VENTILATIOAN SYSTEM PERFORMANCE

11th AIVC Conference, Belgirate, Italy
18-21 September, 1990

Paper 30

IEA - ANNEX 14 "CONDENSATION AND ENERGY": ZOLDER CASE STUDY.

Presentation of the final report with special emphasis on the case studies.

H.Hens, E.Senave

K.U. Leuven, Laboratorium Bouwfysica
Celestijnenlaan, 131
B-3000 Leuven
Belgium

ABSTRACT

The paper summarises the IEA, Executive Committee on Energy Conservation in Buildings and Community Systems, Annex 14 work on Condensation and Energy, a joint research effort of the Federal Republic of Germany, Italy, the United Kingdom, the Netherlands and Belgium, finished end of march 1990.

First the complex relations between mould+ surface condensation, the outside climate, the building fabric, inhabitants behaviour and energy conservation are discussed. Then follows a short overview of the Annex achievements with mayor emphasis on the guidelines and practice results.

These are illustrated by the Zolder case, an example of a problem estate. The causes of the complaints found there, seem typical: social houses with a restricted living space, intensively used, ruinous thermal quality and poor ventilation possibilities. On 3 houses, different curing measures could be evaluated in a systematic way: loft space insulation, inside insulation, double glazing, outside insulation, natural ventilation, demand controlled ventilation. This paper describes the results for 1 of the houses.

0. INTRODUCTION

The IEA- Annex 14 work on mould, surface condensation and energy, generated from a widespread feeling in the 5 countries involved, that too straight forward energy conservation actions during the seventies and early eighties had increased the number of moderate to severe mould cases in the existing housing stock. It was feared that this could enhance any further energy conservation policy. The spread of the problem in the low income housing sector was also quoted as no longer acceptable.

1. A THEORETICAL APPROACH TO MOULD AND SURFACE CONDENSATION

1.1 Condition for mould growth and surface condensation

Mould growth becomes possible when the long lasting mean relative humidity (= the water activity) on a surface remains higher than a threshold value a. This condition can be written as:

$$p \geq a.p' \quad (a \leq 1) \qquad \text{(eq 1)}$$

with p the vapour pressure against and p' the saturation pressure on the surface.

Surface condensation starts each time the relative humidity (RH) on the surface reaches 100%, t.m., each time the vapour pressure p against equals or becomes higher then the saturation pressure p' on the surface:

$$p \geq p' \qquad \text{(eq 2)}$$

1.2 The saturation pressure p'on a surface

The saturation pressure p'in a point on a surface is determined by the local surface temperature Θ_s, Θ_s being given by:

$$\Theta_s = \Theta_e + \tau_{hi} \cdot (\Theta_i - \Theta_e) \qquad \text{(eq 3)}$$

with τ the local temperature factor, coupled to a surface film coefficient h_i, Θ_i the inside reference temperature and Θ_e the outside <sol- air> temperature.

For a flat wall in steady state thermal conditions (= mean thermal situati-on), τ_{hi} becomes an areal property, given by:

$$\tau_{hi} = 1 - U/h_i \qquad \text{(eq 4)}$$

with U the thermal transmittance of the wall and h_i the inside surface film coefficient. For 2D- or 3D- envelope parts in steady state conditions, τ_{hi} is a linear or punctual property, dependant of the specific geometry of the part, the materials combination and the in- and outside surface film coefficients (h_i, h_e). In non steady state conditions, τ_{hi} turns to be time dependant, as shown in fig.1.

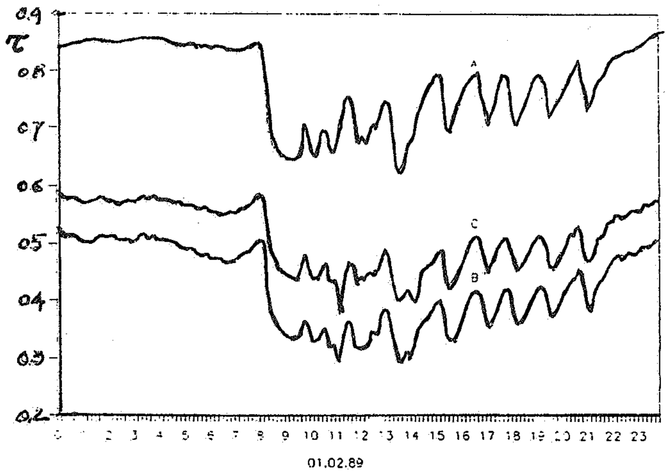


fig 1

the temperature factor of a cavity wall in non steady state

a:middle of the wall

c:corner

b:behind a cupboard

Calculating the temperature factor means: solving in a very detailed way the thermal balance of a building on the level of each thermal zone (heating+ solar gains+ free gains+ enthalpee flow+ convective exchanges/ radiation) and each envelope part (= 1D-,2D- or 3D conduction),with a coupling by the convection+ radiation+ conduction- balance at the inside surfaces (= $\{h_i, \Theta_{ref}\}$).

1.3 The vapour pressure p against a surface.

The vapour pressure p against a surface follows from the hygric balance in each building zone. If one assumes ideal mixing of the zonal air, the balance for zone i becomes:

$$\Sigma(G_{aji} \cdot p_j/RT_i) - p_i \cdot (\Sigma G_{aij})/RT_i + \Sigma \beta_{ki} \cdot A_{ki} \cdot (p'_{ki} - p_i) + \Sigma \beta_{li} \cdot A_{li} \cdot (p_{li} - p_i) + G_{pi} = V_i \cdot dp_i/dt \qquad \text{(eq.5)}$$

with G_{aji} the air flow from zone j to zone i, p_j the vapour pressure in zone j (j= e for the outside), G_{aij} the air flow from zone i to zone j, p_i the vapour pressure in zone i, A_{ki} the surfaces in zone i, where condensation takes place, p'_{ki} the saturation pressure on these surfaces, A_{li} the hygros-copic surfaces in zone i, p_{li} the vapour pressure against these hygroscopic surfaces, β_{ki} and β_{li} the vapour surface film coefficient against the surfaces A_{ki} and A_{li}, G_{pi} the vapour production in zone i and Vi the zonal volume. R is the gass constant of vapour (462 J/(kgK))and T_i the zonal temperature in K.

