Energy Efficiency of Timber Frame Housing

Bill Quigley[1]

Kyoto Protocol – 1997

It is widely accepted by the scientific community that the emission of the so-called 'greenhouse gasses' is the root cause of climate change leading to global warming. The principal greenhouse gases are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)

In 1997 the United Nations Framework Convention on Climate Change (UNFCCC) meeting at Kyoto developed strategies to alleviate climate change under which industrialised countries committed to reduce greenhouse gas emissions. It set out the following:

- Developed countries committed to reduce annual greenhouse gas emissions by 5.2% below the 1990 levels by over the period 2008-2012.

- The European Union committed to a reduction of 8%.

- Under the EU burden sharing arrangement Ireland has been allowed an increase of 13% above its 1990 emission levels (a business-as-usual scenario will see a 37% increase over the same period). This increase was allowed because of Ireland's development status vis-à-vis its EU partners.

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Ireland had already reached and exceeded its 2012 target by the end of 2000. This clearly indicates the enormity of the task ahead to keep emissions at current levels for the next 10 years. In October 2000 the Government published its National Climate Change Strategy in which it focused on ways of reducing greenhouse gas emissions. Energy efficiency was outlined in this strategy as one of the key initiatives to help reduce emissions. The strategy targets a reduction of 0.25 Mt CO_2 in emissions through tighter building regulations that will reduce energy losses.

Energy Use in Buildings

From the following it can be seen that energy use in buildings is of major significance in the Government's fight to reduce greenhouse gas emissions:

- The construction and use of buildings account for 45% of all CO_2 emissions in Ireland

- Residential buildings account for 30% of the total national CO_2 emissions

For these reasons the Department of the Environment and Local Government identified the residential sector as an area for change in its National Climate Change Strategy. There has always been a commitment by the department to reducing energy use in buildings. This has manifested itself by the ever-more stringent standards set in Part L (Conservation of Fuel and Energy) of the Irish Building Regulations.

Significantly in September 2001, Minister Noel Dempsey announced that he was, through his department, proposing a significant change to Part L of the Building Regulations in relation to new dwellings. Whereas it had been proposed to bring in this change in two steps, because of the significance of the problem of CO_2 emissions it was decided to do so in one. The changes proposed are as indicated in Table 1.

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Table 1: Building Regulations for New Dwellings (2002) - Proposed U-values

Element	**1997** W/m²K	**2002** W/m²K
Ground Floor	0.45	0.25
Walls	0.45	0.27
Roof	0.25	0.16
Windows	3.00	2.20

A U-value or Coefficient of Heat Transfer is defined as follows:

The amount of heat/energy that is flowing through 1 m^2 of an element when the temperature difference between the faces of the element is 1 degree Kelvin. It is measured in Watts per square metre per degree Kelvin i.e. W/m^2K. Clearly, the lower the U-value the less heat flows through the element and hence the more energy efficient it is.

The Specific Heat Loss Characteristic of a house is a summation of all of the heat flowing through all of the elements plus an allowance for the amount of heat lost by way of air infiltration and ventilation. The amount of heat flowing through a particular element is calculated by multiplying the area of the element by its U-value. The specific heat loss characteristic for a particular house could be calculated as shown in Table 2.

Table 2: Calculation of heat losses through building elements

Element	**Area** m^2	**U-value** W/m^2K	**Area x U-value** W/K
Floor	50	0.30	15.0
Wall	100	0.40	40.0
Roof	50	0.25	12.5
Windows and doors	25	3.00	75.0
Total			**142.5**

The heat loss due to air infiltration is calculated by the following formula:

0.34 x number of air changes per hour x the volume of the house

The volume of the above house would be approximately 250 m^3 and the air change rate would be typically 1.2 air changes per hour. The heat loss due to air infiltration and ventilation would therefore be 102 W/K (0.34 x 1.2 x 250 = 102 W/K)

The Specific Heat Loss characteristic for the above house is therefore 142.5 + 102 = 244.5 W/K.

This means that for a steady state condition, if the outside air temperature was 0˚C and the desired inside house temperature was 20˚C, then the power of the heating system required to maintain that temperature would be 244.5 W/K x 20˚C = 4,890 W or 4.89 kW.

However, a steady state condition rarely applies and would only be true if the heating system was left on for 24 hours per day and the outside air temperature never varied. This rarely happens and the heating system has to be designed to operate in a highly intermittent mode. Typically heating systems are switched on for approximately 7 hours per day i.e. 2 hours in the morning and 5 hours in the evening. Effectively this means an allowance has to be made for the ‘heating up’ of the building fabric or more technically called the Thermal Capacitance of the house – a house will cool when the heating system is off and will need to be heated up again when the heating system is switched on. A heating system designer would most likely double the Heat Loss Characteristic of the house and add some 3 kW for the heating of domestic hot water. Rounded off this would signify a boiler size of some 13 kW (approximately 45,000 Btu/hour) is required to heat the above house. This is significantly different to the simple Specific Heat Loss Characteristic of 4.89 kW calculated first.

