



**International
Energy
Agency**

Guidelines & Practice

Volume 2

**Energy Conservation in Buildings and Community
Systems Programme.
Annex XIV. Condensation and Energy**

IEA — ANNEX XIV : CONDENSATION AND ENERGY

Volume 2

Guidelines & Practice

INTERNATIONAL ENERGY AGENCY — ENERGY CONSERVATION IN
BUILDING AND COMMUNITY SYSTEMS

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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. 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 Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures all projects fit into a predetermined strategy without unnecessary overlap or duplication but with effective liaison and communication. Twenty-two 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: Ecistics & 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 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 measures.

The Annex objectives were formulated as:

- providing architects, building owners and practitioners as well as researchers 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.

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SYMBOLS

symbol	unit	Physical quantities
a	-	absorbivity
a	m ² /s	thermal diffusivity
a _w	-	water activity
b	J/(m ² .K.s ^{1/2})	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	m ²	air permeability
k _m	s	moisture conductivity
l	m	length
m	kg	mass
p	Pa	partial water vapour concentration
p'	Pa	partial water vapour concentration at saturation
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
w _a	m ³ /m ³	air content
x	kg/kg	water vapour ratio (humidity by mass)

A	kg/m ² s ^{1/2}	water sorption coefficient
D _w	m ² /s	moisture diffusivity
En		Energy consumption
G _m	kg/s	moisture flow rate , vapour production
K _a ^m	m ³ /(m ² .s.Pa)	air permeance
P'		thermal permeance
R	m ² .K/W	thermal resistance
S	-	degree of saturation
T	K	thermodynamic (absolute) temperature

α	K ⁻¹	specific heat strain
δ	s	vapour permeability coupled to a vapour pressure gradient
	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
λ	W/(mK)	thermal conductivity
θ	°C	temperature
τ	-	transmissivity
τ	-	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:

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

INTRODUCTION

Mould problems are a rather widespread reality in the 5 countries of the Annex, especially in the rented and/or social housing sector.

As shown in the source book, the biological and physical context of the phenomenon is not a simple one. In fact, things are so complicated, that treating them for each new design or problem case in a detailed way, using complex heat+air+moisture transport models and implementing all boundary conditions, is a research task everytime, rather than a practically applicable approach.

Therefore, tools and clear performance criteria, easier to check and to handle, are a necessity. So, one of the prime tasks within Annex 14, also described in the objectives, was the elaboration of such a performance set and its translation into this guidelines booklet.

Contrary to what might be expected, the booklet does not contain worldwide applicable rules of the thumb or ready to use performance criteria, to be applied for the avoidance mould and surface condensation. This is in fact, given the difference in outside climate within and between countries, impossible. What is given, is the philosophy behind the way performance criteria could be formulated and a methodology to analyse and solve problems in existing buildings.

Chapter 1 Performance description

Chapter 1 gives the philosophy behind building performance criteria to avoid mould in new design, and the way they can be formulated and translated into building codes.

It also focuses on the methodology of handling problem cases.

Chapter 2 Links with rational use of energy

Chapter 2 shows how building performance criteria against mould and rational use of energy design tend in the same direction: the construction of well insulated, correctly ventilated, comfortably heated buildings.

Chapter 3 Practical consequences of the mould performance checks for new design

Chapter 3 translates the performance checks for new designs into a minimal building quality criteria concerning overall thermal insulation, acceptance levels of thermal bridges, ventilation strategies and heating system practicalities.

Chapter 4 Solving existing mould and surface condensation problems

Chapter 4 applies the methodology of analysing problem cases to mouldy buildings, stressing not only the diagnostics but also the possible solutions.

Chapter 1

PERFORMANCE DESCRIPTION

1.1 GENERALITIES

1.1.1 Conditions for mould growth and surface condensation

The methodology proposed goes back to the simple first order theory of mould and surface condensation, stating that [22][26]:

- surface condensation starts each time the relative humidity (RH) at a surface reaches 100%, that means, each time the vapour pressure (p) in the air against the surface equals or becomes higher then the saturation pressure on the surface p'_{si} :

surface condensation when $p \geq p'_{si}$

- mould germination becomes possible when the mean water activity against / on a nutrient surface remains higher, during a shorter or longer time, than a threshold value 'a', 'a' being a function of the mould species, the temperature, the substrate (nutrient)...

Using the fact that, in steady state, the water activity is nothing other than the R.H., the mould condition becomes:

mould germination when $p \geq a.p'_{si}$

Assuming an ideal mixing of the air in each zone of a building, and disregarding hygric inertia effects against the surface, p in both formulae may be seen as the vapour pressure in the zone.

1.1.2 The saturation pressure on a surface

The saturation pressure at a surface is directly linked to the surface temperature θ_{si} , θ_{si} being given by:

$$\theta_{si} = \theta_e + \tau \cdot (\theta_i - \theta_e) \quad (1.1)$$

with τ the temperature ratio of the surface, defined by:

$$\tau = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e} \quad (1.2)$$

For flat walls in steady state, i.e. for mean conditions, the temperature ratio can be calculated from:

$$\tau = 1 - \frac{U}{h_i} \quad (1.3)$$

with h_i the inside surface film coefficient and U the thermal transmission coefficient of the wall.

For two- and three-dimensional configurations, θ_{si} does not follow from simple formulae such as (1.3), but depends equally and to an even larger extent on the inside surface film coefficient.

In non steady state conditions, τ becomes a function of time, defined by the fluctuating the inside and outside temperatures, by the thermal inertia of the wall and again by the inside surface film coefficient, which is now time dependant.

1.1.3 The inside vapour pressure

The mean inside vapour pressure (mean= 1 week, 1 month) in a single zone building or room is, as long as no long lasting surface condensation is going on, related to the mean outside vapour pressure (p_a), the mean inside vapour production (G_m), the mean outside air ventilation rate (n) and the air-volume of the zone (V). As a formula:

$$P_i = P_o + \frac{462 \cdot (\theta_i + 273) \cdot G_m}{n \cdot V} \quad (1.4)$$

1.1.4 Consequences

The mould and surface condensation conditions and the formulas (1.1) to (1.4) explicitly show all parameters of importance to the phenomenon. These are:

- BIOLOGICAL FACTS:

determine the value of 'a';

- CLIMATOLOGICAL CONDITIONS:

at one side the outside temperature, at the other side the outside vapour pressure or RH or vapour concentration or dewpoint.

A higher mean outside temperature lowers, through increase of the inside surface temperature (formula 1.1), the chance of problems.

A higher outside vapour pressure increases, through increase of the inside vapour pressure (formula 1.4), the chance of problems.

The fact that in a moderately cold, humid climate, higher outside temperatures and higher outside vapour pressures are directly linked, makes the outside climate impact more complicated than is usually thought;

- BUILDING FABRIC AND DESIGN:

not only the U- value of each single envelope part, and through that the thermal properties of the materials, but also the thermally weak spots in the envelope, called THERMAL BRIDGES, the means of ventilation provided, the mould sensitivity of internal finishing layers (a-value) and, through the inside surface film coefficient h_i , combining convection and radiation, the layout of the zone (ratio between outside wall inside surface and total wall surface, room shape), the way furniture is arranged (well or not against outside walls), the kind of curtain provided and the way it is placed ...a.o.

- BUILDING USE:

reflected in the inside temperature, moisture production and ventilation rate. A complicating fact is that these three parameters are not only user-dependant but also a function of the overall building quality:

- * heating is more expensive and, with less heating, inside temperatures are lower, that means, the chance of mould problems is higher, in a badly insulated building;
- * good ventilation becomes more difficult and the chance of mould problems higher, if no ventilation devices are incorporated in the building fabric;
- * if other moisture problems are present (initial moisture content, rising damp, rain penetration), continuous drying by diffusion and convection to the inside may result in a rather high vapour load and through that, an increased chance on mould problems.

The whole of that complex reality must be reflected in the building performance rules for avoiding moulds!

1.2 NEW DESIGN

1.2.1 Aims and questions to solve [15]

The performance structure must be such that:

- it is easy to use;
- a statistically acceptable safety margin against mould problems will result;
- no contradiction emerges with constraints on the rational use of energy;
- the creativity of the designer is not hampered too much.

Within the framework of the first order theory, given above, 4 questions have to be answered before performances can be validated and judged:

First : fixing the 'a'-value!

The mould condition may only result in relevant design information if an 'a'-value (instantaneous, mean?) is specified as the design value;

Second: choice of the inside reference temperature, how to handle the climate to come to a design frame!

Working with the mould and surface condensation condition is in fact only possible if information is available about the outside and inside climate.

A sound definition of the inside reference temperature and the way the dependence of the inside climate on the outside climate is handled, is especially important;

Third : fixing inside reference temperature linked h_1 -values!

h_1 not only depends on the convective and radiative heat exchanges between each surface or point and the surroundings, but also on the reference temperature admitted. Even more, judging mould conditions means that the LOCAL h_1 -value must be known.

Fourth: admitting a sound definition of the temperature ratio and proposing design values!

Once a temperature ratio definition is adopted and design values, related to the inside climate, introduced, a handy instrument to justify U- value choices and to judge thermal bridge realities may be the result.

1.2.2 Answer 1: the 'a'-value

For design purposes, coupling the a-value to information on RH versus time, choices of RH versus material, a RH versus mould species etc. is an impossible way to go.

In fact:

- constructing the time curve for all points on the internal envelope surface in each design situation, supposes that a very sophisticated heat-moisture-air transport calculation tool is available, needing an overwhelming amount of unknown, partly known or guessed input data. It also means knowing perfectly well all future, time dependant boundary

- conditions such as vapour production, building use, climate, ..., implementing a tremendous amount of biological information... etc.;
- it overlooks the reality that, in most cases, walls and ceilings are finished with paint, wall paper, wood..all rather equally mould sensitive materials, and that these surfaces may become dirty...,organic dust being a nutritive mould substrate.
 - some 130000 different mould species are known, each with their own water activity curve...;

The alternative for design purposes is to start from clear experimental data [1]:

- the 'a'- value of all mould species is a function of temperature, with a minimum in the range 20 to 25 °C;
- the lowest a-value is found for aspergillus versicolor: 0.75 on agar. Aspergillus is a species commonly present in mouldy buildings;
- agar is a substrate with a higher nutrition value than building and finishing materials. In fact, on paints, wallpaper, wood, gypsum, dust, mould germination and growth is, in steady state RH and temperature conditions, rarely observed under 85 % RH;
- the lower the RH (from 99% to 80%), the longer the steady state time period before mould becomes visibly present;
- hygroscopic inertia dampens short period oscillations in inside R.H. on and in the surface layer.

to come to the following proposal, adopted by the Annex 14 group:

- take for new design as threshold RH for mould germination [16][19]

'a' = 0.8

- use this value all over the year on

M O N T H L Y M E A N B A S I S

- introduce a substrate correction only for regularly cleaned surfaces with porosity zero (glass, metallic, glazed tiles...). There, put $a=1$, turning the mould germination condition to the instantaneous surface condensation equation: as soon as the vapour pressure against a surface equals the saturation pressure on it, surface condensation starts.

