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Sustainable Timber Frame Diaphragm Development

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ABSTRACT

The EU Directive on Energy Performance of Buildings has the aim of promoting energy performance within the EU and will have a direct impact on current timber frame construction in the UK. As a result of the directive, changes to Part L of the Building Regulations have been implemented in England and Wales with Scotland undertaking amendments to Section 6.1of the Technical Standards in 2007.

To reach the requirements of the Directive it is perceived a timber frame wall detail will have to attain a U-value of 0.27 W/m^{2}K. This paper details a study which was undertaken to derive the optimum option giving due consideration to practicality, cost, sustainability and structural performance.

Key words: Timber Frame Construction, Domestic Dwellings, EU Directive, Wall Diaphragms

1. INTRODUCTION

Timber frame as a method of domestic dwelling construction is experiencing continual growth in the UK due to it lending itself to modern methods of construction, being environmentally efficient and exhibiting structural robustness. However, modern day issues relating to the construction industry require increased fabrication to be carried out off-site such as, the application of insulation, inclusion of services and installation of windows and doors. Continual Government tightening of environmental legislation is resulting in more stringent regulations and will continue to do so in years to come. Therefore, timber frame has to optimise its use of material components to achieve and indeed better future requirements.

2. TIMBER FRAME CONSTRUCTION

According to the latest figures released by the UK Timber Frame Association (2005), Timber Frame Construction grew in the UK by 18% in 2004, compared to a 7.4% increase for all other methods of construction. Timber frame as a result now has a 17% market share in the UK (Scotland 65%, England 10.8%, Wales 10.9% & N. Ireland 7%). As a method of construction timber frame has shown steady year on year market growth, this is due in part to its procurement and construction procedures being inline with the principals of the Construction Task Force Report (1998), its ability to conform with tighter building regulations and its environmental credentials.

The timber frame industry has endorsed partnering arrangements with both the private and public sector and as a result the construction process has improved making it faster and more efficient than other forms. Timber frame lends itself to Off-Site construction and there is now an accredited quality assurance scheme, Q-Mark (The UKTFA Quality Scheme) which covers design, manufacturing and erection. In addition to this a *timber frame erector* is now a recognised trade and the recently launched City & Guilds accredited training programme in the UK will further enhance its industry profile.

The benefits of Off-Site construction are mainly improved time, cost and quality (Gibb and Isack, 2003) and this is reflected in timber frame. Generally the level of off-site construction of timber frame is currently the pre-assembly of wall diaphragms and floor cassettes (Figure 1). However, it is perceived that future advancements in this area would be the application of insulation in the factory, inclusion of services and installation of windows and doors resulting in finished pre-assembled components.

3. SUSTAINABILITY

As a material timber is generally considered to have excellent environmental credentials as it is naturally renewable, easily worked and non-toxic. As a renewable resource, its main attribute is that it absorbs and thus reduces the amount of CO_2 in the atmosphere, only released if it decays or is burnt. In essence every cubic metre of timber used in place of other building materials saves the release of 0.8t of CO_2. Considering an average detached timber frame house this equates to around 4 to 5 tonnes of CO_2 (Harris, 2005).

Figure 1: Timber platform frame during construction

Timber frame is also environmentally efficient when considering the building envelope and falls comfortably within the UK Governments priorities of reducing climate change and providing a low carbon economy with sustainable production and consumption; all with duty of care towards natural resources. In endorsing the EU directive on Energy Performance of Buildings (2002) the recent introduction of the revised Part L of the Building Regulations (2006) will lead to an improvement in the energy efficiency of buildings by around 20%. This improvement in conjunction with other requirements will result in wall U-values in domestic dwellings to be $0.27W/m^2K$.

4. TIMBER FRAME WALL

Shown in Figure 2 is a traditional timber frame wall detail in UK construction with a 50mm outside cavity and external masonry skin the U-value of which is $0.40W/m^2K$. Therefore, the thermal rating of timber frame walls will have to improve. However, timber frame is at an advantage when considering other forms of construction as a result of being able to comply through a number of available options.

The amount of thermal bridging can be reduced. Thermal bridging in timber frame walls is normally caused by gaps in insulation layers within the fabric, structural elements, especially lintels and frames, joints between elements and joints around windows and doors. In regards to this the incorporation of 'Robust Detailing' in the form of a fibre cavity barrier as a replacement to timber is beneficial.

