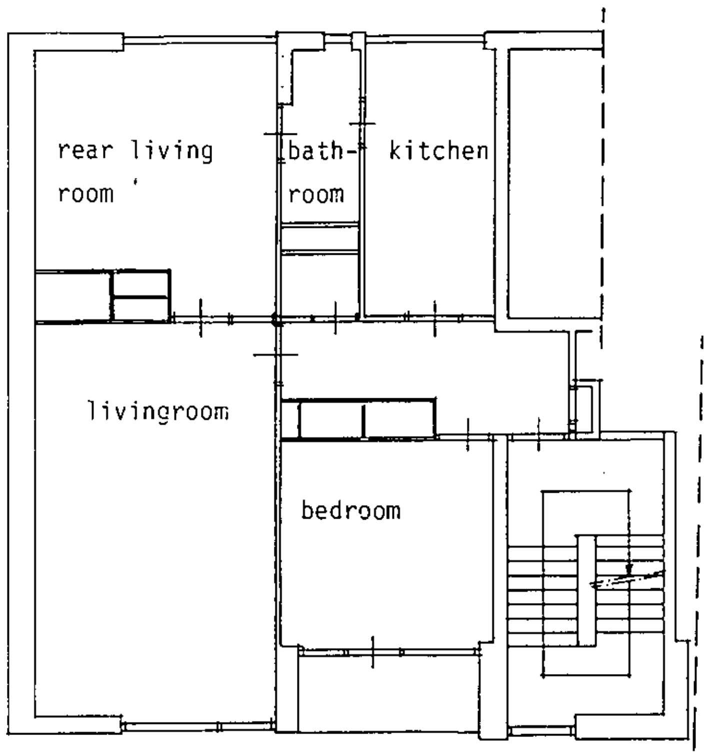
2.2 Lay out

Table

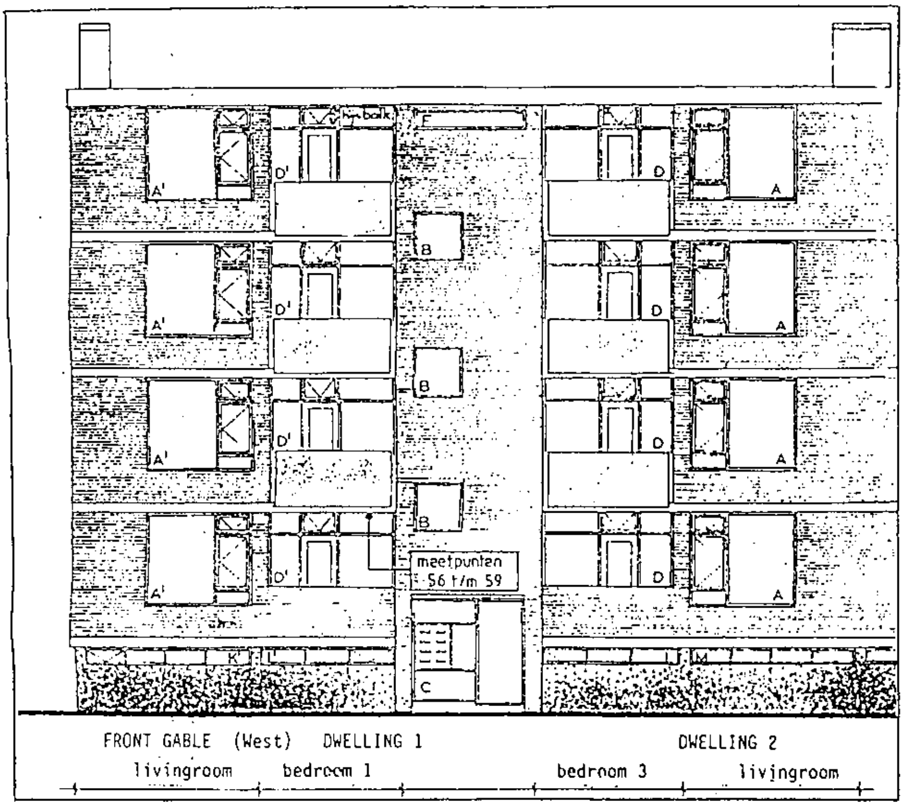
Areas and volumes of several rooms in dwelling 1

room	A [m^2]	V [m^3]
livingroom	20.2	52.5
rear livingroom	13.4	35.0
kitchen	7.7	20.0
bedroom	9.5	24.7

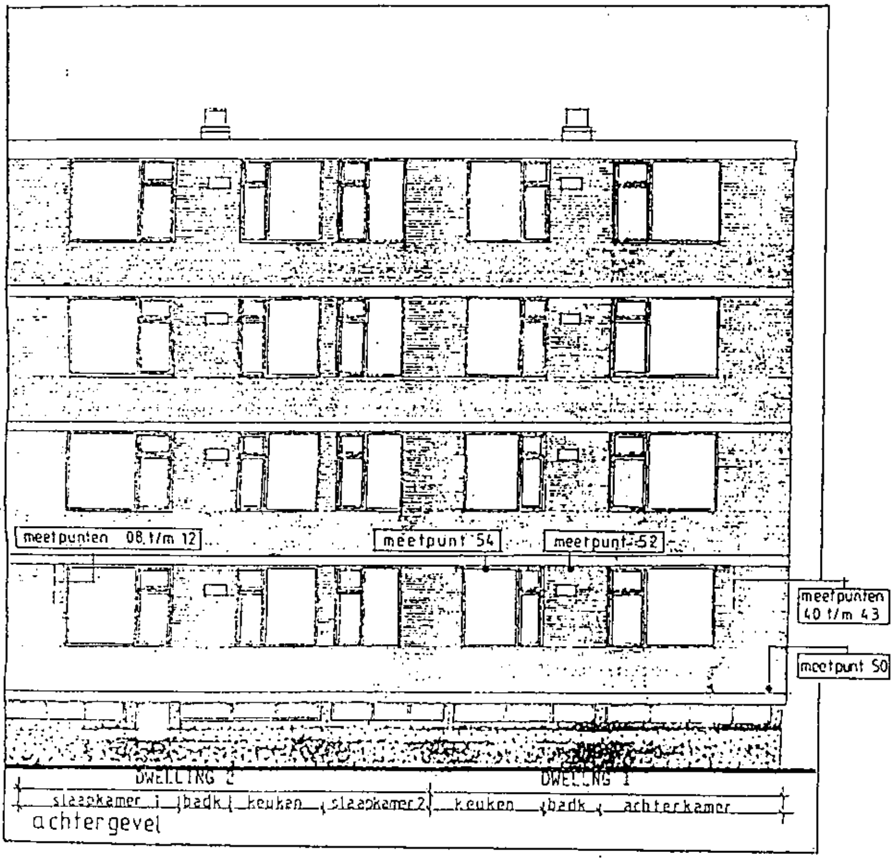
The apartment Vignolastraat 14 is a part of a large concrete skeleton block (1960's) and is located on the first floor above a basement shed.



Ground plan dwelling Vignolastraat 14



FRONTGABLE (West)



BACK GABLE (East)

2.3 Building fabric

2.3.1 Construction parts

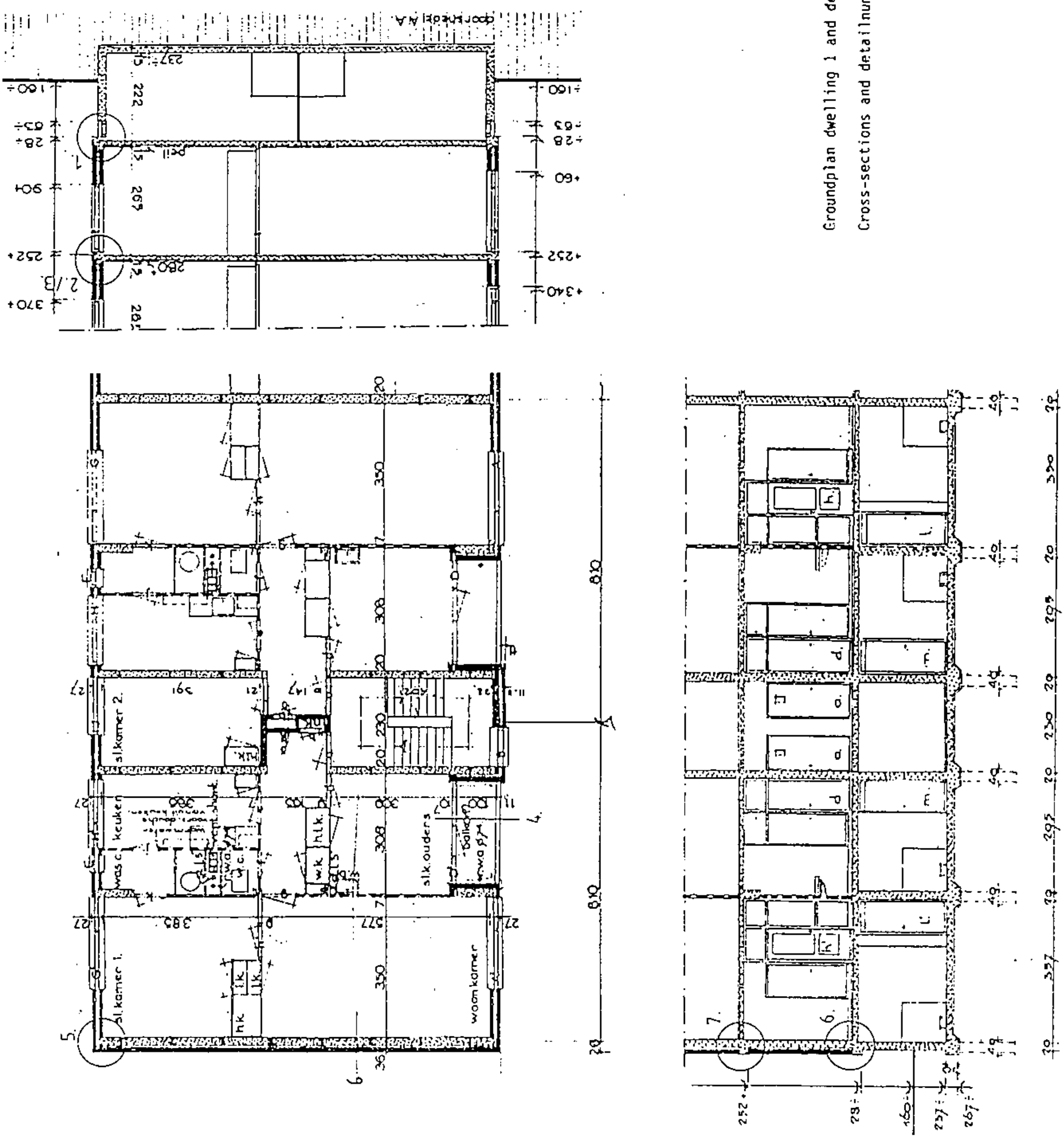
Walls: brick-cavity-brick (in 1978 the walls were cavity filled)
Floors: concrete

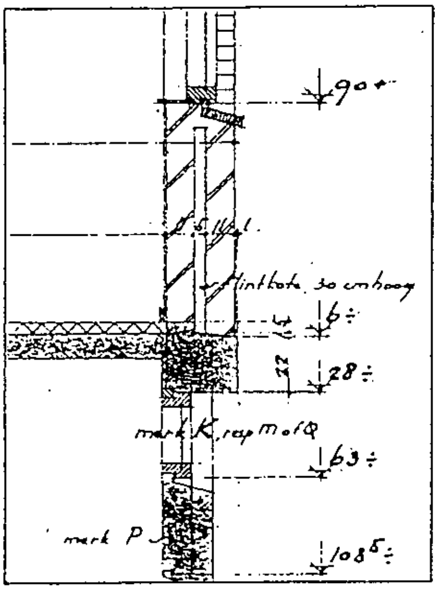
2.3.2 Construction details and finished state

The location of some construction details of the dwelling are presented in the following ground plan and cross sections. A schedule of the finished state of the walls, ceilings and floors in both the apartments is given.

