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Thermal Insulation & Condensation Theory, Tools & Strategies

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Abstract
The increasingly high standards of thermal insulation have undoubted benefits in improving comfort, saving energy and avoiding the spread of mould growth on internal walls. The author, as a practising architect since the mid 1970s, is concerned with avoiding potential difficulties caused by using insulation in inappropriate ways. Since the advent of microcomputers in 1980, he has written software (Energy/1: Thermal Insulation & Condensation) as a tool to understanding and avoiding condensation problems, and applied these tools on behalf of other consultants, manufacturers, roofing contractors etc. as well as supplying the software for use by architects, manufacturers and local authorites etc.

The purpose of this paper is to outline the theoretical bases for the current understanding of condensation, to describe the incorporation of that theory into the development of software and to describe available insulation strategies. [It is proposed that more detailed evaluations of roofs, walls & floors be described in further articles].

Theoretical Bases

Air holds moisture in proportion to its temperature. The Relative Humidity (RH) of the air is expressed as a % of the moisture held in the air as compared with the maximum quantity which that given temperature can sustain. When the air can hold no more moisture it is said to be saturated and has an RH of 100%. When air has reached its point of saturation, the temperature is known as the dewpoint temperature. Condensation occurs where moisture laden air arrives at a relatively cold surface, such that the temperature of that surface is lower than the theoretical dewpoint. The most frequent occurence is on internal surfaces, glazing etc. What 'drives' moisture laden air to migrate is pressure differential, since air at high RH has a higher pressure than at low RH, and again the higher the temperature the higher the pressure for a given RH. The relationship of pressure, temperature and RH is expressed on the psychometric chart. Moisture passing through a construction is going from a high (usually internal) pressure to a lower (usually external) pressure.

What makes the subject of particular interest is that any construction has to be considered as a whole to the extent that the temperature through the various 'layers' of the construction is proportional to the ratio of the thermal resistance of each layer to that of the thermal resistance of the whole. In the same way the prediction of pressure and thus of dewpoint at each 'interface' between layers is proportional to the ratio of the vapour resistance of that layer to the vapour resistance of the whole. This has been little appreciated by many, who have assumed that it is possible to 'add' insulation to a known construction, without recognising that such a construction will then behave quite differently. Condensation at interfaces between materials is by definition 'interstitial'.

This much is well known and incorporated into the BRE digest 110 and BS 5250 (1975). The resultant graphs (fig 1) indicated condensation risk where the dewpoint temperature exceeds the actual temperature. What was appreciated by only a few specialists was that this view was essentially flawed, since in normal circumstances it is quite impossible that the dewpoint should exceed the actual temperature, since the RH cannot exceed 100% (note 1). Early use of software similarly showed that condensation thus predicted was inadequate. One further problem was that the results thus generated showed condensation occurring within light-weight insulation (e.g. glass fibre). Studies at Pilkington's Research Laboratory (note 2) showed that this was not the case, moisture passing through the insulation condensed on the next hard cold surface (usually the inner side of the outer brick skin in the case of cavity fill).

Further research, prompted by Professor Burberry of UMIST and helped by Dr. David Capey of Essex University, came up with a prediction technique that examined the flow of moisture to a given interface and the flow from that interface to the outside air. Where there was a difference between the flow in and the flow out, the difference was the moisture deposited. Often what appeared to be large discrepancies in the graphical evaluation turned out to be insignificant (less than 0.01 grams per hour per square metre). The technique was implemented in the software in 1982 and proved highly successful in the absence of other published calculation methods. However, a weakness of the theory was that in the case of multi-layer condensation, it was possible to predict negative condensation i.e. moisture leaving an interface faster than it got there! This anomally tied up with Pilkington's findings above in indicating that the theoretical model needed further refinement.

