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An Independent Analysis of the Thermal Characteristics of Irish Concrete Hollow Blocks and Hollow Block Wall Upgrades and a Discussion on Hollow Block Design

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An independent analysis of the thermal characteristics of Irish concrete hollow blocks and hollow block wall upgrades and a discussion on hollow block design

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1.0 Preface

Hollow block walls, whether originally built with external render and internal plaster, or more recently with external render and insulated drylining, represent the most common form of wall construction in Leinster over the last 50 years (see image in Figure 8). In terms of vapour movement, air movement and thermal performance it is also one of the least understood forms of construction practiced in Ireland.

This technical paper and two articles by the same author published by Construct Ireland in February and May 2009 (Issues 6 & 7, Vol. 4) form a concerted effort to rectify this knowledge deficit. It is our wish that together these information sources will enable homeowners, architects and builders to deal better with the legacy of this problematic form of construction. The current situation, particularly in relation to filling of cavities, where installers do not understand the full picture (i.e. the consequences for thermal performance, weather tightness and health) and are thus advising values that are unachievable or incorrectly estimated, must be controlled and misrepresentation stopped for the sake of consumers.

Joseph Little Architects

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1.1 Establishing the thermal performance of a bridged layer

U-value calculation at its simplest relates to plane elements of the external envelope that are parallel and uniform. In reality many buildups have non-uniformities, such as the timber studs in a drylined wall or the concrete webs connecting each side of a hollow block. The consequence of non-uniformities is that heat no longer flows in straight lines. The effect of the total heat transfer needs to be allowed for within U-value calculations. The most popular and simple approach is to use the 'Combined Method' as set out in IS EN ISO 6946 [1]. However there are numerous other approaches using detailed computer calculation, generally called *numerical methods*, which are more accurate and can take account of two and three dimensional heat flow.

The 'Combined Method' involves calculation of the upper and lower limits of Thermal Resistance of the elements. Any non-uniform layer is treated as a bridged layer.

> *'The Standard calculates the U-value of the component from the arithmetic mean of these two limits. While the true result always lies somewhere between the two limits, the equal weighting can be an inadequate approximation when the difference between the limits is large.'*
>
> *BR 443, Section 2* [2]

In our study we initially evaluate an individual block using the 'Combined Method' of IS EN ISO 6946 to establish its Thermal Resistance. We then go on to study variations of a length of wall constructed primarily of hollow blocks. We look at these variations using a *numerical method* and then comparing the results to those obtained with the *'Combined Method'.* The calculations for the numerical analysis have been carried out with computer software for two-dimensional conduction heat-transfer analysis [3] based on the finite element method.

The level of difference we found between the mean Thermal Resistance (using the first method) and the calculated Thermal Resistance (using the second method) for a hollow block wall where the cavities are filled with insulation bears out exactly the quote from BR 443 above. An equal weighting of the upper and lower limits of Thermal Resistance is an inadequate approximation for this specific case. In fact it is totally misleading as it over-estimates the level of improvement in filling the cavities by 52% (see Sections 3.2 and 3.5 below).

2.0 Calculation of the mean Thermal Resistance for a single concrete hollow block using the 'Combined Method'

For all calculations in this paper a conductivity (λ) value of 1.33 W/mK has been assumed for concrete with 2000 kg/m³ density, as per Table A1 in Appendix A of TGD L (2007) [4]. The calculation procedure to establish the mean Thermal Resistance as per the 'Combined Method' of IS EN ISO 6946 can be found in TGD L (2007), Appendix A2.2: *Structure with bridged layer(s)*.

Please note the figure we established for the Thermal Resistance of a single hollow block (0.238 m²K/W) is slightly better than that given in TGD L (2007) [5] and that which may be obtained using the free 'Uvaluate' software, 0.21 m²K/W. This is because we have calculated the resistance of the small airspaces in the block cavities as specified in IS EN ISO 6946, Annex B.4: *Thermal Resistance of small or divided unventilated airspaces – air voids*. The sources cited above assume a simpler model where the void is continuous, and thus calculate a lower Thermal Resistance.