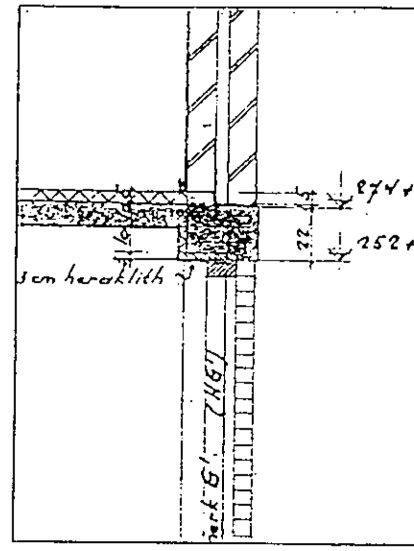
Groundplan dwelling 1 and detailnumbers

Cross-sections and detailnumbers

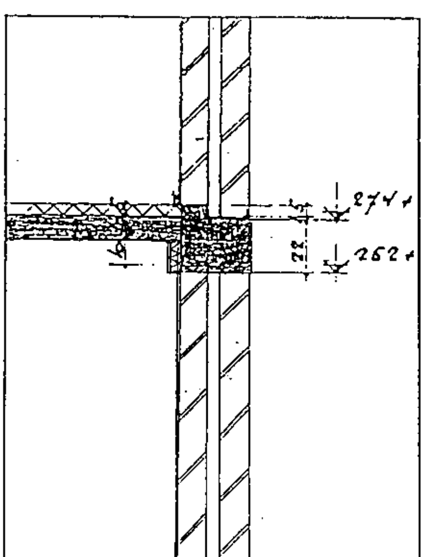




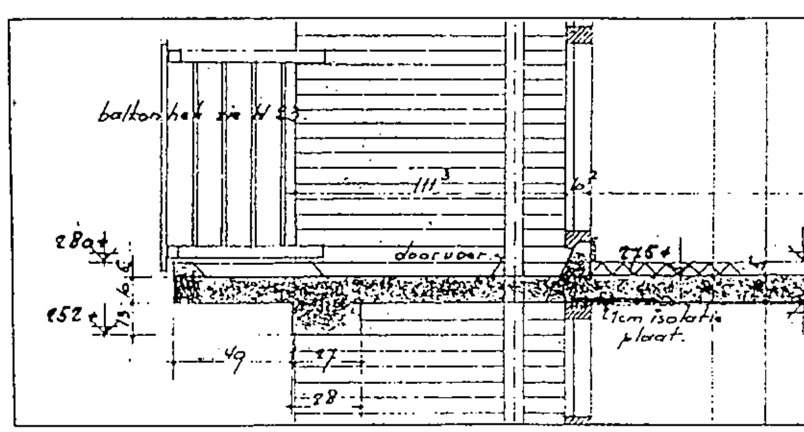
detail 1



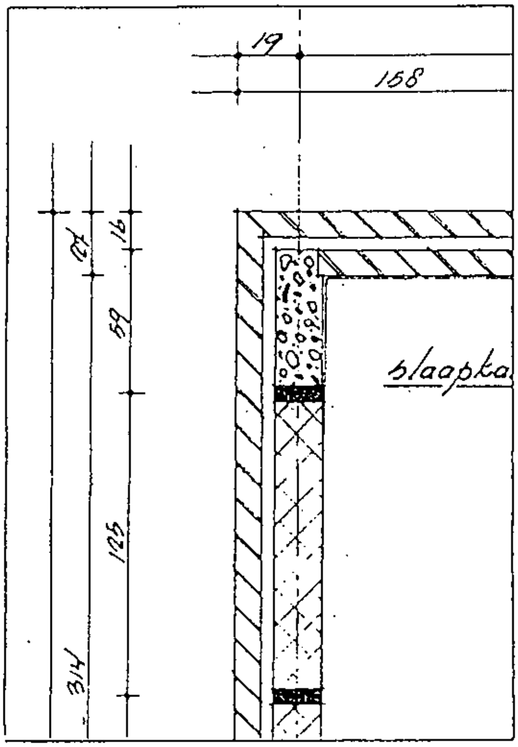
detail 2



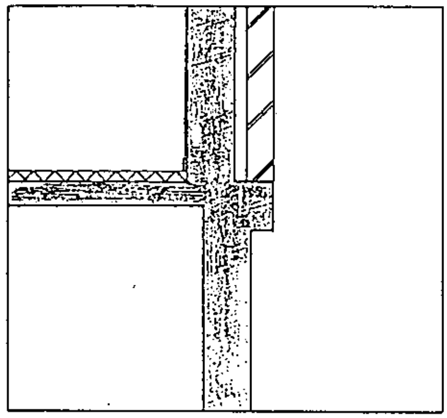
detail 3



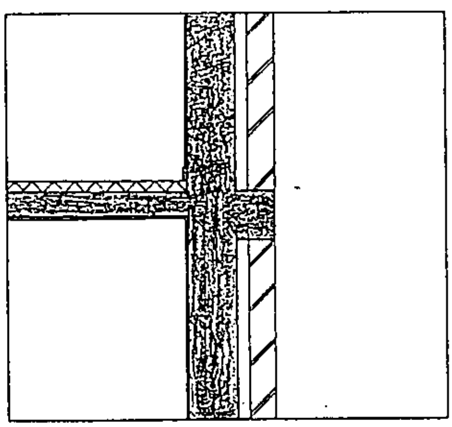
detail 4



detail 5



detail 6



detail 7

Finished state.

	Wall			Ceiling	Floor			
	vinyl paper	wall paper	wall paint	wall paint	carpet	vynyl	parquet	terrazzo
Apartment 1:								
living room	x			x	x			
rear living room	x			x	x			
bedroom		x		x		x		
kitchen			x	x		x		
toilet			x	x		x		
bathroom			x	x				x
hall	x			x		x		
glazing	single-paned glass							
draught prevention	weather stripping large windows and doors (ineffective)							
Apartment 2:								
living room		x		x			x	
bedroom 1		x		x	x			
bedroom 2		x		x	x			
bedroom 3		x		x	x			
kitchen		x	x	x			x	
toilet			x	x		x		
bathroom			x	x				x
hall		x		x			x	
glazing	singel-paned glass							
draught prevention	none							

2.4 The moisture problem

2.4.1 Moisture production and removal

Dwelling no.1 : 2 inhabitants (pensioners) present during the whole day + 1 cat

Dwelling no.2 : 3 inhabitants (2 parents 30-40 years old and 1 child 0-5 years old). One inhabitant is at home during the day. No pets.

MOISTURE PRODUCTION

Dwelling 1 :
- plants : quantity "normal";
- laundry drying: in the basement or outside.

Dwelling 2 :
- plants : quantity "normal";
- laundry drying: in the kitchen.

MOISTURE REMOVAL

The dwellings are provided with a natural ventilation system. There is a natural exhaust valve in the bathroom, kitchen and toilet (shunt-system). The bathroom is well ventilated. The window is always open and the door to the kitchen almost permanent.

2.4.2 Damage

Patterns of the mould damage on contruction parts of dwelling 1 are described in this paragraph. Dwelling 2 showed no appearance of moulds.

Slight mould development in the living room:

- near the corner north facade - ceiling and manifests on the wall paper (about 5 cm wide)
- on the ceiling (spots: 0.5 à 1.0 cm).

Discoloured patches were cleaned up regularily by the inhabitants in the past, but not during the research.

Mould development in the rear living room:

- Near the corner north gable - ceiling the mould damage is stronger than in the living room. A strip of the ceiling (about 30 - 40 cm wide) is discoloured;
- 3D-corner facade - back gable - ceiling;
- 3D-corner facade - back gable - floor (spot: 15 * 15 cm^2).

Mould development in the bedroom:

- Spots: 5 * 5 cm^2 against the ceiling between the outer window frame - curtain-rail;
- Mould strip on the ceiling. Its distance to the curtain-rail is about 10-15 cm;
- Several mould affected spots are distributed all over the ceiling.

2.4.3 The mould species

Table

Determined mould species in dwelling 1

room	site description	discolouration	mould species
bedroom	ceiling West	greenbrown	Aspergillus penicilloides Spegazzini Aspergillus restrictus Smith Penicillium brevicompactum Diercks
living room	facade Nord	green stripes	Aspergillus penicilloides Wallemia sebi
living-room	facade Nord-right	green stripes	Aspergillus penicilloides Wallemia sebi Aspergillus restrictus Smith Cladosporium herbarum Link ex Fries

(source: Kort H.S.M., v.Bronswijk J.E.M.H., Schober G.; Moulds mites and moisture; a preliminary report on six cases of fungal damage in dwellings.).

The determined mould species are able to survive in relatively dry moisture conditions.

2.4.4 Consequences for the inhabitants

Mould growth was discovered about 4 years before the start of the research. One discovered slight discolouration of the wall paper.
It is not known, in what season the mould damage initiated.

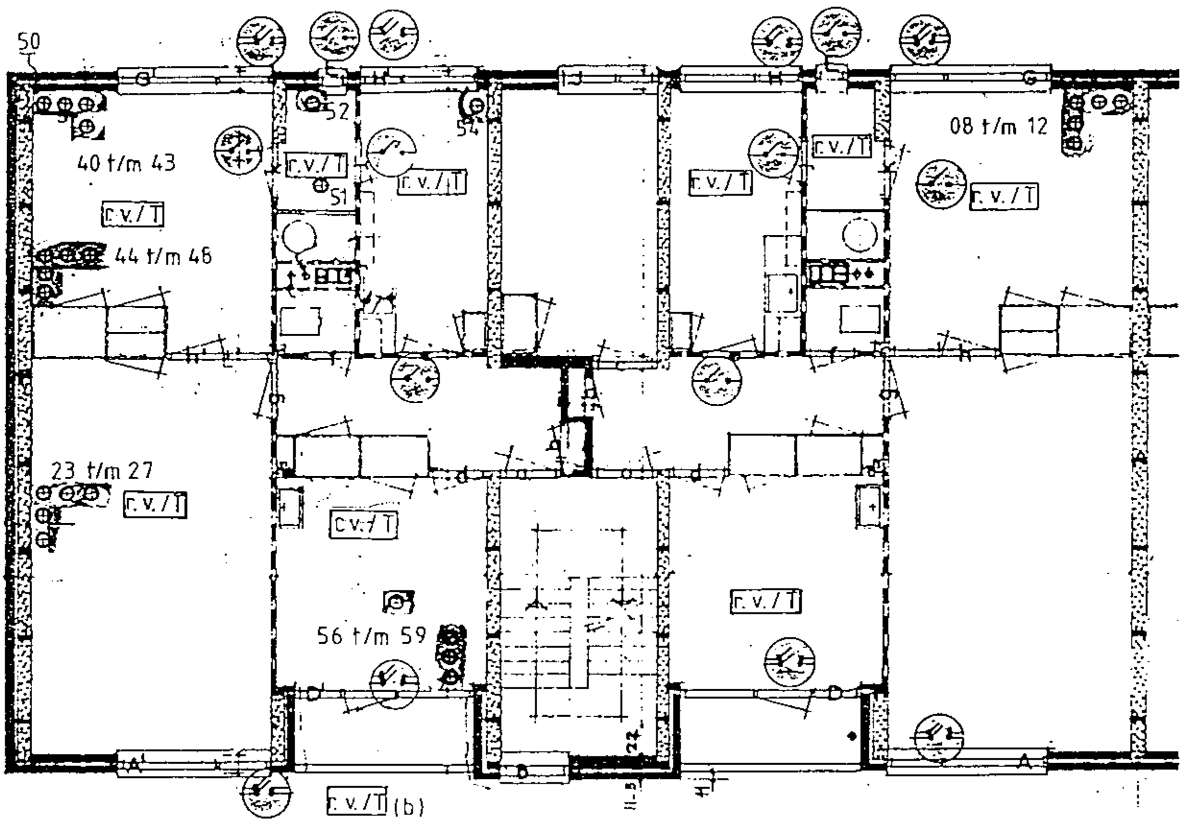
3 Measurements

3.1 What / equipment

What	Equipment
1. Surface temperature	CuCo thermocouples
2. Air temperatures	CuCo thermocouples
3. Air temperatures	Vaisala Humicap HMP111Y
4. Relative humidity	Vaisala Humicap HMP111Y
5. Air tightness	
6. Mould sampling and determination	Scrapings / tape imprints
7. Open/close position of the windows/doors	Switch

3.2 Management

Period of measurement : 14-01-'88 - 08-03-'88
Air temperature and relative humidities were measured in several rooms in both the dwellings.
In rooms combating mould-problems surface temperatures had been measured (especially boundary planes mould/no mould and also surface temperatures on "reference constructions" without mould-damage).
Next ground plan shows a review of the measuring sensors in dwelling 1.