Because of the theoretical nature of the discussion, the necessary amendments to BS 5250 have taken a long time in coming, the draft for public comment being released in late 1986. The calculation technique in the proposed BS provides the necessary refinement of the earlier models. First a procedure parallel to that of the earlier BS is used to establish potential problem areas. Where potential risk occurs the theoretical pressures are converted to those expected at 100% RH at the given temperature (quite simply the dewpoint temperature becomes the actual temperature). Next the moisture flow is calculated to each interface as is the flow leaving it to the next interface. The difference is the quantity of moisture deposited (fig 2). However, where this is negative deposition, the technique assumes that the system is unbalanced, omits that layer as a risk and starts again from the first 'at risk' interface. Using this technique over the past year has proved beneficial, and it is unlikely that it is necessary to refine it further for some time, since however good the physics the process of building itself and material inconsistencies provided the greater challenge.

Development of tools

To carry out 'manual' calculations for condensation prediction is enormously time consuming, and it is probably because of this that these calculations have never been made mandatory under Building Regulations. However, the necessity for extensive reiteration lends itself to computerisation, all the more so through the latest proposals for the BS 5250. In tackling the task of developing the appropriate software there are 3 main considerations:

Database of Materials

Because of the constantly changing availability of new materials and the developing understanding and testing of existing materials it is necessary to maintain a library of materials, which on computer follows a database structure. For the purposes of calculation materials fall into 3 main

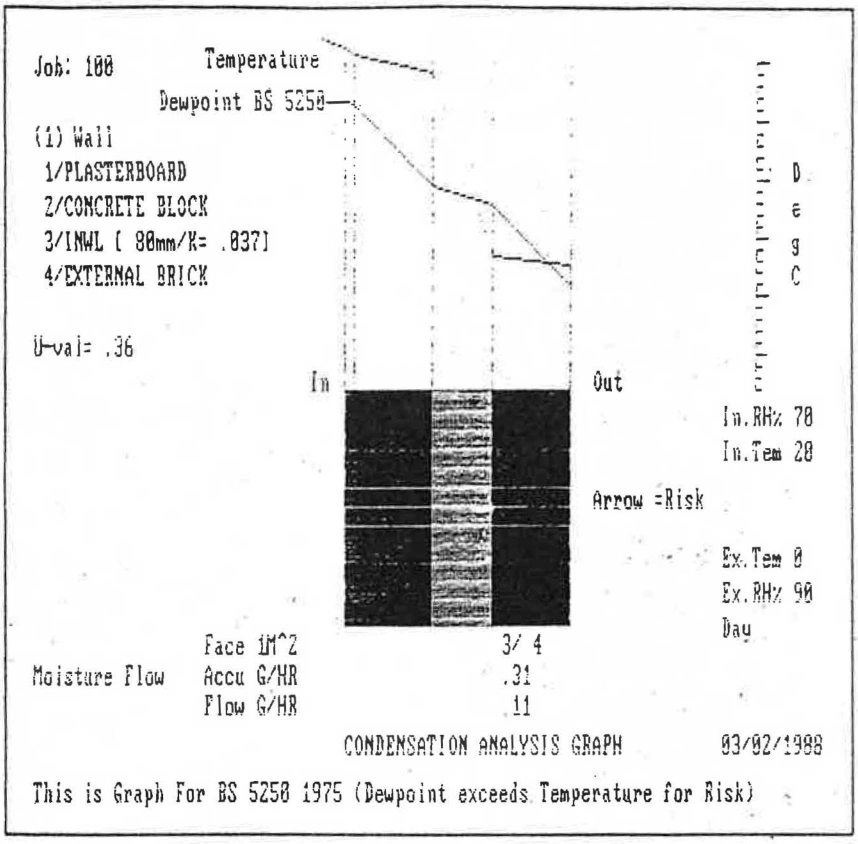

Fig 1 *Condensation in cavity filled masonry wall as BS 5250 1975, showing the theoretical dewpoint exceeding temperature, and condensation within the mineral wool itself.*