In this hygric balance, the air flows follow from an interzonal air exchange calculation.

The local vapour pressure p_{li} against each hygroscopic surface is linked to the vapour transport in the surface material by the surface vapour balance:

$$\beta_{li}\cdot(p_{li}-p_i)= [\delta .\ \mathrm{grad}(p)]_{sl} \qquad \text{(eq.6)}$$

and the mass balance in the material:

$$\mathrm{div}[\delta .\ \mathrm{grad}(p)]_{sl}= \delta w_{Hs}/\delta t \qquad \text{(eq.7)}$$

In eq.6 and 7, δ is the vapour conductivity and w_{Hs} the hygroscopic moisture content of the surface layer.
w_{Hs} is given by the suction isotherm.

If steady state or long lasting mean conditions are looked for, then the time derivates in eq. 5 and 7 equal 0 and the vapour pressure against each hygroscopic surface p_{li} becomes the zonal vapour pressure p_i. If further only outside air ventilation plays and G_{aei} is written as $n.V_i$ with n the outside air ventilation rate in zone i, the hygric balance simplifies to:

$$p_i= p_e + \frac{462.T_i.G_p-\Sigma\beta_{ki}.A_{ki}.(p_i-p'_{ki})}{n.V_i} \qquad \text{(eq.8)}$$

If nor surface condensation nor surface drying are present, (eq.8) reduces to the very simple expression:

$$p_i= p_e + \frac{462.T_i.G_{pi}}{n.V_i} \qquad \text{(eq.9)}$$

saying that the mean inside vapour pressure has as lowest value the mean outside vapour pressure and that the difference between both increases when:
- more vapour is produced in the zone (G_{pi} <);
- less ventilation is present (n >);
- the zonal volume is smaller (V >).

Eq.8 adds that, if surface condensation or surface drying are present, the influences of vapour production and ventilation are weakened.
See fig.2.

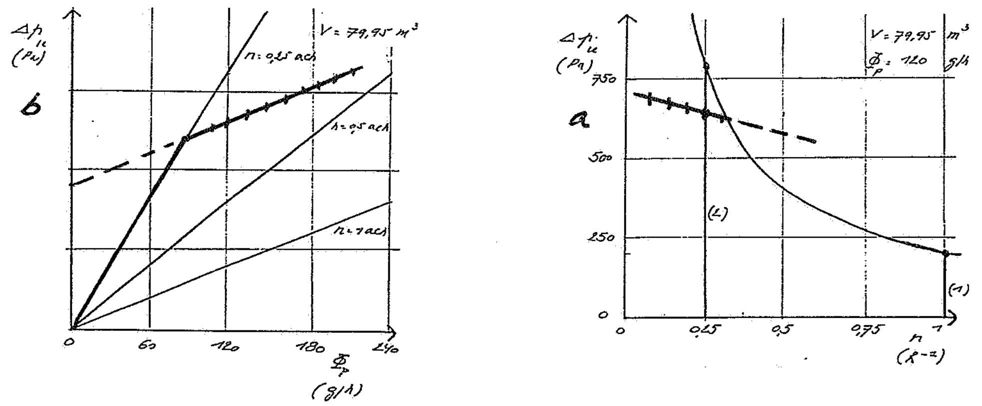


fig 2 the diff. in outside - inside vapour pressure as a function of the mean ventilation rate and vapour production :

— : no cond.
+++: cond. on 7.1 m² of double glazing
-- : drying (Zolder living room)

1.4 Conclusions

The formulas 1 and 2 show in a nutshell that the chance on mould/ surface condensation increases with lower surface temperature Θ_s and higher inside vapour pressure p_i.
The further theory learns that both depend of:

1.- the outside climate

. the temperature Θ_e and the vapour pressure p_e: the lower Θ_e and the higher p_e, the more probable mould and surface condensation. A low temperature and a high vapour pressure however are in conflict: they cannot occur together;

. the wind velocity: the lower, the lower the ventilation rate n and the more probable mould and surface condensation...

2.- the building fabric

. the volume: the smaller V, the more probable mould and surface condensation;

. the thermal quality: the lower the temperature factor, the more probable mould and surface condensation. A low temperature factor implies high U-values, thermal bridging and low surface film coefficients h_i;

. the airtightness: the basic ventilation rate n_b is a direct result of the airtightness of the fabric.The lower n_b, the more probable mould and surface condensation.

. the h_i-value: h_i depends of convection and radiation.The last is to a significantly influenced by the overall thermal quality of the fabric and the 'outside wall area-total wall area'-ratio, in the sense that the worser the thermal quality and the higher the defined ratio, the lower radiation and the more probable mould and surface condensation;

. The inside temperature: Θ_i is fabric coupled, in the sense that,if the dwelling is badly insulated, maintaining a sufficient high temperature reveils too energy consuming and expensive for the inhabitants. The lower the inside temperature, the more probable mould and surface condensation!;

. the vapour production: a high vapour production G_p may be a consequence of other building fabric coupled moisture problems. The higher G_p, the more probable mould and surface condensation.

