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PASSIVE THERMAL CONTROL FOR BUILDINGS IN TEMPERATE REGIONS- COMPARISON OF CAVITY WALLS AND CONVENTIONAL WALLS

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Abstract: **Providing thermal comfort without excess space and conditioning costs is one of the primary requirements of buildings. Therefore, thermal control is an important aspect in almost all buildings. Understanding heat transfer and the temperature distribution through building materials and assemblies is also important for assessing energy use. Thermal comfort, thermal movements, durability, and the potential for moisture problems. The control of heat flow in buildings requires insulation layers compromised with few thermal bridges, an effective air barrier system, good control of solar radiation, and management of interior heat generation. Walls play a huge role in the heat gain and loss in buildings, thus, making wall an important subject in passive thermal control in buildings. This article is aimed at analyzing cavity walls and solid brick walls and comparing them for home construction in temperate regions. Temperate regions need good insulating walls, thus reducing heat loss via walls to its minimal, which in turn reduces the cost of active heating measures in buildings.**

Keywords: **walls, masonry wall, cavity wall, solid brick wall, insulation, thermal resistance, thermal insulation.**

1. INTRODUCTION

Building construction in temperate regions requires good passive insulation and thermal control systems to reduce the excessive cost of active heating. Heat loss and transfers in buildings occur in three ways; conduction, convection and radiation. Heat can be lost in a building through various building assemblies; roof, slabs, openings and walls. It is also important to note that walls are the highest medium in which heat is lost in a building. Thus, it is very important to choose a good wall type to reduce heat loss to its minimal. We will take two wall types into consideration; Cavity wall and Solid Brick wall, which are the two major typologies we see in temperate regions for home construction. Both wall types have their advantages and disadvantages, heat resistance abilities and insulation cost.

2. METHOD

This study analyses the modern construction material for wall assembly in temperate regions and focusing on the United Kingdom (UK) as a case study. It aims at comparing between cavity walls and solid brick walls, their advantages and disadvantages, aesthetics, price and efficiency. This study acquires material resistance and assembly data from Francis D.K. Ching (1943). Building construction illustrated. New Jersey, cost analysis from the Energy Saving Trust UK (2012). Save energy at home. Retrieved from. http://www.energysavingtrust.org.uk/, and energy consumption data from Paula Owen (2010). Powering a nation. Retrieved from. http://www.energysavingtrust.org.uk/sites/default/files/reports /PoweringthenationreportCO332.pdf. All data will be analyzed and applied for this comparative study to draw a

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reasonable conclusion for preferable wall choice assembly in temperate region. The Energy Saving Trust UK is a non-governmental organization (NGO) which works in partnership with the government and local authorities to help reduce carbon emissions.

2.1. Building in temperate regions

Building in temperate regions require the maximum passive thermal control measures. Many authors have carried out quantitative studies on the behavior of traditional and modern buildings in different seasons, showing the capacity of these buildings to secure indoor comfort by means of passive thermal control systems (Cardinale & Al. 2009). Some authors have experimentally compared the behavior of traditional and modern buildings, not only showing how the former are preferable but from the point of view of comfort in terms of both comfort and energy saving (Martin and Al. 2010) but also identifying the limitations of energy legislation which tends to encourage the latter (Yilmaz 2007; C. Di Perna and Al; 2009)

2.2. Building construction in the United Kingdom (UK)

The English national survey (EHS) 2008 report covers several thousand dwellings in the country. The survey covers a whole range of attributes from whether the dwelling has a cavity wall to the income of the homeowner. The survey does not explicitly record specific type of cavity wall. Information is acquired by qualified surveyors physically surveying a dwelling and interviewing the homeowners/occupiers. EHS contains data from around 16,000 dwellings. Each dwelling in the survey is considered to be a single data point for purpose of this study. The report shows that only 20% of houses use cavity wall for construction, while solid walls of either brick or concrete constitutes of about 65%. An increased in the use of cavity walls should be achieved in other to reduce the annual CO_2 emission.

3. HEAT TRANSFER IN BUILDINGS

Heat can be gained or lost in a building by Conduction, Convection, and Radiation. Although, heat transfer occurs on various building assemblies; walls play a huge role in this respect due to their large surface areas, about 35% of heat loss or gain via uninsulated walls. Thus, wall choice is a very important subject when it comes to thermal control.

