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IEA- ANNEX 14: CONDENSATION AND ENERGY
AIMS, METHODOLOGY, RESULTS

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ABSTRACT

The paper summerises the work of the International Energy Agency, Executive Committee on Energy Conservation in Buildings and Community Systems, Annex 14: Condensation and Energy, a joint reserch effort of the Federal Republic of Germany, Italy, the United Kingdom, the Netherlands and Belgium.
First an overview of the motivations are given. Then follows a first order theory, sketching the relation between mould+surface condensation and the outside climate, the building fabric and the building use. After, the relation with energy is explained The paper ends with an overview of the results.
The practice guidelines found are: a good thermal insulation, avoiding thermal bridges with a too low temperature factor, a permanent minimum ventilation rate and a minimal heat input.

0. INTRODUCTION

Motivations to implement Annex 14 were a widespread but difficult to prove feeling of badly balanced energy conservation actions during the seventies and early eighties, having increased the number of moderate to severe mould complaints in the housing stock, the fear that at the end, this could enhance any further energy conservation policy, and the conviction that the spread of the problem in the low income housing sector in the 5 countries is such that it's socially no longer acceptable.

1. A FIRST ORDER THEORETICAL APPROACH ON MOULD AND SURFACE CONDENSATION

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

$$p_i \geq p' \qquad \text{(eq 1)}$$

Mould growth becomes possible when the long lasting relative humidity (= the water activity) on a surface remains higher then a threshold value a, or when:

$$p_i \geq a.p' \quad (a \leq 1) \qquad \text{(eq 2)}$$

For longtime, a has been taken 1.

Now, <u>the saturation pressure p'</u>on a surface increases with rising surface temperature θ_s, θ_s being given by:

$$\theta_s = \theta_e + \tau.(\theta_i - \theta_e) \qquad \text{(eq 3)}$$

with τ the temperature factor of the surface, 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 situation), τ equals:

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

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

The <u>mean inside vapour pressure p_i</u> at the other hand is related to the outside vapour pressure p_e, the moisture production Φ_m and the ventilation rate n, according to:

$$p_i = p_e + \frac{[462.(T_i+273.16).\Phi_m]}{(n.V)} \qquad \text{(eq 5)}$$

with V the zonal volume. This simple relation holds for a steady state single zone situation, no surface condensation taking place.

This simple first order theory shows that the probability of mould/ surface condensation increases, the lower the surface temperature θ_s and the higher the inside vapour pressure p_i. Both depends of:

- **<u>the outside climate</u>**
  - 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 are in conflict: they cannot occur together;
  - the wind: the lower the wind velocity, the lower the ventilation rate n and the more probable.mould and surface condensation...

- **<u>the building fabric</u>**
  - 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 Φ_m may be a consequence of other building fabric coupled moisture problems. The higher Φ_m, 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)

- <u>the inhabitants behaviour</u>

. 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 Φ_m, 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

There's no doubt from the review that all 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 non-insulated dwellings, t.m. houses with a high basic energy demand. More, avoiding mould in these, asks for a substantial ventilation rate, especially when intensively used. This counts for an important extra demand. Also, economising by lowering the mean inside temperature θ_i is counteracted by a compelling need for more ventilation, the lower θ_i.This results in a total loss of energy demand elasticity in these badly insulated houses, if one wants to avoid mould problems.
Insulated houses give complaints as far as problematic thermal bridges are left. These have a net energetical impact, tilting in negative cases the conductive heat losses with as much as 30 %. To avoid mould, also a substantial ventilation is needed, pushing the energy demand further up.

3. ORGANISATION OF THE ANNEX

3.1 General Structure

As general structure for the annex was adopted:

GATHERING DATA
MODELLING ↔ CASE STUDIES
GUIDELINES AND PRACTICE

The four parts weren't clearly splitted, but woven as a constant through the three years of common work.