. the internal finishing: some materials,paints,wall papers are more mould sensitive then others or, the threshold relative humidity 'a' may be lowered by the choice of the finishing solutions (as far as clean)

- **the inhabitants behaviour**

. the inside temperature: depends also of the heating habits.The less heating, the lower Θ_i and the more probable mould and surface condensation;

. the ventilation rate: the lower n, the more probable mould and surface condensation. Inhabitants have a substantial effect on excess ventilation

. the moisture production: the higher G_p, the more probable mould and surface condensation. Living in and using a dwelling inevitably means vapour production. Nevertheless, using it in an unadapted way, may result in too much

These three sets of influencing parameters are interrelated.

2. LINKS WITH ENERGY USE FOR HEATING

The parameter check makes clear that mould and surface condensation are most probable in badly insulated dwellings, t.m. houses with a high basic energy demand. More, avoiding mould in these, asks for a substantial ventilation rate, especially when the dwellings are intensively used. This means: a still higher demand. Economising by lowering the mean inside tempera-ture Θ_i also is counteracted by an increasing ventilation need, if one wants to avoid mould. The result is a total loss of energy demand elasticity.

Insulated houses give complaints as far as problematic thermal bridges are left. These have a net energetical impact, multiplying in negative cases the conductive heat losses with a factor 1.3. To avoid mould on these, also a substantial ventilation is needed, pushing the energy demand further up.

This makes clear that avoiding mould complaints, realising low energy demands and having a good comfort and acceptable IAQ, all point in the same direction:

the construction of well insulated, problematic thermal bridges free, correctly ventilated buildings.

The mould reality adds: 'provided with a heating possibility in each thermal zone'

3. ACHIEVEMENTS OF THE ANNEX

3.1 In general

The main achievement are 4 reports, the first entitled the source book (1), the second being a Catalogue of Material Properties (2), the third handling all Case Studies (3) and the fourth summerising Guidelines and Practice (4).

The source book contains 6 chapters:

1. Material properties (B)
2. Mould (U.K.)
3. Modelling: thermal aspects (I, FRG, NL, B)
4. Modelling: hygric aspects (B)
5. Modelling: heat-air-moisture transfer (NL)
6. Boundary conditions (FRG)

The first gives extended information on the hygrothermal material properties and introduces the catalogue of material properties. The second describes mould and all related aspects. The thirth, fourth and fifth concern the physics involved. They develope the theoretical framework for modelling. The sixth gives practical information on outside climate, vapour production, ventilation, building use...For more information, see (5).
The source book forms the reference for the guidelines report, the translation to practice of the annex work.

3.2 Guidelines and Practice

These have been developed, starting from 4 question:

1.- Condition for mould germination on a surface? (=asking for the value of the threshold-RH a)

2.- Handling of the inside climate in view of mould problem checks: reference temperature, climate charts, climate classes?

3.- Value of the inside surface film coefficient h_i?

4.- Temperature factor τ: exact definition, value?

The answers to these questions are found implicitely throughout the 6 chapters of the source book. Their explicite formulation, given in the Guidelines report, sounds:

Question 1:
Mould germination on a surface becomes very probable, if the monthly mean RH on the surface exceeds 80%. Or:

$a = 0.8$ on monthly mean basis

Question 2:
As inside reference temperature Θ_i is taken

the AIR TEMPERATURE at 1.7 m height in the center of the zone

The climate chart to be used in judging mould problems, is a 3D-one, with on the x- axis the outside temperature, on the y- axis the inside reference temperature and on the z- axis the difference in inside- outside vapour pressure Δp_{ie}. See fig. 3. This difference stays for the ratio between the vapour production and the ventilation rate (see eq.9)

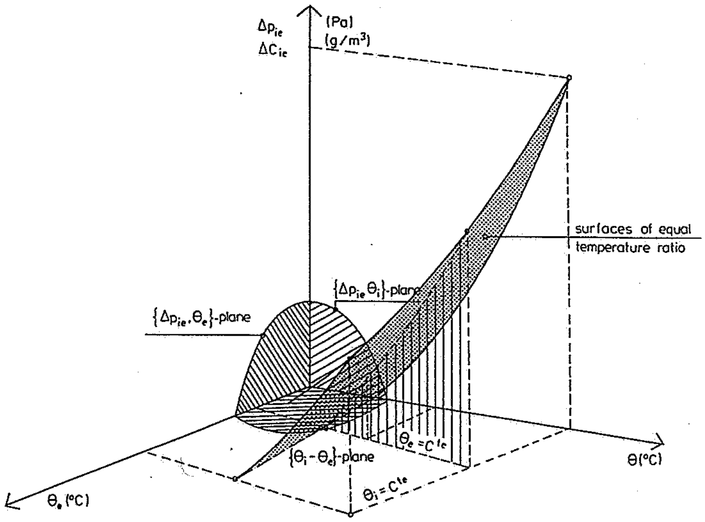


fig 3

the 3-D climate chart with a surface of equal temperature factor or ratio

<u>Question 3</u>:
A clear methodology has been developed to calculate the local inside surface film coefficient h_i, combining heat transfer by convection and radiation and linked to the inside reference temperature Θ_i. If detailed information on the zone is known (thermal quality of all parts, heating system), the methodology allows to calculate $\{h_i,\Theta_i\}$. If not, a set of h_i- values is offered:

upper edges and corners : 4 W/(m²K)
vertical edges at mid height: 4 W/(m²K)
lower edges and corners : 2.9 W/(m²K)
glazing : 6.7 W/(m²K)
shielded surfaces : 2 W/(m²K)

all being lower than the value for vertical walls, used in energy and power demand calculations: 8 W/(m²K)!