1.2.3 Answer 2: inside reference temperature, climate chart

REFERENCE TEMPERATURE

For heating power and energy demand control purposes, the zonal reference temperature, used in different countries and within Eurocode, is the dry resulting temperature, being the mean of the central air temperature and radiative temperature in the zone.

For mould problem and surface condensation evaluations, this is a less attractive choice. In fact, all thermodynamic moist air properties, needed so intensely in these calculations, are linked to the air temperature, together with the vapour pressure, the fundamental state variable of the gas mixture called moist air.

If the dry resulting value were to be used as reference in hygrothermal calculations, we would need, in the same run, two references! This can only result in an unpleasant confusion.

Therefore, the Annex 14 group has chosen as reference inside temperature [16]:

T H E C E N T R A L A I R T E M P E R A T U R E θ_1 I N A
R O O M A T A H E I G H T O F 1.7 M E T E R

CLIMATE CHART

The methodology proposed goes back to formula (1.4).

The information, given in that formula can also be written as:

$$p_i - p_e = \frac{462 \cdot (\theta_i + 273) \cdot G_m}{n \cdot V} \quad \text{or} \quad c_i - c_e = \frac{G_m}{n \cdot V}$$

or, the difference in vapour pressure or vapour concentration holds for the ratio of two building use parameters: vapour production and outside air ventilation rate.

That difference and, as a consequence, that ratio, is now linked to the outside temperature and inside temperature, to give a three dimensional $(\Delta c_{ie}, \theta_i, \theta_e)$ - or $(\Delta p_{ie}, \theta_i, \theta_e)$ - climate chart (fig.1).

This chart can be used, once the temperature ratio is defined, to introduce temperature ratio linked inside climate classes for mould and surface condensation [16][21].

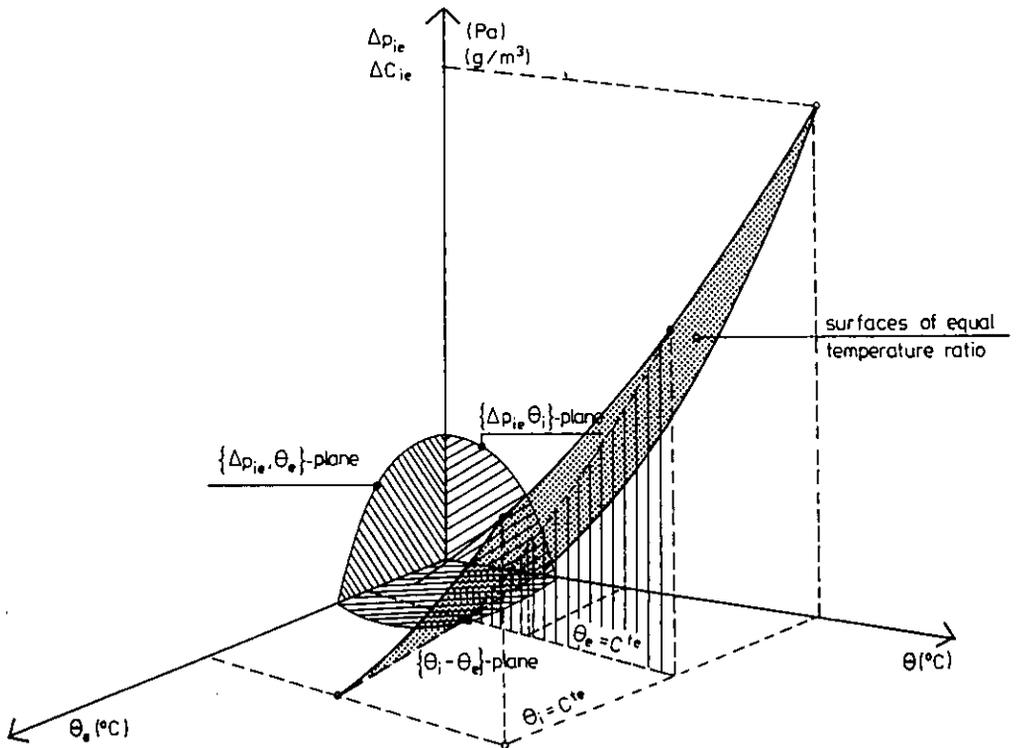


fig.1. The three-dimensional climate chart.

1.2.4 The local inside surface film coefficient h_{ix}

The inside surface film coefficient covers the heat exchange with the environment by convection and radiation. Here, heat exchange by condensation / evaporation is not taken into account.

Use is made of the methodology, explained in the source book and in [4],[5],[6],[17].

POSSIBILITY 1: Detailed information about the zone / room available

1. CONVECTIVE PART h_c

- step 1

Take as the convective surface film coefficient h_c , coupled to the local air temperature: $2.5 \text{ W}/(\text{m}^2\text{K})$.

- step 2

Calculate the local air temperature θ_{ix} with the formula:

$$\frac{\theta_{ix} - \theta_e}{\theta_i - \theta_o} = 1 + (C_a \cdot p_c \cdot U_m) \cdot y \quad (1.5)$$

with:

θ_i : the reference temperature

$C_a = 0.2 \text{ m}^2\text{K}/\text{W}$

$p_c = 1$ for air heating systems

0.9 for convectors and shielded radiators

0.4 à 0.8 for radiators

0.4 for floor heating

U_m - the mean U-value of all room walls, with the value for inner walls weighted by the ratio 'temperature difference over the wall/ inside-outside difference'.

U-values are calculated with the standard surface film coefficients

y - vertical distance between $h=1.7\text{m}$ and the local height ($y=0$ for $h=1.7\text{m}$, $y<0$ for $h<1.7\text{m}$, $y>0$ for $h>1.7\text{m}$)

Remark

window reveals: for windows with curtains, without a direct path to the heating element, when closed, the local air temperature becomes the 'daily period of closed and open'-weighted mean of the reference temperature (= when open) and the air temperature in the cavity window-curtain (=when closed)!

2. RADIATIVE PART h_{rx} - step 1

Take as the radiative surface film coefficient h_r :

$$(e_L \cdot 5.5) \text{ W/(m}^2\text{K)},$$

e_L being the long wave emission factor of the surface. Calculate the local radiative surface film coefficient h_{rx} :

type 1: surfaces at a distance of at least 0.5 m from an edge between 2 outside walls: $h_{rx} = h_r$

type 2: surfaces at a distance less than 0.5 m from an edge, but at a distance of at least 0.5 m from a corner: $h_{rx} = h_r/1.7$

type 3: surface at a distance less than 0.5 m from a corner:
 $h_{rx} = h_r/2.5$

- step 2

Calculate the zonal radiative temperature with the formula:

$$\frac{\theta_r - \theta_e}{\theta_i - \theta_e} = \frac{h_c}{h_c + \frac{p_c - 0.4}{0.6} \cdot u_m} \quad (1.8)$$

with:

U_m, p_c : see formula (1.7)

h_c convective surface film coefficient

Remarks

- window reveals, no curtains: $h_{rx} = h_r$ the radiative temperature is the mean between the glass temperature and the zonal radiative temperature;
- window reveals, curtains: $h_{rx} = h_{ri}$ the radiative temperature is the 'daily period of closed and open'- weighted mean of the value for no curtains and the value with curtains, being the mean of the glass and curtain temperature;

3. COMBINED LOCAL INSIDE FILM COEFFICIENT h_{ix} , COUPLED TO THE REFERENCE TEMPERATURE

Calculate:

$$h_{ix} = \frac{h_c + h_{rx} - P_T}{1 + P_T \cdot R'} \quad (\text{W/m}^2\text{K}) \quad (1.13)$$

with:

$$P_T = \frac{h_c \cdot (\theta_i - \theta_{ix}) + h_{rx} \cdot (\theta_i - \theta_r)}{\theta_i - \theta_e} \quad (\text{W/m}^2\text{K}) \quad (1.14)$$

R' - the 'inside surface-outside'- equivalent thermal resistance of the wall
($R' = 1/h_e + \Sigma(1/R_i)$, $\text{m}^2\text{K/W}$)

POSSIBILITY 2: Only poor information about the zone/ room available

Use the following values [17]:

upper edges and corners	:	$h_{ix} = 4$	$\text{W}/(\text{m}^2\text{K})$
vertical edges at mid height:	$h_{ix} = 4$	$\text{W}/(\text{m}^2\text{K})$	
lower edges and corners	:	$h_{ix} = 2.9$	$\text{W}/(\text{m}^2\text{K})$
glazing	:	$h_{ix} = 6.7$	$\text{W}/(\text{m}^2\text{K})$
shielded edges and corners	:	$h_{ix} = 2$	$\text{W}/(\text{m}^2\text{K})$

Remark

Furniture against outside walls is taken into account by putting as overall h_{ix} -value:

$$h_{ix} = 2 \text{ W}/(\text{m}^2\text{K})$$

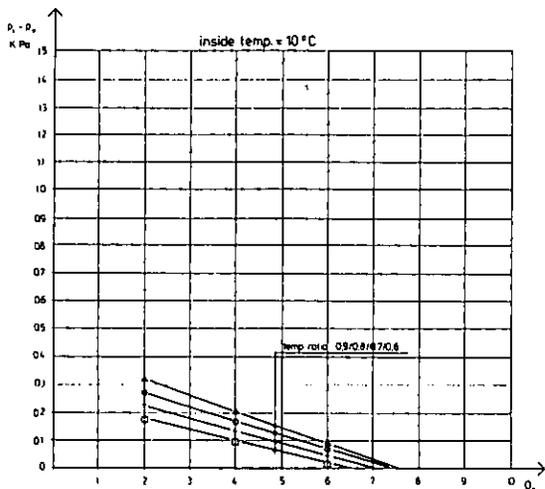


fig. 2.a Climate chart with lines of equal temp. ratio
[To be constructed as F(outside climate)]