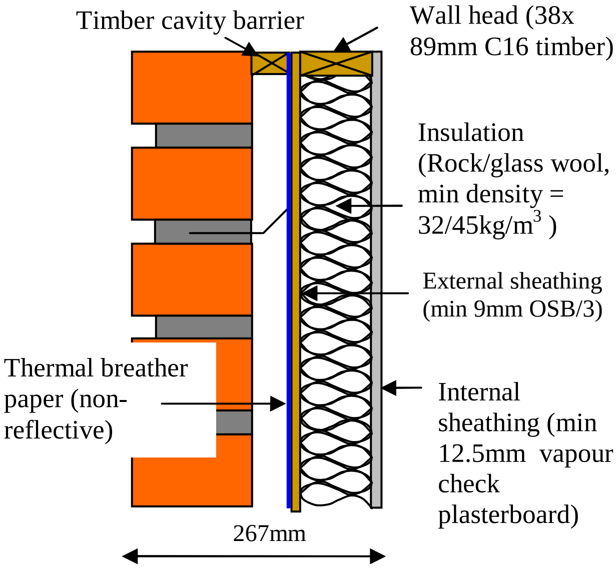


Figure 2: Standard timber frame wall detail

Use of a low emissivity surface in the form of reflective breather paper can reduce the radiation transfer across an airspace, so that the airspace has a higher thermal resistance which results in a constant U-value rating reduction of 0.02 W/m^2K compared with one bounded by surfaces of normal (high) emissivity. It is to be noted that low emissivity can not be considered to have an effect on the U-value if the surface is not adjacent to an airspace of at least 22mm wide in the construction (Ward, 2001).

Internal or external sheathing with improved thermal conductivity can be used. However, this is limited as the primary function of the external sheathing is to provide racking resistance to the wall diaphragm and as a result is required to be a Category 1 primary board material (BS 5268: Section 6.1: 1998), examples of which are 9.5mm plywood, 9.0mm medium board, 6.0mm tempered hardboard or 9.0mm oriented strand board grade 3 (OSB/3) which normally have a thermal conductivity, λ value, of 0.13Wm/K. The thermal conductivity performance of external sheathing can be improved by processes such as bitumen impregnation but this is limited to 0.05Wm/K (Hunton Fibre, 1994). In regards to the internal sheathing a 12.5mm minimum thickness of plasterboard (λ = 0.29Wm/K) is required for external walls in domestic dwellings such that fire and sound transfer regulations are met. In instances where added racking resistance is required an internal sheathing layer of Category 1 primary board material would be added although the added benefit in terms of thermal performance is limited, Figure 3 shows the relationship between sheathing thickness for a range of λ values when considering the wall detail in Figure 2 incorporating a fibre cavity barrier and a low emissivity cavity. The sheathing thickness given could be an accumulative thickness, i.e. 9mm internal and external sheathing of the same λ value would result in 18mm thickness.

The insulation contained within the wall can be a variety of materials, as shown in Table 1, the thickness of which is determined by the stud width. External timber frame wall studs are limited to a minimum size of 38x72mm by BS 5268: Section 6.1, but normal practice is to use either a 38mm thick by 89 or 140mm wide C16 timber section although other available stud widths include 97, 114, 120, 145, 170, 184 and 195mm (TRADA, 2005). In particular a 38x89mm stud, which is currently the common stud size, is the preferred option as a result of availability of section and also due to the fact it limits the erosion of the surface area of the dwelling.