The key points in saving energy in new houses are therefore as follows:

- the house should be both well insulated and effectively insulated i.e. the insulation must work in the way it is designed which means it must be correctly placed by the installer,
- the house should be reasonably air-tight and should be mechanically ventilated with heat recovery on the extract air,
- the house should be able to respond quickly to the occupants’ requirements for heat in winter.

Effective Insulation

Effective insulation means that if a certain thickness of insulation is placed in a wall, for example, then the calculated and the measured U-value should be approximately the same.

The following examples illustrate the differences in effectiveness of insulation in two wall constructions. The first is a typical traditional masonry cavity wall insulated with partial fill board insulation while the second is a typical modern timber frame wall.

Both of these wall constructions are designed to meet the existing Building Regulations (1997) i.e. to have a U-value of 0.45 W/m²K.

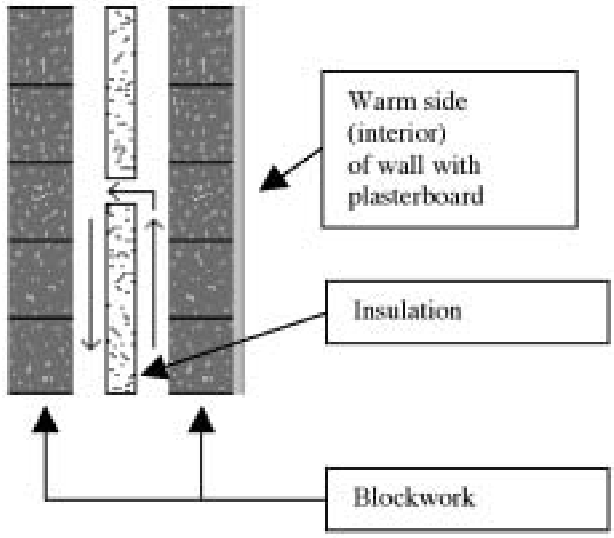

***Figure 1: Insulated cavity wall with board insulation.* Note that air can circulate from the warm side of the insulation to the colder cavity. This is due to the existence of an air gap. This air movement is known as 'Thermal Looping' and it seriously increases the U-value of the wall.**

The size of the air gap that occurs affects the U-value of the wall. Lecompte (1990) supports the relationship between the air gap and the deterioration of U-values. His work indicated that if the insulation was 10 mm from the surface of the inner leaf of blockwork:

- a 3 mm gap between sheets caused the U-value to be 158% of its calculated value, and
- a 10 mm gap between sheets caused the U-value to be 193% of its calculated value.

Figure 2: Mortar keeping insulation from the blockwork leading to significant air gap and thermal looping.

It is important to note that this is not a function of the insulation board itself but entirely due to the way it is fixed on site. In effect this means that the U-value of a cavity wall instead of satisfying the 1997 Building Regulations requirements for walls i.e. a U-value of 0.45 W/m²K, could have a U-value as high as 0.9 W/m²K. A Building Research Establishment (BRE) field investigation of the thermal performance of construction elements also recorded this phenomenon in insulated cavity walls.

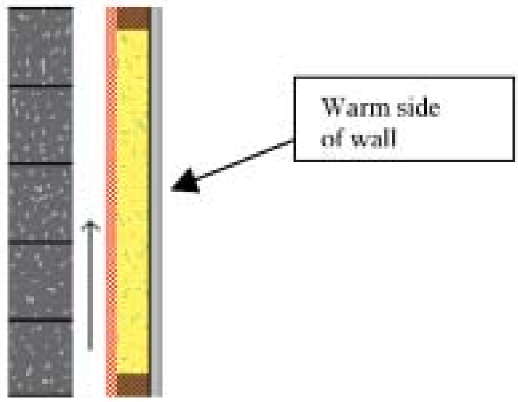

Figure 3: Timber frame wall with its insulation firmly fixed between the timber studs and sandwiched between the plywood/OSB and the plasterboard.

Note that there are no air gaps and hence the measured U-value and the calculated U-value are similar.

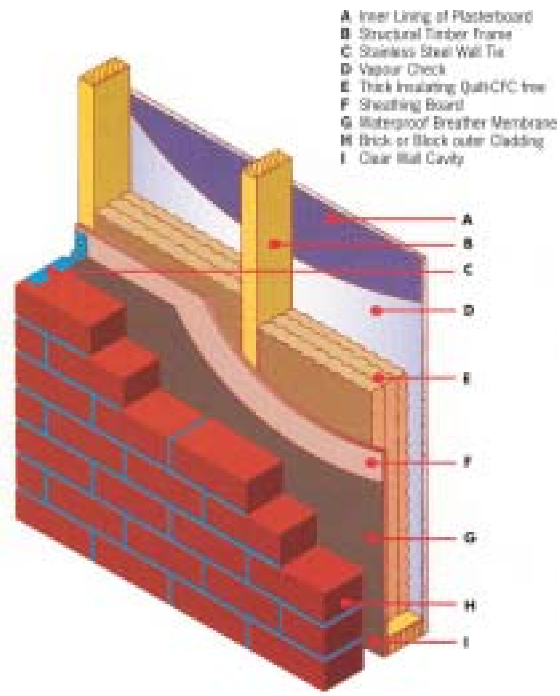

Figure 4: Timber Frame cut away showing detail of each component.