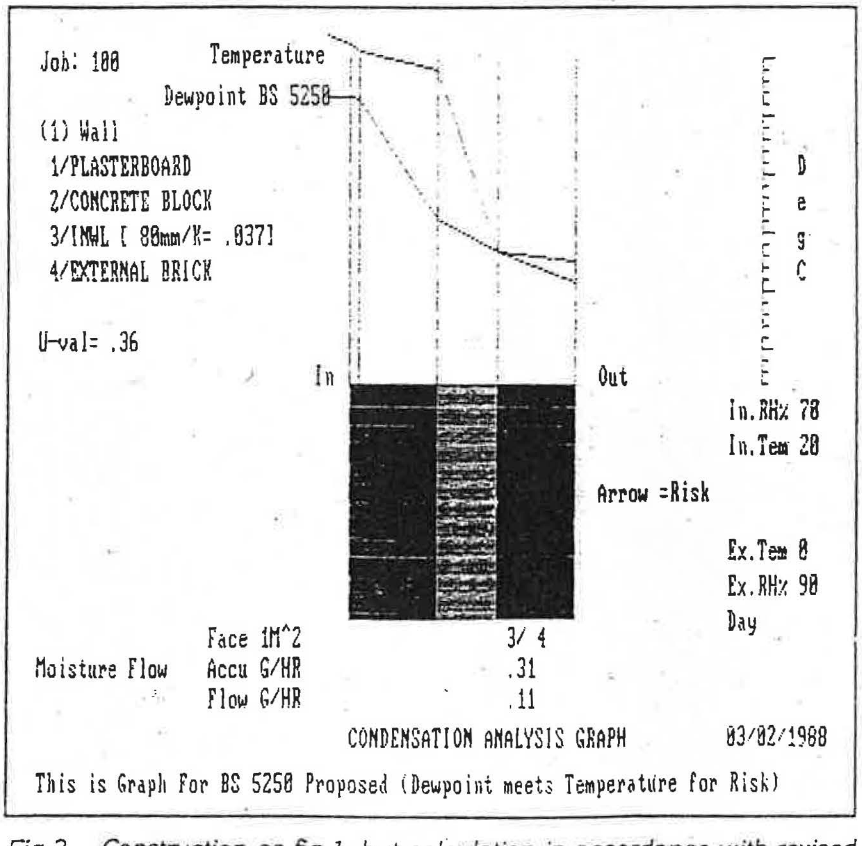

Fig 2 *Construction as fig 1, but calculation in accordance with revised BS5250 showing dewpoint meeting temperature curve and deposition rates at Mineral Wool/External Brick interface.*

types

(a) Insulants: which have both low K-values, vapour resistance (proportional to their thickness) and come in set incremental sizes according to type (e.g. Quilt, Sheet etc.)

(b) Vapour checks: (or vapour control layers) which are sheet materials whose vapour resistance is independent of thickness and which have negligible thermal resistance (e.g. Polythene, Gloss Paint)

(c) Buildings Materials: which are dense and whose vapour resistance and thermal resistance is proportional to thickness (e.g. plaster, brickwork)

As mentioned above, it is difficult to obtain accurate figures from manufacturers particularly for vapour resistance of materials. There are a number of sources (note 3), but many make the mistake of putting in unrealistically high values for sheet materials, which can never be carried out in practice since sheet materials are susceptible to tearing and the sheet is as efficient as the joints.

Libraries can also include data on cost, thermal capacity and coefficients for thermal movement, (note 4) which is another critical factor in thermal design (the recent failure of the Liverpool Roman Catholic Cathedral was largely due to the use of aluminium rather than copper for the roof).

The calculation method itself requires:

(a) interpolation from the psychometric chart, which is experimentally based. Mathematical approximations have to be used that take into account the difference in calculation technique for water vapour pressure over ice and that over water, since very often one is dealing with examining buildings under extreme conditions, particularly for overseas work.

(b) allowing for both day and night conditions. At night the external roof temperature can be up to 5 deg C lower than the air temperature due to radiation effects (for walls this is 3 deg C). The practical outcome of using this is that for constructions with a thin outer skin there is always condensation on the underside. This is particularly significant since allowance must be made for the draining of night-time condensate from the underside of metal roofs.