3.2 Working scheme

The research was devided in steps, each step being the responsability of 1, 2, 3 or all countries:

STEP 1	MATERIAL PROPERTIES	B
STEP 2	MOULD DATA	UK
STEP 3	MODELLING, THERMAL	I,FRG,NL
STEP 4	HYGRIC	NL,B
STEP 5	COMBINED HEAT,AIR,MOISTURE	NL
STEP 6	BOUNDARY CONDITIONS	FRG
STEP 7	CASE STUDIES	all
STEP 8	COMMON EXERCISES	all
STEP 9	GUIDELINES	B

B= Belgium, UK= the United Kingdom, I= Italy, FRG= Federal Republic of Germany, NL= the Netherlands.

1 and 2 mean: data gathering. 3,4 and 5, modelling, focuss on thermal bridge calculations (temperature factor τ), surface film coefficients (couple $\{\theta_{ref}, h_i\}$), hygroscopic influences on the inside RH and the combined phenomena of ventilation, heat transfert and hygric response, with as aim to broaden the first order theory, explained above. The case studies brought together a set of well documented cases, gaining a common experience and creating the possibility to evaluate models. To promote the last, two common exercises were implemented on the case studies.
Apart of the common work, each participating country ran a national research on mould and surface condensation, focussing on 1 or more of the first 7 steps mentioned.

4. THE RESULTS OF THE ANNEX

4.1 In general

The visible result is a set of 4 reports, the first entitled the source book (1), the second being a Catalogue of Material Properties (2), the third containing all Case Studies (3) and the fourth summerising Guidelines and Practice (4).

4.2 Material properties

Extended information on material properties, of importance for hygrothermal modelling, has been collected, using an array scheme, referring to the fundamental division between capacitive, transfer, combined and 'consequence of' properties. As far as possible, for the building, insulating and finishing materials studied, relations 'property x- influencing parameters y_i' have been defined (thermal conductivity- moisture content, diffusion resistance- relative humidity....). All results are tabelled in the catalogue report (2).

4.3 Mould (1)

Here, literature and new research have been combined, with as mayor conclusions:

- the number of mould species is enormous and their biology rather complicated. However, as far as dwellings are concerned, it seems reasonable to focus on aspergillus, penicillium and cladosporium;
- for germination, growth and sporulation, temperature and free water activity (= RH) are the important parameters.They are interrelated in the sense that a too low or too high temperature asks for a higher RH, with the minimum RH around 25 °C;
- most experimental data are gained from cultivation on special substrates, the resulting 'temp.-RH'-couples being too pessimistic as mould design values, as was confirmed by work, done in the F.R.G., NL and B;
- a realistic design condition, adopted by the annex, looks like:

mould germination on a surface becomes probable if, on **monthly basis**, the mean **RH** against the surface exceeds **80%**, t.m. a in (eq 2) = 0.8.

4.4 Modelling (1)

4.4.1 Thermal

With the software available on the market, calculating the temperature field in and heat flow densities in and through 2 and 3-dimensional thermal bridges is no longer a challenge. However, the temperature ratio (τ)- result strongly depends on little differences in section specification, on the thermal conductivity values used, and in a pregnant way of the local inside surface film coefficient. The choice of the couple 'surface film coefficient -reference temperature' has been thoroughly discussed. In fact, surface heat transfer is the sum of convection and radiation, convection being linked to the local air temperature and radiation to the environmental radiation temperature, as seen by the surface. Both differ from point to point,and, in non steady state, change with time. The solution adopted is:

- taking as reference temperature the air temperature in the middle of **the room at a height of 1.7 m**;
- coupling the local convective and radiative surface film coefficient, both calculated in a straight forward way with an algorithm, including geometry, air temperature gradient, the overall thermal quality of the room, the ratio 'outside wall area- total wall area' and some heating system characteristics, to the reference.

The lowest h_i- value found is linked to the situation 'cupboard against outside wall': 2 W/(m^2K)

4.4.2 Hygric

Important achievement is a better understanding of the hygroscopic influences:

- hygroscopicity dampens and shifts the inside RH- fluctuations. In this, on daily basis, only the first mm of all inside surfaces are active (f.e the wallpaper and a thin layer of plaster). On yearly basis, the whole envelope thickness has some influence;
- furniture, books, draperies, carpets, being often to always made of very hygroscopic materials and having a high specific surface, are a very active hygroscopic mass;
- by hygroscopic inertia, the RH against a surface uncouples to some extend from the vapour pressure in the room and from the surface temperature. This results in a non response to short RH-peaks in the air and may explain why,as long as no surface condensation takes place, these short peaks don't cause mould problems.
- hygroscopic inertia strongly reduces the positive effect of peak ventilation, except if coinciding with peaks in moisture production or to promote surface condensate drying. Otherwise, as soon as ventilation stops, the inside RH returns to his pre-peak level;
- hygroscopic moistening of wall paper goes on 2 to 3 times quicker then hygroscopic drying.