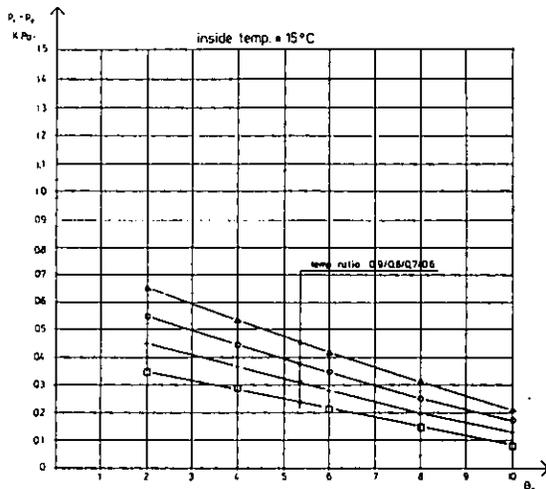


fig. 2.b. Climate chart with lines of equal temp. ratio
[To be constructed as F(outside climate)]

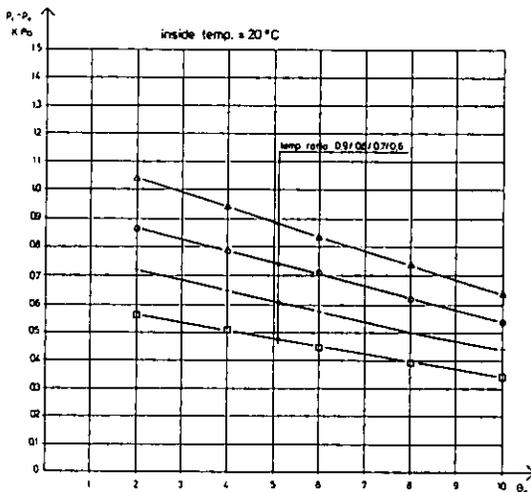


fig 2.c. Climate chart with lines of equal temp. ratio
[To be constructed as F(outside climate)]

1.2.5 Temperature ratio, design values

As the definition of the TEMPERATURE RATIO it is proposed by the Annex 14 group:

$$\tau = (\theta_{si} - \theta_e) / (\theta_i - \theta_e)$$

with:

θ_i : inside reference temperature,

θ_e : the outside air temperature

θ_{si} : the local surface temperature.

Fixing DESIGN VALUES of τ is the responsibility of each country.

The methodology proposed however is as follows:

case 1: MOULD PROBLEMS

1.

On the climate chart, defined under 1.2.3, the surfaces of equal temperature ratio are constructed by (fig.2):

- . calculating, for each monthly mean pair of values (θ_i, θ_e) , the surface temperature $\theta_{si} = \theta_e + \tau \cdot (\theta_i - \theta_e)$;
- . fixing the acceptable difference in inside- outside vapour pressure by putting $(p_i - p_e) = 0.8 \cdot p'(\theta_{si}) - p_e$ with p_e the monthly mean outside vapour pressure.

These formulae show that the surfaces of equal temperature ratio differ from climate zone to climate zone!

They also show that, the higher the temperature ratio, the higher for a given outside temperature and inside reference temperature, the difference $(p_i - p_e)$, that means, less permanent ventilation is needed and/or the more vapour production is allowed;

2.

On a national level, upper limit values of expected $(p_i - p_e)$ -differences must be defined:

These may follow from a statistical analysis of a meaningful set of measured weekly mean values, taking for example the 95%-limit as the design value,

or

may be calculated using the IAQ minimum value for the permanent ventilation and the high load approach for the vapour production,

or

they can follow from the inside climate classes introduced in the frame of an interstitial condensation approach.

3.

On a national level, design inside temperatures must be fixed. Here, lower limit lines have to be accepted, taking into account heating habits and the major scattering between individual cases.

When putting this $(p_i - p_e)$ -upper and θ_i -lower limit information on the climate chart, a direct reading of the temperature ratio design value becomes possible!

case 2: SURFACE CONDENSATION

Here, all depends on the performance required:

- If surface condensation has to be avoided at all costs, a non steady state analysis and a design choice so, that, indeed, it does not happen, is the only alternative.
- If surface condensation may happen, but not lasting too long, then the problem is narrowed to: correct material choice, enough insulation, peak ventilation during or after the vapour production, enough heating etc.. A daily mean check, proving that, on a daily basis, no resulting surface condensate is possible, is the tool to be used.

Or, a general methodology concerning surface condensation cannot be given. However, avoiding long lasting surface condensation is a less severe constraint than avoiding mould germination.

1.3 PROBLEM CASES

1.3.1 Aims

In problem cases, the two questions are:

- why mould?
- how to solve?

The first concerns the 'a'-values on the mouldy spots, the second a thorough analysis of what to do.

1.3.2 'a'-value

In problem cases, the design rule, established for new buildings, is too primitive. In fact, we know from mould research that, with very high R.H., mould may germinate on a substrate after a fairly short time. In other words, at least we have to introduce a time scale in the 'a'-judgement.

A proposal, introducing the length of the measuring period, being a weighted combination of various schemes, discussed in the frame of the Annex, is given in fig. 3. In this, a multiplier f is introduced, being a logarithmic function of time, with the 1-month, $a = '0.8'$, as the starting value: see also table 1, [16][18][19][20][21].

Table 1

MEAN INSIDE R.H. OVER..	f	$a' = f.a$
1 month	1	0.80
1 week	1.11	0.89
1 day	1.25	1.00

It would be better if a substrate-correction could also be made. But, too few convincing research results are available, to propose a clear correction. Also, in an overwhelming number of cases, the substrate is either wall paint or wall paper, and is polluted with organic dust.

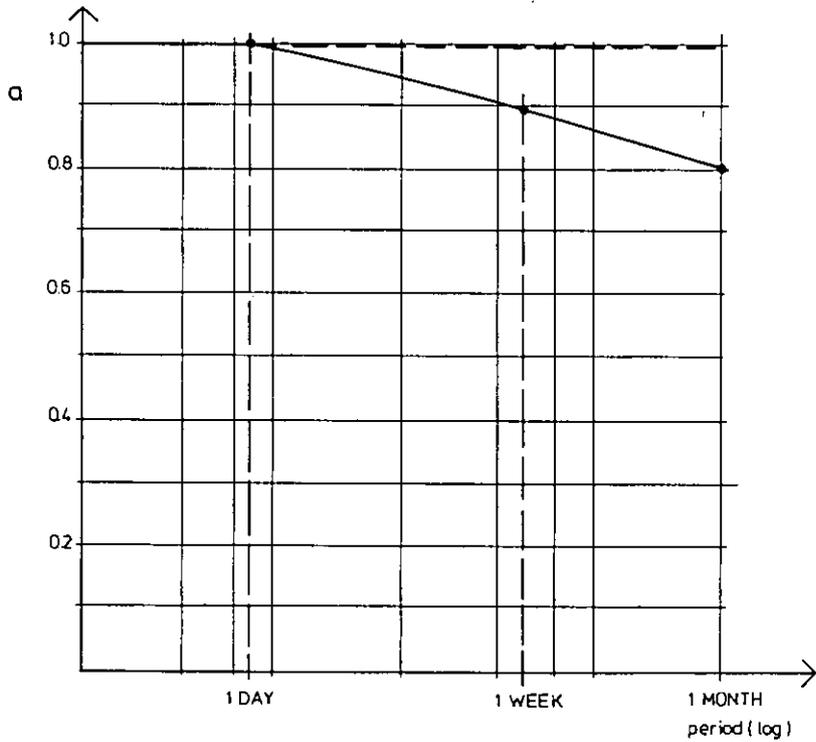


fig. 3 alpha - value

— paint, paper...

- - - clean, non porous surfaces

1.3.3 Analysis, Solutions

DEFINITIONS of inside reference temperature, climate chart, inside film surface coefficient, temperature ratio: see 1.2 New Design

DATA- GATHERING

Outside climate (θ_e, Φ_e)

Can be taken from the nearest weather station

Inside climate (θ_i , Φ_i)

Knowing the inside climate in the problem zones of the building is a minimum prerequisite to come to a judgment. The essentials, if measured, are:

- at least a continuous recording of the air temperature and the RH over a period of 1 month during the colder season;
- calculation of the daily, weekly and monthly mean inside temperature and ($p_i - p_e$)-values;
- use of the weekly mean to implement on the climate chart.

Temperature ratio

If possible, measure temperature ratio's. This asks for a continuous recording of the surface temperatures and the inside and outside air temperature over a period of at least 2 weeks.

If this is not possible, use a steady state 2-or 3-dimensional thermal bridge software package to calculate the temperature ratio's and check the surface temperature calculation results with instantaneous measurements. It is important, when calculating, is to use the correct h_i -value (See design rules).

Judgment

Is based on 3 checks [12]:

1. Are temperature ratio's higher or lower than the reference value for new design?
2. Is inside temperature higher or lower than the reference values/lines used in the climate chart to establish the τ -design value?
3. Is the difference ($p_i - p_e$) higher or lower than the reference values/lines used in the climate chart to establish the τ -design value?

Further: see Chapter 4.