<u>Question 4</u>:
The temperature factor τ is defined as:

$$\tau = (\Theta_s-\Theta_e)/(\Theta_i-\Theta_e)$$

with Θ_i the inside reference temperature, Θ_s the local surface temperature and Θ_e the outside <sol air> temperature, the three taken on monthly mean basis. τ is used to introduce temperature factor- classes in the climate chart: see fig.3. This is done by calculating the surfaces of equal τ_{hi}- value with the formulas ($x= \Theta_e$, $y= \Theta_i$, $z= p_i-p_e$):

$$\Theta_{si} = x + \tau.(y-x)$$
$$p'_s = p'(\Theta_s)$$
$$z = p'_s - p_e$$

The final performance criterium to avoid mould in new buildings exists in implementing a τ- class. The more severe this class, the more freedom exists in building use and living habits: vapour production, ventilation, heating.
The less severe the τ- class performance, the more restrictions are introduced in the building use: less vapour production, more ventilation, more heating! A save way to come to a τ- class- value is by handling a high but still normal vapour production, the minimal mean ventilation rate for IAQ- requirements and "normal" heating. This leads to:

$$0.65 \leq \tau \leq 0.7$$

Implementing this performance criterium results, in designing new buildings or curing problem cases, in 4 practice rules

1.A sufficient overall thermal quality: $R \geq 1.5$ to 2 m^2K/W
2.No unacceptable thermal bridges: $\tau \geq 0.65$ to 0.7, U_l as low as possible
3.Implementing a ventilation system, that guarantees $n_{mean} \geq 0.5$ ach
4.Heating possibility in each zone

4. THE ZOLDER CASE STUDY

The Zolder estate has functioned, throughout the annex, as practice laboratory, to judge the problem causes and evaluate retrofitting actions in accordance with the 4 design rules given.

4.1 Generalities

The Lindeman estate, consisting of some 140 dwellings, was build shortly after world war 2 by the "Kempische steenkoolmijnen NV". The 2 story- houses, containing cellar and loft space, were erected with maconry cavity walls, a tiled roof and single glazing in metallic frames. They were coal-fire heated, with a chimney in each room.
In the early eighties, intensive renovating actions were done: a reorganisation of the ground floor, joining the kitchen and little living in 1 larger living room, transforming the washing room in kitchen and adding a bathroom. All chimneys, except one, were demolished and the coal fires removed for a gass fired central heating with radiators in each room. The single glazed, leaky metallic windows were replaced by airtight PVC- windows, double glazed, with an openable part in all rooms, except for the streetside window in the living room. The kitchen was equipped with a hood above the gass fire.
No ventilation system was build in (grids in windows and doors, vertical vents in bathroom and kitchen) nor was any further thermal upgrading, other than double glazing, done (no loft floor insulation, no cavity filling....)
See also fig.4..

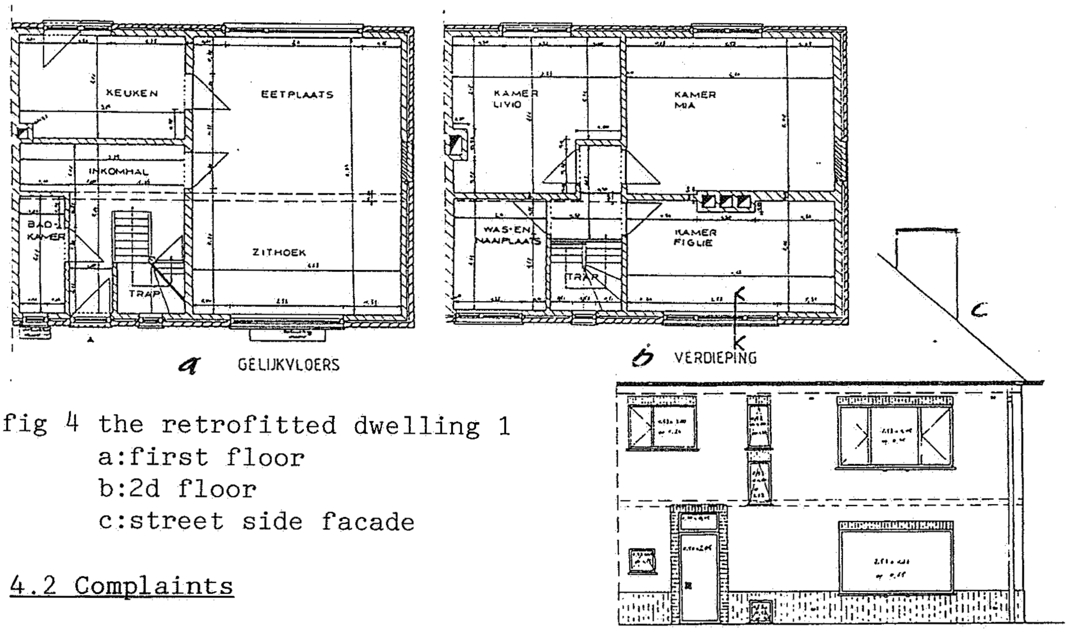


fig 4 the retrofitted dwelling 1
a:first floor
b:2d floor
c:street side facade

4.2 Complaints

Shortly after the retrofit, the first rumours on bad smell, mould and moisture started. An enquiry in 110 houses of the estate, organised in 1987 at the beginning of the Annex, revealed all houses having wet cellar walls, while 75 showed more or less severe mould damage:

Mould in/on:

in	on	number	%
bedrooms	lintels,entire ceiling, 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

Health problems, attributed by the inhabitants to the bad state of their dwelling, were noted in 26 cases out of the 75 with mould.