The upper and lower limits of Thermal Resistance are established by two different models for the movement of energy through a bridged structure: the 'parallel heat flow model' and the 'parallel isotherm model'. The 'parallel heat flow model' assumes heat to flow in parallel lines which are perpendicular to the element's surfaces, so no lateral deviations of heat exist. This model gives the upper bound for the resistance. The 'parallel isotherm model' assumes that planes parallel to the block's surface are at uniform temperature (isothermal). In this case, so as long as materials with different conductivities are involved, a lateral movement of heat must therefore exist. This model gives the lower bound for the resistance.

2.1 Upper Thermal Resistance

Assuming that heat flows in straight lines perpendicular to the element's surfaces, there are two heat flow paths – (a) through the concrete webs and (b) through the cavities. The resistance of each of these paths is calculated as follows.

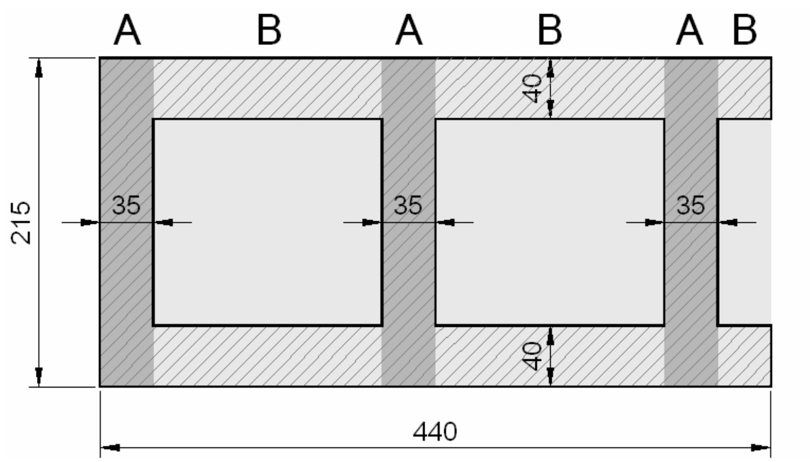

Figure 1: calculating the 'parallel heat flow model'

Fractional areas:

$F_A = 3 \times 35 / 440 = 0.239$

$F_B = 1 – F_A = 0.761$

Resistance through fractional area A:

$R_A = 0.215$ m / 1.33 W/mK = 0.162 m²K/W

Resistance through fractional area B:

(resistance of airspace calculated through IS EN ISO 6946, as per BR 497[6])

$R_g = 0.226$ m²K/W

$R_B = 2 \times 0.04$ m / 1.33 W/mK + 0.226 m²K/W = 0.286 m²K/W

The upper Thermal Resistance is $R_U = 1 / (F_A / R_A + F_B / R_B)$ = **0.242 m²K/W**

2.2 Lower Thermal Resistance

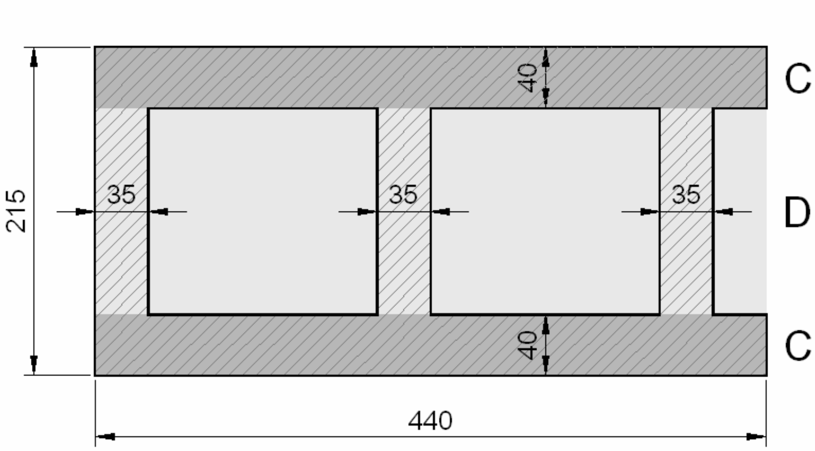

Figure 2: calculating the 'parallel isotherm model'

Assuming an isothermal plane on each face of the bridged layer, the resistances of all layers are combined in series to give the lower resistance.