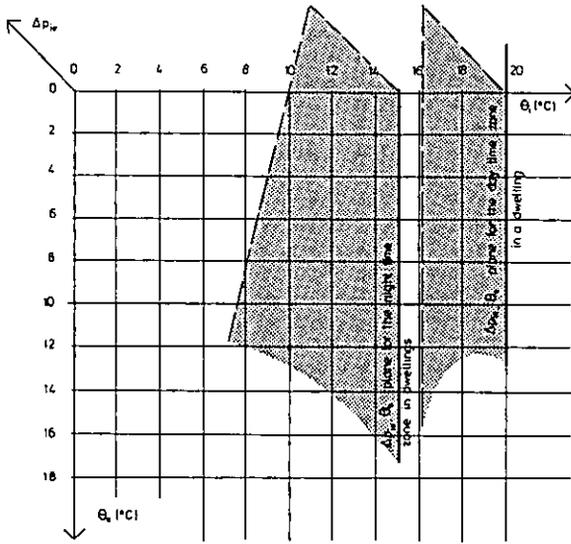


fig 4. Inside temperature reference lines in the $\{\theta_i - \theta_e\}$ -plane of the climate chart, defining the $\{\Delta p_w, \theta_e\}$ planes for daytime and nighttime rooms (climate data for Belgium[1])

Inside climate chart
inside temp. = 20°C

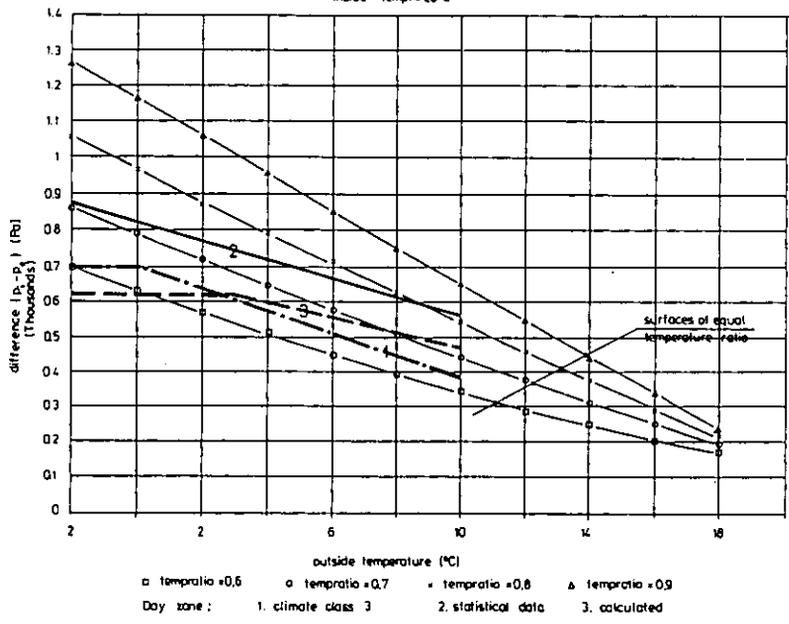


fig 5 $\{\Delta p_w, \theta_e\}$ - plane for the daytime zone: $\{p_w - p_e\}$ - reference lines

1.4 EXAMPLE OF 'HOW TO COME TO A TEMPERATURE RATIO DESIGN VALUE'

1.4.1 The climate chart

 (θ_i) - REFERENCE LINE

To construct the inside temperature reference line, we may use statistical data. An example: for Belgium, from large scale measurements [26], we know that, in social dwellings, the day zone is well heated, the night zone not. The 50%-line through an extended set of weekly mean values gave:

$$\text{Day- zone : } \theta_i = 20 \quad (^\circ\text{C})$$

$$\text{Night- zone: } \theta_i = 13 + 0.37 \cdot \theta_e \quad (^\circ\text{C})$$

Instead of the $\omega\theta_i = f(\theta_e)$ functional dependance for the night zone in the interval $\theta_e = 0^\circ\text{C}$ to $\theta_e = 10^\circ\text{C}$, a constant value can be used: 15°C .

Both θ_i -values define a $(p_i - p_e, \theta_e)$ - plane in the three- dimensional climate chart (fig 4), one for the day- zone and one for the night zone.

 $(p_i - p_e)$ - REFERENCE LINE

To construct the 'difference in inside- outside vapour pressure'-reference line, either inside climate class data, or statistical data or a calculated reference can be introduced.

Inside climate class

In Belgium and the Netherlands, the inside climate class concept has been adopted for interstitial condensation evaluation.

The Dutch climate classes are given, as $(p_i - p_e)$ -curves, in fig.6.

The Belgian are summarised in fig.7

For example, with the Belgian data, we find as a reference-line for social housing (inside climate class 3),(fig.5):

$$\theta_e < 0^\circ\text{C} \quad p_i - p_e = 700 \quad [\text{Pa}]$$

$$\theta_e \geq 0^\circ\text{C} \quad p_i - p_e = 700 - 30.4 \cdot \theta_e \quad [\text{Pa}]$$

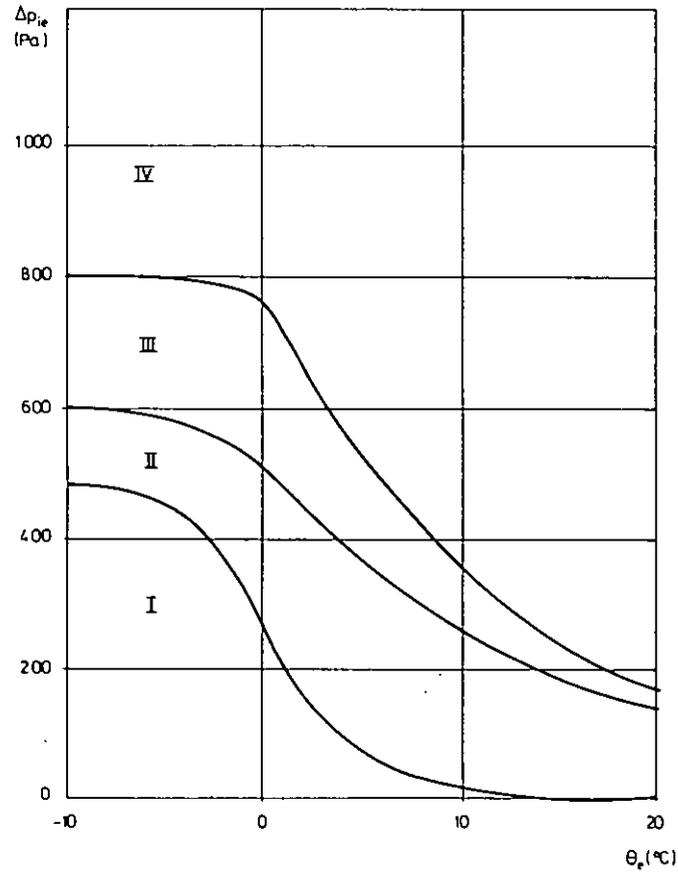


fig.6. The dutch inside climate classes.

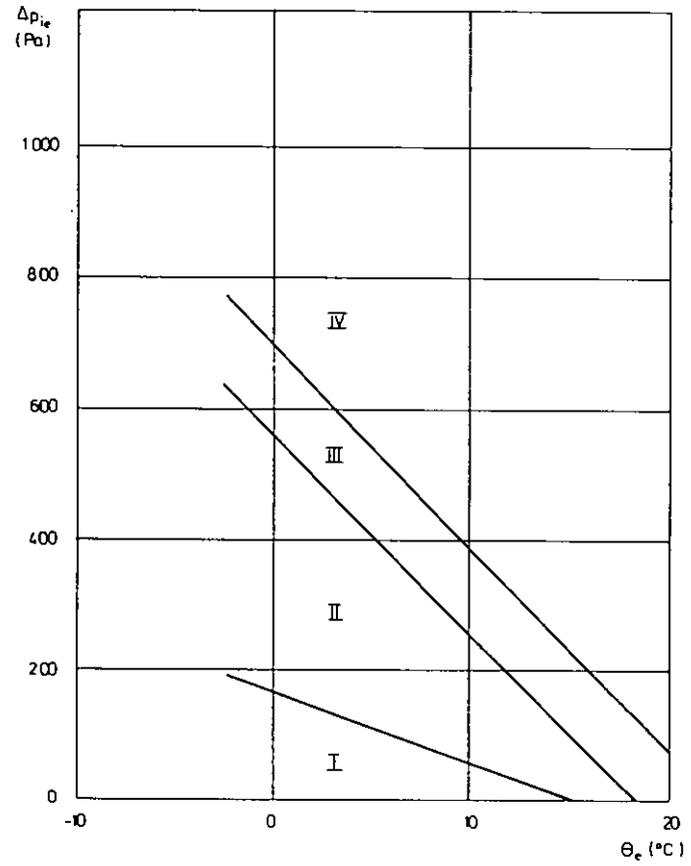


fig.7 The Belgian inside climate classes.

Statistical data

For Belgium, the large scale inside climate measurements, discussed in [26], give as the 90% ($p_i - p_e$)-line through the weekly mean results (10 % of the social dwellings show more severe conditions!) (fig.5):

$$\text{Day- zone : } p_i - p_e = 820 - 24.5 \cdot \theta_e \quad [\text{Pa}]$$

$$\text{Night- zone: } p_i - p_e = 490 - 13 \cdot \theta_e \quad [\text{Pa}]$$

Calculated values.

an example:

for the coldest month, the ventilation rate n is fixed at the internationally accepted 0.5 ach., the lowest level from a healthy building and energy economy point of view, and, for all other months, it is coupled to the rising temperature, following an empirical relation:

$$n = 0.5 + 0.029 \cdot (\theta_e - \theta_{e,m}) \quad [\text{h}^{-1}]$$

$\theta_{e,m}$: lowest monthly mean temp.

Lower outside temperatures than the coldest monthly mean are fitted with $n = 0.5$ ach.

As mean moisture production, the so called high load is taken:

$$G_m = 14 \text{ kg/day};$$

The dwelling volume is fixed in accordance with national, federal or state building codes for social housing.

The calculations have been performed for a building volume of 250 m³. Result (fig.4):

$$\theta_e < 3^\circ\text{C} \quad p_i - p_e = 620 \quad [\text{Pa}]$$

$$\theta_e \geq 3^\circ\text{C} \quad p_i - p_e = 688 - 21 \cdot \theta_e \quad [\text{Pa}]$$

In each country, reference lines can be determined in the way explained. The particular heating and building use habits have to be reflected in it. Never use lines based on a rational 'that is what it should be' ideas, so trying to come to less severe results.

1.4.2 The temperature ratio design value

Methodology:

- The $(p_i - p_e)$ -reference lines, defined above are drawn in the respective θ_i - planes for the day and night zone of the climate chart (fig.5);
- the design value taken is, the value of the "line of equal temperature ratio", not intersected by the " $(p_i - p_e)$ -reference line" in the cold season outside temperature interval (for Belgium: $\theta_e < 10^\circ\text{C}$).

Judgement:

The methodology has been applied on the Belgian data.

Result: temperature ratio ≥ 0.82 .

This value lies so high, looking at the low surface film coefficients, that, even with a very good insulation quality, it may not be realised in corners, behind furniture...etc.

So, a lower value could be adopted, introducing stricter constraints on minimal heating levels and minimal permanent outside air ventilation, than present in the reference lines used for θ_i and $p_i - p_e$.

A possible choice is:

$$\text{temperature ratio} \geq 0.70$$

KEEP IN MIND THAT THIS ONE NUMBER REFLECTS THE MINIMAL ENVELOPE THERMAL QUALITY NEEDED.

Important remark:

The mould germination condition imposes, when the monthly mean outside RH stays higher than 80%, a minimal inside temperature level, below which even excessive ventilation ($n = \infty \text{ h}^{-1}$) no longer solves the problems.