renvooi

r.v./T = relative humidity and temperature probe

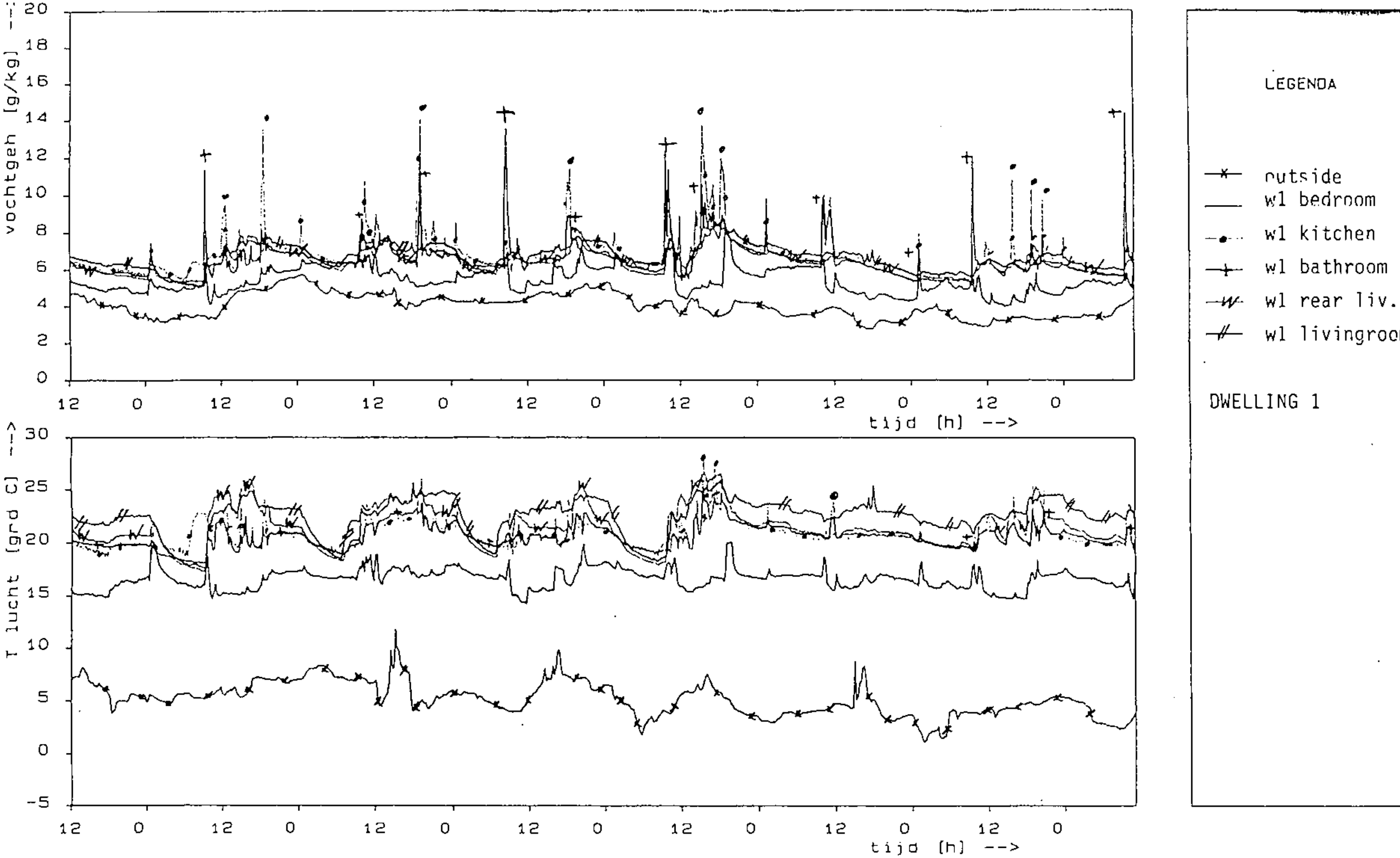
= thermocouple

= window / door switch

= window / door / valve window switch

Channel	Dwelling	Room	Measuring	Type
0	2	bedroom 3	airtemp.	Vaisala
1	2	bedroom 3	R.H.	Vaisala
2	2	kitchen	airtemp.	Vaisala
3	2	kitchen	R.H.	Vaisala
4	2	bathroom	airtemp.	Vaisala
5	2	bathroom	R.H.	Vaisala
6	2	bedroom 1	airtemp.	Vaisala
7	2	bedroom 1	R.H.	Vaisala
8	2	bedroom 1 TB1	surf.temp.	thermocouple
9	2	bedroom 1 TB2	surf.temp.	thermocouple
10	2	bedroom 1 TB3	surf.temp.	thermocouple
11	2	bedroom 1 TB4	surf.temp.	thermocouple
12	2	bedroom 1 TB5	surf.temp.	thermocouple
21	1	outdoors	R.H.	Vaisala
22	1	outdoors	airtemp.	Vaisala
23	1	living TB1	surf.temp.	thermocouple
24	1	living TB2	surf.temp.	thermocouple
25	1	living TB3	surf.temp.	thermocouple
26	1	living TB4	surf.temp.	thermocouple
27	1	living TB5	surf.temp.	thermocouple
28	1	living	airtemp.	thermocouple
29	1	bedroom	airtemp.	thermocouple
30	1	bathroom	R.H.	Vaisala
31	1	rear-living	R.H.	Vaisala
32	1	living	R.H.	Vaisala
33	1	bedroom	R.H.	Vaisala
34	1	kitchen	R.H.	Vaisala
40	1	rear-l TB0	surf.temp.	thermocouple
41	1	rear-l TB1	surf.temp.	thermocouple
42	1	rear-l TB2	surf.temp.	thermocouple
43	1	rear-l TB3	surf.temp.	thermocouple
44	1	rear-l TB4	surf.temp.	thermocouple
45	1	rear-l TB5	surf.temp.	thermocouple
46	1	rear-l TB6	surf.temp.	thermocouple
47	1	rear-living	airtemp.	thermocouple
48	1	rear-l TB8	surf.temp.	thermocouple
49	1	rear-l TB9	surf.temp.	thermocouple
50	1	rear-l TB10	surf.temp.	thermocouple
51	1	bathroom	surf.temp.	thermocouple
52	1	bathroom TB	surf.temp.	thermocouple
53	1	bathroom	airtemp.	thermocouple
54	1	kitchen TB	surf.temp.	thermocouple
55	1	kitchen	airtemp.	thermocouple
56	1	bedroom TB1	surf.temp.	thermocouple
57	1	bedroom	surf.temp.	thermocouple
58	1	bedroom TB2	surf.temp.	thermocouple
59	1	bedroom TB3	surf.temp.	thermocouple
60	2	ring inside	resistance	resistance
61	2	ring outside	resistance	resistance
62	1	ring outside	resistance	resistance
63	1	ring inside	resistance	resistance

Review measuring sensors.

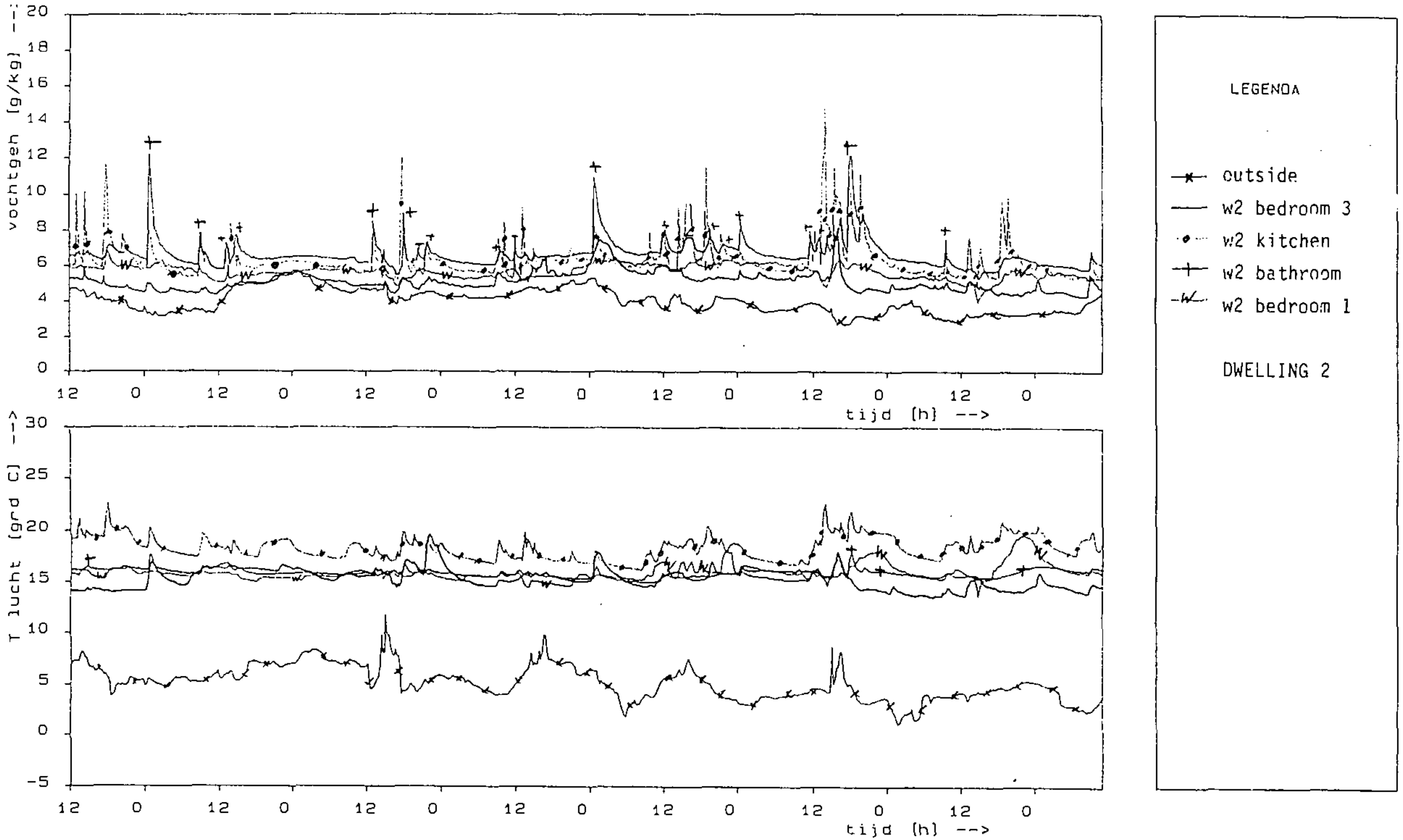


Case study Alexanderpolder

CAUBERG - HUYGEN RAADGEVENDE INGENIEURS B.V. MAASTRICHT ROTTERDAM ZWOLLE	ANNEX XIV Case-study Werknr.9901 Init. AA Datum : week 04 / 02 feb - 09 feb 1988 <u>Figuur M1</u>

M.89.367.A.