(c) the calculation of average Equivalent Moisture Contents for timber in the construction. Knowing the RH at each interface it is possible to calculate the predicted EMC of timber, which if

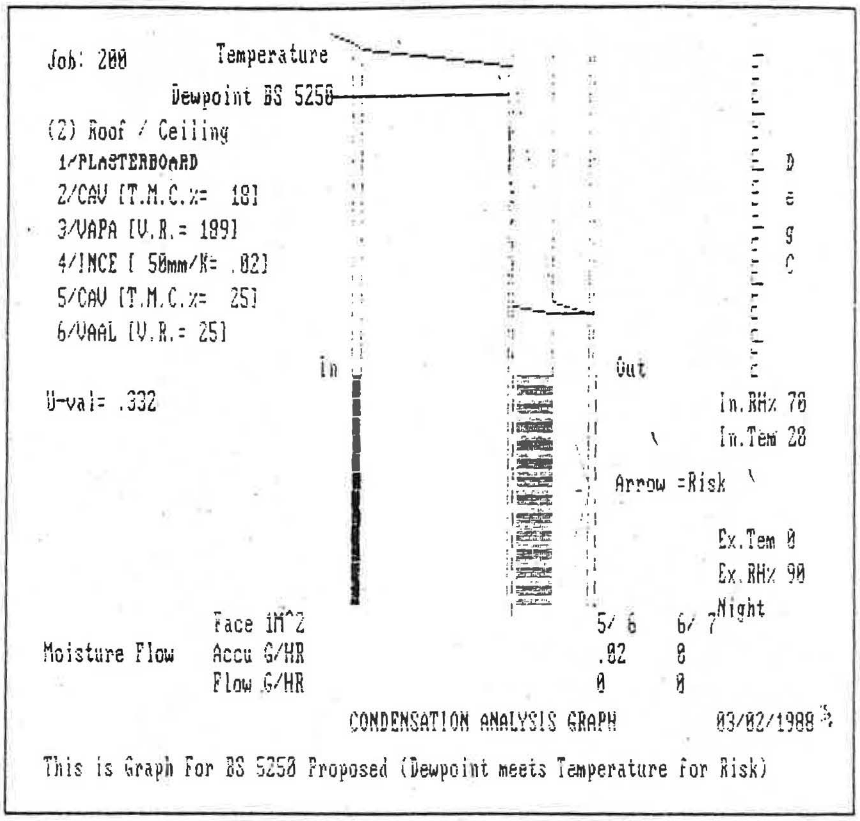

Fig 3 Night time condensation in an industrial roof, where external roof temperature 5 degC lower than air temperature due to radiation effects.

in excess of 20% indicates the possibility of fungal decay (note 5). Constructions can avoid condensation whilst maintaining timber & ply at high EMCs, should this be the case it is necessary to specify ventilation and/or timber treatment.

Graphical display of results

BS 5250 (1975) and BRE digest 110 both base their analysis on the study of the gradients of temperature and theoretical dewpoints in the construction. The proposed BS 5250 also uses graphical techniques, although these are used alongside calculation procedures. Whatever the limitations, graphical output is immediately visually instructive as to the magnitude of a given problem. This immediacy is somewhat lost when confronted with rows of figures, and it is best to run the two methods in parallel. Over the past 10 years those using the original graphical displays will have built up a considerable recognition facility as to what visually constitutes a problem. The graphical display thus remains an important part of the evaluation procedure.

Strategies for evaluation

There are three ways of controlling condensation:

(a) heating
(b) ventilation
(c) insulation

It is vital that these 3 be kept in balance. Two without the third is quite inadequate i.e. to insulate and ventilate without heating will not be enough, heating without insulating is uneconomic etc. BS 5250 as proposed contains a very useful algorithm for the prediction of Internal RH and Temperature given heating input, ventilation rate and conductivity of the structure. The algorithm itself is a simple reworking of the steady heating equation. [In order to include solar gain through the fabric the author has modified the algorithm, which has proved useful in assessing factory overheating.]

For any situation at any given time there will be an optimum balance of these three elements. Certainly one can insulate to an extreme, but at the risk of over-stressing the fabric and at the same time increasing the capital cost excessively. [The field of evaluating 'payback' periods can be very specialist and deserves a separate article].