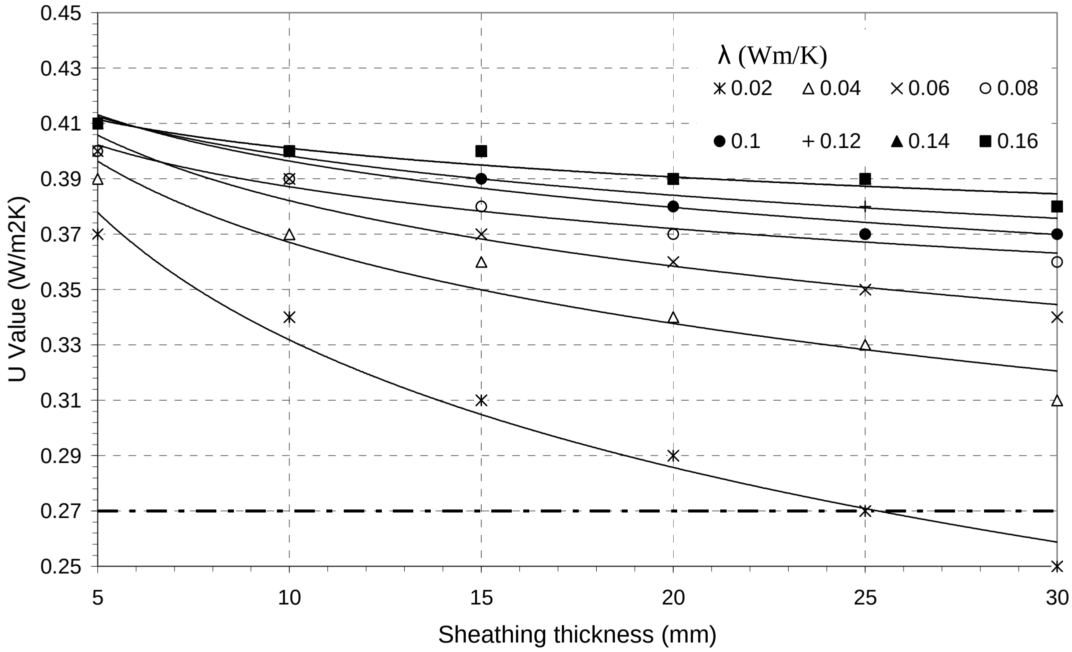


Figure 3: Relationship of wall detail U-value with changing sheathing thickness and λ value

Table 1 Insulation materials and their associated ratings

Insulation Type	Life Cycle Assessment	Thermal conductivity, λ (Wm/K)	Cost £/m^2
Corkboard insulation with density 120kg/m^3	Medium	0.050 – 0.040	£7 - £11
Expanded polystyrene (EPS)	Low	0.040 – 0.032	£5 - £7
Extruded polystyrene (XPS) (HCFC free) with density less than 40kg/m^3	High	0.036 – 0.027	£10 -£12
Foamed glass insulation	Medium	0.042	£14 - £17
Glass wool insulation with a density of 10 - 32kg/m^3	Low	0.040 – 0.033	£2 - £10
Rock wool insulation with a density of 23 - 45kg/m^3	Low	0.033 – 0.040	£1 - £15
Polyurethane insulation (PU) (HCFC free)	Medium	0.028 – 0.022	£7 - £8
Recycled cellulose insulation	Low	0.044 – 0.038	£2 - £4

The environmental ratings contained in Table 1 are based on Life Cycle Assessment (LCA) considering a 60-year building design life, the costs are indicative as built costs inclusive of materials, labour and plant (Howard & Anderson, 1998) with thermal conductivity based on information from Elmurst SAP Energy Rating Software (BRE accredited software). Figure 4 shows the relationship between internal insulation (between studs) thickness for a range of λ values when considering the wall detail in Figure 2 incorporating a fibre cavity barrier along with a low emissivity cavity.