Buildings lose sensible heat to the environment (or gain sensible heat from it) in three principal ways:

I) Conduction: The transfer of heat between substances which are in direct contact with each other. Conduction occurs when heat flows through a solid.

II) Convection: The movement of gases and liquids caused by heat transfer. As a gas or liquid is heated, it warms, expands and rises because it is less dense resulting in natural convection.

III) Radiation: When electromagnetic waves travel through space, it is called radiation. When these waves (from the sun, for example) hit an object, they transfer their heat to that object.

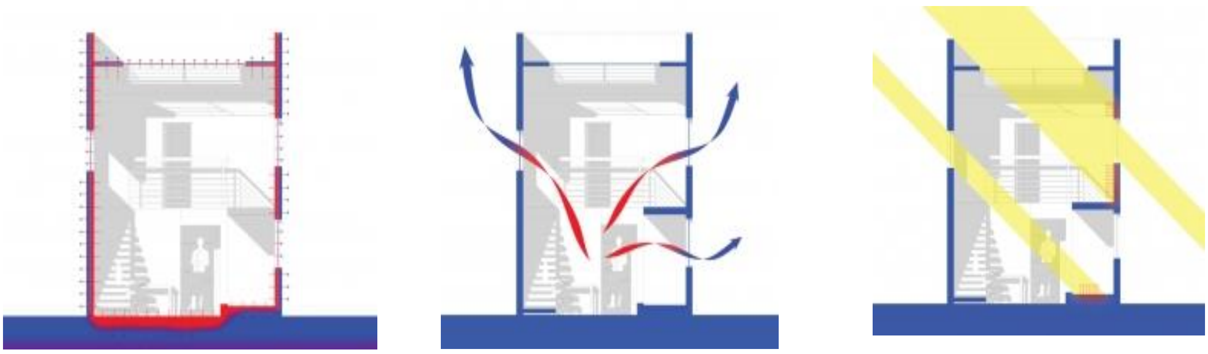

Figure 3.a. conduction, convection and radiation

Images retrieved from: http://auworkshop.autodesk.com/library/building-science/heat-energy-flows-buildings
Figure 3.a. conduction, convection and radiation illustrated with above images.

Conduction, convection, and radiation heat transfer take place almost everywhere we look. In a building envelope, conduction primarily takes place through opaque envelope assemblies, convection is usually the result of wind or

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pressure-driven air movement, and radiant heat transfer is primarily from the sun through fenestrations. Building HVAC systems are typically designed to provide comfort using convective or radiant modes of heat transfer.

3.1. Thermal resistance

The tables below can be used to estimate the thermal resistance of a construction assembly. For specific R-values of materials and building components such as windows, consult the product manufacturer.

$R = F^{o}/Btu/hr \cdot sf$, where:

- R is a measure of thermal resistance of a given material. It is expressed as the temperature difference required to cause heat flow through a unit area of material at the rate of one heat unit per hour.
- $U = 1/R_t$, where:
- R_t is the total thermal resistance for a construction assembly and is simply the sum of the individual R-value of the component materials of an assembly.
- U is a measure of the thermal transmittance of a building component assembly. It is expressed as the rate of heat transfer through a unit area of a building component or assembly caused by a difference of one degree between the air temperatures on the two sides of the components or assembly. The U-value for a component or assembly is the reciprocal of its R-value.
- $Q = U \times A \times (t_i - t_o)$, where:
- Q is the rate of heat flow through a construction assembly and is equal to:
- U=overall coefficient of assembly
- $(t_i - t_o)$ = difference between the inside and outside air temperatures

Francis D.K. (1943). Building construction illustrated.

