GLC BULLETIN 144

ITEM 4 (COMMITTEE DATE 10/84)

Condensation prevention: loft ventilation — a discussion paper

ABSTRACT

This is the third item in a series on methods for predicting condensation risks within structures. It answers criticisms made of the method described in Bulletin 142 Item 8, on the basis that the method does not give the same answers, nor does it take account of the effect of the occurrence of condensation on the vapour pressure gradient within the structure, as does the graphical method described in Bulletin 141 Item 9. The present item explains how the original equations may be altered to produce the same answers as the graphical method, and goes on to discuss the practicalities of the ventilation of roof spaces, with particular reference to the current and anticipated future requirements for the insulation of roofs, and draws conclusions relating to the inclusion of vapour-resistive layers and the position of the insulant.

1 RECONCILIATION BETWEEN GRAPHICAL AND NUMERICAL ASSESSMENT OF CONDENSATION RISK

Since publication of Bulletin 142 Item 8, it has been pointed out by several correspondents that the equations (2a)-(2d) and (5) given in that Bulletin item produce different results from those obtained following the Glaser method of establishing condensation planes, or when using the alternative graphical method given in Bulletin 141 Item 9. Not unreasonably, the question was raised whether the GLC is using different methods giving disparate results of assessing condensation risks.

Attention was also drawn to a recent BRE Report [1] which estimated that in the UK over 1.5 million dwellings are severely affected by condensation and that another two million dwellings have slight condensation problems, the problem being spread throughout all housing types, housing sectors and locations. Scotland has received attention in a separate report making equally grim reading [2].

The process of calculation set out in Bulletin 142 Item 8, unlike that given in Bulletin 141 Item 9, locates planes of condensation by comparing calculated vapour pressures with saturated vapour pressures at interfaces, and assumes a condensation plane where the saturated pressure is exceeded, following BS 5250: 1975.

This simplified process fails to consider the drop to the saturation pressure occurring at condensation planes; it consequently overestimates the amount of condensate.

While such a simplified approach may be adequate for making a choice between "good" and "bad" constructions at design stage, given suitably chosen control values, comparison with measurements in the field or in the laboratory are not possible. Furthermore, the more exact graphical methods mentioned are already in more widespread use than was anticipated.

It is, therefore, accepted that the approach given in the equations mentioned is oversimplified and should be corrected.

When counting material layers (from warm to cold faces) from 1 to n, and interfaces between layers also from 1 to n, eg interface 3 being the colder face of layer 3, then the quantitative discrepancy will be corrected by changing all expressions $(x-1)$ in equations (2a)-(2d) and (5) to $(x+1)$.

These equations are then applied whenever the calculated vapour pressure exceeds the saturation vapour pressure at an interface. The saturated vapour pressure needs then to be used as the operative pressure, and the revised pressure distribution recalculated throughout the building element. More than one application of this procedure may be necessary to establish the true steady state distribution of condensation planes at which the condensate quantities can then be calculated.

The computer program in use has been modified to include this procedure, giving identical results with the two graphical methods mentioned. An illustration of the results for a (very) fictitious flat roof is given in Tables 1 and 2 and Fig 1, where steady state condensation planes are found by applying the above procedure to the first series of values p^1 which follow the method given in BS 5250: 1975, from which the "true" condensation planes, condensate quantities and winter/summer comparison of conditions are then established. (Note that even summer conditions can result in condensation for the environmental conditions chosen in this example.)