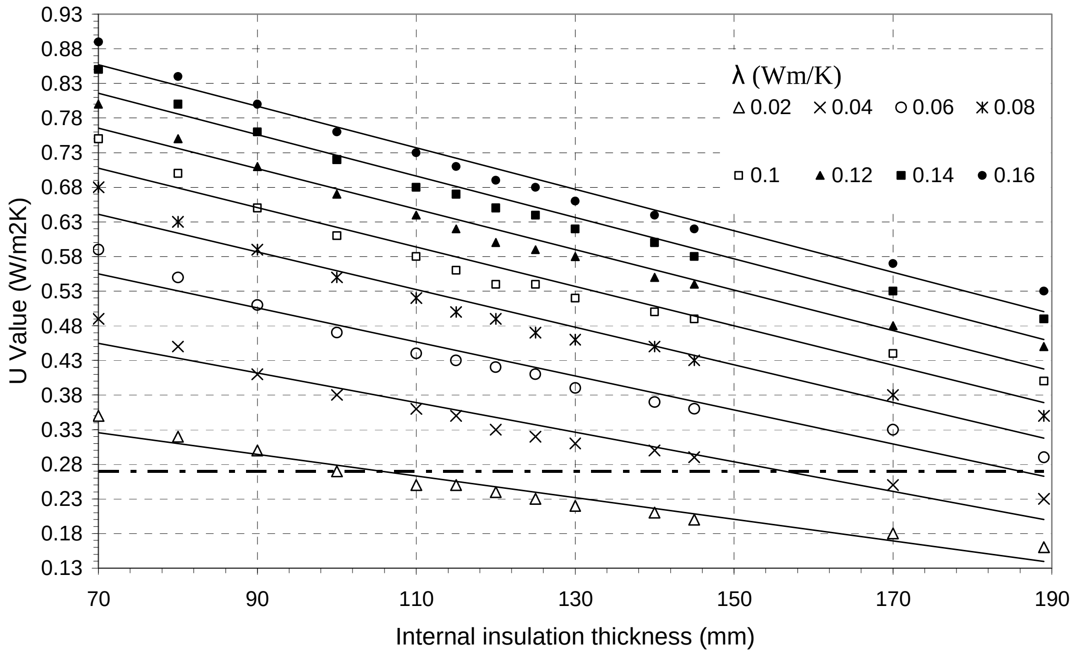


Figure 4: Relationship of wall detail U-value with internal insulation(between studs) thickness and λ value

Further to this an internal or external thermal laminate can also be applied. A thermal laminate will normally be fixed to the external sheathing board by stainless steel nails at specified centres up to a maximum thickness of 50mm due to on-site practicality. Internally thermal laminate will be fixed to the studs or internal sheathing material beneath the plasterboard. Alternatively the internal thermal laminate will form part of the wallboard whereby the thermal laminate is bonded to the plasterboard prior to fixing which could be placed upon battens to form a service void. Figure 5 shows the relationship between thermal laminate thickness for a range of lambda values when considering the wall detail in Figure 2 incorporating a fibre cavity barrier and a low emissivity cavity.

Considering the relationships contained in Figures 3 to 5 and the associated trend lines, with R^2 values of the order of 0.97 or above, equation 1 was derived to conservatively estimate the U-value of a timber frame wall detail as shown in Figure 2 incorporating robust detailing, a layer of 12.5mm plasterboard on the internal face, a low emissivity cavity and the following parameters are met:

λ_{el} is the thermal conductivity of the external thermal laminate in $Wm^{-1}K^{-1}$ ($0.02 \leq \lambda_{el} \leq 0.16$)
λ_{sh} is the thermal conductivity of the sheathing material in $Wm^{-1}K^{-1}$ ($0.06 \leq \lambda_{sh} \leq 0.16$[1])
λ_{il} is the thermal conductivity of the internal thermal laminate in $Wm^{-1}K^{-1}$ ($0.02 \leq \lambda_{il} \leq 0.16$)
λ_{ii} is the thermal conductivity of the internal insulation (between studs)in $Wm^{-1}K^{-1}$ ($0.02 \leq \lambda_{ii} \leq 0.06$)
t_{el} is the thickness of the external thermal laminate in mm ($5 \leq t_{el} \leq 40$)
t_{sh} is the thickness of the sheathing material in mm ($5 \leq t_{sh} \leq 30$)
t_{il} is the thickness of the internal thermal laminate in mm($5 \leq t_{il} \leq 40$)
t_{ii} is the thickness of the internal insulation in mm ($80 \leq t_{ii} \leq 190$)