That level directly depends of the temperature ratio chosen.

EXAMPLE: Belgium and the Scilly Islands:

January outside climate:	BELGIUM	SCILLY ISLANDS
θ_e [$^{\circ}$ C]	2.6	7.7
ϕ_e [%]	86.0	83.0

Minimal January inside temperature (θ_i [$^{\circ}$ C]) to avoid mould:

TEMP. RATIO	BELGIUM	SCILLY ISLANDS
0.3	5.9	9.7
0.4	5.1	9.1
0.5	4.6	8.9
0.6	4.3	8.7
0.7	4.0	8.6
0.8	3.9	8.5

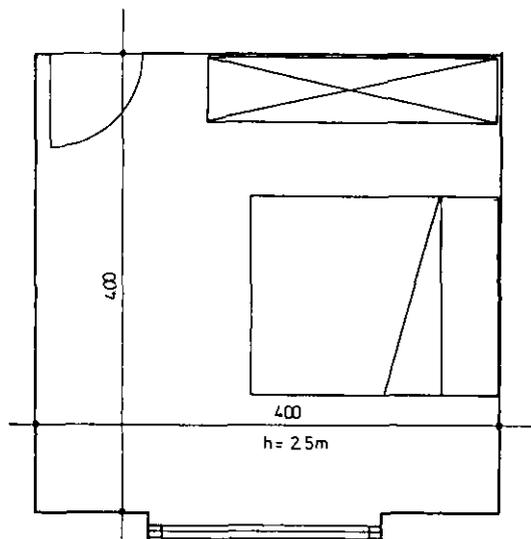


fig 8

Minimal monthly mean January inside temperature (θ_i [$^{\circ}\text{C}$]) to avoid mould in a sleeping room with volume $V= 40 \text{ m}^3$, mean ventilation rate 0.5 h^{-1} and a mean vapour production of 0.044 kg/h (fig. 8)

TEMP. RATIO	BELGIUM	SCILLY ISLANDS
0.3	20.9	21.3
0.4	16.4	18.0
0.5	13.6	15.9
0.6	11.8	14.5
0.7	10.5	13.6
0.8	9.5	12.8

That reality of minimal inside temperatures, below which a reasonable ventilation can no longer cure moulds, may explain the many mould problems encountered in the U.K.: the housing stock is thermally of such a doubtful quality and heating is a so sparse activity that, in more cases than wished, the inside temperature drops below that minimum...

The results also show that, the more severe the envelope quality criterion, the less restrictive the inside climate constraints...

Chapter 2

LINKS WITH RATIONAL USE OF ENERGY

From the review of the first order theory in chapter 1, it may be clear that mould and surface condensation are most likely in badly insulated dwellings, i.e. buildings with a high basic energy demand.

Also, avoiding mould in these energetical ruins, requires a substantial permanent ventilation rate and a rather high mean inside temperature, both further lifting the already high demand for energy.

On the other hand, preventing mould problems by fixing an overall thermal quality, translated to a temperature ratio, is a very positive RUE- decision (RUE = Rational Use of Energy).

With a high quality thermal envelope, also the stress on the basic ventilation rate and minimal mean inside temperature to prevent mould germination, is softened and the way to a minimum ventilation rate for IAQ-control (Indoor Air Quality) (0.5 h^{-1}) and a rational use of energy for inside temperature management is more or less unconditionally open.

The best way to illustrate this, is by means of the results of a case study (Zolder case study, see Case studies Report)

The dwellings concerned are of a very poor thermal quality: apart from double glazing, no further insulation used.

The lowest temperature ratio measured in the living room is as low as 0.4!! If we take the heavy vapour load (14 kg/day) and try to ventilate and heat the dwellings in such a way that no mould problems could result, we get, as a function of the heating season mean inside temperature, for the Belgian standard year, the heating demand of table 2, column 2.

If no mould problems existed, we could, with acceptable IAQ, lower the demand to the values of column 3 ($n = 0.5 \text{ h}^{-1}$).

Table 2
ZOLDER, EXISTING SITUATION, HEATING DEMAND E_n
(Calculated with the 1-zone "verbruik"-software [24])

θ_{im}	AVOIDING MOULD	NO MOULD CONCERN ($n \geq 0.5 \text{ h}^{-1}$)	$((2)-(3))/(3)$
	kWh	kWh	%
14	35300	18450	91
16	36250	24330	49
18	37230	31500	18

The result shows that with mould control the elasticity in energy demand, coupled to the inside temperature, disappears totally: the demand remains practically constant, independent of the inside temperature:

$$\Delta E_n / \Delta \theta_i = 480 \text{ kWh}/(\text{y.K}) \text{ instead of } 3260 \text{ kWh}/(\text{y.K})$$

In fact, the ventilation rate needed, including some inevitable extra heating in mid-season, goes up so quickly with lower inside temperature that the increasing ventilation losses cancel in a very effective way the lower conductive losses.

Or, the dwelling is, by definition, energy spending.

Now, we retrofit the dwelling, introducing double glazing, insulating the loft space with 12 cm MW, and executing outside insulation of the type "INSULATION SLAB + REINFORCED OUTSIDE RENDERING".

The result is a good overall thermal quality, with in the living room temperature ratio's higher than 0.7

Recalculating the heating demand now gives the results of table 3

Table 3
ZOLDER, AFTER RETROFITTING: HEATING DEMAND E_n
(Calculated with the 1-zone "verbruik"-software [24])

θ_{im}	AVOIDING MOULD	NO MOULD CONCERN ($n \geq 0.5 \text{ h}^{-1}$)	$((2)-(3))/(3)$
	kWh	kWh	%
14	9690	7810	24
16	10620	10610	-
18	12040	14180	-15

The picture changes drastically: avoiding mould becomes possible with the IAQ-ventilation rates, except for the lowest mean inside temperature, where some surplus ventilation and some extra heating in mid season remains necessary. Or, the energy saving elasticity remains unaffected.

This example proves that avoiding mould problems and RUE are coupled. The correct way to tackle the first and favour the second is:

INTRODUCE IMPROVED THERMAL QUALITY PERFORMANCE FOR THE ENVELOPE,
BEFORE FOCUSING ON VENTILATION AND HEATING

Chapter 3

PRACTICAL CONSEQUENCES OF THE MOULD PERFORMANCE CHECK FOR NEW CONSTRUCTIONS

3.1 GENERALITIES

Avoiding mould and surface condensation in new constructions means:

IMPOSING AN OVERALL INSULATION QUALITY

AVOIDING UNACCEPTABLE THERMAL BRIDGING

IMPLEMENTING A CORRECT VENTILATION LEVEL

THE POSSIBILITY OF FULL HEATING

3.2 OVERALL INSULATION QUALITY

The starting point in defining the insulation quality, is the imposed temperature ratio value.

To turn that performance into an overall U-value, one should rest on three design realities:

1. when making buildings, even well insulated ones, so called pure geometrical thermal bridges cannot be avoided: edges and corners;

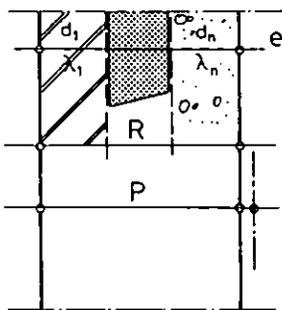
2. the way a layout is organised depends on restrictions, different from thermal or energetical ones: terrain, orientation, economics, esthetics etc. So, the probability of having rooms with so few inside walls, that no choice remains other than putting furniture against outside walls, is real;
3. changing the insulation thickness from corners to mid-wall as a function of the local value needed to fulfil the temperature ratio performance, has no sense, from a practical and energetical point of view.

As a consequence, the overall insulation quality follows from two calculations:

1. the U-value for an outside wall behind furniture, fulfilling the temperature ratio performance;
2. the U-value, giving the temperature ratio requested in corners.

The lower of both defines the insulation quality, needed to avoid mould. The value found must be seen as a minimal performance. Energetical and / or ecological motivations may inspire more severe exigences.

3.2.1 CASE 1:
 OUTSIDE WALL BEHIND FURNITURE ($h_1 = 2 \text{ W}/(\text{m}^2\text{K})$) (fig.9)



$$R = \sum \frac{d_i}{\lambda_i}$$

fig. 9

Using the formulas:

$$P' = h_i \cdot (1 - \tau) / \tau$$

$$R = 1/P' - 1/h_o$$

$$h_o = 23 \text{ W}/(\text{m}^2\text{K})$$

with P' the thermal permeance inside surface - outside and R the thermal resistance of the wall, we find:

temperature ratio τ	P' [$\text{W}/(\text{m}^2\text{K})$]	R [$\text{m}^2\text{K}/\text{W}$]
0.60	1.33	0.71
0.65	1.08	0.88
0.70	0.86	1.12
0.75	0.67	1.45
0.80	0.50	1.96

This gives as standard U-value ($h_i = 8 \text{ W}/(\text{m}^2\text{K})$):

temperature ratio	U [$\text{W}/(\text{m}^2\text{K})$]
0.60	1.15
0.65	0.95
0.70	0.78
0.75	0.62
0.80	0.47

3.2.2 CASE 2:

3D- CORNER, 2 outside walls + a flat roof (fig 10)

$h_{i,x}$ - value:

Suppose we have a corner room with 3 outside walls: 2 facade walls and a flat roof (This kind of rooms is found on the highest storey of apartment buildings, in single floor dwellings etc.).

Heating system: a radiator central heating. All adjacent rooms are heated to the same temperature as the corner room!

Floor surface: 32 m², room height: 2.5 m,

3 m² of double glazing.

U-value of the envelope walls : ? / starting value: , 0.78 W/(m²K), that means a R' -value of 1.16 (m²K/W).