Material	1/k*	1/C†
Concrete		
Concrete		
Sand & gravel aggregate	0.08	
Lightweight aggregate	0.60	
Cement mortar	0.20	
Stucco	0.20	
Masonry		
Common brick	0.20	
Face brick	0.11	
Concrete block, 8" (205)		
Sand & gravel aggregate		1.11
Lightweight aggregate		2.00
Granite and marble	0.05	
Sandstone	0.08	
Metal		
Aluminum	0.0007	
Brass	0.0010	
Copper	0.0004	
Lead	0.0041	
Steel	0.0032	
Wood		
Hardwoods	0.91	
Softwoods	1.25	
Plywood	1.25	
Particleboard, 5/8" (16)		0.82
Wood fiberboard	2.00	
Roofing		
Built-up roofing		0.33
Fiberglass shingles		0.44
Slate roofing		0.05
Wood shingles		0.94
Siding		
Aluminum siding		0.61
Wood shingles		0.87
Wood bevel siding		0.81
Vinyl siding		1.00
Building Paper		
Vapor-permeable felt		0.06
Polyethylene film		0.00
Plaster & Gypsum		
Cement plaster,		
sand aggregate	0.20	
Gypsum plaster,		
sand aggregate	0.18	
perlite aggregate	0.67	
Gypsum board, 1/2" (13)		0.45
Flooring		
Carpet & pad		1.50
Hardwood, 25/32" (20)		0.71
Terrazzo		0.08
Vinyl tile		0.05
Doors		
Steel, mineral fiber core		1.69
Steel, polystyrene core		2.13
Steel, urethane core		5.56
Wood hollow core, 1-3/4" (45)		2.04
Wood solid core, 1-3/4" (45)		3.13
Glass		
Single, clear, 1/4" (6)		0.88
Double, clear, 3/16" (5)space		1.61
1/4" (6) space		1.72
1/2" (13) space		2.04
Double, blue/clear		2.25
gray/clear		2.40
green/clear		2.50
Double, clear, low-e coating		3.23
Triple, clear		2.56
Glass block, 4" (100)		1.79
Air Space		
3/4" (19), nonreflective		1.01
3/4" (19), reflective		3.48

* 1/k = R per inch of thickness
† 1/C = R for the thickness indicated

Figure 3.1.a. Thermal resistance of materials.

Image retrieved from: Francis D.K. (1943). Building construction illustrated.

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3.2. Thermal insulation

The primary purpose of thermal insulation is to control the flow or transfer of heat through the exterior assemblies of a building and thereby prevent excessive heat loss in cold seasons and heat gain in hot weather. This control can effectively reduce the amount of energy required by heating and cooling equipment to maintain conditions for human comfort in a building. Francis D.K. (1943). Building construction illustrated.