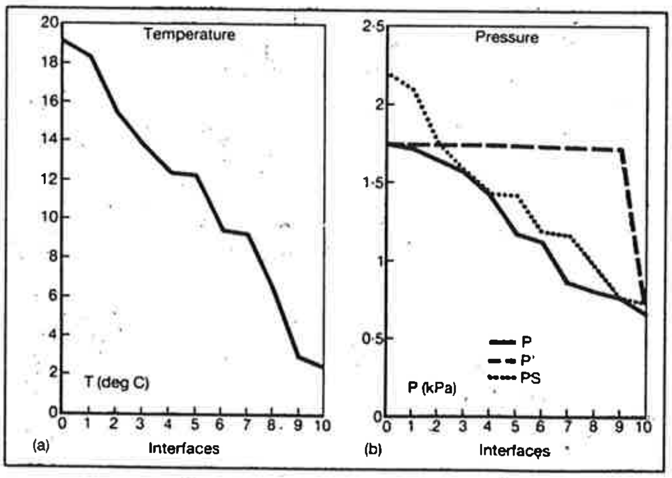

Fig 1: (a) Temperature graph (b) pressure graph

2 VENTILATION OF ROOF SPACES ABOVE INSULATION LAYERS

When using equations (7) to (10) given in Bulletin 142 Item 8, together with the methods in BS 5925 for wind-driven ventilation, it becomes possible to assess the amount of ventilation openings required, as well as their relationship to the amount of vapour resistance provided in the ceiling. Both determine the risk of condensation in the roof void when compared to external climatic conditions.

Domestic roofs are by far the most common application of this type of roof construction and are considered in some detail here. The understanding of all inter-relationships is complex, and there is little documented field experience with which a calculation method intended as a predictive, or rather preventative, design tool could be compared. Nevertheless, it is thought that the proposed calculation method, combined with earlier published work, may give a direction for future design approaches.

First of all, it is necessary to illustrate what we have done to domestic roofs over the last 30 years or so, and what is almost certain to happen to all roofs, old and new, during their future useful life.

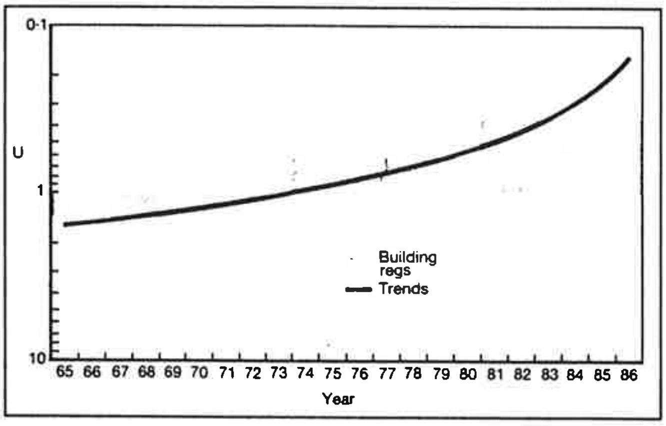

Fig 2: UK development of U-values for domestic roofs.

Fig 2 illustrates the development of statutory insulation standards since 1965 [3]. The trend line is derived by a least squares approximation. The likely optimum end result of 0.15 for roofs (and 0.2 for walls?) becomes foreseeable in less than a decade — although statutory control will more likely be expressed in terms of annual fuel consumption in, say, W/m² year of useful floor area, leaving designers free to find a combination of fabric, ventilation and plant to achieve the energy target.

Nevertheless, the combination of very high standards of insulation with passive solar design and mechanical ventilation with heat revovery could make the installation of heating systems in domestic buildings superfluous [4]. There would, therefore, be little change in capital requirements for building houses when such energy-conscious design is employed. Only halfway measures between current and optimum standards are likely to be substantially more expensive.

Built examples of this approach to design are described in most publications dealing with energy-conscious design. One recent description of Canadian and UK examples is referred to as of particular current interest [5].

Fig 3 shows the effect of higher insulation standards in domestic roofs, expressed as the temperature difference between the felt underlay below the roof tiles and the outside air during average winter conditions. Before statutory insulation values were introduced, heat escaping into the roof space kept the underlay about 3°C warmer than external air. Now, and more so in future, the difference is close to zero. This alone illustrates an increase of condensation risk in roof voids.