R_C = 2 x 0.04 m / 1.33 W/mK = 0.060 m²K/W

$R_D = 1 / (F_{D\ (webs)} / R_{D\ (webs)} + F_{D\ (cavities)} / R_{D\ (cavities)})$

$F_{D\ (webs)}$ = 3 x 35 / 440 = 0.239
$F_{D\ (cavities)} = 1 – F_{D\ (webs)}$ = 0.761

$R_{D\ (webs)}$ = (0.215 – 2 x 0.04) m / 1.33 W/mK = 0.102 m²K/W
$R_{D\ (cavities)} = R_g$ = 0.226 m²K/W

From these values R_D = 0.175 m²K/W

The lower resistance is $R_L = R_C + R_D$ = **0.235 m²K/W**

2.3 Total, or mean, Thermal Resistance

The total Thermal Resistance is assumed to be the mean of the upper and lower resistances.

The total, or mean, Thermal Resistance is $R_T = (R_U + R_L) / 2$ = **0.238 m²K/W**

3.0 Calculation of the U-value and Thermal Resistance for concrete hollow block walls using the 'Combined' and Numerical Methods

In this set of calculations we are looking at the performance of a metre long length of an external wall where hollow blocks have been used, using numerical analysis methods. Please note that the corner of a wall represented in the graphics below is illustrative only: the calculations are based on a straight section of wall.

These calculations for hollow block walls do not take into account of the effect of mortar joints as allowed in TGD L (2007) Appendix A1.2 as they are generalised for a plane length of wall. They also do not take account of localised changes in the wall buildup, such as (1) a band beam, a junction of two walls or local reinforcement at a door jamb, nor (2) penetrations through the wall such as those created for gas flues, inset electricity boxes, eave conditions where the top of the wall has not been closed-off, or bad workmanship. Since TGD L (2007) came into force our Building Regulations have at last made detailed provision for the first category (linear thermal bridges) but make none for the second category. This latter group could significantly worsen a hollow block wall's performance in terms of thermal efficiency and wind- and air-tightness. Other countries, such as Sweden, have long allowed a factor against quality of workmanship and the localised under-performance in their building regulations.

3.1 Existing wall

This wall represents the original construction of many houses built from the Second World War to mid-1970s with external render and internal plaster.

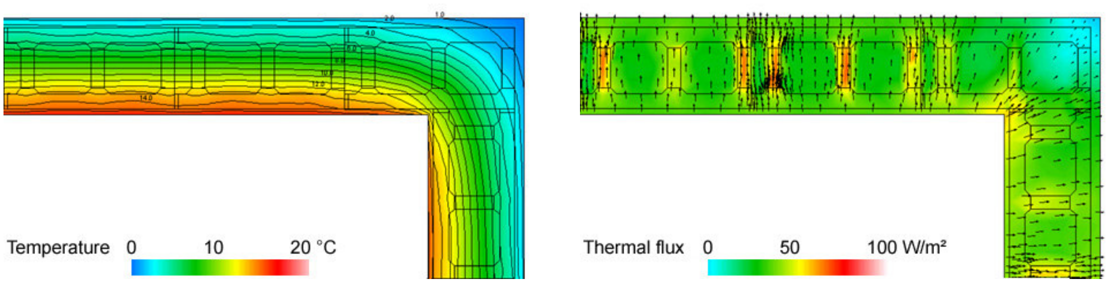

Figure 3: temperature and heat flux diagrams for an existing wall

Buildup (listed from inside):
Internal surface resistance
15 mm plaster (gypsum), on
215 mm concrete hollow block (40 + 135 + 40) with air layer horizontal heat flow, on
20 mm external rendering (cement/sand)
External surface resistance

U-value = 2.09 W/m²K **Thermal Resistance R = 0.48 m²K/W**

3.2 Existing wall cavities filled with insulation

This condition represents the discredited practice of filling the cavities in the hollow block wall. No other changes are made to the original wall.