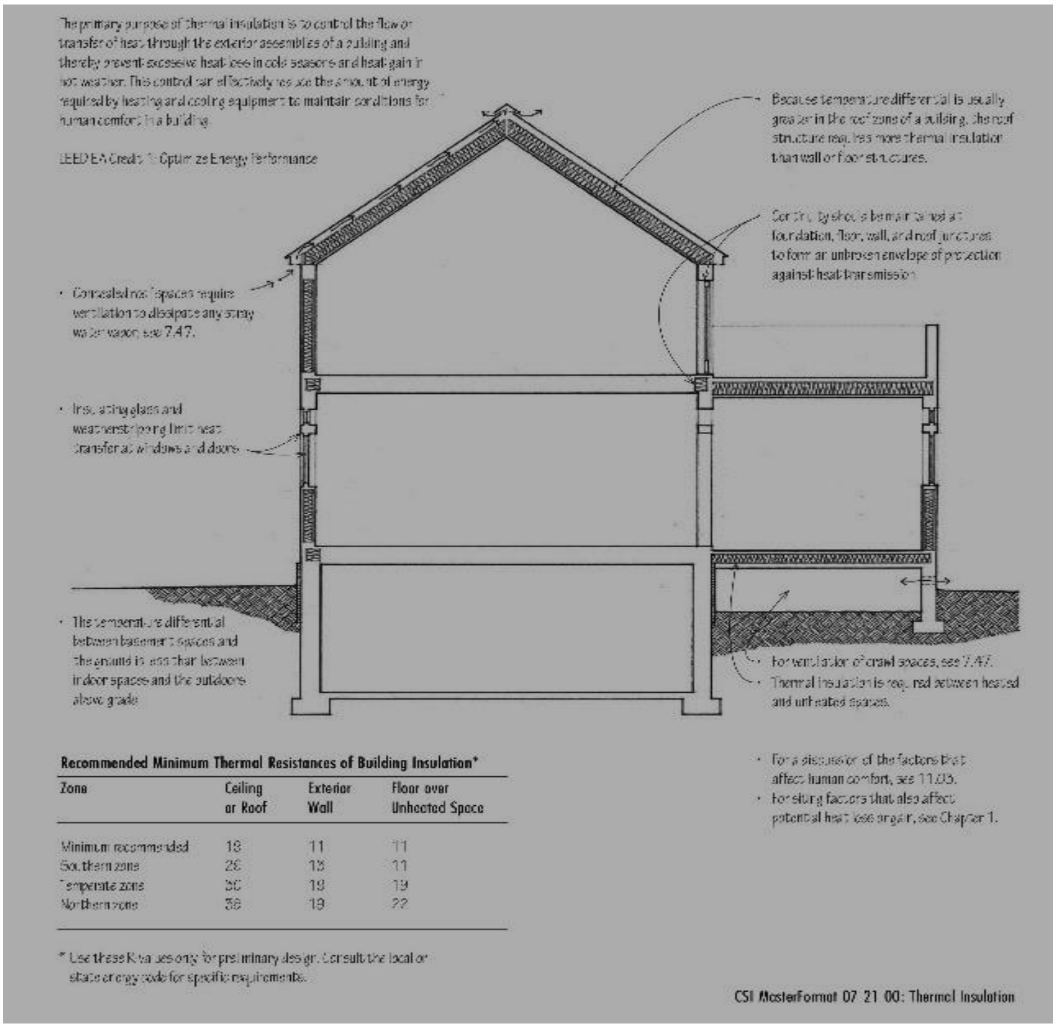

Figure 3.2.a Recommended thermal insulation in a building.

Image retrieved from: Francis D.K. (1943). Building construction illustrated.

3.3. Insulating materials

Almost all building materials offer some resistance to heat flow. To achieve the desired R_t value, however, walls, floor and roof assemblies usually require the addition of an insulating material. Below is an outline of the basic materials used to insulate the components and assemblies of a building. Note that all effective insulating materials usually incorporate some form of captured dead air space.

- Batt insulation consists of flexible, fibrous thermal insulation of glass or mineral wool, made in various thicknesses and lengths and in 16'' or 24" (406 or 610) widths to fit between studs, joists and rafters in light wood frame construction, sometimes faced with a vapor retarded of Kraft paper, metal foil or plastic sheet. Batt insulation is also as a component in sound-insulating construction.
- Rigid foam insulation is a performed, nonstructural insulating board of foamed plastic or cellular glass. Cellular glass insulation is fire-resistant, impervious to moisture and dimensionally stable, but has a lower thermal-resistance value

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than foamed plastic insulations, which are flammable and must be protected by a thermal barrier when used on the interior surfaces of a building. Rigid insulations have closed-cell structures, such as extruded polystyrene and cellular glass, are moisture-resistant and may be used in contact with the earth.

- Foamed-in-place insulation consists of a foamed plastic, as polyurethane, that is sprayed or injected into a cavity where it adheres to the surrounding surfaces.
- Loose-filled insulation consists of mineral wool fibers, granular vermiculite or perlite or treated cellulosic fibers, poured by hand or blown through a nozzle into a cavity or over a supporting membrane.
- Reflective insulation uses a material of high reflectivity and low emissivity, as paper-backed aluminum foil or foil-backed gypsum board, in conjunction with a dead air space to reduce transfer of heat by radiation.

Francis D.K. (1943). Building construction illustrated.

Form	Material	R-value per Inch of Thickness	
Batt or blanket	Fiberglass Rock wool	3.3 3.3	Installed between studs, joists, rafters, or furring; considered incombustible except for paper facing
Rigid board	Cellular glass Polystyrene, molded Polystyrene, extruded Polyurethane, expanded Polyisocyanurate Perlite, expanded	2.5 3.6 5.0 6.2 7.2 2.6	Boards may be applied over a roof deck, over wall framing as sheathing, in cavity walls, or beneath an interior finish material; the plastics are combustible and give off toxic fumes when burned; extruded polystyrene can be used in contact with the earth but any exposed surfaces should be protected from sunlight
Foamed in place	Polyurethane	6.2	Used to insulate irregularly shaped spaces
Loose fill	Cellulose Perlite Vermiculite	3.7 2.7 2.1	Used to insulate attic floors and wall cavities; cellulose may be combined with adhesives for sprayed application; cellulose should be treated and UL-listed for fire resistance
Cast	Insulating concrete	1.12	Used primarily as an insulating layer under membrane roofing; insulating value depends on its density

Figure 3.3.a. Insulating materials with R_t Values

Image retrieved from: Francis D.K. (1943). Building construction illustrated.