dgmr

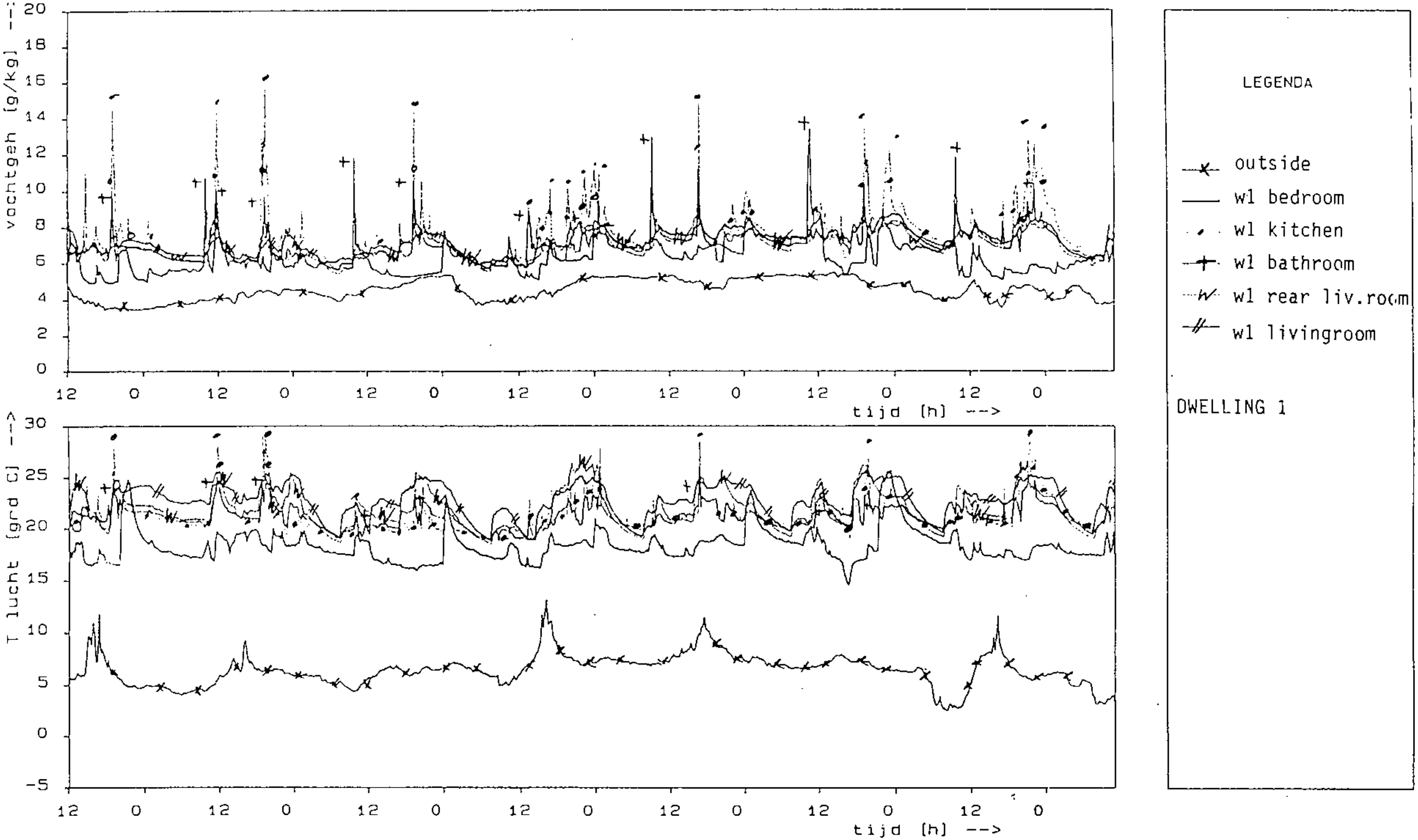


Case study Alexanderpolder

CAUBERG - HUYGEN RAADGEVENDE INGENIEURS B.V. MAASTRICHT ROTTERDAM ZWOLLE	ANNEX XIV Case-study Werknr.9901 Init. AA Datum : week 04 / 02 feb - 09 feb 1988 Figuur M2

M.89.367.A.

dgmr



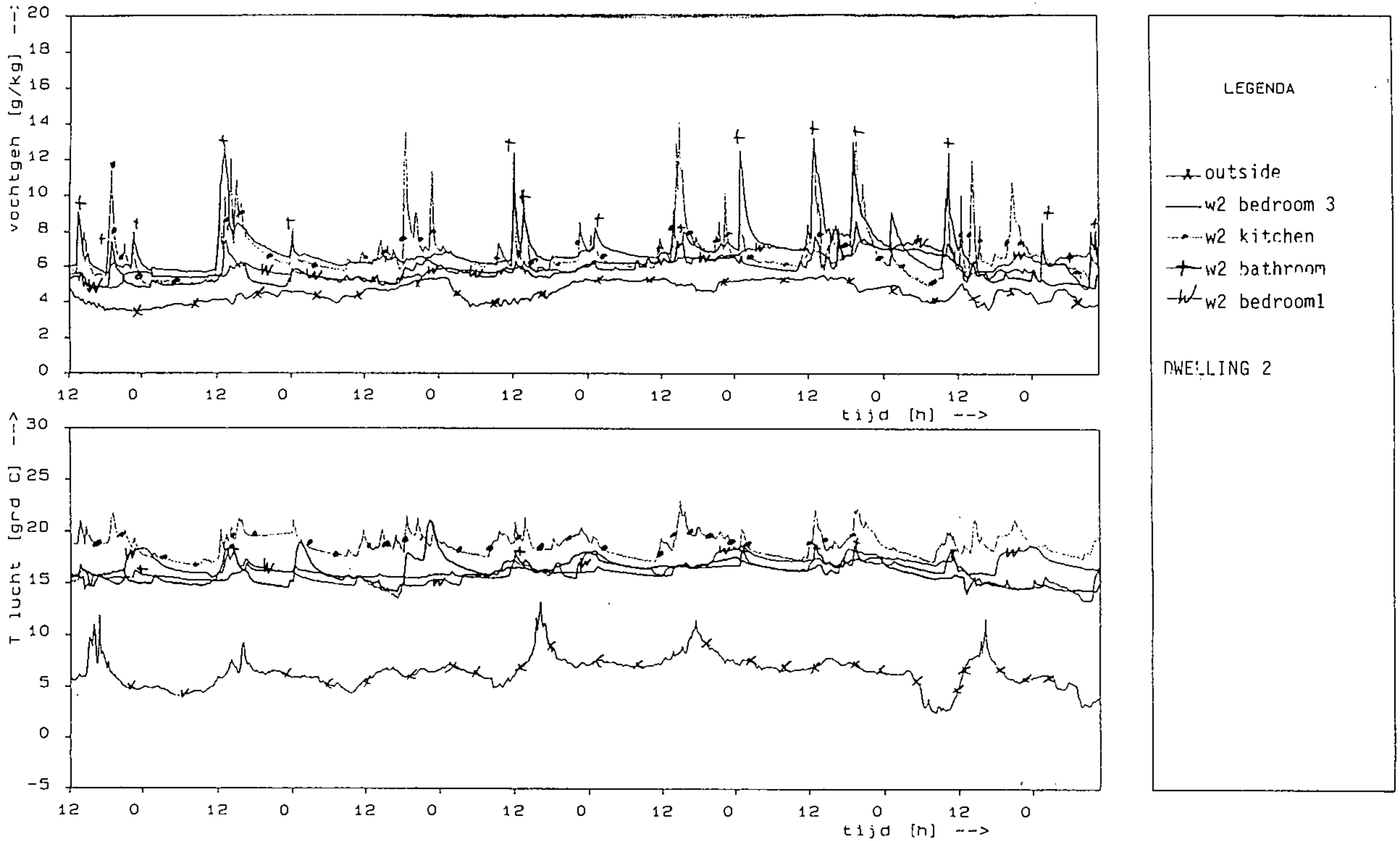
Case study Alexanderpolder

CAUBERG - HUYGEN RAADGEVENDE INGENIEURS B.V. MAASTRICHT ROTTERDAM ZWOLLE	ANNEX XIV Case-study Werknr.9901 Init. AA Datum : week 06 / 16 feb - 23 feb 1988 Figuur M3

M.89.367.A.

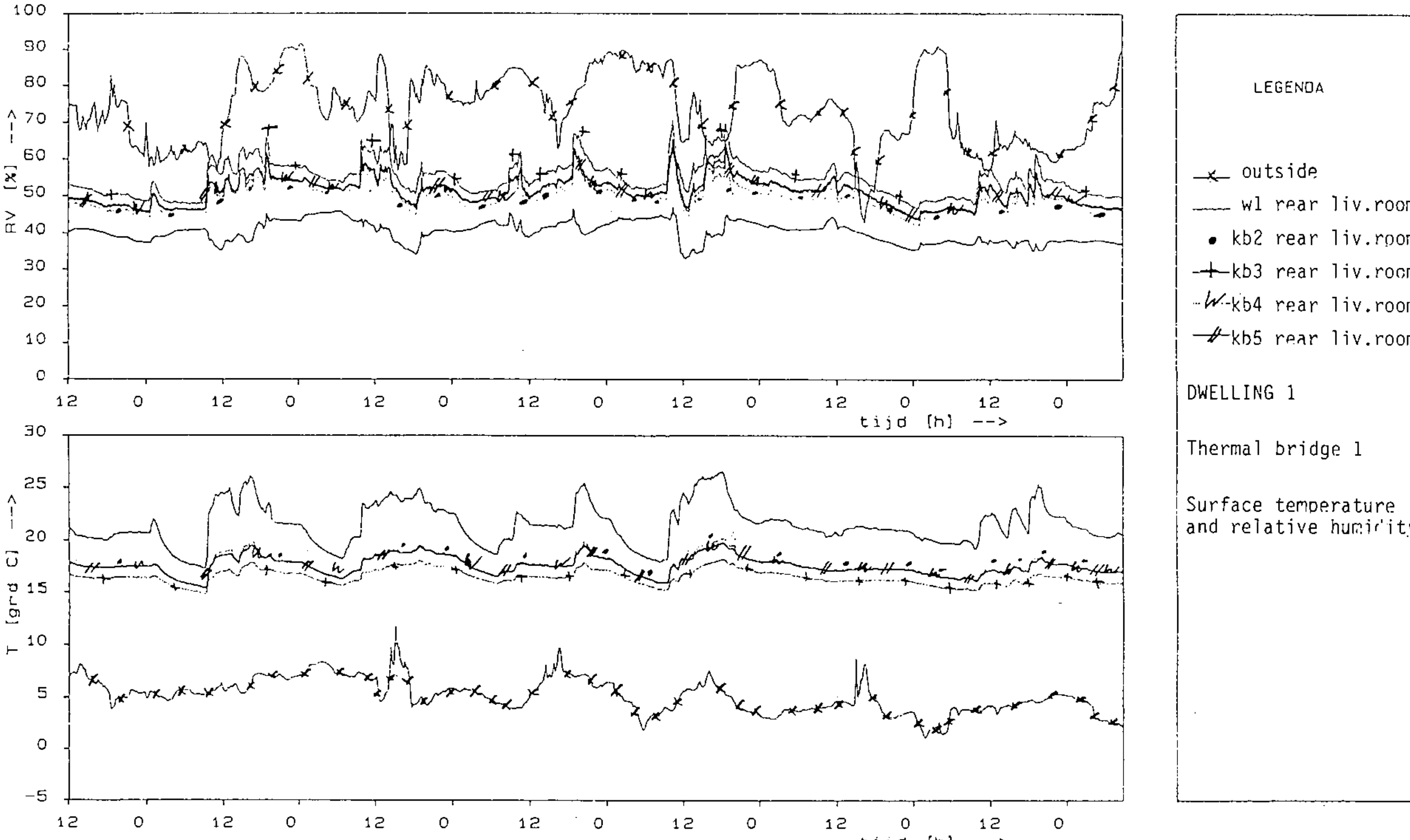
- 25 -

dgmr



Case study Alexanderpolder

CAUBERG - HUYGEN	ANNEX XIV Case-study
RAADGEVENDE INGENIEURS B.V.	Werknr.9901 Init. AA
MAASTRICHT ROTTERDAM ZWOLLE	Datum: week 06 / 16 feb - 23 feb 1988 Figuur M 4



Case study Alexanderpolder

CAUBERG - HUYGEN RAADGEVENDE INGENIEURS B.V. MAASTRICHT ROTTERDAM ZWOLLE	ANNEX XIV Case-study Werknr.9901 Init. AA Datum: week 02 / 20 jan - 26 jan 1988 Figuur M5	M.89.367.A. - 27 -

dgmr

4.2 The building performance

4.2.1 Building fabric

Air thightness n_{50} h^{-1}

Dwelling 1 : grid valves open : $n_{50} = 4.05\ h^{-1}$

grid valves closed : $n_{50} = 3.18\ h^{-1}$

Dwelling 2 : grid valves open : $n_{50} = 4.62\ h^{-1}$

grid valves closed : $n_{50} = 3.39\ h^{-1}$

Ventilation rate

Dwelling 1 : grid valves open : $n = 0.72\ h^{-1}$

grid valves closed : $n = 0.61\ h^{-1}$

Dwelling 2 : grid valves open : $n = 0.84\ h^{-1}$

grid valves closed : $n = 0.57\ h^{-1}$

Heating cost

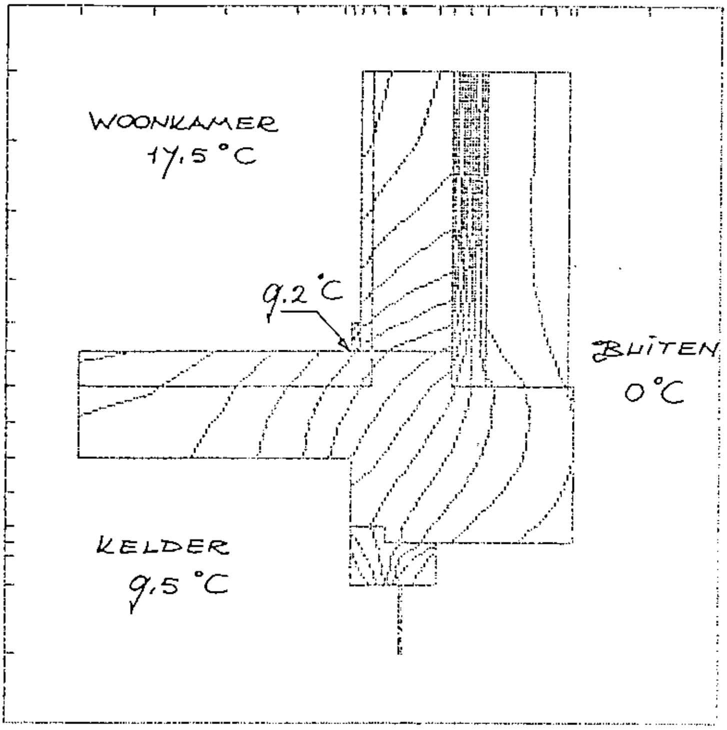
Table

Consumption of thermal units (TU)