The numerical analysis proves that filling these cavities gives a substantially smaller reduction to the U-value of the original wall (~33%) than suggested by the 'Combined Method' (as set out in TGD L Appendix A 2.2). When used the latter methodology gives a reduction of ~50% from the U-value of the original wall, which we can prove is an over-estimation of the value of filling the cavities of 52%. See Figure 7 for comparison of the calculated U-value with that approximated under the 'Combined Method'. Please also see Construct Ireland magazine (Issues 6 & 7, Vol. 4, published February & May 2009) for additional information on problems associated with filling cavities of hollow block walls.

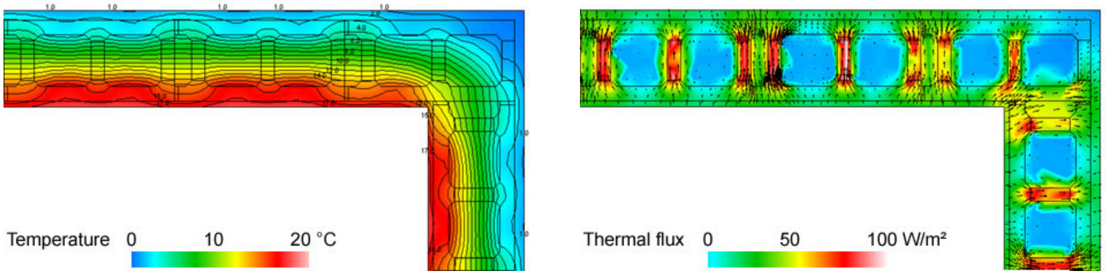

Figure 4: temperature and heat flux diagrams for a wall with insulation fill in its cavities

Buildup (listed from inside):
Internal surface resistance
15 mm plaster (gypsum), on
215 mm concrete hollow block (40 + 135 + 40) cavities filled with EPS (λ = 0.04 W/mK), on 20 mm external rendering (cement/sand)
External surface resistance

U-value = 1.33 W/m²K **Thermal Resistance R = 0.75 m²K/W**

3.3 Existing wall drylined

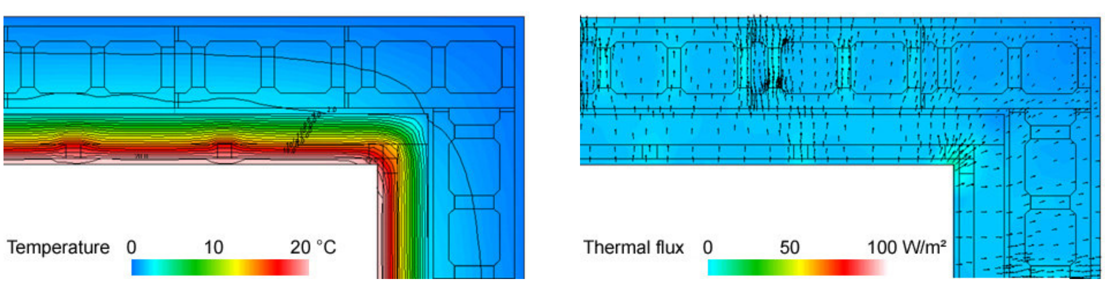

Figure 5: temperature and heat flux diagrams for a drylined wall

Buildup (listed from inside):
Internal surface resistance
15 mm plasterboard, on
38 mm sheep wool (λ = 0.04 W/mK) between timber battens, on
80 mm wood fibre board (λ = 0.04 W/mK), on
15 mm plaster, on
215 mm concrete hollow block (40 + 135 + 40) with air layer horizontal heat flow, on
20 mm external rendering (cement/sand)
External surface resistance