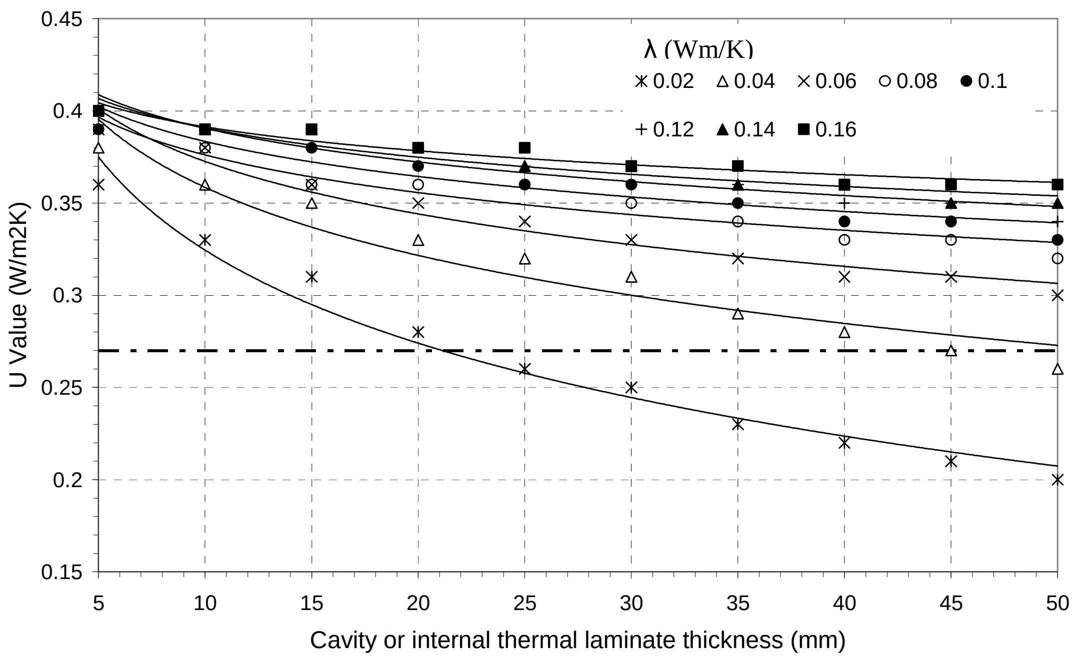


Figure 5: Relationship of wall detail U-value with cavity or internal thermal laminate thickness and λ value

$$U = 4\times10^{-4}\left\{\left[25.8Ln(K)+30.2\right]Ln\left(\sum t_i\right)-27.7Ln(K)-(9.3\lambda_{ii}+1.7)t_{ii}+(310.6Ln(\lambda_{ii})+2010)\right\} \qquad (1)$$

Where:

$$K = \frac{t_{el}}{\sum t_i}\lambda_{el} + \frac{t_{sh}}{\sum t_i}\lambda_{sh} + \frac{t_{il}}{\sum t_i}\lambda_{il}$$

$\sum t_i = t_{el} + t_{sh} + t_{il}$ is the sum of thicknesses t_{el}, t_{sh} & t_{il}

Using the derived equation various wall make-ups were considered of which the three contained in Figure 6 were taken forward and checked using SAP software for U-value compliance (Table 2). In addition to the U-value calculations the wall details were rated in relation to sustainability using the insulation LCA ratings of Table 1 as a result of the other materials being consistent and a full material cost was also calculated using supplier information.

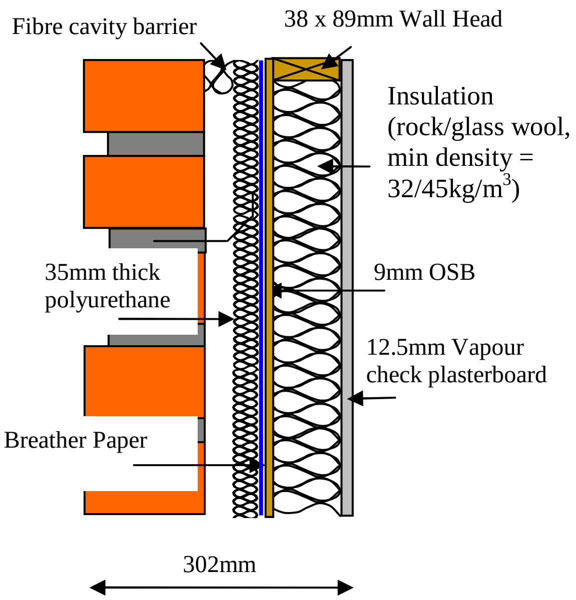
Table 2 Wall detail ratings

Detail	Life Cycle Assessment (LCA)	Material Cost £/m	U-Value W/m^2K
1	Medium	30	0.27 (0.29)*
2	Medium	34	0.27 (0.29)
3	Medium	43	0.29 (0.28)