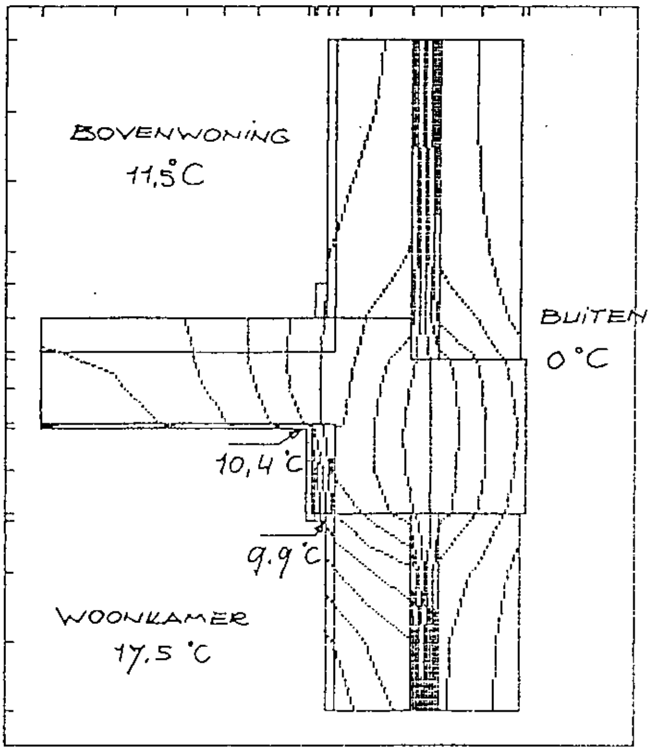
Heating period	Apartment 1 Vignolastraat 14 TU	Apartment 2 Vignolastraat 22 TU
1984/1985	41.75	20.75
1985/1986	48.25	28.75
1986/1987	49.50	28.25

F-factors

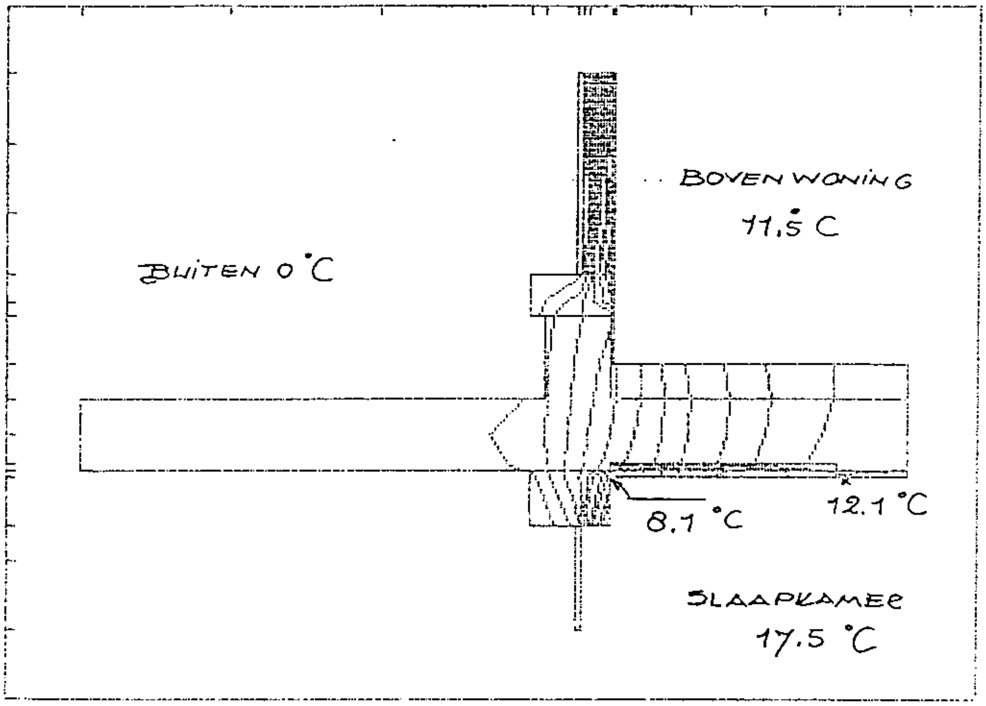
The value of the f-factor [$(T_{o,i} - T_e) / (T_i - T_e)$] of construction details 1, 3, 4 and 7 is given in next figures.



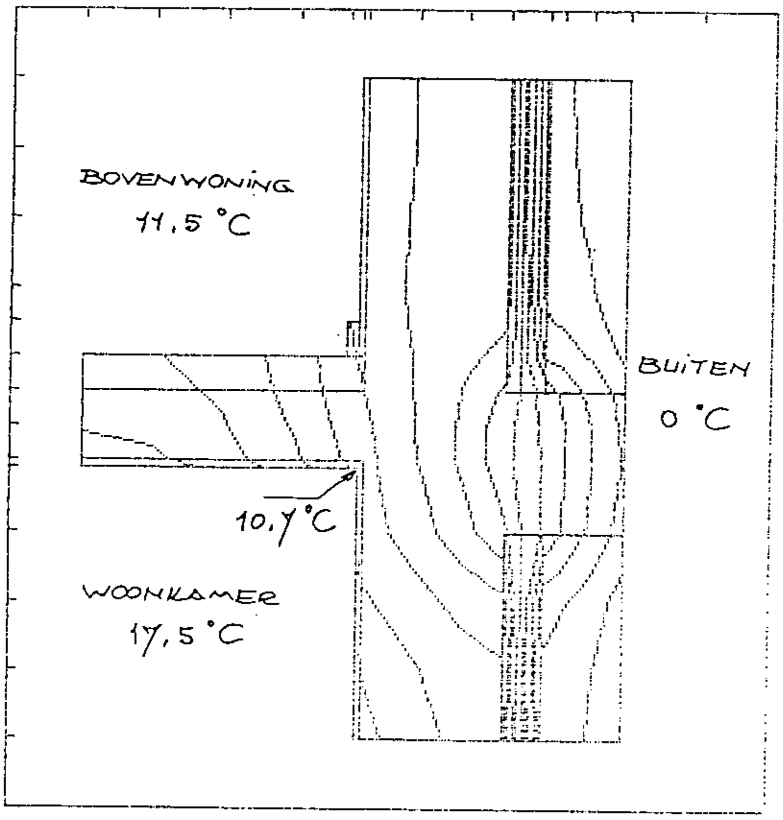
Detail 1 : calculation-results of the TB f=0.53



Detail 3 : calculation-results of the TB f=0.57



Detail 4 : calculation-results of the TB f=0.46



Detail 7 : calculation results of the TB f=0.61

4.2.2 Surface conditions

Table Quantification surface layer phenomena; standard indices.

Measuring place	Measuring point (channel)	$T_{s,i}$		$RH_{s,i}$		Time (%) $RH_{s,i}$ >				RH_t[1]		Mould development
		mean	standard deviation	mean	standard deviation	>50%	>60%	>70%	>90%	10%	5%	
1	08	17,7	0,77	52,8	5,18	70	7	0	0	59,4	61,3	
	09	17,1	0,81	54,7	5,33	82	15	0	0	61,5	63,4	
	10	16,4	0,83	57,2	5,60	89	33	>0	0	64,4	66,4	} no
	11	17,2	0,99	54,5	5,42	80	15	0	0	61,4	63,4	
	12	17,7	0,85	52,7	5,18	70	6	0	0	59,3	61,2	
2	23	20,6	0,94	45,6	5,02	20	>0	0	0	52,0	53,8	
	24	20,6	0,90	45,5	5,02	19	>0	0	0	51,9	53,7	
	25	18,6	0,53	51,6	5,86	57	8	>0	0	59,1	61,2	} yes
	26	20,3	0,60	46,6	5,45	28	>0	0	0	53,6	55,5	
	27	21,4	0,65	43,5	5,24	11	>0	0	0	50,2	52,1	
3	40	19,6	2,10	47,2	5,54	27	1	>0	0	54,3	56,3	
	41	19,7	2,27	46,7	5,66	25	1	>0	0	53,9	56,0	
	42	16,8	1,18	56,0	6,06	84	23	2	0	63,8	65,9	} no
	43	20,3	1,74	44,9	5,25	16	>0	0	0	51,6	53,5	
4	44	18,4	1,00	50,6	5,62	50	6	>0	0	57,8	59,8	
	45	16,6	0,77	56,8	6,47	85	29	3	0	65,1	67,4	
	46	17,9	1,01	52,4	5,68	61	9	>0	0	59,7	61,7	} yes
	48	19,5	1,02	47,3	5,38	29	1	0	0	54,2	56,1	
	49	17,7	0,94	53,0	5,83	65	11	>0	0	60,5	62,6	
5	50	12,8	1,13	72,7	7,53	100	98	60	2	82,3	85,0	yes
6	51	19,2	0,81	48,6	7,59	34	5	1	>0	58,3	61,0	
	52	16,5	0,82	57,6	8,32	86	30	6	1	68,2	71,2	} no

Measuring place	Measuring point (channel)	$T_{s,i}$		$RH_{s,i}$		Time (%) $RH_{s,i}$ >				RH_t [1]		Mould development
		mean	standard deviation	mean	standard deviation	>50%	>60%	>70%	>90%	10%	5%	
7	54	22,7	4,19	42,1	10,30	22	4	>0	>0	55,3	59,0	no
8	56	16,6	1,88	49,6	7,57	46	9	>0	0	59,3	62,0	) yes
	57	16,5	1,03	49,7	6,42	43	7	>0	0	57,9	60,2	
	58	16,0	2,38	51,9	9,18	59	20	2	0	63,7	67,0	
	59	17,1	2,81	48,5	9,62	48	11	>0	0	60,8	64,3	

1 = value of $RH_{s,i}$ which is only exceeded 10%, respectively 5% of the time.

Measuring place 1: Apartment 2, thermal bridge bedroom 1 (parents)
Measuring place 2: Apartment 1, thermal bridge living room
Measuring place 3: Apartment 1, thermal bridge 2, rear living room
Measuring place 4: Apartment 1, thermal bridge 1, rear living room
Measuring place 5: Apartment 1, lower corner rear living room
Measuring place 6: Apartment 1, surface temperature ceiling + thermal bridge bathroom
Measuring place 7: Apartment 1, thermal bridge kitchen
Measuring place 8: Apartment 1, thermal bridge bedroom

5 Remedial measures

During the case study "Rotterdam-Alexanderpolder" no remedies were taken.

6 Conclusions

6.1 Cause of the problem

In this paragraph causes of the mould damage according to "Cauberg-Huygen" are presented and also the conclusions of participants in Integration Exercise 2 dealing with the mould damage in "Rotterdam-Alexanderpolder".

Conclusions: **Cauberg Huygen**

- The measured results do not give a ready answer to the question why mould has developed.
- Preliminary conclusions tend to indicate the high but short excesses are less likely to cause the development of mould rather than lower but longer periods of excess.

Main conclusions: **participant Belgium**

- One thought the cause of the problem originated from bad conditions in the past.

Main conclusions: **participant UK**

- The tenants have altered the way in which they use the building during the monitoring period.
- Moisture is somehow penetration from the outside.
- The flat is plagued with a SUPER mould.