4.3 Mould species

These were analysed in 3 dwellings. As most important species were found:

species	in ... of the 10 samples
Ulocladium Consortiale	7
Aspergillus Fumigatus	6
Cladesporium Cladesporoides	6
Penicillium Cyclopium	4
Mucor sp.	4

The species on the samples differed from one dwelling to another, from one room to another and in the same room between finishing layers.

4.4 Causes of the problem

2 dwellings were taken as reference, the first- an end of the row house- retrofitted, inhabited by 2 pensioners and having all of the above problems, the second- also an end of the row house- not yet retrofitted, inhabited by a family with 3 little childrens and showing mould in the bedrooms and the bathroom, proving that also before the retrofit, at least some problems existed.
As anti-mould measure, implemented by the housing society, the double glazing in the first dwelling was exchanged for single glass. Curing effects: NONE.

- INSIDE CLIMATE
This was measured in all rooms of dwelling 1:

room	$\Theta_i=f(\Theta_e)$ °C	$p_i-p_e=f(\Theta_e)$ Pa
living room	$17.8-0.08.\Theta_e$ (r^2=0.17)	$562-4.7.\Theta_e$ (r^2=0.25)
kitchen	$19.2-0.09.\Theta_e$ (r^2=0.19)	$506-3.8.\Theta_e$ (r^2=0.14)
bathroom	$13.6-0.01.\Theta_e$ (r^2=0.00)	$478-4.0.\Theta_e$ (r^2=0.20)
hall down	$13.7+0.16.\Theta_e$ (r^2=0.39)	$327-6.3.\Theta_e$ (r^2=0.29)
hall up	$12.2+0.15.\Theta_e$ (r^2=0.10)	$374-4.2.\Theta_e$ (r^2=0.25)
bedroom 1	$11.5+0.16.\Theta_e$ (r^2=0.32)	$356-9.7.\Theta_e$ (r^2=0.35)
bedroom 2	$10.2+0.29.\Theta_e$ (r^2=0.68)	$401-1.0.\Theta_e$ (r^2=0.10)
bedroom 3	$10.4+0.42.\Theta_e$ (r^2=0.41)	$373-3.3.\Theta_e$ (r^2=0.43)
bedroom 4	$8.1+0.38.\Theta_e$ (r^2=0.70)	$399-8.6.\Theta_e$ (r^2=0.39)
cellar	$10.3+0.31.\Theta_e$ (r^2=0.55)	$217-15.\Theta_e$ (r^2=0.29)

If one implements these results on the climate chart, and compares with the reference lines (dayzone: Θ_i= 20°C, nightzone: Θ_i= 15°C/ dayzone: p_i-p_e= $688-21.\Theta_e$) and the lines of equal τ- value, than the conclusions are (fig.5):

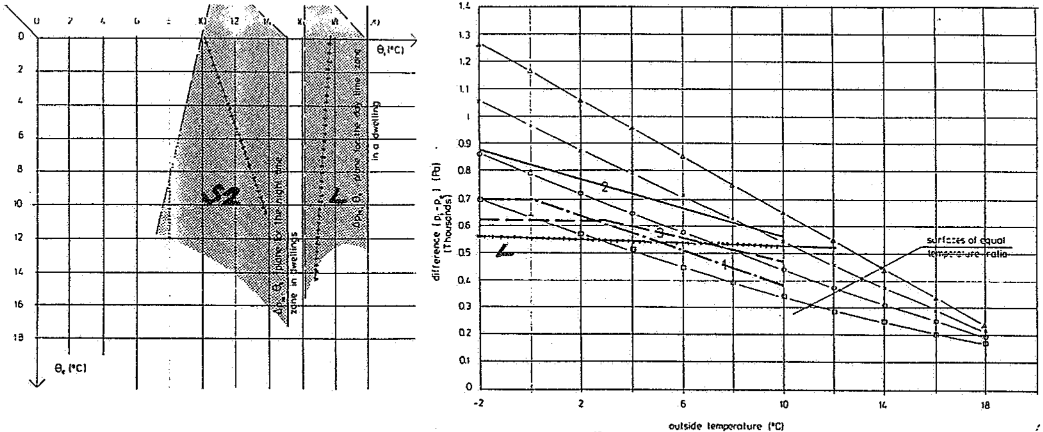


fig 5 the Zolder results against the Δp_{ie} and Θ,-references : colder/high Δp_{ie} (L:living room, S2: sleeping room 2)

- the dwelling is rather poorly heated.This may be caused by a bad insulation quality, making full heating too expensive!;
- the difference in inside- outside vapour pressure is high. This

may be caused by or poor ventilation, or by an important moisture production, or by vapour transfer from the wet cellar to the living space. The last could be excluded after a detailed measuring campaign.The second is rather impossible, because of 'inhabited by only two retired people'.

- to avoid mould problems,a temperature factor ≥ 0.78 is needed in the dayzone. In the nightzone, the RH in the air already exceeds 80%, mould problems being unavoidable!!

- THERMAL QUALITY

The thermal quality was evaluated by calculations and measurements.

<u>Calculated results:</u>

Mean U-value: dwelling 1: Compacity : 1.34 m
Mean U- value : $U_m = 2.0$ W/(m^{2}K)
dwelling 2: Compacity : 1.32 m
Mean U- value : $U_m = 2.1$ W/(m^{2}K)

The actual legislation in the Flemish country asks for a mean U-value 0.77- 0.78 W/(m^{2}K) for social housing with a compacity 1.32-1.34 m, t.m. 3 times lower than present here: the dwellings of the Lindeman estate are in fact of a very poor insulation quality...