As inside surface thermal film coefficient, we get (see chapter 1):

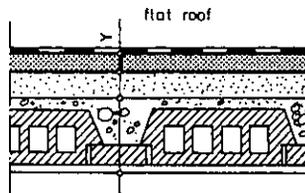
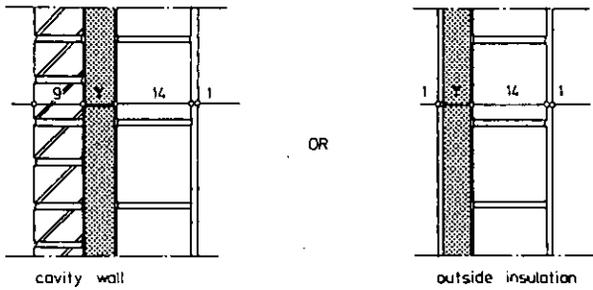
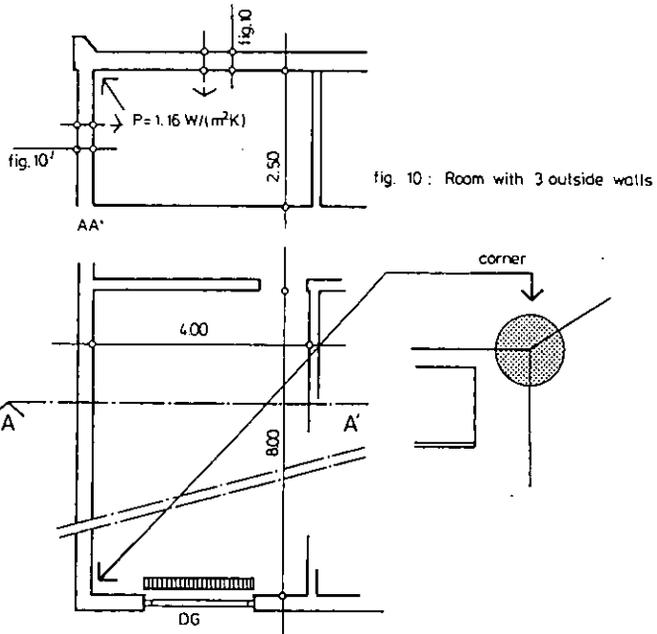


fig. 10' Outside wall solutions, used in the example

* convective part:

_____ step 1: reference convective film coefficient, coupled to the local air temperature: $h_c = 2 \text{ W}/(\text{m}^2\text{K})$

_____ step 2: local air temperature:

$$U_m = \frac{3 \cdot 3 + 59 \cdot 0.78}{124} = 0.44 \text{ W}/(\text{m}^2\text{K})$$

A central heating with radiators means: $p_c = 0.6$.

The height of the 3-D corner is 2.5m, t.m., 0.8 m above the reference level of 1.7 m, or, $x = 0.8\text{m}$ and:

$$\begin{aligned} \theta_{ix} &= \theta_e + (\theta_i - \theta_e) \cdot (1 + 0.2 \cdot 0.6 \cdot 0.44 \cdot 0.8) \\ &= 1.042 \cdot \theta_i - 0.042 \cdot \theta_e \end{aligned}$$

f.e. with $\theta_i = 20^\circ\text{C}$ and $\theta_e = 0^\circ\text{C}$, we have : $\theta_{ix} = 20.8^\circ\text{C}$

* radiative part

_____ step 1: reference radiative surface film coefficient:

$$h_r = 0.9 \cdot 5.5 \approx 5 \text{ W}/(\text{m}^2\text{K})$$

local radiative surface film coefficient:

$$h_{rx} = 5/2.5 = 2 \text{ W}/(\text{m}^2\text{K})$$

_____ step 2: reference radiative temperature ($\theta_i = 20^\circ\text{C}$, $\theta_e = 0^\circ\text{C}$):

$$\theta_x = \theta_e + \frac{2.5 (\theta_i - \theta_e)}{2.5 + (0.2/0.6) \cdot 0.44} = 18.9^\circ\text{C}$$

* h_{ix} (local surface film coefficient, coupled to the reference temperature)

$$p_T = \frac{2.5 \cdot (20 - 20.8) + 2 \cdot (20 - 18.9)}{20} = 0.01$$

$$h_{ix} = \frac{2.5 + 2 - 0.01}{1 + 1.160 \cdot 0.01} = 4.4 \text{ W}/(\text{m}^2\text{K})$$

Used in the thermal bridge calculations is:

$$h_{ix} = 4 \text{ W}/(\text{m}^2\text{K})$$

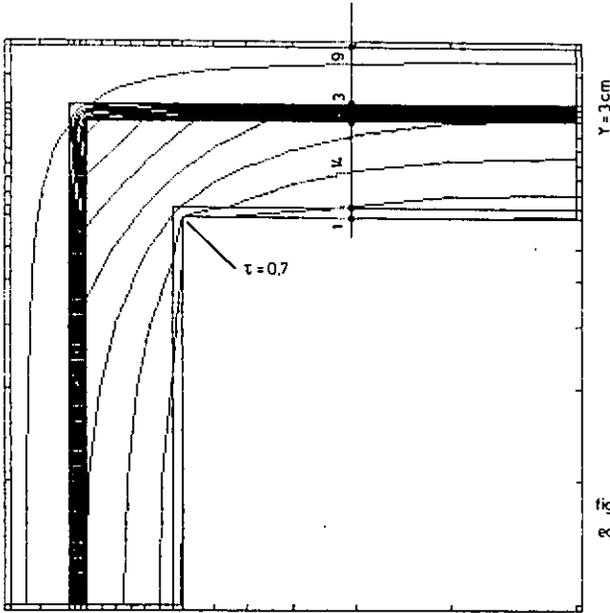


fig. 11 : Isotherms in the edge of 2 cavity walls.

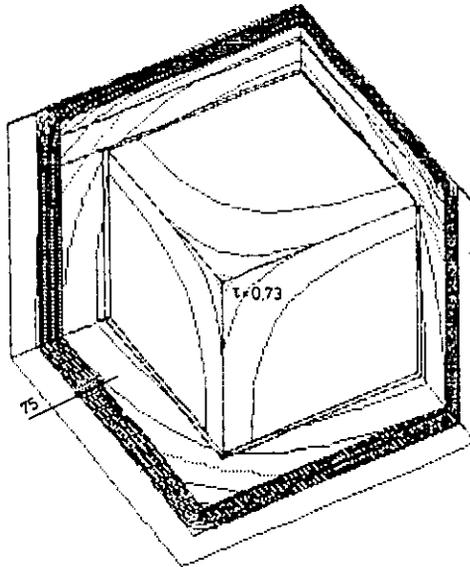


fig. 12 . Corner between 2 cavity walls and a flat roof : inside surface isotherms.

U- value:

The exterior walls analysed are (fig 10'):

1. a cavity wall with brick outside leaf of 9 cm, full filling with y cm MW and a plastered sandlimestone inside leaf of 15 cm, $\lambda_{MW} = 0.04 \text{ W/(mK)}$
2. a plastered sandlimestone wall, d= 15 cm, with an outside insulation, thickness y cm, $\lambda_{MPS} = 0.04 \text{ W/(mK)}$

The roof is a prefabricated floor slab, $R = 0.15 \text{ m}^2\text{K/W}$, with a screed, y cm insulation and a roofing felt, $R = 0.05 \text{ m}^2\text{K/W}$.

* APPROXIMATE CALCULATION

We calculate the corner, using the results of a 'flat wall' and a 2D-edge between the two facade walls' temperature ratio calculation, stating:

$$r_{(\text{corner})} = 2 r_{(\text{wall})} - r_{(\text{edge})}$$

The 1D- calculation of the wall, the 2D- KOBRU 86 computer calculation [7] of the edge and the 3D-approximate formula give for the temperature ratio, as function of the insulation thickness (see also fig.11):

y cm	cavity wall			outside insulation				
	P'_2 W/(m ² K)	1D	2D	3D	P'_2 W/(m ² K)	1D	2D	3D
3	0.96	0.81	0.70	0.59	0.99	0.80	0.69	0.58
4.5	0.68	0.85	0.76	0.67	0.72	0.85	0.75	0.65
6	0.51	0.89	0.80	0.71	0.56	0.87	0.79	0.69

or,

- imposing a temperature ratio in the corner, more severe than 0.7, quickly leads to unrealistic insulation thicknesses;
- $P' \approx 0.5 \text{ W/(m}^2\text{K)}$ seems a correct permeance level in a corner, independent of the structural solution. With high probability we then get a temperature ratio ≥ 0.7

This represents a R-value and a standard U-value
of:

$$R \approx 2.00 \text{ W}/(\text{m}^2\text{K}); U \approx 0.46 \text{ W}/(\text{m}^2\text{K})$$

$$(h_e = 23 \text{ W}/(\text{m}^2\text{K}); h_i = 8 \text{ W}/(\text{m}^2\text{K}))$$

a result, more severe than found for a wall behind a cupboard.
Or, the corner defines the lower R and upper U-value limit for opaque envelope parts, other than doors.

Energy and ecology policies may impose more severe limits!

* 3D-CALCULATION

A 3D-calculation has been performed for the cavity wall, using the TRISCO software package [8].

As function of the insulation thickness, we get (see 3D-column):

y cm	cavity wall			
	P ₂ W/(m ² K)	1D	2D	3D
3	0.96	0.81	0.70	0.59
4.5	0.68	0.85	0.76	0.65
6	0.51	0.89	0.80	0.69
7.5	0.43	0.90	0.82	0.73

this means, a result, hardly different from the values, found with the approximate method.

The conclusions remain: an envelope part R-value $\geq 2 \text{ m}^2\text{K}/\text{W}$ is needed to be sure that mould problems in corners may become a problem in only a statistically limited number of cases.

fig.12 gives the surface isotherms in the 3D- corner.

3.3 THERMAL BRIDGES

Acceptable thermal bridging means that, using the inside surface film coefficient calculation methodology given in chapter 1, the temperature ratio

of unavoidable non geometrical thermal bridges must not be lower than the performance value imposed.

This sentence implies that the design must be of such quality that:

- avoidable thermal bridges are solved structurally;
- unavoidable, non purely geometrical thermal bridges such as balconies, window eaves, roof parapets are constructed in such a way that:
 - . the energetic impact does not falsify the overall thermal quality (that means, one has to take the linear and point U-values into account when calculating the thermal performance of the envelope; these have to be as low as possible);
 - . the temperature ratio value satisfies the performance criterion.

EXAMPLE 1

To illustrate the first rule,

fig.13 shows some solutions for thermal bridges by adapting the first design.