U-value = 0.30 W/m²K **Thermal Resistance R = 3.37 m²K/W**

3.4 Existing wall externally insulated

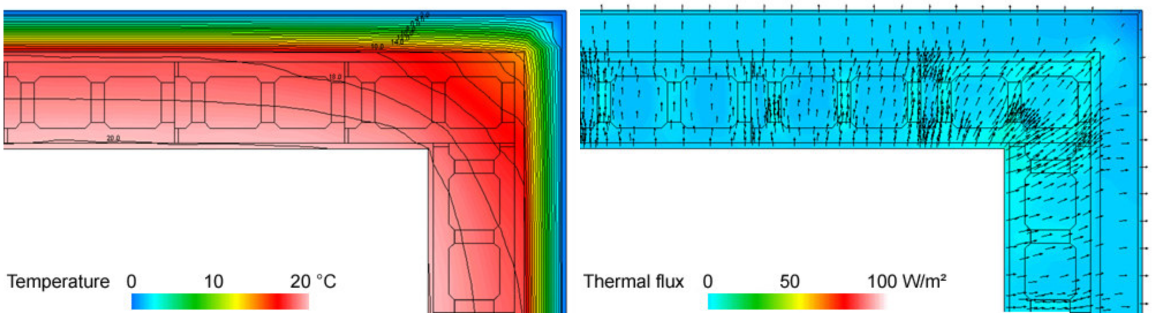

Figure 6: temperature and heat flux diagrams for an externally insulated wall

Buildup (listed from inside)
Internal surface resistance
15 mm plaster, on
215 mm concrete hollow block (40 + 135 + 40) with air layer horizontal heat flow, on
20 mm rendering (cement/sand), on
100 mm expanded polystyrene (λ = 0.04 W/mK), on
10 mm external rendering
External surface resistance

U-value = 0.33 W/m²K **Thermal Resistance R = 3.13 m²K/W**

3.5 Comparison of Thermal Resistance results obtained from numerical method and 'Combined Method' for variations of a hollow block wall (as per 3.1 to 3.4)

Figure 7 below is very instructive in that it visually compares the results gained from the 'Combined Method' (in red) with those from numerical analysis (in blue). Thermal Resistance values are presented on a linear scale.

As stated already the 'Combined Method' takes the mean of an upper and lower limit of Thermal Resistance (obtained from two different models of calculation) as an acceptable approximation for the actual Thermal Resistance of a bridged structure. However, BR 443 states that the mean can be 'an inadequate approximation' where the limits are far apart. Just such an incidence of a large gap between limits can be seen in the case where the cavities are filled below.