<u>Measured results:</u>

. Thermal resistance, U- value, Temperature factor τ, surface film coeff. h_i

dwelling 1		R m^{2}K/W	U W/(m^{2}K)	τ -	h_i W/(m^{2}K)
Living room,	cavity wall	0.47	1.47±0.1	0.75	6.3
	id.,behind cupboard			0.36	
	id.,lower corner			0.45	
	id.,upper corner			0.60	
Sleeping room,	cavity wall	0.66	1.10±0.4	0.72	3.9
	ceiling	0.26	2.23±0.05	0.67	5.8

These results sharply underline the poor thermal quality, 0.36 being the lowest temperature factor. With the measured inside climate, a safety value ≥ 0.78 was needed in the living room!! One also finds surface film coefficients, much lower than 8 W/(m^{2}K). Remarkable is the U-value of the cavity wall, being lower in the sleeping than in the living room. Explanation: the living room is heated, the sleeping room not. The cavity air, warmed at groundlevel, raises by stack effect to the first floor and diminuishes there the heat flow through the inside leaf. This is translated in an fictitious higher thermal resistance. Applying this to the measuring results, gave a constant thermal resistance 0.27 m^{2}K/W for the inner leaf and a mean cavity temperature $\Theta_c = 3.4 + 0.72 . \Theta_e$ ($\Theta_e \leq 10^\circ$C).

. Mould and surface condensation

Mould is visibly present on all spots with a temperature factor lower than 0.7. Where the temperature factor is lower than 0.5, surface condensation regularly appears.

- VENTILATION

The ventilation was checked by calculations and measurements.

Calculated results:

Calculations have been done for dwelling 1, situation before the retrofit,coal fire burning and leaky metallic windows:

dwelling 1	wind speed m/s	n h^{-1}
Living room	0	0.3
	4	0.85
	8	2.0
	16	4.9

Measured results:

Measurements were performed on dwelling 1, situation after the retrofit.

Pressuration test

dwelling 1	n_{50} h^{-1}
overall	5.1
hood in the kitchen airtighted	4.8
cellar airtighted	3.9
entry to the loft space airtighted	3.2
joints between doors and floors airtight	2.1
windows airtighted	1.0

These results prove that after the retrofit, the airtightness is so high, that no divice directed natural ventilation cannot be effici-ent!!

Decrease in vapour pressure

From the exponential decrease in vapour pressure in the living room, a ventilation rate 0.17 h^{-1} was deduced. This in fact is a very low value, proving that indeed poor ventilation and not a too high vapour production is the cause of the high difference in inside- outside vapour pressure.

However, because of the overall airtightness and the impossibility to have cross ventilation in the daytime zone, a better ventilation is not possible.

CONCLUSION

The causes of the mould problems in the Lindeman estate are:

- the very poor thermal quality of the houses;
- lack of ventilation, especially in the retrofitted dwellings.

Precisely the last has aggravated the situation after the renovation of the early eighties.

4.5 Remedial measures

The remedial measures in dwelling 1 and 2 focussed on improving the thermal quality and increasing the mean ventilation rate. Only the measures and results for dwelling 1 are discussed, the evaluation of the retrofitting actions on dwelling 2 still going on (loft space insulation, new windows, double glazing, outside insulation, a devise coupled natural ventilation).

Measure 1:
improving the loft floor insulation with 12 cm thick mineral wool slabs.
Effects
1. Mean U-value :decreased from 2.0 to 1.46 $W/(m^2K)$ (calculated)
2. R- value ceiling:increased from 0.26 to 3.3 $W/(m^2K)$(measured)
3. τ- value ceiling:increased from 0.67 to 0.85 (measured)
4. h_i-value ceiling:decreased from 5.8 to 1.6 $W/(m^2K)$ (measured)
5. air temperatures:INCREASED

	before	after
living room	$17.8-0.08.\Theta_e$ (r^2=0.17)	$17.7+0.09.\Theta_e$ (r^2=0.14)
kitchen	$19.2-0.09.\Theta_e$ (r^2=0.19)	$18.7+0.00.\Theta_e$ (r^2=0.01)
bathroom	$13.6-0.01.\Theta_e$ (r^2=0.00)	$16.1-0.07.\Theta_e$ (r^2=0.07)
hall down	$13.7+0.16.\Theta_e$ (r^2=0.39)	$14.0+0.05.\Theta_e$ (r^2=0.16)
bedroom 1	$11.5+0.16.\Theta_e$ (r^2=0.32)	$13.2+0.12.\Theta_e$ (r^2=0.68)
bedroom 2	$10.2+0.29.\Theta_e$ (r^2=0.68)	$13.3+0.16.\Theta_e$ (r^2=0.69)
bedroom 3	$10.4+0.42.\Theta_e$ (r^2=0.41)	$13.0+0.36.\Theta_e$ (r^2=0.70)
bedroom 4	$8.1+0.38.\Theta_e$ (r^2=0.70)	$13.3+0.07.\Theta_e$ (r^2=0.50)

Through the increase in air temperature, the RH in all rooms dropped (in bedroom 2 from 79 to 68%). The temperature factor of the ceiling in the bedrooms also turned out high enough to avoid further mould germination, althrough the lower h_i-value counteracted to some extend the positive influence of the loft floor insulation.