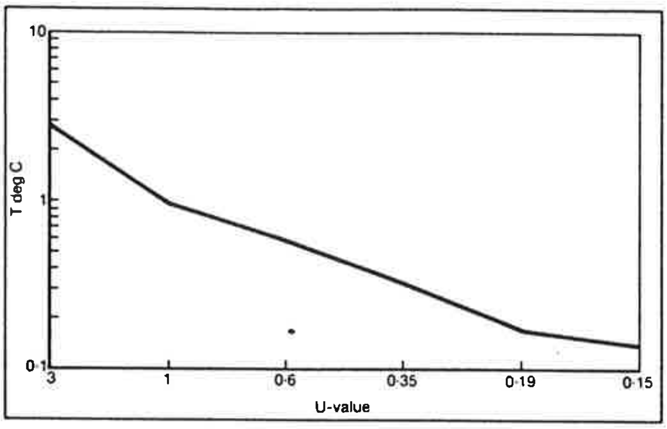

Fig 3: Temperature difference between the underlay and outside temperature.

Higher insulation standards for the fabric will force attention on reduced air change rates to lower the increasingly significant heat losses due to ventilation. This, in turn, implies that internal relative humidities will rise rather than fall (odour levels and contamination are not considered here, but will also require attention) — a second pointer that in the near future there may be an increase rather than a decrease in potential condensation risks.

When examining the drying capacity of average winter external air (the difference between its actual water content and its maximum possible water content at saturation pressure) throughout the UK, East Anglia appears as the nation's worst area, with the "epicentre" in the vicinity of Bury St Edmunds.

Fig 4 shows the calculated eaves openings (calculated for a variety of loactions, in mm equivalent slot widths) in relation to internal relative humidities at 20°C internal temperature. For Bury St Edmunds, the resultant eaves ventilation slots on both sides of a domestic building (two-storey, depth 10 m, plasterboard ceiling) are 27 mm for an internal RH of 50%, 52 mm for an internal RH of 70%.

Before taking such "calculated" results as design guidance, it is important to appreciate something which has not been mentioned in relation to the external climatic assumption, namely that average winter conditions of +2°C 94.4% RH for Bury St Edmunds are "assumed". But when the winter Easterlies blow over East Anglia, it is not unlikely that temperatures may be as low as -5°C for several weeks. Taking RH to be 95% at this temperature, the drying capacity of air is much reduced from the earlier "average" assumption, and calculated ventilation openings would be 135 mm for RH_i = 70% — assuming, of course, that the "average wind" keeps on blowing.

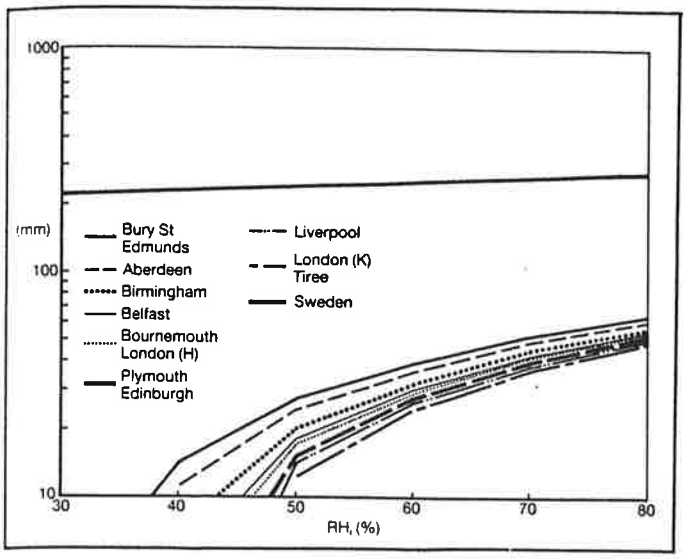

Fig 4 Eaves openings related to internal relative humidity.