Main conclusions: participant The Netherlands

- One thought that mould growth under the measured conditions is impossible without periodical surface condensation. Vapour peaks are caused by opening the door from the bathroom to the rear living room after taking a shower.
- A theory concerning the bedroom supposes high relative humidities during autumn and spring and perhaps during a part of the summer.

6.2 Remedies

Remedies mentioned by Cauberg-Huygen:

- The occupants should be advised to keep the door between the bathroom and rear living room closed while taking a shower until the moisture contents of the bathroom air has been decreased strongly.
- Improving ventilation:
  The swing windows in the kitchen and bedroom were not opened by the occupants. One should advise to replace a burglar-proof ventilation system and to give instructions in effective ventilation.
- Local insulation of the thermal bridge in the facade with outside insulation material.
- Mould already present in the dwelling should be treated with a fungicide agent and removed. Mould-resistant fabrics should be used if finishing materials are to be reapplied.

Remedies: participant Belgium

- No remedial measures are necessary, just remove the moulds en redecorate.

Remedies: participant UK

- Wipe clean the mould with a fungicidal wash and monitor the mould growth and internal RH in affected rooms.

Remedies: participant The Netherlands

- Inform the occupants not to use the door between the bathroom and the rear livingroom within one quarter of an hour after bathing.
- Install ventilating devices in all windows.
- Desirable: Install mechanical exhaust on top of the shunt channel, with exhaust from the bathroom, the kitchen and toilet.

- Recommandable:
  . Outside insulation of the end-walls of the apartment blocks.
  . Insulation of the ceiling in the basement shed.
  . Insulation of the walls of the staircase.
  . Winthdrawal of the passport from the neighbour upstairs.

The Hague, 7th of December 1989

Ir G. Meerdink Ir A.M.S. Weersink

C. SANDERS

CASE STUDY 6

"EDINBURGH"

UNITED KINGDOM

International Energy Agency
ENERGY CONSERVATION IN BUILDINGS
AND COMMUNITY SYSTEMS PROGRAMME

ANNEX XIV
Condensation and Energy

1.SITUATION

Ten houses and flats
Edinburgh
Scotland

Long 3 10' W
Lat 55 56' N
Alt 20-60 m

CLIMATE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Temp :C	3.1	2.9	4.8	6.9	9.5	12.8	13.5	13.6	12.3	9.6	5.1	3.2	8.1
R H :%	87	84	80	78	78	78	79	82	84	85	88	87	85

During the winter of 1987-88, temperatures, humidities and mould spore counts were monitored for one week in 94 houses and flats in Edinburgh as part of an on-going study into the effects of housing conditions on the incidence of respiratory diseases in children. On the basis of the results so far, ten dwellings with high internal humidities and mould problems were selected for more intensive study for four weeks during January and February 1988.

Brief details of the houses and families are summarised in table 1. Figures 1.1 to 1.6 show photographs of the typical house types.

TABLE 1 SUMMARY OF HOUSE DATA

HOUSE TYPE : T=TERRACED
SD=SEMI-DETACHED
F=LOW RISE FLAT
HRF=HIGH RISE FLAT

HEATING TYPE: GCH=GAS CENTRAL HEATING
GF=GAS FIRE IN LIVING ROOM
EF=ELECTRIC FIRE IN LIVING ROOM

HOUSE NO	HOUSE TYPE	NO OF ADULTS	NO OF CHILDREN	HEATING TYPE	ENERGY USE KWh/WEEK
1	T	2	3	GCH	262
2	SD	2	3	GF	210
3	F	2	2	GCH	130
4	HRF	2	2	EF	-
5	F	3	1	GCH	152
6	SD	2	2	GCH	172
7	F	2	3	EF	230
8	SD	4	1	GF	202
9	F	2	4	GCH	140
10	T	2	3	GF	-

FIG 1.1 House 1 : end terrace 19th century ('X' shows the location of mould growth; see section 3)

FIG 1.2 House 4 : seventh floor flat

FIG 1.3 House 5 : second floor flat

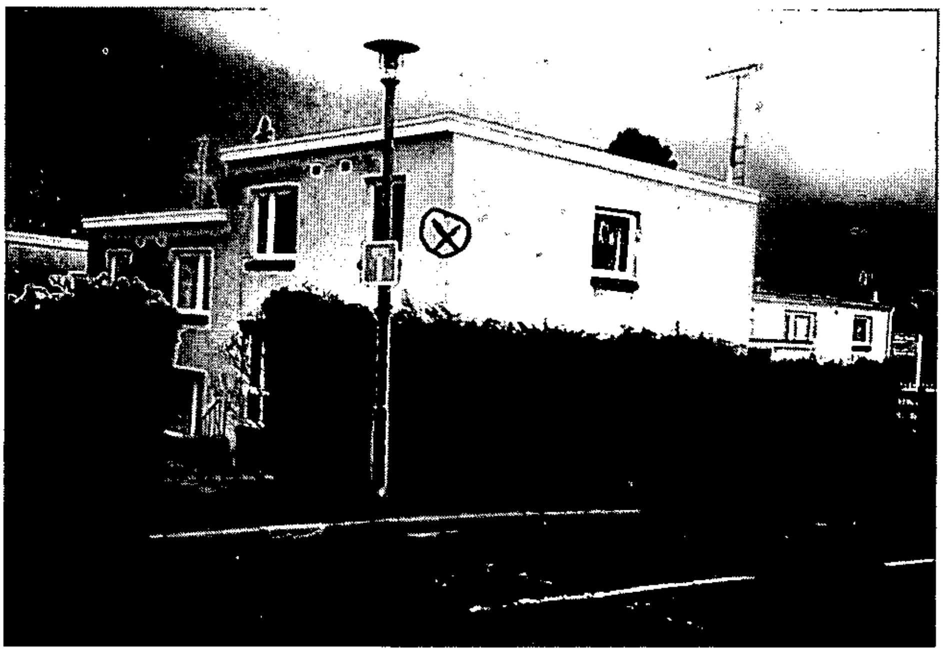


FIG 1.4 House 6 : end terrace/detached house ('X' shows the location of mould growth ; see section 3)

FIG 1.5 House 7 : first floor flat ('X' shows the location of mould growth; se section 3)

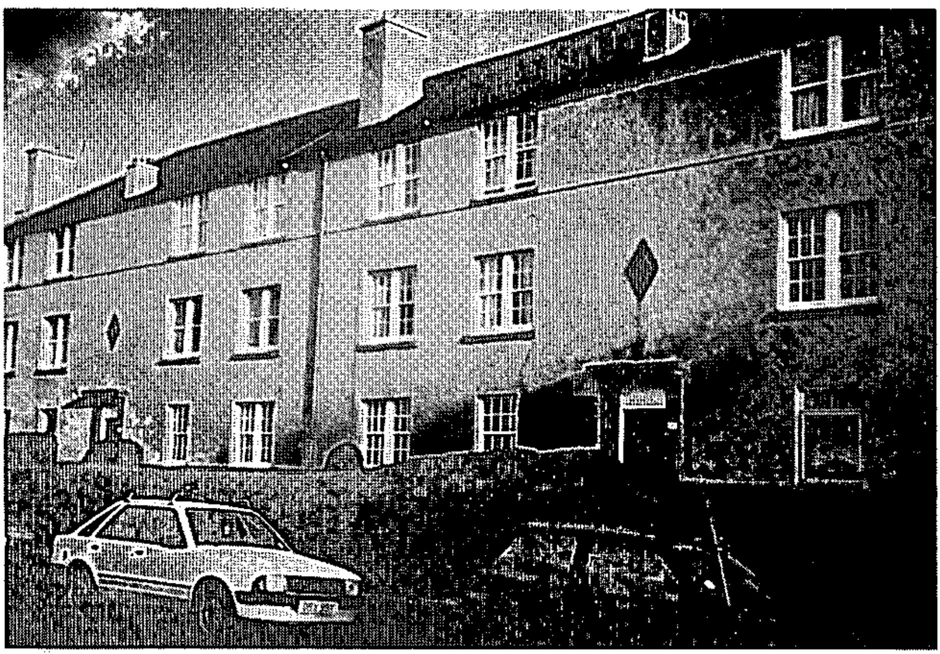


FIG 1.6 House 9 : ground floor flat

2. LAYOUT AND BUILDING FABRIC

In the nature of the study, little detailed data on the building fabric was available. Most of the houses were of brick-cavity-brick construction rendered on the outside, with few thermal bridging problems, except:

House 1 had solid masonry walls approximately 30cm thick.

House 4 was a steel frame construction with infill panels of rendered brick with a plasterboard lining.

House 7 was a concrete frame construction with brick infill panels as above.

No insulation had been added to the walls of any of the houses.

3. MOISTURE PROBLEMS

Although all ten houses had reported mould problems in the past, there were relatively few problems visible during the monitoring period. The most significant ones were:

- House 1 : extensive mould growth on the gable wall of one bedroom (figs 3.1 and 3.2; within location 'X' on fig 1.1). This had been present for a number of years; there was no evidence of rain penetration.
- House 2 : slight mould growth around the bedroom window reveals.
- House 3 : persistent mould growth 1-2 cm above ground floor level in two bedrooms.
- House 4 : slight mould growth in the window reveals.
- House 6 : persistent mould growth on an exterior corner; on the ground floor in an unheated hall off the kitchen (fig 3.3); on the first floor in a bedroom built in wall cupboard. (within location 'X' on fig 1.4)
- House 7 : mould growth on a external corner in a bedroom (fig 3.4; within location 'X' on fig 1.5)

FIG 3.1 House 1 : mould growth on bedroom gable wall.

FIG 3.2 House 1 : mould growth on gable with surface temperature sensors

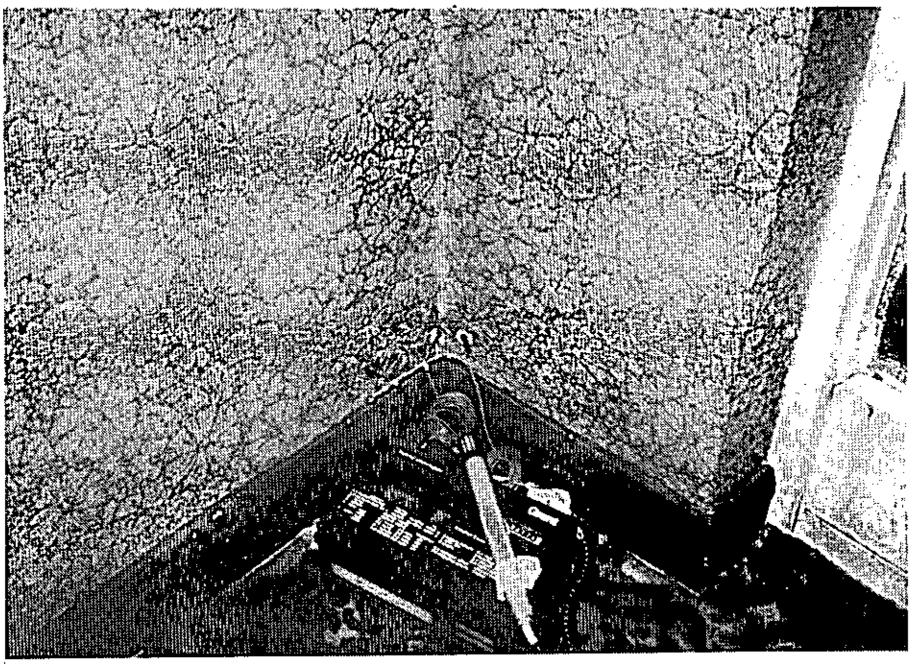


FIG 3.3 House 6 : mould growth in external corner with temperature sensors

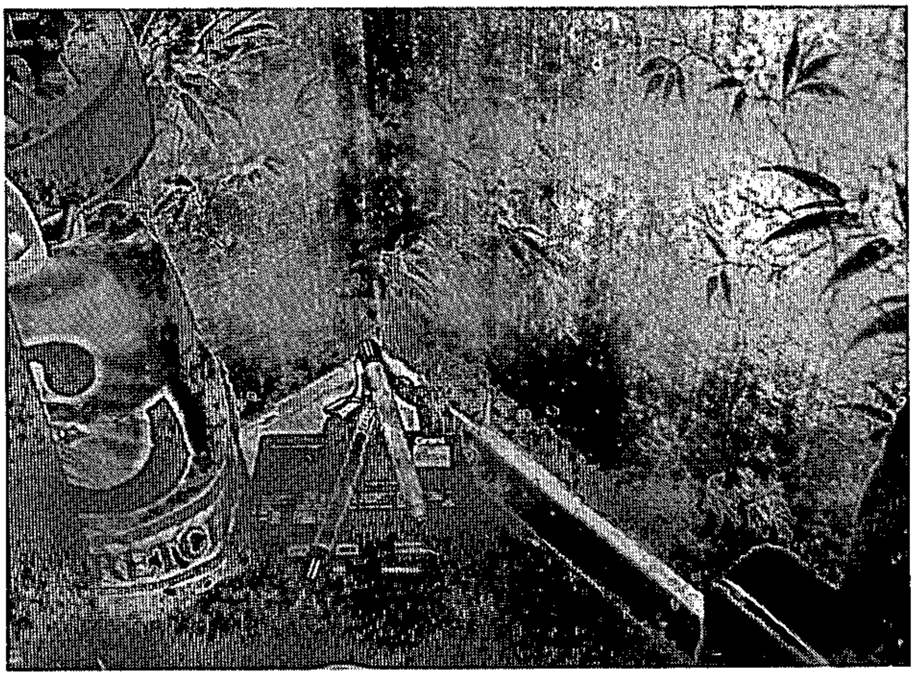


FIG 3.4 House 7 : mould growth on thermal bridge in bedroom

FIG 4.1 AGEMA Thermovision equipment.