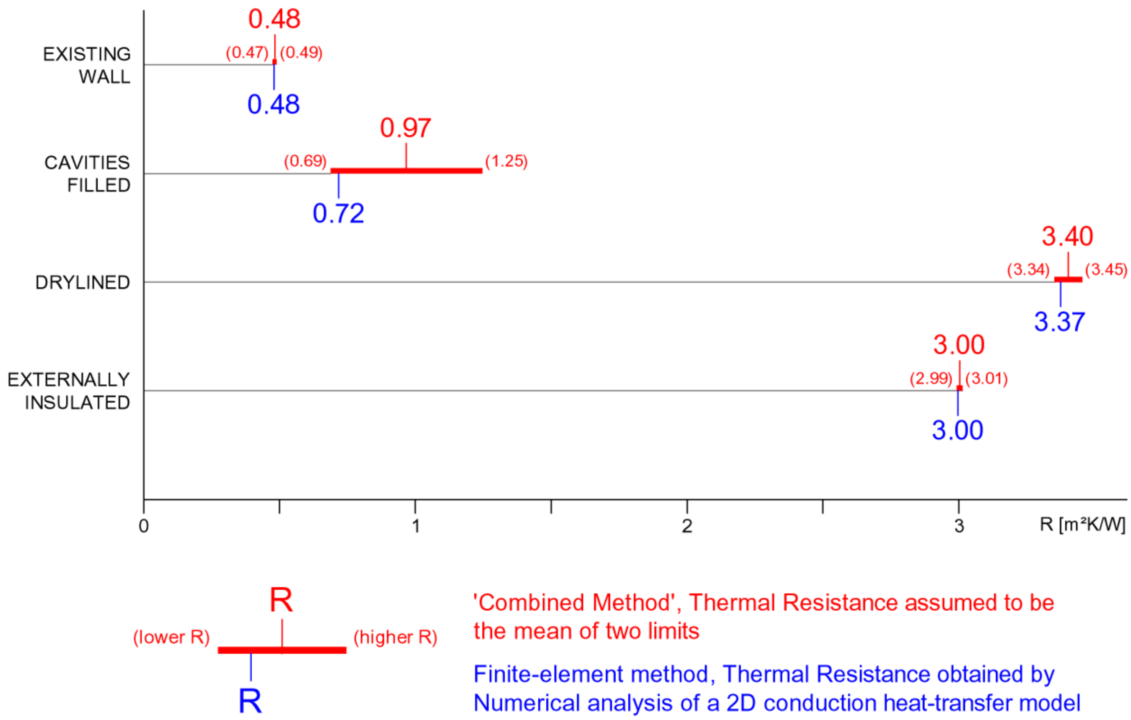

Figure 7: Comparing results from the 'Combined Method' and numerical analysis

In assessing the thermal performance of a structure with non-uniformities (or bridged layers), several factors have to be considered: (issue 1) the thermal conductivity of both materials, especially that of the material that is bridging, (issue 2) the ratio between both conductivities, and (issue 3) geometrical issues involving the bridging fraction and the shape and relative position of such bridges.

The ratio between the thermal conductivities critically affects the distance between the upper and lower limit. When the ratio is reasonably close (i.e. below 5:1) the geometrical factors have a low impact. However, when the difference between the conductivities is large, geometrical issues can become critical and then must be considered.

When using the 'Combined Method' to assess a timber-frame wall or a domestic pitched roof (as shown in A2 and A3 of Appendix A of TGD L (2007)) for instance, the mean is very near to the calculated value and the upper and lower limits of Thermal Resistance are quite close. Because (issue 1) the thermal conductivity of the softwood timber (0.13 W/mK) is reasonably low, (issue 2) the ratio between the conductivities is small (softwood timber has a conductivity about three times greater than mineral wool) and (issue 3) as the distance between the timber studs is usually many times larger than the layer thickness, a significant part of the heat goes through the insulation rather than travel the long path to avoid it.

If we compare this case with a hollow block, we have to consider that (issue 1) the thermal conductivity of concrete is much higher (1.33 W/mK). On the other hand, (issue 2) the thermal performance ratio between concrete and air in these blocks (2.22:1) is in fact in the same range as that between timber studs and mineral wool (3.25:1). This means that the upper and lower limits will be close *in cases where the cavities are left unfilled*. However what makes the mean inaccurate here is the internal geometry of the block, since (issue 3) the concrete webs are large and almost the same distance apart as they are long, making it easier for a greater portion of heat to follow the line of least thermal resistance. This explains why all four examples in Figure 7 above show their calculated Thermal Resistance closer to the left (i.e. the lower limit predicted by the 'parallel isotherm model') than would be found in a study of a normal timber framed structure for instance. However the closeness of the upper and lower limits to each other in the examples with unfilled cavities still leaves the means as relatively adequate approximations.

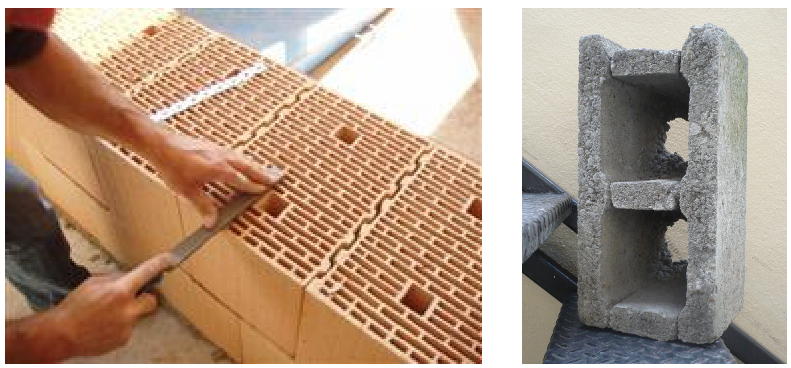

Figure 8: 'Thermoplan Ziegel' wall from NBT and an Irish hollow block

When the cavities of the Irish hollow block are insulated the shift towards the lower limit of Thermal Resistance (i.e. left of the mean in Figure 7) is much exaggerated and the distance between the limits greatly extends. This is because the difference in thermal performance between concrete and insulation jumps to a ~33:1 ratio. This extreme difference in thermal performance now compounds the effect of the specific geometry and a thermally unstable, under-performing composite structure results. The thermal flux image in Figure 4 shows how extreme the energy flow along the path of the webs becomes in this case. It is important to remember that not just heat but vapour too will now travel far quicker along these paths than before.