3.4. Wall insulation

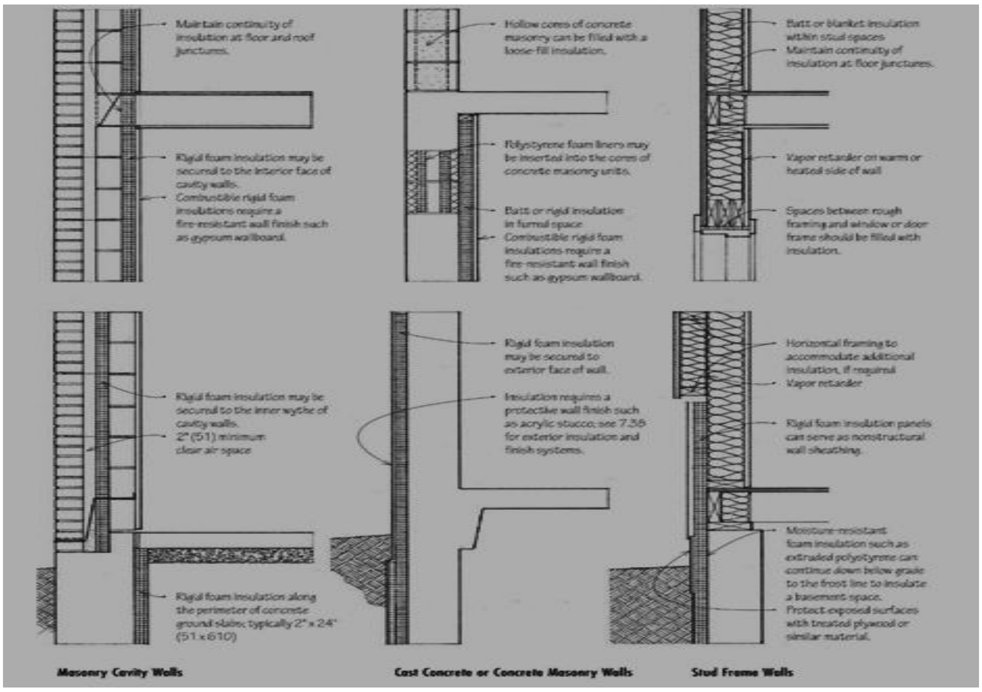

Figure 3.4.a. Insulating wall techniques: masonry cavity wall, cast concrete wall and wood stud frame wall.

Image retrieved from: Francis D.K. (1943). Building construction illustrated.

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4. WALLS

Walls are the vertical constructions of a building that enclose, separate and protect its interior spaces. They may be loadbearing structures of homogeneous or composite construction designed to support imposed loads from floor to roofs, or consist of a framework of columns and beams with nonstructural panels attached to or filling in between them. The pattern of these loadbearing walls and columns should be coordinated with the layout of the interior spaces of the building Francis D.K. (1943). Building construction illustrated.