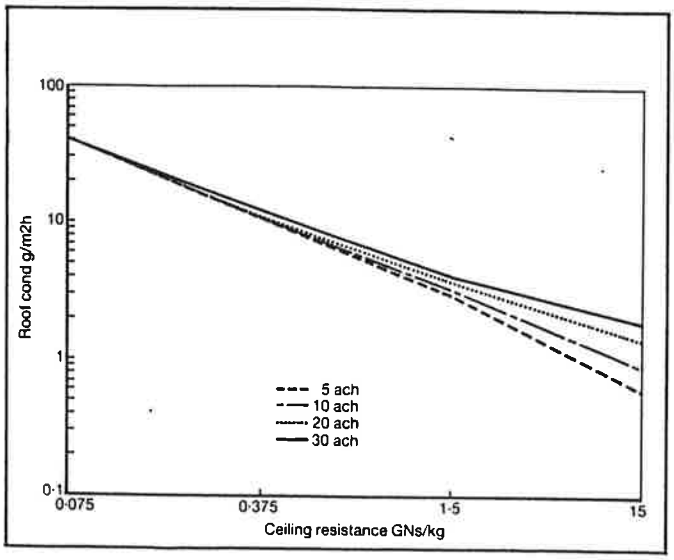

Fig 5: Condensation related to vapour resistance of ceiling and void ventilation.

Surely it would be prudent for any designer to choose such more severe external conditions rather than average assumptions to avoid risks from condensation?

Will such large ventilation openings increase the risk? As the area is in an agricultural part of the UK, this question might easily be overlooked; barns are known to work quite well in the area, keeping precipitation at bay while providing maximum ventilation. The air that keeps the hay in the barn dry will, of course, equally keep your loft insulation dry — "on average".

This comparison between barns and lofts, however, ignores transient condensation which might arise when general dew or hoar frost conditions exist externally. This may not be a worry in barns, but in domestic lofts such risks would not be acceptable if found to be significant.

The problem of dew and hoar frost in ventilated roof spaces was first described in 1958 by A W Pratt [6]. In his conclusions and recommendations he states that: "It is recommended that the diffusance of a vapour barrier at ceiling level should not exceed 0.005 lb/ft^2 h atm." In current terms this says that the resistance of a vapour control layer should not be less than 14.94, say, 15 GNs/kg. Although the roofs which Pratt describes are metal and corrugated asbestos cement sheeted roofs, the behaviour of the outer skin of any roof is not likely to be significantly different when the effects of current and future insulation standards are considered (Fig 3).

However, when it comes to recommending ventilation requirements between ceiling and roof covering, his conclusions give no easy guidance, and the body of the text needs to be referred to. His Table 2 is reproduced in graph form and translated into SI units as Fig 5. At his recommended vapour resistance for the ceiling of 15 GNs/kg, there is a significant difference of dew/hoar frost condensation risk between various ventilation rates expressed as air changes per hour (ach) of the roof space. At 5 ach the amount of possible condensate is 0.6 g/m^{2}h, while at 30 ach the quantity can rise to 1.9 g/m^{2}h.

A roof of 30° pitch with a span of 10 m, having 20 mm equivalent slot eaves openings and at a reference wind speed of 1.26 m/s (inner city location), would have approximately 2 ach. This rate would be more than adequate to remove any vapour permeating through a ceiling with a vapour resistance of 15 GNs/kg (if that can be achieved in practice), with the roof remaining free of risk of the formation of dew or hoar frost.

It is worth remembering that such dew or hoar frost conditions arise from radiation losses from the outer skin to the night sky, so that they are unlikely to last for more than 4 - 6 hours. The total quantity of condensate is, therefore, not likely to exceed 3 - 4 g/m^2 — equivalent to a film thickness of 0.003 to 0.004 mm. This amount of dew/hoar frost, if removed the following day as a result of ventilation having been provided, is not thought to represent a significant contribution to moisture in the roof.

Conversely, however, ceilings of plain plasterboard with a resistance of about 0.065 GNs/kg would attract a dew/hoar frost contribution to roof condensate of about 41 g/m^2 h, irrespective of air change rate, according to figures given in Pratt's Table 2 (Fig 5). This would result in a film thickness of about 0.2 to 0.3 mm — 100 times the amount previously estimated, and certainly a risk. No wonder that 26 years ago Pratt called for vapour control at ceiling level in the order of 15 GNs/kg.