In the case of a timber frame wall the situation is quite different. There are no air gaps to allow thermal looping to occur within the insulated part of the wall.

BRE confirmed in their 2001 study that the measured U-values for timber frame walls were very similar to their calculated values. The values, allowing for the bridging of the timber studs, were invariably less than 0.40 W/m^{2}K. This means that these walls were well inside the 0.45 W/m^{2}K limit set by the Building Regulations.

It is important to clearly understand the significance of this difference between calculated and actual U-values. The state is committed to build reasonably low energy-demand houses. Houses can only be energy efficient if the calculated U-values of the designed elements are actually achieved in practice. It is known that timber frame housing performs extremely well from a thermal viewpoint. This has been demonstrated by work carried out not only in Britain and Ireland but also in countries which have extremely cold winter climates such as Sweden, Finland and Canada.

The Proposed 2002 Building Regulations

The U-values for walls of domestic dwellings in the Elemental Method of the proposed 2002 Regulations has been set at 0.27 W/m^{2}K. There are a number of ways in which the timber frame house manufacturers will meet this requirement. Probably one of the most economic ways will be as follows:

- 19 mm external rendering
- 100 mm standard concrete block
- 50 mm cavity
- Breather membrane on OSB bracing
- 139 mm timber stud
- 139 mm mineral wool insulation (18 kg density with a λ-value of 0.036 W/mK)
- Vapour barrier
- 12.5 mm plasterboard

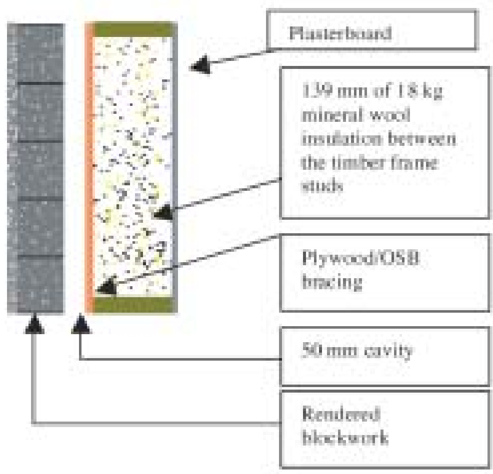

Figure 5: Timber frame configuration satisfying the proposed 2002 Building Regulations.

This construction has a calculated U-value of 0.27 W/m^{2}K and hence will meet the requirement. Furthermore, as has been shown by the BRE, it will meet the requirement in practice also and hence will deliver greater comfort and actual energy savings and consequent reductions in CO_2 emissions.

Energy Savings and Reductions in CO_2 emissions

It is worthwhile comparing the amount of energy that is used in houses of different construction that nominally meet the Building Regulations but, mainly because of workmanship, have markedly different performance characteristics.

Table 3 compares a typical house built in different manners to comply with both the 1997 and the proposed 2002 Building Regulations. The house type selected for this comparison was a typical 4-bed, two storey, semi-detached house with 118 m^2 of living space.

The heating costs referred to above are based on a 12-hour per day heating regime where when the heating is on the house temperature is maintained at 20˚C.

Table 3: Energy use in a typical 118 m^2, 4-bed, two storey, semi-detached house

	Cost of heating and hot water. € p.a	**Corresponding CO_2 emissions per year tonnes**	**Reduction in CO_2 %**
Traditional Cavity Wall (1997 Building Regs.)	852	6.7	Base
Timber frame house – 89 mm stud (1997 Building Regs.)	656	4.8	-28%
Timber frame house – 139 mm stud (2002 Building Regs.)	522	3.8	-43%

* NB THIS PAGE FOLDS IN. TRIM TO I93 MM

The costs were calculated using a computer-based model which simulates a house in the Irish climate and takes into account many of the variables that occur in Irish housing such as thermal capacity, where the insulation is placed, etc. The climate model is based on a Test Reference Year from Met Eireann.

It is worth noting that even greater fuel savings can be achieved in timber frame houses as they are thermally lightweight and therefore respond much quicker to heat inputs when compared to the thermally heavyweight concrete block house. As timber frame houses achieve high comfort levels very quickly, they need only be heated when required. This means they use even less energy and makes them ideally suited to today's lifestyle of intermittent and variable occupancy.

Conclusions

Modern timber frame houses built to the proposed 2002 Building Regulations will have real savings in CO_2 emissions of some 43% over the typical traditional concrete block house that was built to nominally meet the 1997 Regulations. With an intermittent heating regime, timber frame houses will give higher levels of comfort than a concrete block house for the same inputs of heat/energy.

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