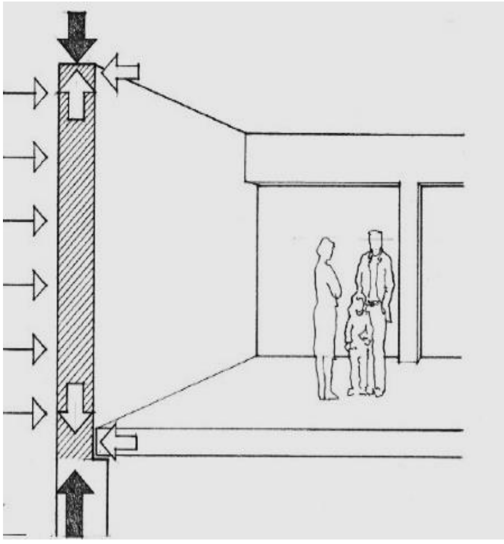

Figure 4.a. wall

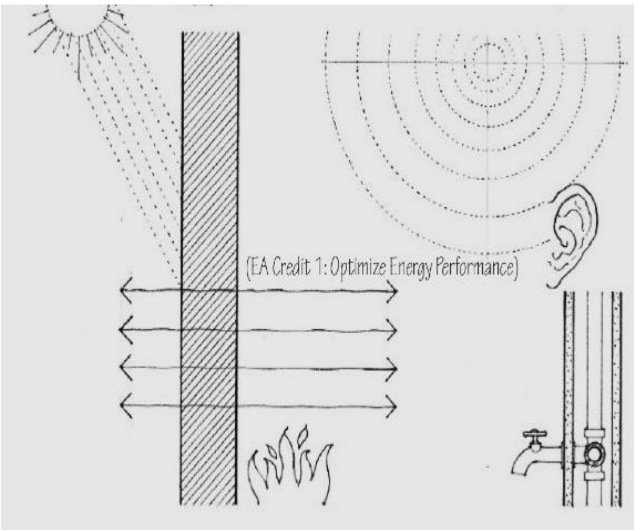

Figure 4.b. wall efficiency

Image retrieved from: Francis D.K. (1943). Building construction illustrated

4.1. Masonry walls

Masonry walls consist of modular building blocks bonded together with mortar to form walls that are durable, fire-resistant and structurally efficient in compression. The most common types of masonry units are bricks, which are heat-hardened clay units and concrete blocks, which are chemically hardened units. Other types of masonry units include structural clay tile, structural glass block and natural or cast stone.

- Masonry walls may be constructed as solid walls, cavity walls or veneered walls.
- Masonry walls may be unreinforced or reinforced.
- Unreinforced masonry walls, also called plain masonry, incorporate horizontal joint reinforcement and metal wall ties to bond the wythes of a solid or cavity wall.
- A wythe refers to a continuous vertical section of a wall that is one masonry unit in thickness.
- Reinforced masonry walls utilize steel reinforcing bars embedded in grout-filled joints and cavities to aid the masonry in resisting stresses.
- Masonry bearing walls are typically arranged in parallel sets to support steel, wood or concrete spanning systems.
- Common spanning elements include open-web steel joist, timber or steel beams and site-cast or precast concrete slabs.
- Pilasters stiffen masonry walls against lateral forces and buckling and provide support for large concentrated loads.
- Openings may be arched or spanned with lintel.
- Exterior masonry walls must be weather-resistant and control heat flow.
- Water penetration must be controlled through the use of tooled joints, cavity spaces, flashing and caulking.

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- Differential movements in masonry walls due to changes in temperature or moisture content or to stress concentrations require the use of expansion and control joints.

Francis D.K. (1943). Building construction illustrated.

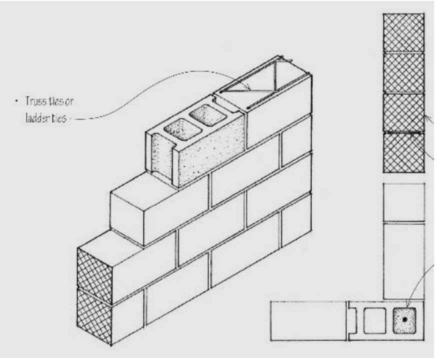

Figure 4.1.a. concrete masonry wall.

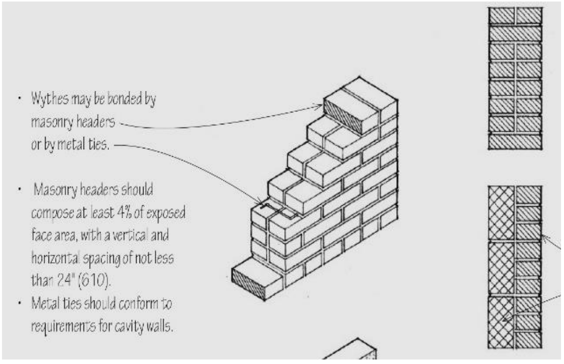

Figure 4.1.b. brick masonry wall.