The Irish hollow block, due to its material and its shape, is representative of the poorest performing hollow blocks being manufactured in Europe today. A different geometry where there are, for instance, many medium-sized staggered slotted cavities, or better still hundreds of small slotted or pencil-shaped cavities, will give a higher Thermal Resistance for the same total void area. This is because the route around the many small cavities becomes longer and longer forcing a greater portion of heat to travel through the voids.

Many British, French and German manufacturers of hollow blocks have long understood this, combining these geometric advantages with materials with far lower thermal conductivities such as autoclaved aerated concrete or terracotta. The fhermal conductivity of the former can be 0.17 W/mK, while the latter can be as low as 0.1 W/mK. In contrast heavyweight concrete used in hollow blocks is up at 1.33 W/mK, ten times worse. Good examples of terracotta cellular blocks are the 'Poroton' blocks imported by FBT and NBT's 'Thermplan Ziegel' blocks imported by Lochplace, Econstruction and Lagan Bricks.

3.6 Conclusion

We hope this study elucidates a relatively dark corner of the world of thermal performance assessment, the impact of bridged layers. It should certainly be clear from the work that the 'Combined Method' is not intended to be used for the assessment of the value of filing the cavities of hollow blocks.

The numerical analysis shown and discussed above proves that filling the cavities of hollow blocks gives a substantially smaller reduction to the U-value of the original wall (~33%) than suggested by the 'Combined Method' (as set out in TGD L Appendix A 2.2). The latter calculates a reduction of ~50% from the U-value of the original wall, which we have shown is an over-estimation of the value of filling the cavities of 52%. This is a shocking over-estimation. Even if there will be a certain level of improvement in the wall's general thermal performance (under normal conditions) it will not be of the order that homeowner is paying for or would gain from another approach.

In light of this research and given the wider discussion in the 'Breaking the Mould' articles that appeared in Construct Ireland magazine (Issues 6 & 7, Vol. 4, published February & May 2009) we ask what is being done to control or police a situation where homeowners are being encouraged by 'men in white vans' to use an insulating system that is based on inappropriate methodologies, inaccurate calculations and results in an external wall that is unstable in terms of heat and vapour. This practice needs to be clearly and publicly discredited.

The Irish hollow block, with its large squarish voids, made of dense highly-conductive concrete, is representative of the very poorest thermal performing hollow blocks being manufactured in Europe today. We are confident that the technology and know-how is available in Ireland to replace this block with a far, far better performing block on the model set-out above. In light of the national targets for both carbon reductions and energy efficiency in both use and construction (and the international context in which those targets have been set) we advise that the use of Irish hollow blocks as currently-designed for purposes other than sheds or the inner leaf of cavity walls should cease.

We would be happy however to assist in the design of an Irish-made low carbon and thermally high-performing alternative.

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[1] ISO (2007), *EN ISO 6946 - Building components and building elements – Thermal resistance and thermal transmittance – Calculation method*, Geneva, ISO
[2] BRE (2006), *BR 443 - Conventions for U-value calculations*, Watford, BRE
[3] We used THERM Finite Element Simulator from LBL, version 5.0. This is freely downloadable but must be used alongside a range of standards and explanatory documents (a good one being BR 497) and the user's own spreadsheet
[4] DoEHLG (2007), *Technical Guidance Document L: Conservation of Fuel and Energy – Dwellings*, Dublin, Stationery Office
[5] *Ibid.,* Table B17, p.56
[6] Ward, T. & Sanders, C. (2007), *BR 497 - Conventions for calculating linear thermal transmittance and temperature factors,* Watford, BRE