4.4.3 Heat-Air-Moisture Transfer

Here, apart from a literature survey, experimental work on the spread of vapour, produced locally, in a room and between rooms learned that the development of a vapour front reflects the convective air circulation and exchanges: in a room from bottom to the ceiling and back to the floor, between rooms from downstairs to upstairs. A modelling exercise also proved the importance of hygroscopicity and a greater air volume in dampening the vapour peaks in rooms, adjacent to the peak producing one. This questioned an opinion as: avoid open doors between peak production rooms and others..

4.5 Boundary Conditions (1)

Information has been gathered on:

- vapour production in dwellings (mean, high load);
- climatic standard year data for the 5 countries involved: monthly mean outside temperature, relative humidity, vapour pressure and wind velocity;
- ventilation rates;
- heating.

For the last two, as well climatic, fabric as inhabitants habits influences have been analysed.

4.6 Case Studies (3)

COUNTRY	CASE	SUMMARY
B	Zolder	miners estate, build shortly after world war 2, retrofitted in the earl eighties. Since,very severe mould problems. Causes: poor ventilation possibilities,ruinous thermal design Monitoring before and after remedial treatment (air dryers, ventilation system, in- and outside insulation, loft space insulation (or, or))
NL	Pijnacker	end of a row one-family dwelling Insulated, but, with thermal bridges left. Moderate mould growth. The monitoring gave no conclusive information on the cause of the mould presence. It seemed as if past circumstances were responsible
	Alexander polder	not insulated. Diffuse mould growth in a first floor flat. The monitoring gave no conclusive information on the cause of the mould presence.It seemed as if past circumstances were responsible..
I	IACP-building	a 10-stories building, not insulated, single glazed. Widespread mould problems. The monitoring revealed a poor ventilation and thermal bridging
U.K.	Edingburg	large scale investigation on the relation between damp houses and lower respiratory symptoms in children,living in these.Confusing results in the sense that a parents survey gave a strong but a monitoring campaign a less convincing relation.
FRG	Ruhr Gebiet	large scale investigation, showing that limited volume, intensive use and thermal bridges are clear causes of mould problems

4.7 Guidelines and Practice (4)

4.7.1 Methodology

Agreement has been reached on and a methodology is proposed to handle:

- conditions for mould germination: RH against a surface ≥ 80% on monthly mean basis;
- h_i:

. reference inside temperature= air temperature on 1.7 m height in the middle of the room;

- the calculation methodology to quantify the local value and coupling it to the reference temperature;
- the definition of the temperature ratio: $\tau = (\theta_s - \theta_e)/(\theta_i - \theta_e)$ with θ_i the reference temperature, θ_s the local surface temperature and θ_e the outside sol air temperature, the four on monthly basis;
- the way to handle inside climate data: introduction of a three-dimensional $[(p_i - p_e), \theta_i, \theta_e]$- climate chart with τ- classes. Choice of a τ class fixes the acceptable (inside temperature-ventilation rate-moisture production)-combinations

4.7.2 Guidelines and practice

Avoiding mould problems in new constructions, means a balanced combination of:

Overall thermal quality
No unacceptable thermal bridges
Ventilation
Heating

In damage cases, only a straight forward analysis, including an evaluation of the thermal quality of the envelope,long term inside climate registration and,if possible, surface temperature logging, may lead to a correct diagnosis and solution. Defined as bad, in the frame of the Annex, are all measures, increasing the energy use for heating (f.e. replacing double by single glazing), and all measures, trying to change the inhabitants habits in a physically doubtful or wrong way (f.e. pushing on excessive peak ventilation in thermally bad buildings with a low basic ventilation rate).

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