Image retrieved from: Francis D.K. (1943). Building construction illustrated

4.2. Solid brick walls

Solid brick wall is exactly like it sounds. Typically, two bricks wide, with each row of bricks interlocking to form a completely solid 9-inch brick wall. There is no gap between the bricks to insulate, and so you must either add insulation to the inside of the property, or do so externally. In constructing solid brick walls, bricks are typically held together by mortar. In most cases either the interior or exterior is usually coated with gypsum plaster. Solid brick wall can either be structural or non-structural members of a building. They are considerably cheap in the construction industry. Solid walls tend to need insulation due to their high level of conductivity and thus, could prove very expensive and may also require active heating in temperate regions, insulating your solid walls could cut your heating costs considerably, because solid walls let through twice as much heat as cavity walls do. The good news is they can be insulated.

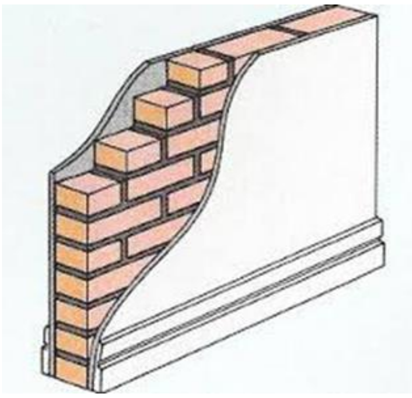

Figure 4.2.a. solid brick wall.

Image retrieved from: http://www.insulationireland.net/solid_walls.htm

4.3. Cavity walls

A cavity wall is made up of two masonry brick walls running parallel to one another with a space (cavity) between them of at least 50mm. Masonry bricks are very absorbent, so moisture absorbed by the outer wall as well as from the inside of the house as from outside. The cavity serves to drain water back out through weep holes at the base of the wall system or above windows. The weep holes allow wind to create an air stream through the cavity and the stream removes evaporated water from the cavity to the outside. Usually weep holes are created by intentionally leaving several vertical joints, also open head joints, open about two meters apart at the base of in every story. Weep holes are also placed above windows to prevent dry rot of a wooden window frame. A cavity wall with masonry as both inner and outer skins is more commonly referred to as a double Wythe masonry wall. Typically drains through the cavity, rather than coming into the home,

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helping to prevent damp issues. This type of wall construction became the norm in the 1930s superseding solid walls and as time has gone on, the size of the cavity between the two skins of brick has continued to grow – a typical cavity wall now is between 280-300mm thick.

The skins are commonly masonry such as brick or concrete block. Masonry is an absorbent material, and therefore will slowly draw rainwater or even humidity into the wall, A home can lose as much as 35% of its heat through uninsulated external walls. Therefore, if these can be insulated, the home retains heat better, which means lower energy bills. The concept of insulating a cavity wall is really very simple – it involves filling the cavity between the two skins of masonry bricks with an insulating material, which slows the movement of heat through the wall.

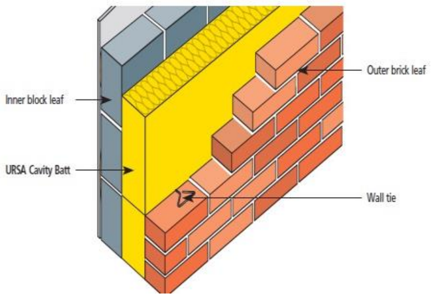

Figure 4.3.a. cavity wall.

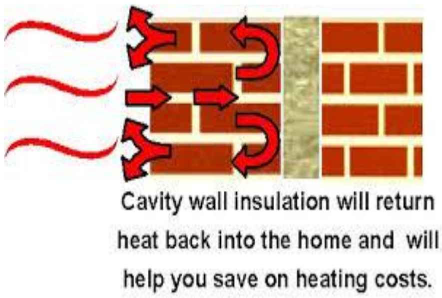

Figure 4.3.b. insulation of cavity wall.

Images retrieved from: http://www.iqbuildersmerchant.com/ursa-fg-032-cavity-insulation-2023-p.asp & http://www.keepwarmltd.co.uk/cavity-wall-insulation.html

5. COMPARISON

5.1. Results

What is the cost difference?