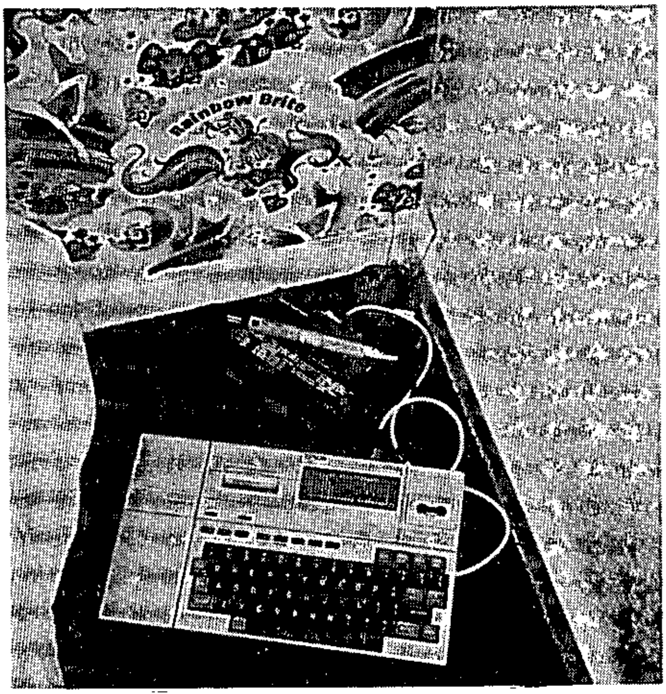


FIG 4.2 Temperature and Humidity logging equipment.

4. MEASUREMENTS

1) In all ten houses, weekly thermohydrographs recorded conditions in the living room, kitchen and children's bedroom for the four weeks. The charts were digitised with a graphics tablet and microcomputer and hourly values of temperature, moisture content and relative humidity stored.

2) Readings of the electric and gas meters were taken at the end of each week in each house (except house 4 where the the meter cupboard was kept locked)

3) An AGEMA thermovision camera (fig 4.1) was used to carry out a thermovision survey of houses 1,3,4,6 and 7, in which the construction suggested that thermal bridging was likely to be a cause of condensation and mould problems.

4) Small portable data loggers which recorded air temperature and relative humidity and two surface temperatures with thermistor probes (fig 4.2) were installed in houses 1,3,4,6 and 7 in locations determined by the thermovision survey as summarised below:

House 1 : six points on the bedroom gable wall covered in mould shown on figs 3.1 and 3.2.

House 3 : four points on the area of mould growth 1 cm above the ground floor skirting board in a bedroom.

House 4 : a) two points in the kitchen window reveal.
b) two points in an external corner of the bedroom 1 cm above the skirting board in an area recently redecorated over mould. (see fig 4.2)

House 6 : a) two points in the corner of the ground floor hall 1 cm above skirting board level (see fig 3.3)
b) two points in the bedroom cupboard vertically above a)

House 7 : four points on the thermal bridge in an external bedroom corner (see fig 3.4)

5. THE INSIDE CLIMATE

The mean temperature, moisture content and relative humidity in each of the three rooms over the four weeks are summarised in table 2 and plotted room by room on the psychrometric charts figs 5.1, 5.2 and 5.3, which also show the mean outside conditions (T=4.3 C, G=4.12 g/kg)

Mean house temperatures were calculated by weighting the the individual rooms by volume and the temperature excess (mean inside - outside) plotted against weekly fuel usage (from table 1) on figure 5.4. It can be seen that, in general, the houses fall into two groups based on their built form. Houses 3, 5 and 9 are traditional flats, with low external wall areas; house 7 is the modern flat with complex form and large external areas; houses 1, 6 and 8 are semidetached or end terraced houses. The exception to this pattern is the semi detached house 2, which, owing the unusually warm living room, has an anomalously high temperature excess. It is possible that there is an unrecorded energy input from paraffin or calor gas; the high moisture content in this living room tends to support this.

There is a wide spread of moisture contents between houses in all the rooms. In each room the houses fall into two groups with high or low moisture contents, however none of the houses is consistently in either group. There appears to be little interaction between the rooms in these houses. The one obvious feature is the very high moisture content in the bedroom of house 9, in which four children sleep.

The mean relative humidities exceeded 70% in only the bedroom of house 7, though they came close in some of the other rooms. In general, high relative humidities were associated with high moisture contents rather than with low temperatures.

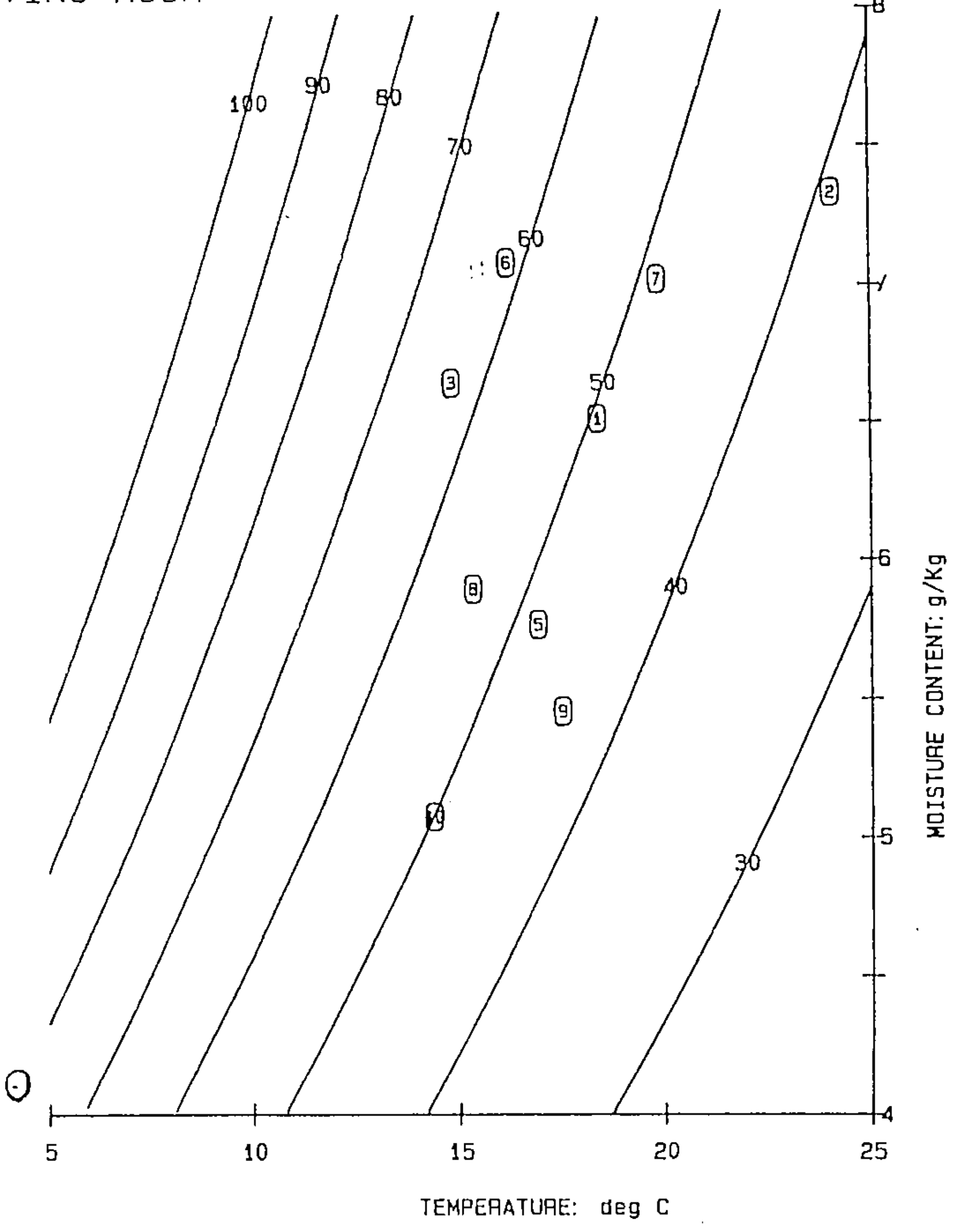
TABLE 2 MEAN DATA FROM EACH ROOM FOR FOUR WEEKS MONITORING

T: TEMPERATURE C
G: MOISTURE CONTENT g/Kg
RH: RELATIVE HUMIDITY %

HOUSE	LIVING ROOM			BEDROOM			KITCHEN		
NO	T	G	RH	T	G	RH	T	G	RH
1	18.8	6.53	48	14.7	6.47	63	17.1	6.28	52
2	24.6	7.35	38	16.0	5.59	50	17.6	6.53	52
3	15.2	6.66	62	17.7	5.65	45	14.9	5.22	50
4	15.0			12.4	5.15	58	17.7	6.59	52
5	17.3	5.78	47	16.5	6.34	55	20.4	6.85	46
6	16.6	7.10	60	13.9	6.28	64	13.2	4.94	52
7	20.3	7.04	48	11.6	6.34	74	16.3	6.22	54
8	15.7	5.91	54	11.2	5.03	61	15.9	7.16	64
9	17.9	5.47	43	16.1	7.35	65	15.3	4.84	44
10	14.7	5.09	49	12.0	4.59	53	15.1	6.34	60

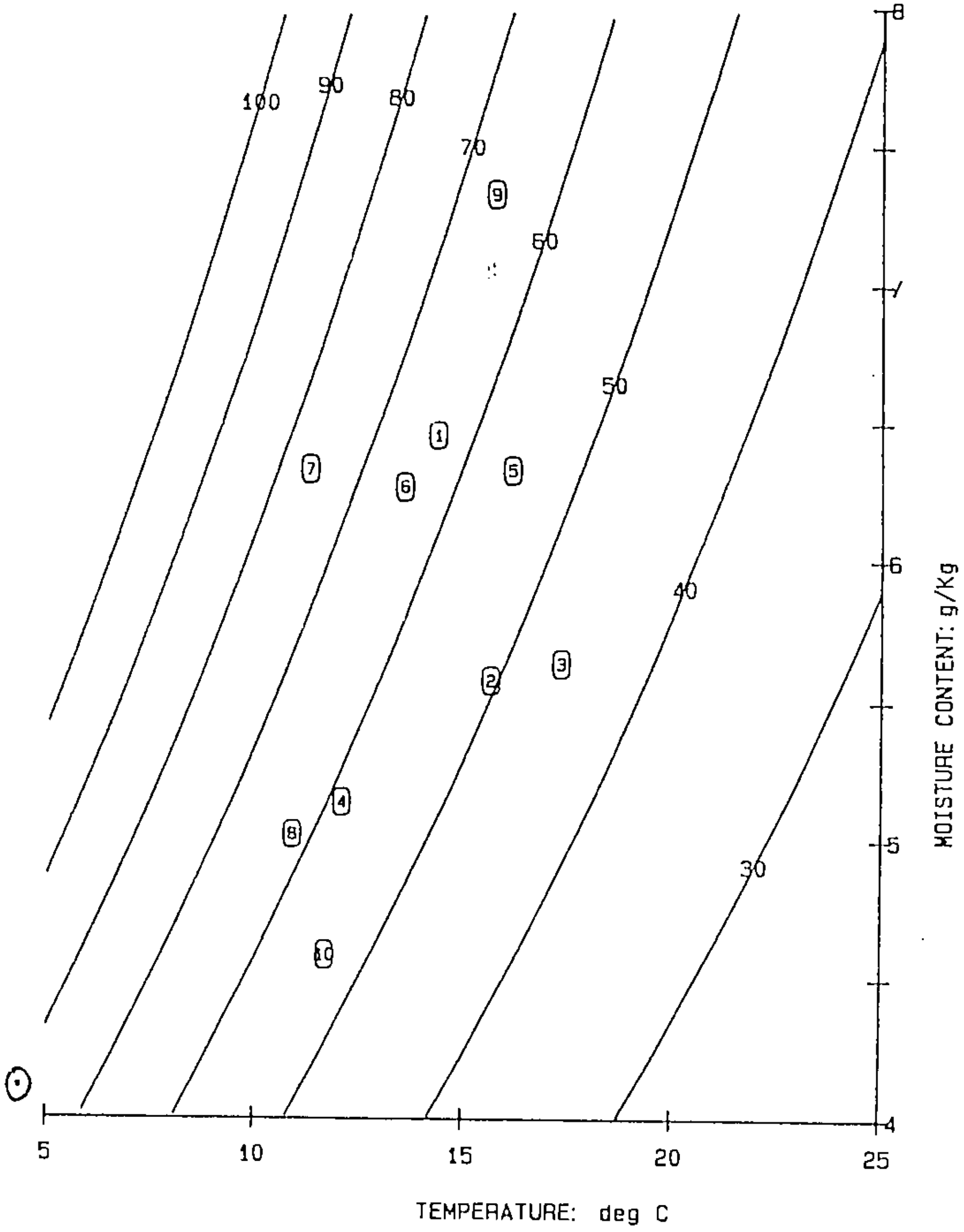
THERMOHYDROGRAPH DATA : MEANS OVER 4 WEEKS