As an architect the strategy taken is:

(a) Estimate current problems and conditions in an existing building, or optimum design criteria in a new building.

(b) Insulate the fabric to a level which can be physically and visually accommodated by the construction, such as to accommodate (i) above. Often this may involve some dozens of alternative calculations of the 'what if' variety, increasing internal conditions, reducing external conditions, varying the efficiency of the vapour check. The position of the insulation and vapour check is critical. It is well known that the vapour check should be placed on the warm side of the insulation, what is less well known is that then to increase the thermal resistance on the warm side of the vapour check will at best lower the tolerance of the structure to high internal RH, but at worst can be disastrous (e.g. the practice of adding insulation over suspended ceilings). Other factors to take into account when selecting insulation are fire performance, likelihood of damage, resultant depth of fabric, cost, short term reversible movement, long term shrinkage, porosity, water retention, availability, chemical incompatibility between materials and ease of fixing.

(c) Evaluate the overall performance of the building as compared with either Building Regulations requirements or, in the case of an existing building, the current situation.

(d) Decide whether or not it is cost effective to further increase the insulation thickness. Depending upon the position of the insulation in the fabric, risk is either increased by further thickening of the insulation (where the insulation is on the inside) or decreased where the insulation is on the outside (thermal sheathing).

(e) Attention also has to be placed on cold bridging effects around lintels, floor wall junctions etc. The recent proposed amendment to the Building Regulations (in line with Scottish Regulations) is to have minimum U-value of 1.2 W/m2degC through any part of the fabric. I wholeheartedly agree with this though add the caveat that filling the voids of steel lintels is virtually useless, most of the heat tracks around the line of least resistance (i.e. the steel). [The author has developed calculation techniques to assess the average U-values through metal sections e.g. aluminium windows, pressed steel studs, steel beams etc.]

(f) Ventilate the fabric where necessary. Condensation always occurs under sufficiently severe conditions, and always on the external surface on a cold night due to radiation effects. The designer's job is to ensure that condensation risk is minimalised and takes places in an area where it can be ventilated. Ventilation is a complex subject and is dependent on stack effect, wind speed and flow, resistance of material, building detailing etc. In addition to these complexities there is discussion as to whether ventilation brings in more moisture than it takes away, which can contribute to failure particularly in industrial roofs etc (fig 3). To omit ventilation from risk areas can perhaps avoid short term problems, but in my opinion will result in a rash of long term failures. History has shown that well ventilated structures survive. Our job is to ensure long term life whilst cutting down on short term heat loss. Ventilation of the external cavity contributes little to heat loss, and dries out moisture percolating through, detailing must make allowance for run off of excess night time condensate.

It is apparent that the high insulation construction of today is becoming very complex to design and get right. Many of our award-winning buildings fail techically after a few years. Only in the last few months has the total replacement of the aluminium double skin panels on the Sainsbury Centre been announced – after less than 10 years. Increasingly the onus is on manufacturers of insulation, components and structure to collaborate in the development of constructional systems and details that save energy whilst avoiding the associated pitfalls of condensation, cold bridging etc. Experience has shown that such design is possible, and tests by the Agrement board on large scale sections have shown the theory to be proved right in practice. It is a specialist area, in which 'a little knowledge is a dangerous thing'. With the correct tools and the right understanding of the physics it is possible to move into higher insulation design, but slowly and with caution!

Notes:

Note 1: Where Condensation Forms: Dr. Peter Barrett, Building Magazine, 2 Dec 1982.

Note 2: Interstitial Condensation in Domestic Cavity Walls. Ken Johnson of Pilkington R&D. Energy in Buildings Feb/March.

Note 3: R.D. Prangnell Extrait de Materieux et Construction No. 24 Vol 3. BRE.

Note 4: BRE New Metrick Handbook: Architectural Press. BRE Advisory Services.

Note 5: BRE Digest 227 & 228.

Note 5: BRE Princes Risborough are at present researching the relationship between Equivalent Moisture Contents, Relative Humidity and Temperature with respect to examining conditions in wood-based products which encourage fungal decay. The results will be published in due course.