Before dealing with the consequences for design resulting from deliberations so far, it is necessary to consider what may be the "correct" internal humidity assumptions. Existing houses, due to their hitherto low insulation standards in lofts, are not a good guide in this respect, as already shown in Figs 2 and 3. User behaviour also differs widely [7]. To cater for all types of users — and there is little to choose between the private and the public housing sectors — it has become practice to adopt an internal overpressure of 1000 Pa for design purposes, and GLC experience would support this. There is, however, the unresolved question of "overpressure over what external pressure?". Over the partial vapour pressure resulting from "average" winter climate, or those from extreme lows, or those for bad periods of one week or more?

In view of Pratt's publication in 1958, an outside design temperature of -5°C at, say, 85% RH (as in BS 6229) can, with equal validity, be assumed as external climatic conditions covering the whole of the UK for the design assumption for roofs in assessing condensation risks. With regard to internal assumptions, however, the 1000 Pa should be assumed to prevail over the winter (January) *average* conditions, as these would govern the risk of interstitial condensation.

The result is that internal relative humidities for design, all at 20°C internal temperature, range from 70.9% in Carlisle to 79.5% in Milford Haven (Plymouth 78.3%, London 73.5%) if 1000 Pa overpressure is assumed.

SUMMARY

It is possible to draw together the implications of the points discussed so far, as follows:

1. Due to current and future higher levels of insulation, there is no longer any significant heat transfer into the loft from dwellings below. The external leaf (eg tiles and underlay, or any other roof covering) is at temperatures equal to external air, at times approximately 5°C below that, due to night radiation losses, with faster and more pronounced temperature rises from solar gain.

2. Ventilation of the loft space above the insulation serves the dual purpose of

   — removing water vapour migrating through the inner leaf (ceiling and insulation), and
   — removing unavoidable condensate arising from dew or hoar frost conditions which limit the amount of ventilation to be provided and require vapour control at ceiling level.

3. Vapour control at ceiling level should be in the order of 15 GNs/kg. The difficulty in practice will be in achieving this standard of resistance over the whole ceiling construction.

4. A more suitable location for roof insulation is, therefore, between and below rafters rather than above ceiling level. This location would protect water tanks and services from frost, allow extension of accommodation into the loft space, and permit inspection and repair of vapour control layers. (The void between insulation and underlay would remain to be ventilated.)

5. In future, the use of mechanical ventilation systems combined with heat recovery may significantly alter the situation by lowering internal relative humidities.

   Although there is every reason why such methods of ventilation should be used on grounds of energy conservation, humidity control and building cost, when combined with high levels of insulation, this practice will not become the rule in the near future, whether in new or existing dwellings. Changes in this respect may, however, come faster than generally assumed [5].

CONCLUSIONS

1. For reasons of buildability, of standardisation of components, and of dew or hoar frost considerations, large ventilation openings should be avoided. Taking the acknowledged "rule of thumb" of 0.4% of ceiling area (BS 6229) as an accepted guide for the common eaves-to-eaves distance in houses of up to 10 m, the ventilation openings could be standardised at eaves at 20 mm continuous slot equivalent. Additional ridge ventilation would then be optional in duo-pitch roofs at fairly nominal sizes without the need for complicated calculations. For mono-pitch roofs, however, ridge ventilation, in addition to cross-ventilation at eaves or its corresponding level at the steep side of the roof, would need to be provided at a proposed minimum of 10 mm equivalent slot width.