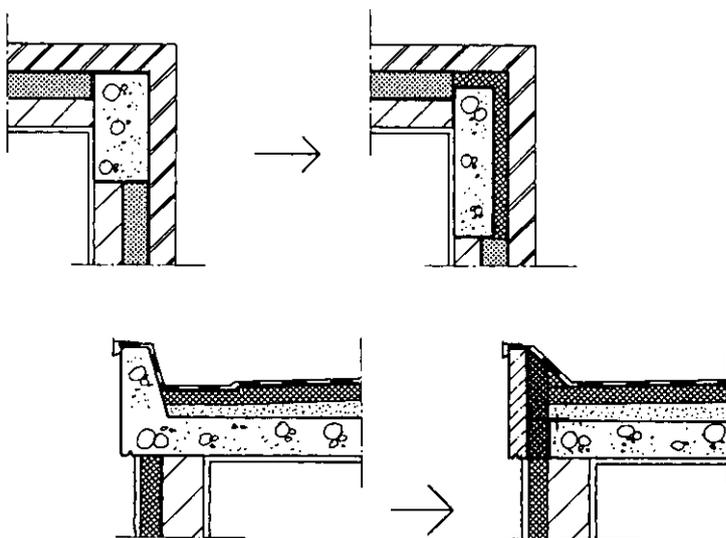


fig.13. Avoiding thermal bridges during the first design stage.

EXAMPLE 2

To illustrate the second rule, fig.14 shows the influence of the position of the window frame in a massive cellular concrete wall with U-value 0.46 W/(m²K) (dry conditions), in the heat losses through, and the lowest temperature ratio on, the window reveals.

We may conclude that, looking at the temperature ratio, the best solution is aligning the window with the inside surface.

From a heat loss point of view however, this is the worst solution.

Optimising both is possible shifting the windows to the outside and insulating the reveals.

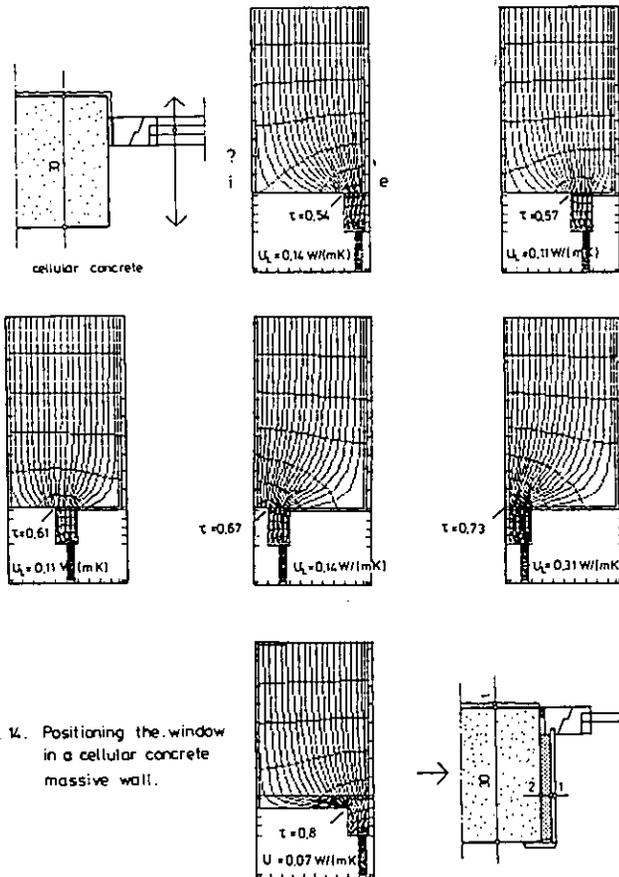


fig. 14. Positioning the window in a cellular concrete massive wall.

EXAMPLE 3

To illustrate the second rule, fig.15 gives the influence on the inside temperature ratio at a balcony of using inside or outside insulation against a concrete wall. Outside insulation looks, from a temperature ratio point of view, unambiguously the best. The difference in heat loss is rather limited.

Using a thermally cut insulation block between balcony and wall gives, compared to outside insulation alone a limited further improvement (fig.16). The rather poor upgrading is a direct consequence of the important influence of the steel reinforcement in the block on the heat flow between balcony and floor (λ_{eq} insulation block with steel being 0.9 W/(mK) instead of the 0.035 W/(mK)) of the XPS

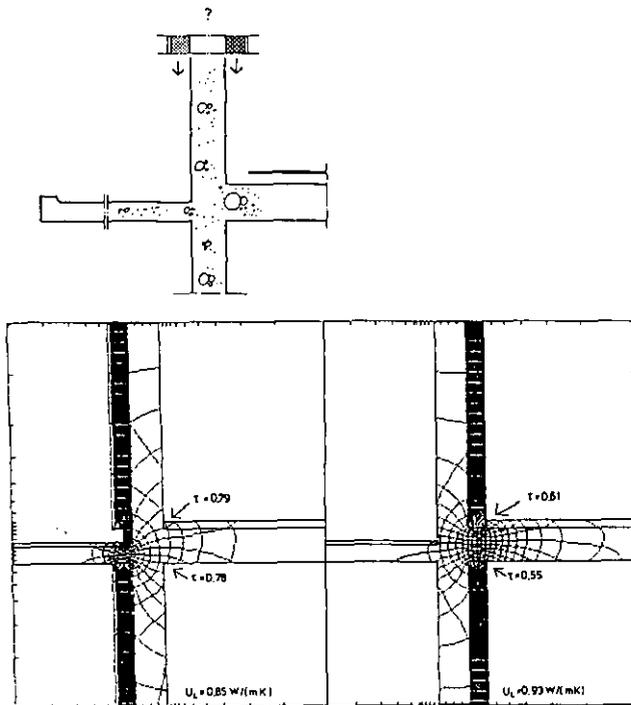


fig. 15 . The balcony problem in massive walls with in- or outside insulation.

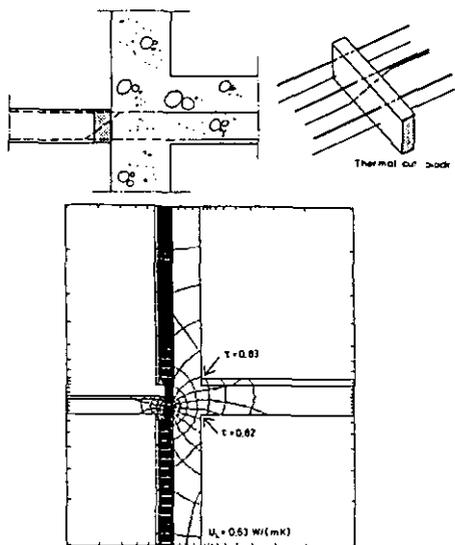


fig.16.: The balcony problem in massive walls with in- or outside insulation :
using a thermal cut-block.

3.4 VENTILATION

3.4.1 Basic ventilation rate

With a temperature ratio ≥ 0.7 and a minimal heating level present, the basic ventilation rate needed lies between 0.5 and 1 h^{-1} , the values currently put forward to ensure IAQ- conditions.

To be sure this will be realised in low rise, one family dwellings, a calculated natural ventilation SYSTEM has to be installed, including (fig.17):

AIR INLETS

in the living room, kitchen, storage room and sleeping rooms

AIRFLOW OPENINGS

in the doors

AIR OUTLETS

conducts, working on stack effect and wind suction in the kitchen and sanitary rooms (toilet, bathroom)

It is not acceptable, as the unique ventilation measure in low rise, to count on the non-designed air leakage of windows and fabric and on window use by the inhabitants. This in fact opposes to the basic performance philosophy, adopted in this guidelines report: a fabric quality, such that only the improper use of devices is left as the cause of mould problems.

Multifamily dwellings are better off with a forced system: in medium rise a non balanced exhaust solution performs well, in high rise a balanced system must be the rule.

For all buildings, energy policy concerns may shift, any ventilation solution to a balanced system with heat recovery. Calculations show that for the moderate climate zone, in low rise dwellings, such a decision is economically not justified. If it is nevertheless imposed, heat recovery is essential.

3.4.2 Peak ventilation

Apart from the global provisions, a local, high flow density, suction system is needed in kitchens, to remove the excess moisture and fat production during cooking (fig.18).

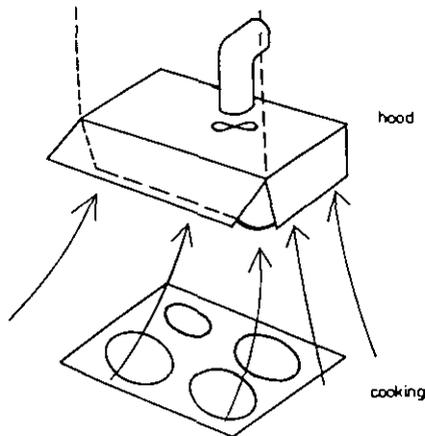


fig.18: Kitchen hood.

In bathrooms, a local system is not as effective, especially because of the nature of the moisture production sources. There, the unavoidable surface condensation during use has to be neutralised by a correct choice of wall and ceiling finish:

good: ceramic tiling, oil- paint

bad: hygroscopic materials (wall paper, chipboard)

and by providing a peak ventilation, high enough to dry, after use, the wet walls. This peak ventilation may be realised by use of windows or a timed ventilator on the exhaust.

3.4.3 Demand control?

RH- controlled systems do not provide many advantages nor energy savings in new design, with the overall thermal quality proposed. In fact, the basic remaining ventilation demand is coupled to IAQ-requirements, rather than to RH-limits; peak vapour production in a wet room cannot really be removed in an efficient way by a global demand controlled system.

3.5 HEATING

In the first chapter, we proved that neither insulating the building fabric, nor excessively ventilating the dwelling may prevent mould problems, if there is not enough heating. In fact, a minimal difference of inside temperature - outside temperature was needed.

The best way to ensure it is by providing a heating device in all rooms, including the sleeping rooms.

That may be central heating. Perhaps central heating in the daytime rooms and local heating with thermostat in the sleeping rooms is better...

The choice has to be made by the designer.

Chapter 4

SOLVING EXISTING MOULD AND SURFACE CONDENSATION PROBLEMS

4.1 ANALYSIS

To come to a good judgement of a problem case, we need:

- as much information as possible on the building fabric, the heating and the ventilation system and the heating and ventilation habits.

Good sources of information are

- . the architectural drawings;
- . observations on site;
- . the measurement of surface temperatures.

Building fabric information is needed to judge thermal bridging... The heating and ventilation system knowledge may help a lot in interpreting inside climate measurements; Surface temperatures give directly, in combination with the inside and outside temperature, the temperature ratio's!

- the inside and outside climate. As stated in chapter 1, at least a period of 1 month of continuous recording during the colder season is needed.

Once all information is gathered, analysis must concentrate on:

- the daily, weekly and monthly mean ($p_i - p_e$)- and θ_i -values. The weekly mean values are shown on the climate chart for comparison with the reference lines;

- the overall thermal quality and thermal bridges: temperature ratio, U-values ...;
- the daily, weekly and monthly mean R.H. against the mouldy surfaces.