Many people get a shock when they hear the cost of solid wall insulation. It is a very labor intensive, material rich job that takes weeks rather than hours to properly install. Cavity wall insulation can be done in a few hours on an equivalent property, and the cost is an order of magnitude lower. £5-8 per square meter for cavity wall compared to £100 per square meter for solid wall insulation. Unfortunately, you can't choose between the two, it depends on the build type of your property as to the type of insulation you will need. Below is a typical example of the cost of installing insulation for Cavity wall and Conventional solid wall in the United Kingdom;

SOLID BRICK WALL

Table 5.1.a. typical gas-heated home. All data obtained from the energy saving trust (EST).

Solid wall insulation			
Type of property	**Insulation cost**	**Savings per year**	**CO2 savings per year (kg)**
Detached house (4 bedrooms)	Between £ 5,000 and £ 18,000	£ 455	1,900
Semi-detached house (3 bedrooms)	Between £ 5,000 and £ 18,000	£ 260	1,100
Mid-terrace house (3 bedrooms)	Between £ 5,000 and £ 18,000	£ 175	720
Detached bungalow (2 bedrooms)	Between £ 5,000 and £ 18,000	£ 180	740
Mid-floor flat (2 bedrooms)	Between £ 5,000 and £ 18,000	£ 145	610

Table retrieved from: http://www.which.co.uk/reviews/insulation/article/solid-wall-insulation/solid-wall-insulation-costs-and-savings.

CAVITY WALL

Table 5.1.b. typical gas-heated home. All data obtained from the energy saving trust (EST).

Cavity wall insulation			
Type of property	**Insulation cost**	**Savings per year**	**CO2 savings per year (kg)**
Detached house (4 bedrooms)	£ 720	£ 272	1,100
Semi-detached house (3 bedrooms)	£ 475	£ 160	650
Mid-terrace house (3 bedrooms)	£ 370	£ 105	430
Detached bungalow (2 bedrooms)	£ 430	£ 110	450
Mid-floor flat (2 bedrooms)	£ 330	£ 90	360

Table retrieved from: http://www.which.co.uk/reviews/insulation/article/cavity-wall-insulation/cavity-wall-insulation-costs-and-savings

5.2. Advantages and disadvantages

Advantages:

Solid brick walls

- Economical (raw material is easily available).
- Durable.
- Low maintenance required.
- Easy demolition when required.
- Reusable and recyclable.
- High fire resistance.
- Produces less environmental pollution during manufacturing process.

Cavity wall

- Diameter size advantage.
- Heat loss reduction.
- Mold prevention.
- Lower energy bills.
- There is no possibility of the moisture travelling from the outer wall to the inner wall.
- These have good sound insulation property.

Disadvantages:

Solid brick wall

- Time consuming construction.
- Cannot be used in high seismic zones.
- Since bricks absorb water easily, it causes fluorescence when not exposed to air.
- Very less tensile strength.
- Rough surfaces of bricks may cause mold growth if not properly cleaned.
- Cleaning brick surfaces is a hard job.
- Color of low quality brick changes when exposed to sun for a long period of time.

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Cavity wall

- Construction cost.
- Shoddy work.
- Possible insulation restriction.
- Not applicable to all construction types.
- Heavy in weight.
- Can only be used in exterior walls.

6. CONCLUSION

Wall insulation is always worth it in the long term, once you factor in the savings you will make annually on cooling and heating. From all the above data, analysis, research, study and comparison, cavity walls are more ideal when constructing a building in temperate regions. Cavity walls are more thermal resistant in comparison to solid brick walls. Solid walls in temperate regions are less ideal due to their less thermal resistance and prom to moisture plus easy weathering of wall assembly. Solid walls in temperate regions still need a form of thermal control which will result in either extra cost of insulation installation or active thermal control measures (HVAC) which incurs high heating costs. Therefore, when it comes to building construction in temperate regions, cavity walls are a better option, cavity walls insulate not just thermally by also acoustically. Cavity walls are also more feasible and cost effective because they slash active thermal control cost by over 65% annually. The UK government through the energy saving trust (EST) is holding seminars to advice on the issue of energy efficient buildings to reduce the rate of carbon emission and the ideal walls for buildings are also cavity walls. Cavity walls are the ideal choice when it comes to building construction in the UK which is a temperate region and all other temperate regions too.

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