Measure 2:
replacing single by double glazing.
Effects
1. Mean U-value :decrease from 1.46 to 1.23 $W/(m^2K)$ (calculated)
2. air temperature:INCREASED

	before	after
living room(*)	$17.7+0.09.\Theta_e$ (r^2=0.14)	$18.5+0.01.\Theta_e$ (r^2=0.00)
kitchen	$18.7+0.00.\Theta_e$ (r^2=0.01)	$19.1+0.07.\Theta_e$ (r^2=0.14)
bathroom	$16.1-0.07.\Theta_e$ (r^2=0.07)	$18.8+0.37.\Theta_e$ (r^2=0.87)
hall down	$14.0+0.05.\Theta_e$ (r^2=0.16)	$14.2+0.08.\Theta_e$ (r^2=0.50)
bedroom 1	$13.2+0.12.\Theta_e$ (r^2=0.68)	$14.7+0.11.\Theta_e$ (r^2=0.82)
bedroom 2	$13.3+0.16.\Theta_e$ (r^2=0.69)	$14.9+0.07.\Theta_e$ (r^2=0.73)
bedroom 3	$13.0+0.36.\Theta_e$ (r^2=0.70)	$14.6+0.23.\Theta_e$ (r^2=0.76)
bedroom 4	$13.3+0.07.\Theta_e$ (r^2=0.50)	$14.5+0.23.\Theta_e$ (r^2=0.23)

(*): included the effect of inside insulation: see measure 3

3. Difference in inside- outside vapour pressure : no increase,except in the bedroom in use

	before		after	
bedroom 2	$401-1.0.\Theta_e$	$(r^2=0.10)$	$505-4.2.\Theta_e$	$(r^2=0.17)$

Through the increase in air temperature, the RH in all rooms,except bedroom 2, stabilised or further dropped. In bedroom 2, there was a slight increase. Reason: the higher difference in inside- outside vapour pressure, caused by the loss of the air drying effects by surface condensation on single glass.

Measure 3:
<u>Internal insulation in the living room: 3 cm PS, with a gypsum board internal lining.</u>
Effects

1. Mean U-value :decrease from 1.23 to 1.15 W/(m^{2}K) (calculated)
2. R- value wall:increased from 0.43 to 1.23 W/(m^{2}K) (measured)
3. τ- value wall:increased from 0.75 to 0.82 (measured)
4. h_i-value wall:decreased from 6.3 to 3.6 W/(m^{2}K) (measured)
5. τ- value adjacent 2 and 3-dimensional parts: from no influence to a slight decrease.
6. air temperature in the living room: see double glazing
7. Difference in inside- outside vapour pressure : no change

Applying inside insulation was not a convincing retrofit: the situa-tion ameliorates on the insulated parts but deteriorates on the adjacent non insulated parts!

Measure 4:
<u>Installing a natural ventilation system: grids in windows and doors, dimensionned in accordance with the Dutch standards NEN 1087 and NPR 1088</u>
Effects

1. air temperature:DECREASED, except in living room and kitchen

	before		after	
living room	$18.5+0.01.\Theta_e$	$(r^2=0.00)$	$18.7-0.19.\Theta_e$	$(r^2=0.21)$
kitchen	$19.1+0.07.\Theta_e$	$(r^2=0.14)$	$21.0-0.30.\Theta_e$	$(r^2=0.41)$
bathroom	$18.8+0.37.\Theta_e$	$(r^2=0.87)$	$14.4+0.38.\Theta_e$	$(r^2=0.38)$
hall down	$14.2+0.08.\Theta_e$	$(r^2=0.50)$	$13.1+0.33.\Theta_e$	$(r^2=0.17)$
bedroom 1	$14.7+0.11.\Theta_e$	$(r^2=0.82)$	$11.1+0.45.\Theta_e$	$(r^2=0.48)$
bedroom 2	$14.9+0.07.\Theta_e$	$(r^2=0.73)$	$12.4+0.33.\Theta_e$	$(r^2=0.39)$
bedroom 3	$14.6+0.23.\Theta_e$	$(r^2=0.76)$	$13.5+0.22.\Theta_e$	$(r^2=0.63)$
bedroom 4	$14.5+0.23.\Theta_e$	$(r^2=0.23)$	$12.8+0.34.\Theta_e$	$(r^2=0.17)$

3. Diff. in inside- outside vapour pressure :DECREASED (fig 6)

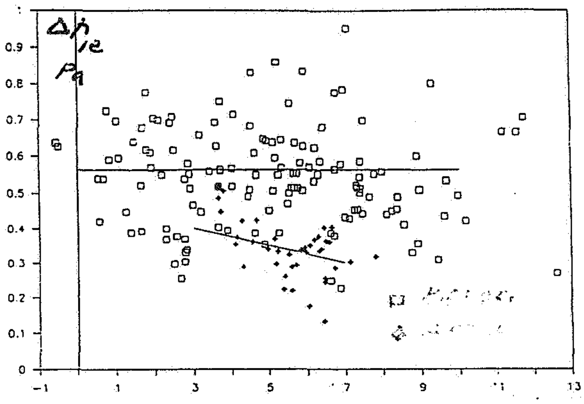
	before		after	
living room	$562-4.7.\Theta_e$	$(r^2=0.25)$	$525-35.\Theta_e$	$(r^2=0.21)$
kitchen	$506-3.8.\Theta_e$	$(r^2=0.14)$	$539-41.\Theta_e$	$(r^2=0.36)$
bathroom	$488-4.0.\Theta_e$	$(r^2=0.20)$	$279+5.0.\Theta_e$	$(r^2=0.07)$
hall down	$327-6.3.\Theta_e$	$(r^2=0.29)$	$142+1.0.\Theta_e$	$(r^2=0.23)$
bedroom 1	$356-9.7.\Theta_e$	$(r^2=0.35)$	$118+16.\Theta_e$	$(r^2=0.13)$
bedroom 2	$401-1.0.\Theta_e$	$(r^2=0.10)$	$322+17.\Theta_e$	$(r^2=0.17)$
bedroom 3	$373-3.3.\Theta_e$	$(r^2=0.43)$	$187-5.0.\Theta_e$	$(r^2=0.30)$
bedroom 4	$399-8.6.\Theta_e$	$(r^2=0.39)$	$131+16.\Theta_e$	$(r^2=0.02)$

This decrease caused a significant fall in inside RH, finally lowering the chance on persisting mould problems to practically 0. In fact, a control showed that in all rooms with the ventilation system functioning, the surface RH on a spot with τ- value 0.7, dropped definitively under 80%.