2. Control of the rate of permissible water vapour migration into the loft space through the inner leaf needs to be achieved by specific inclusion of vapour control layers below the insulation at a resistance of not less than 15 GNs/kg. Detailed attention in design and construction would have to be given to hatches and services penetrating the ceiling, as illustrated in BRE Defect Action Sheets 1, 3, 4, and 6 [8]. A more suitable location for the insulation may, therefore, be at rafter level. The target design value of 15 GNs/kg for the vapour resistance below insulation in domestic buildings, in conjunction with 20 mm ventilation openings at eaves, would be capable of accommodating all user requirements and UK locations. A by-product would be the elimination of any calculations for the ventilation requirements of domestic roofs.

3. While the required values of vapour resistance fall within those quoted by manufacturers as being provided by plasterboards with integral vapour control layers, little information is available on actual transmission rates achieved in practice in occupied dwellings — except for the reported failures in construction leading to the need for BRE guidance [8].

4. In existing dwellings, where retrofit insulation is installed in lofts, there is a large need for paint systems, including requisite fillers, which could reliably increase the vapour resistance of ceilings by filling of cracks and overpainting. The target value of 15 GNs/kg to be achieved should not be too onerous — gloss paints already achieve resistances in the order of 8 GNs/kg. Needless to say, such paint systems would be equally applicable to new construction. Ease of use and reliability on ageing would be the main points in establishing the usefulness of such vapour-controlling paint systems [9].

Further comments on this topic would be welcome; they should be addressed to the Deputy Technical Policy Architect (7562).

REFERENCES

1 *Dampness — one week's complaints in five local authorities in England and Wales.* Sanders C H and Cornish J P, BRE Report, 1982, HMSO.

2 *Condensation in housing,* Scottish Development Department, Building Directorate, Scottish Office Library, Edinburgh, May 1984.

3 GLC "INSULATION", Report SCE 10 to Science and Energy Panel, 5 July 1983.

4 GLC, "SOLAR ENERGY", Report SCE 11 to Science and Energy Panel, 5 July 1983.

5 "The Journal of the Chartered Institution of Building Services", September 1984, p 28 ff.

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7 BRE Information Paper IP 21/82, Building Research Station, Garston, Watford WD2 7JR.

8 "Defect Action Sheets", Housing Defects Prevention Unit, Building Research Station, Garston, Watford WD2 7JR.

9 GLC D&M Bulletin 141/9 "Interstitial condensation — assessment of risk" J C D Twiston Davies

10 GLC D&M Bulletin 142/9 "Condensation — prevention better than cure" L M Hohmann

Table 1 Winter condensation

Climate:

	air temp (deg C)	RH (%)	Vp (kPa)	Vps kPa)	M(e) g/kg	MS(e) g/kg
Internal	20.0	75.0	1.752	2.335		
External: Winter	2.2	93.9	0.671	0.715	4.168	4.440
Summer	12.8	82.8	1.222	1.476	7.629	9.237

Layer no	Description	Lx (m)	kx W/mK	rvx (GNs/kgm)	tx (deg C)	Vpx (kPa)	Vpsx (kPa)	Results to BS 5250:1975
-	inside air				20.000	1.752	2.335	
-	surface res				19.040	1.752	2.200	ok
1	Plasterboard	0.013	0.160	35.000	18.260	1.751	2.095	ok
2	Eps	0.010	0.035	100.000	15.516	1.750	1.760	ok
3	Void	0.200	1.111	5.200	13.787	1.748	1.575	See Fig 1
4	Boarding	0.020	0.140	100.000	12.416	1.746	1.440	See Fig 1
5	Felt	0.003	0.133	1500.000	12.199	1.740	1.419	See Fig 1
6	Eps	0.010	0.035	100.000	9.455	1.739	1.182	See Fig 1
7	Felt	0.003	0.133	1500.000	9.239	1.733	1.165	See Fig 1
8	Eps	0.010	0.035	100.000	6.495	1.732	0.966	See Fig 1
9	Cork	0.015	0.042	52.000	3.066	1.731	0.760	See Fig 1
10	3-Lyr Felt	0.008	0.133	1E+05	2.488	0.671	0.730	ok
-	surface res				2.200	0.671	0.715	ok
-	ext air				2.200	0.671	0.715	

U - Value — 0.539 W/m²K (for standardised surface resistances).