These are found either by combining the calculated temperature ratio's with the climate measurements or by combining the surface temperature measurements with the climate measurements.

4.2 MEASURES

The result of the analysis of data may be:

either

- the RH on the mouldy surfaces obeys the mould condition, discussed in chapter 1,
- or
- the RH on the mouldy surfaces does NOT obey the mould conditions discussed in chapter 1,

4.2.1 CASE 1

THE RELATIVE HUMIDITY ON THE MOULDY SURFACE OBEYS THE MOULD CONDITIONS

(- A DIRECT PROOF OF THE UNAVOIDABILITY OF THE PROBLEM)

Gf the Leumann village, IACP- building and Zolder case studies in the case study report [3]

1. The overall thermal quality is much lower than the one, asked for new design (temperature ratio's are lower than the performance demand for new design)

CAUSE : THERMALLY BAD DESIGN

MEASURE: THERMAL RETROFIT

2. θ_i lower than the reference line, used to establish the r -performance

CAUSE : NO POSSIBILITY OF HEATING, THERMALLY BAD DESIGN and/or NO OR TOO LITTLE HEATING USE

A distinction between one or the other follows from observations

MEASURE: INSTALLING A HEATING SYSTEM, THERMAL RETROFIT, IMPOSING A BETTER SYSTEM USE

3. (π -pe) higher than the reference line, used to establish the r -performance

CAUSE : OR A HIGH MOISTURE PRODUCTION OR A TOO LOW MEAN VENTILATION RATE

A distinction between the one and the other follows from a check on the abundance of mould - a high moisture production gives richer mould growth than a low ventilation rate - and from fabric observation: absence of a ventilation system, stripped windows...

MEASURE: INSTALLING OR AMELIORATING THE VENTILATION SYSTEM, PROVIDING A KITCHEN HOOD, REMOVING UNACCEPTABLE VAPOUR SOURCES, INSTALLING AIR DRYERS (- provisional solution)

In cases where 1 and/or 2 and/or 3 are combined, the solution supposes a correct, economically optimised choice of measures.

2.2 CASE 2

THE RELATIVE HUMIDITY ON THE MOULDY SURFACE DOES NOT OBEY THE MOULD CONDITIONS

(Cfr the Alexander Polder case study in the case study report [3][9][10][11])

Different reasons may exist:

- . the moulds are a result of previous periods which were too moist;
- . the measuring period is not representative: more heating, less vapour production, more ventilation than usual. Here, some mutual influences of the enquiry-habits must be considered;
- . the inside climate is measured at the wrong spots, omitting local peaks;
-

The best way to proceed is as if the mould conditions were proved: distinguish between fabric and climate, cure what's missing (insulation, thermal bridges, ventilation system, heating possibilities...)

4.3 GOOD AND BAD RETROFITS

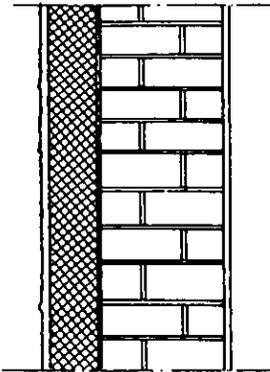
Good retrofits are measures, which not only solve the mould problem, but also ameliorate the thermal and IAQ quality of the building.

Bad retrofits are measures lowering the thermal and/or IAQ quality of the building, including all advice, appealing to the willingness of the inhabitants to change habits and increasing the energy use, if followed.

4.3.1 EXEMPLES OF GOOD RETROFIT CHOICES ARE:

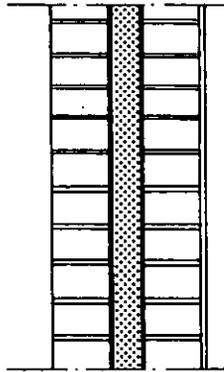
1. CURING DEFICIENT THERMAL QUALITY BY: OUTSIDE INSULATION (fig.19), CAVITY FILLING (fig.20) INSIDE INSULATION (fig.21)

fig. 19



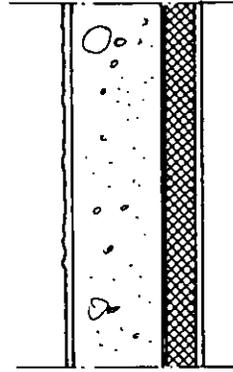
outside insulation

fig. 20



cavity filling

fig. 21



inside insulation

The best but the most expensive solution is outside insulation:

- * No possibility of convective air flow in the construction
- * Optimal use of thermal capacity
- * Best thermal protection of the load bearing walls
- * If correctly done, no moisture problems
- * Least thermal bridging
- * Easy control of the execution quality

but

- * Difficult to cure part of a building

More critical but a lot less expensive is cavity filling:

- * With thin cavities, a real chance of bad filling
- * Higher U-value than expected is possible, caused by convective flow,
- * Outside leaf is in more critical thermal and hygric conditions after filling
- * With a poorly executed cavity wall, more chance of rain penetration after than before filling
- * Not all thermal bridges cured
- * ± no control of execution quality
- * Difficult to cure part of the building

A rule of good practice is not to fill if:

- the mortar joints or facade stones are in bad conditions;
- structural thermal bridges are present;
- the cavity is rather thin or of variable thickness
- no dampproof course at the bottom of the cavity, above lintels etc. is present
- the outside leaf is painted..

In these cases, outside insulation is recommended.

Critical and rather expensive is inside insulation

- * If ceiling and floor joints not sealed, a higher U-value than expected, caused by inside air convection, is possible;
- * The load bearing walls are in more critical thermal and hygric conditions after insulating;

- * Sensitive to moisture problems: interstitial condensation by convection and diffusion, slow or no drying of the brickwall during the cold season, possibility of summer condensation against the backside of the internal lining.
- * Creates thermal bridges instead of solving them
- * Difficult to execute: removal of piping, radiators... before insulating, adapting all electrical switches and sockets, insulating the window reveals....

but

- * Easy to cure part of the building

In some specific cases, we may restrict the thermal retrofit to a local solving of thermal bridges.

Example: an insulated dwelling with clear thermal bridges left: the roof parapet, a deficient loft space insulation, an inside-outside concrete column or beam...(fig.22)

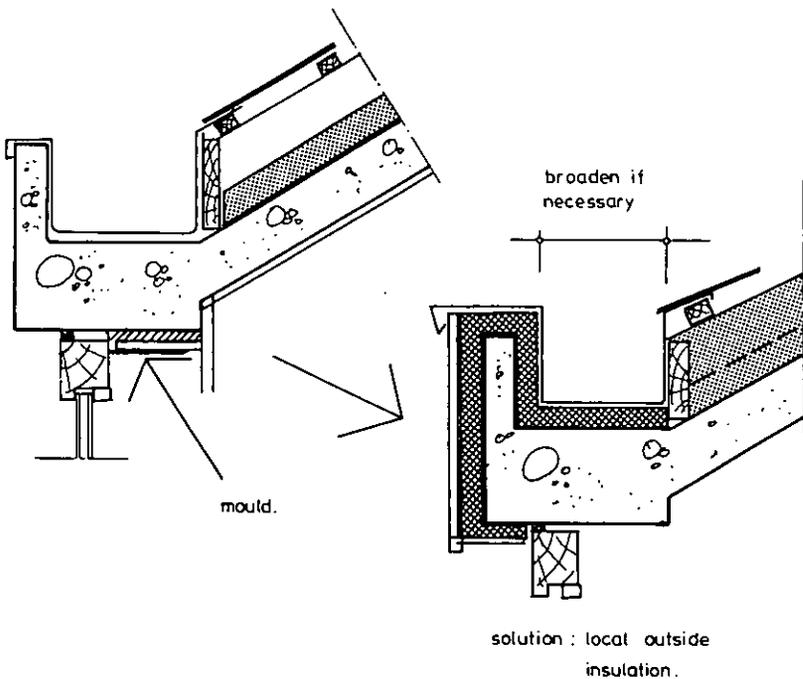


fig. 22.

2. AMELIORATING THE VENTILATION POSSIBILITIES BY PROVIDING A NATURAL VENTILATION SYSTEM

Means:

1. Ventilation grids in living room, kitchen and sleeping rooms
2. Air flow possibilities in all room doors
3. Exhaust pipes in kitchen (hood), toilet and bathroom.

In cases of poor thermal quality and no money to do a thorough thermal retrofit, a relative humidity controlled ventilation system may be an answer to the mould problem.

3. IMPROVING THE HEATING SYSTEM

This measure has no sense if it is not coupled to a thermal retrofit of the building. Otherwise, an energy efficient, but mouldy building may turn to an energy consuming construction..

4. CHANGING THE WALL FINISHES

This measure is only sensible in rooms, where instantaneous surface condensation is unavoidable (bath rooms). To solve all problems, it must be coupled to a correct ventilation strategy.

5. USING AIR DRYERS

A possibility, when, because of investment cuts, no other choices are left. Good air dryers must run automatically, quietly and with a minimum of energy use. The latent heat recovered gives some extra free heat.

IMPORTANT!

All retrofitting measures against mould must be accompanied by:

- a fungicidal treatment of the mouldy surfaces;
- a repapering, repainting or refinishing only of treated surfaces.

4.3.2 EXEMPLES OF BAD RETROFIT CHOICES ARE:

1. REPLACING DOUBLE BY SINGLE GLAZING

The idea behind this is the realisation of a decrease in mean R.H. by an

increase in air drying capacity through surface condensation on the single glazing. To have that effect, huge single glass surfaces are needed, introducing a unacceptable lowering in thermal quality of the envelope, a lift in energy use and worse thermal comfort;

2. **REMOVING WEATHER STRIPS** between the operable and fixed windows parts, the result being more uncontrollable ventilation, to be paid for with an increase in draught problems, and perhaps more energy use;

3. **IMPOSING AN EXCESSIVE WINDOW USE**

Because of the associated heating need, this advice which is often given may lead to an unacceptably high energy use or, if it is not coupled to heating, has no curing influence at all..

The retrofitting scheme shows that solving mould problems in existing buildings is not a question of a bit more ventilation, a bit less moisture production, a bit more heating, repapering... etc. but concerns far-reaching, expensive decisions.

The word expensive is especially an eternal motivation for a reality of 'no solution - much discussion - long lasting court procedures' reality.

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