LIVING ROOM



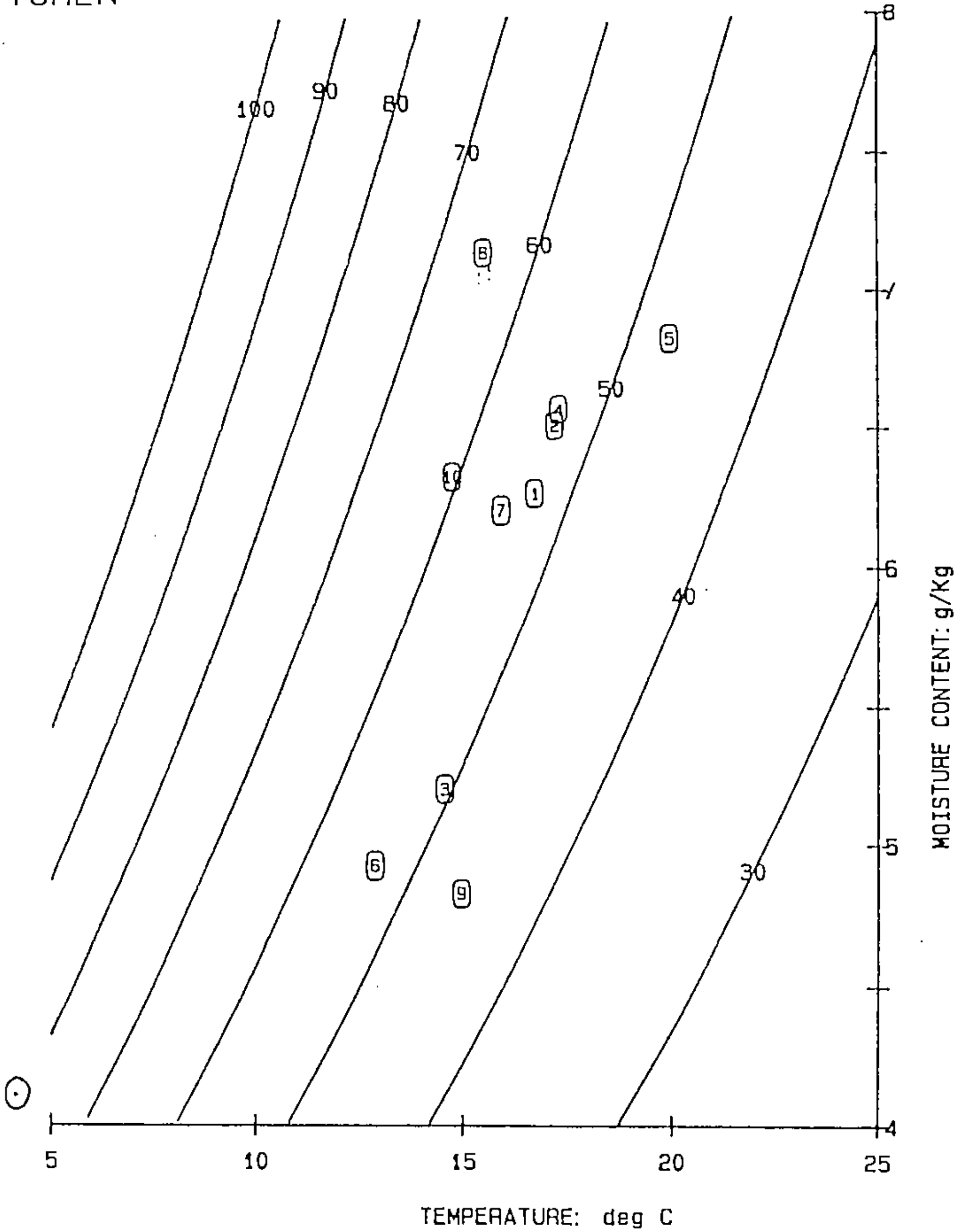
THERMOHYDROGRAPH DATA : MEANS OVER 4 WEEKS

BEDROOM



THERMOHYDROGRAPH DATA : MEANS OVER 4 WEEKS

KITCHEN



6. SURFACE CONDITIONS

Figures 6.1 and 6.2 show the two most significant thermovision pictures recorded during the survey. 6.1 shows the gable wall covered in mould in house 1 (see fig 3.1). 6.2 shows the ceiling adjacent to the external wall in house 4; the picture in this location was repeated throughout the flat; evidently the ceiling slab was acting as a thermal bridge. Mould growth was said to be common in these locations, but had been cleaned off during the monitoring period.

Two parameters were calculated from the air and surface conditions record in the locations specified in section 4/4.

a) The temperature ratio $= \dfrac{\text{surface} - \text{outside}}{\text{air} - \text{outside}}$

b) The surface relative humidity =

$$\frac{100 * \text{vapour pressure in the air}}{\text{saturated vapour pressure at the surface temperature}}$$

In both of these cases one must decide what are the most appropriate air conditions to use. Should conditions typical of the room air as a whole be used or should one use air conditions local to the surface? This choice involves making assumptions about the relative mixing of heat and water vapour within the room and having to assess the effect of unventilated corners etc. as thermal bridges in themselves.

In the present study conditions typical of the air in the room as a whole have been used.

Table 3 summarises the mean surface temperatures, temperature ratios, surface relative humidities and the hours per day that the SRH exceeded 85%.

Rather surprisingly, house 1 with extensive mould growth shows the lowest values of SRH with values exceeding 85% for only short periods in one location. Investigations into the wall have shown no evidence of rain penetration or other forms of moisture ingress. Further investigations are needed to establish the cause of the mould in this case.

The four measuring points in the bedroom of house 3 all have similar temperatures and consequently similar values of SRH, which exceeds 85% for at least 15 hours per day.

In the kitchen of house 4 the temperature ratios in the window reveal are exceptionally low, down to 0.289 near the frame. This reflects the combined effect of the thermal bridge at the reveal and the chilling effect of the window on the adjacent air.

A similar effect is noticeable in the hall way of house 6 where the very low temperature ratio and consequently high SRH (110% on average) is due to a

FIG 6.1 House 1 : Bedroom gable wall

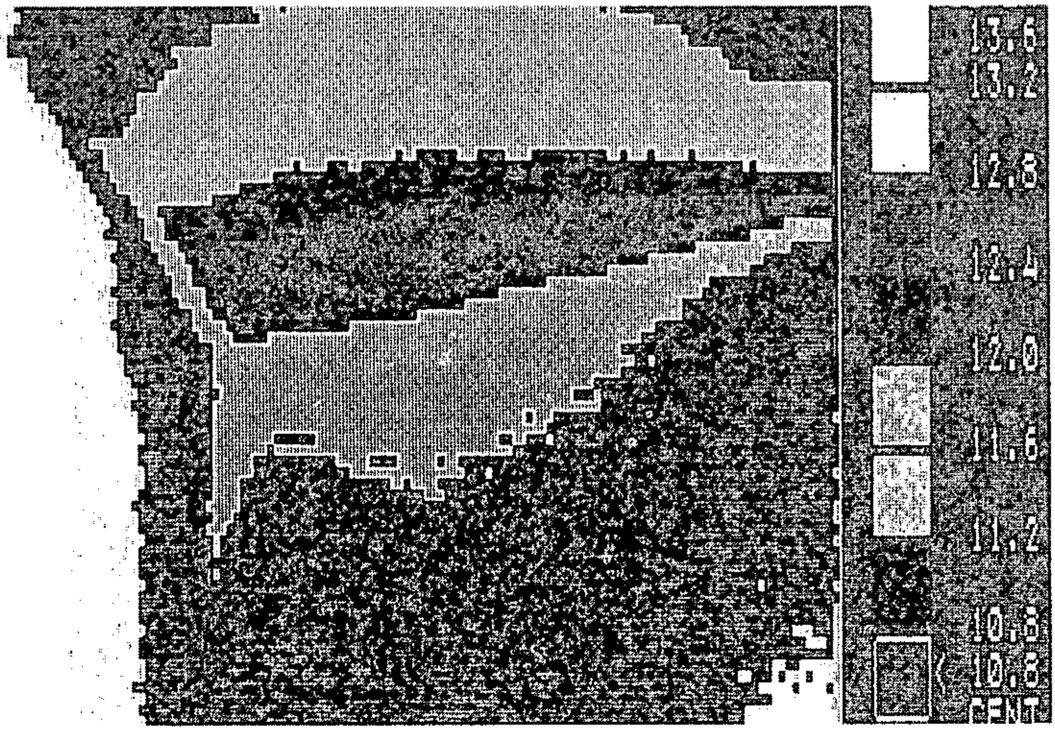


FIG 6.2 House 4: Thermal bridge at ceiling/external wall junction.

TABLE 3 MEAN SURFACE CONDITIONS OVER FOUR WEEKS MONITORING

	POINT	TEMP C	TEMP RATIO	R H %	HRS/DAY RH >85%
HOUSE 1					
BEDROOM	1	11.1	.872	72.3	0.0
	2	11.5	.929	70.3	0.0
	3	11.0	.855	73.0	0.0
	4	9.8	.699	78.9	2.5
	5	10.2	.750	76.9	0.4
	6	10.3	.762	76.5	0.3
HOUSE 3					
BEDROOM	1	8.6	.786	90.4	17.3
	2	8.7	.793	90.1	17.1
	3	9.1	.850	87.9	15.4
	4	8.6	.779	90.6	17.4
HOUSE 4					
KITCHEN	1	8.2	.289	97.2	16.1
	2	10.5	.462	83.1	9.7
BEDROOM	1	8.2	.465	76.1	6.1
	2	8.2	.468	75.9	5.7
HOUSE 6					
HALL	1	7.5	.296	110.3	24.0
	2	8.2	.313	104.3	23.0
BEDROOM	1	6.8	.254	101.7	24.0
	2	6.9	.262	101.2	24.0
HOUSE 7					
BEDROOM	1	6.2	.682	92.8	23.8
	2	6.8	.864	88.9	19.9
	3	6.3	.703	92.2	21.1
	4	7.1	.911	87.6	18.9

thermal bridge at floor level combined with local low air temperatures.

7. CONCLUSIONS

The ten houses studied in this initial report seem to be typical of those towards the more humid end of the spectrum of housing in Edinburgh. Relatively little mould growth was found; this was also true in the larger group of ninety four houses studied over the winter and may be a consequence of the mild winter weather this year.

As yet few details of the construction have been taken into account, however even the simplest measure of built form can be used to relate internal temperatures to energy use.

With the exception of one house which needs further investigation all the areas of observed mould growth were associated with low temperature ratios and values of surface relative humidity which exceeded 85% for long periods.