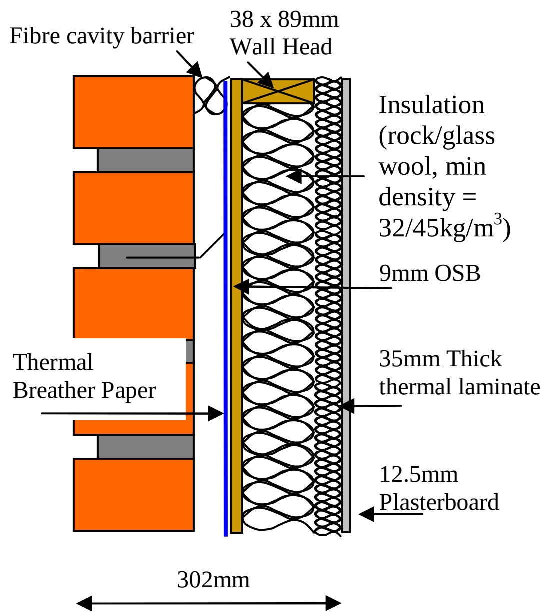
*(bracket enclosed values are estimations using equation 1)

Considering the information presented, the most appropriate wall detail for future requirements is Detail 1 if a 38x89mm stud is to be maintained. Detail 1 meets the U-value requirement of 0.27 W/m^2K which will assist envelope compliance and has a comparable LCA rating, relative to the other options considered. In terms of material cost Detail 1 is also economically more viable.

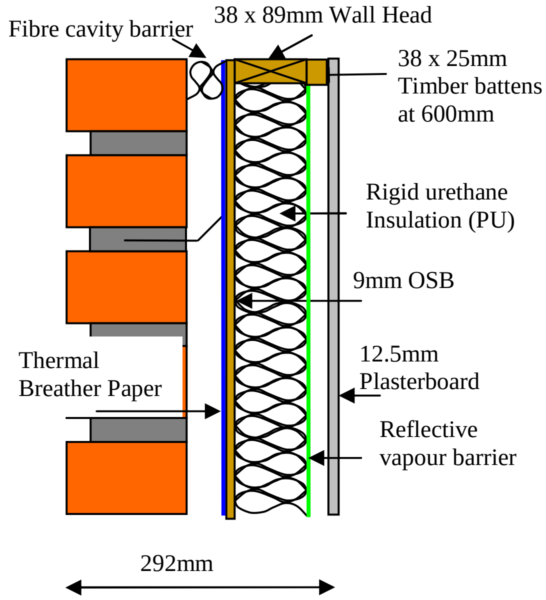
The implications of each detail have not been measured in terms of impact to on-site erection. However, it can be predicted without true measurement that Details 1 and 3 will take longer to construct as a result of additional work. Detail 1requires the installation of thermal laminate in the cavity and Detail 3 requires the additional fixing of battens to the internal face. In regards to Detail 2 the thermal laminate would be bonded to the plasterboard which would be fitted as normal resulting in no extra work. Additional work would result in additional cost and therefore Detail 2 could be a more favourable option depending on the nature of the project and any additional erection cost.



Detail 1: Cavity installed polyurethane insulation board



Detail 2: Polyurethane insulated plasterboard



Detail 3: Polyurethane insulation install ed within the frame

Figure 6 Timber Frame Wall Options

5. CONCLUSION

As a result of the EU Directive on Energy Performance of Buildings and the corresponding revisions to the Building Regulations being implemented, the energy efficiency of dwellings will have to improve by around 20%. For the energy efficiency of timber frame systems to comply with the revised regulations the required U-value will have to be reduced to 0.27W/m^{2}K to ensure overall Standard Assessment Procedure (SAP) rating compliance.

To examine the affect of sheathing, internal insulation and thermal laminate thickness and thermal conductivity on U-value rating a series of parametric studies were conducted. From the parametric studies conducted a semi-empirical model was developed which, with a relatively high degree of accuracy, provides a simplified method of estimating the U-value of masonry clad timber frame walls. The developed model was used to determine a range of wall detail solutions which were then checked for full compliance using BRE accredited software.

The use of 38x89mm stud is prevalent in timber frame construction due to availability of section. If a 38x89mm stud is to be maintained there available of options of which the introduction of a thermal laminate into the cavity space is the most appropriate in terms of U-value rating and material cost. However, plasterboard with a bonded on thermal laminate is another available which although more expensive in terms of material cost would reduce on-site work.

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