The fact that in 5 of the 8 rooms, the $\Delta p_{ie}(\Theta_e)$-line shows, contrary to all theoretical predictions of the necessity of a negative slope, a positive one, could be explained by the hygroscopic moisture release, the first weeks after the implementation of a better ventilation.

A multivariational analysis on all measuring results confirmed that in all rooms, outside air ventilation became, compared to the inter-zonal airflow, more important after than before the system came in use.

Tests in a sleeping room on only peak ventilation by opening the window, proved the deficiency of that option, showing that after closing, the inside vapour pressure quickly returned to his preopening level. Cause: hygroscopic inertia (fig.7)!



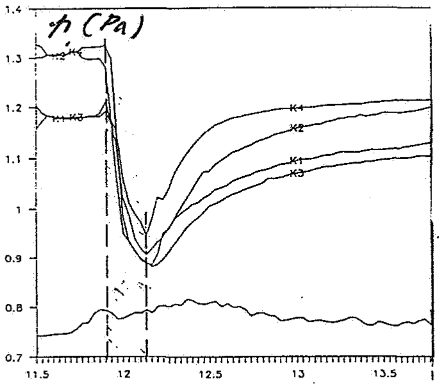


fig 7 living room
Δp_{ie} (Θ_e) before and after the ventilation improvement

fig 8 effect of peak ventilation on p_i in the 4 sleeping rooms

CONCLUSION

The retrofitting actions on dwelling 1 learned that especially efficient were:

- insulation of the loft space floor. This measure is a must in all dwellings of the estate;
- replacing single by double glazing;
- ameliorating the ventilation.

The importance of a good insulation was stressed by the only partly heating of the house, giving a good insulation the extra impetus of increasing the inside temperature in the non heated and through that mould sensitive rooms. This partly and intermittently heating was the only way for the 2 pensioners to kept the heating bill payable..

5.GENERAL CONCLUSION

The diagnosis and retrofitting work in the Zolder case study proved the correctness of the 4 practice rules to avoid mould problems:

1.A good overall thermal quality: $R \geq 1.5$ à 2 m^2K/W
2.No unacceptable thermal bridges: $\tau \geq 0.65$ to 0.7, U_l as low as possible
3.Implementing a ventilation solution, that guarantees ≥0.5 ach
4.Heating possibility in each zone

5. REFERENCES

1. IEA- Annex 14, Condensation and Energy, Source Book, Acco Uitgeverij, Leuven, 1990
2. IEA- Annex 14, Condensation and Energy, Catalogue of material properties, Acco Uitgeverij, Leuven 1990
3. IEA- Annex 14, Condensation and Energy, Case studies, Acco Uitgeverij, Leuven 1990
4. IEA- Annex 14, Condensation and Energy, Guidelines Book, Acco Uitgeverij, Leuven 1990
5. Hens H., Senave E.,IEA-Annex 14, Condensation and Energy. Aims, Methodology, Results, CIB symposium on Energy, Moisture and Climate, Rotterdam, 3- 6 september 1990.
6. Senave E., IEA-Annex 14,Case study Zolder, Final report, report B-T7-36/1990
7. Hens H.,Keynote on Surface Condensation and Mould,CIB symposium on Energy, Moisture and Climate, Rotterdam, 3- 6 september 1990.
8. Erhorn H., Buildings affected by Mould Growth, a Survey on the situation in West- Germany, CIB symposium on Energy, Moisture and Climate, Rotterdam, 3- 6 september 1990.

Discussion
Paper 30

P.Wouters (Belgian Building Res. Inst., Belgium)

Comment

The sensor for the relative humidity is in a part where indoor air is flowing. But at this place this indoor air has not the temperature of the indoor air in the centre of the room, so there are still more problems. But this system is better than to have no system for supply air.

K-J Albers (University of Dortmund, Germany)

Comment

A problem of this and the French system is that they measure the relative humidity of the outside air more than of the indoor air.

J Axley (USA)

Regarding comment solving moisture problems by considering moisture sources, I don't believe any of the morning presenters directly discussed moisture sources.

H Hens (Leuven, Belgium)

Yes and No. Yes, they weren't mentioned. No, because the performance criteria, formulated in the Annex XIV report goes back to a moisture production assumption. In the source book Chapter 5 is devoted to that subject.

W Raatschen (Dornier GmbH, Germany)

In houses where you do not have the possibility of installing better insulation, and where you want to install a humidity driven ventilation system, what practical recommendation would you give to get the proper setpoint for a humidity sensor?

H Hens (Leuven, Belgium)

In cases where bad insulation is combined with no heating, more ventilation, humidity driven or not, may not solve the problems. A good humidity driven system should measure the temperature on a cold, mould sensitive spot, the air temperature and the air humidity. These 3 quantities allow us to calculate the RH next to the surface (= a processor).

C-A Roulet, LESO, Switzerland

In many countries it is shown that air inlets are often taped or closed by the occupants. Is it not time to take this fact into account and act in order to avoid this behaviour? (e.g. hide the inlets, avoid the drafts, inform inhabitants, etc).

H Hens, (Leuven, Belgium)

The air inlets should be placed so that drafts are avoided (at the top of a window, etc.). On the other hand, the possibility always remains that inhabitants seal the inlets. Fear of a too high energy consumption is one of the motives. The only weapon to avoid that behaviour is informing them about the function of the inlets and the necessity for ventilation.