Condensation quantities		kg/m² 60 days	Lyr no.	Int'f no.	condensate	Known Actual Vapour Pressure (Vpx—Vpsx at condensation planes)	
at intl surface	ok			1		1.752	
at interface 1/2	ok	0.000	1/2	2			See Table 2
2/3	ok	0.000	2/3	3			See Table 2
(layer 3/4	cond	0.018	3/4	4	0.018	1.575	
numbers) 4/5	cond	0.051	4/5	5	0.051	1.440	
5/6	ok	0.000	5/6	6			See Table 2
6/7	ok	0.000	6/7	7			See Table 2
7/8	ok	0.000	7/8	8			See Table 2
8/9	ok	0.000	8/9	9			See Table 2
9/10	cond	0.298	9/10	10	0.298	0.760	
at extl surface	ok	0.000		11		0.671	
Total condensate:		0.367 kg/m²			0.367 kg/m²		

Table 2 Summer Evaporation

Climate:

	air temp (deg C)	RH (%)	Vp (kPa)	Vps kPa)
Internal	20.0	75.0	1.752	2.335
External: Winter	2.2	93.9	0.671	0.715
Summer	12.8	82.8	1.222	1.476

Layer no	Description	Lx (m)	kx (W/mK)	rvx (GNs/kgm)	tx (deg C)	Vpx (kPa)	Vpsx (kPa)	Results to BS 5250:1975
-	inside air				20.000	1.752	2.335	
-	surface res				19.612	1.752	2.280	ok
1	Plasterboard	0.013	0.160	35.000	19.296	1.751	2.236	ok
2	Eps	0.010	0.035	100.000	18.186	1.751	2.086	ok
3	Void	0.200	1.111	5.200	17.487	1.750	1.996	ok
4	Boarding	0.020	0.140	100.000	16.932	1.749	1.927	ok
5	Felt	0.003	0.133	1500.000	16.845	1.746	1.916	ok
6	Eps	0.010	0.035	100.000	15.735	1.745	1.785	ok
7	Felt	0.003	0.133	2E+03	15.647	1.743	1.775	ok
8	Eps	0.010	0.035	100.000	14.537	1.742	1.653	cond
9	Cork	0.015	0.042	52.000	13.150	1.741	1.511	cond
10	3-Lyr Felt	0.008	0.133	1E+05	12.917	1.222	1.488	ok
-	surface res				12.800	1.222	1.476	ok
-	ext air				12.800	1.222	1.476	

U - Value — 0.539 W/m²K (for standardised surface resistances).

Condensation quantities		Winter: real Vp:	Winter:	emc of timber (if any) Winter:	Summer:	Evaporation kg/² 60 days Summer:	
at intl surface	ok	1.752		15.9%	15.0%	0.000	
at interface 1/2	ok	1.719	0.000	16.8%	15.5%	0.000	
2/3	ok	1.648	0.000	21.6%	17.4%	0.000	
3/4	cond	1.575	0.018	24.8% -water	18.8%	0.507	cf: emc's
4/5	cond	1.440	0.051	25.0% -water	20.1%	0.000	cf: emc's
5/6	ok	1.180	0.000	18.0%	20.3%	0.000	
6/7	ok	1.122	0.000	23.0%	23.3%	0.000	cf: emc's
7/8	ok	0.863	0.000	15.2%	23.5%	0.000	cf: emc's
8/9	ok	0.805	0.000	18.3%	27.4%	0.000	cf: emc's
9/10	cond	0.760	0.298	25.4% -water	33.7%+water-	0.075 cond	cf: emc's
at extl surface	ok	0.671	0.000	21.6%	17.5%	0.000	

Total condensate: 0.367 kg/m² Total evaporation: −0.075 kg/m² REDESIGN

ANNUAL BALANCE: −0.442 kg/m² Compare evaporation to condensation at each interface, totals alone may not reflect interface conditions.