

Environmental Evaluation Of The Building Envelope Using Plastic Foam Insulation

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Abstract

In Turkey there is a widespread use of plastic foam insulation (either extruded-XPS or expanded polystyrene-EPS) that covers the entire building surface. Concrete skeletal structural system is generally used in low and medium rise residential buildings. In order to avoid excessive thermal bridges through the thermal envelope the placement of insulation seems to be a right design solution. By reducing heating and air-conditioning requirements of a building, insulation materials reduce pollutant and greenhouse gas emissions from fossil fuel combustion. This benefit almost always outweighs environmental problems associated with certain materials, including the energy use and other impacts associated with manufacture. But increased awareness towards the environment and public health is leading to an integrated evaluation of insulation materials and there is significant potential for improving their overall performance, in terms of environmental impact from cradle to grave. Insulation is only one component of a building envelope system. When choosing insulation materials, the future performance of the entire system in terms of energy efficiency, durability, maintainability, and reusability should also be considered. This paper will analyze the existing plastic foam insulation applications in Turkey and offer alternative solutions that have comparative performance

1 Introduction

Buildings are usually designed to shelter occupants and achieve thermal comfort in the occupied space backed up by heating and air-conditioning systems as necessary. Significant energy savings could be

realized in buildings if they are properly designed and operated. As a least cost energy strategy, conservation should be supported in the energy future. For every unit of energy saved by a given measure of technology, resources will be saved, and the annual operating costs associated with producing that unit of energy will be reduced. Global warming is also the most immediate threat to global sustainability, driven primarily by CO₂ emissions. Achieving optimum **thermal design of buildings** can achieve large cuts in CO₂, with numerous other benefits. Therefore, building designers can contribute to solving the energy problem if proper early design decisions are made regarding the selection and integration of building components. The thermal resistance of insulation materials is the most important property that is of interest when considering thermal performance and energy conservation issues. They are the effective means in protecting the building from excessive environmental temperatures and in minimizing the potential risks occur from the production, use and recycle of the material during its life cycle. It is also clear that in order to achieve the tighter standards insulation materials have to improve their features. This is even more the case, as requirements have increased not only in terms of thermal properties, but also with respect to indoor environmental quality and the environmental impact. Increased awareness towards the environment and public health is leading to an integrated evaluation of insulation materials and there is significant potential for improving their overall performance, in terms of environmental impact from cradle to grave. As the health properties become more important, the establishment of commonly accepted assessment methods and benchmarking values is inevitably the next step in the process of European harmonisation [1].

When coming to evaluate the performance of insulating materials and to set aims for their future development, one cannot fail to observe that even the physical properties of a single type of material vary significantly, according to the specific structural application, which determines the sort of the material that has to be used. On the other hand the quality of an insulating material depends on its adaptability to national, regional or even local building ways and traditions. In that sense, materials that are wide-spread in specific regions are rare in others, though, from the scientific point of view, any material could be used instead of the other [1]. In 2004, the growth rate of the insulation materials sector of Turkey was 33% than the previous year. The magnitude of the sector reached 3.6 million cubic meters which means the quantity consumed per capita is 0.05 m³. This same value is approximately 1 m³ in USA, and 0.6 m³ in Europe [2]. This data shows that Turkey has a greatest insulation potential than the other countries. So, substantial local resources in producing and using insulation materials needs to be encouraged instead of importing them [3]. This paper investigates the suitable insulation materials that can safely be used in residential buildings in Turkey by analyzing the available building materials and principles of thermal protection. The subject is overviewed on walls

2 The Importance of Thermal Insulation in Turkey

Turkey imports approximately 65% of its energy. 37% of total energy is consumed in buildings and 82% of this quantity is consumed for the heating loads. Heating energy spent per a unit of a dwelling is 5 or 6 times greater than the developed countries. By taking the necessary provisions in insulating buildings energy savings of 25% to 50% can be achieved [4].

In Turkey, heat insulation standards for new residential and commercial buildings are regulated by TS 825. In preparation of the TS 825 and the last "Regulation on Heating Insulation at Buildings", ISO 9164 and EN 832 standards have been adapted to the national conditions. Turkey is separated into four main heating regions, within the context of "The Regulation on Heating Insulation at Buildings". The most convenient construction and insulation materials are to be chosen in these regions in order to minimize the energy needed and maintain the desired comfort level. Council Directive 93/76/EEC ("Omnibus Directive") of 13 September 1993 to Limit Carbon Dioxide Emissions by Improving

Energy Efficiency (SAVE) is the initial base of the implementation of the EU energy efficiency acquis in Turkey. The existing regulations cover most provisions of the “Omnibus Directive”. Nevertheless, a more comprehensive/targeted approach is deemed necessary through implementation of integrated programs for compliance with this Directive as well as for effective monitoring of compliance [5].

3 The Principles of Thermal Insulation

The building envelope forms a barrier between the outdoor often unfavorable conditions and indoor controlled environment. Thermal insulation can control this heat flow through elements of the building envelope. This can be of three kinds: Reflective, Resistive and Capacitive. Reflective insulation, e.g., a bright aluminum foil, is useful where the mechanism of heat transfer is primarily radiation. Such a surface has both a low emittance and a low absorptance. Resistive insulation is the insulating property of a material which is expressed by its conductivity. Of all common materials air has the lowest thermal conductivity. In an air filled cavity, conductive heat transfer is negligible: heat will be transferred by radiation and convection. The function of any material used for thermal insulation is to prevent convection. Fibrous or porous materials are used for this purpose and the best ones are those that use the least amount of material per unit volume to encapsulate air in closed bubbles. The use of resistive insulating materials reduces the heat flow rate and this effect is instantaneous, i.e., there is no delaying effect. Capacitive insulation is influenced by the conductivity of the material, but the main factor is the thermal capacity of the element. This is the product of its surface density and the specific heat capacity of its material (J/kgK). Significant differences occur under conditions of periodic heat flow. Capacitive insulation is best provided by building materials such as brick or concrete where mass is their most important characteristics.

3.1 Moisture Related Problems in Thermal Protection

A problem which must be considered together with insulation is condensation. Water vapor from warm places (warm inside air in cold winter or hot humid outside air in summer) to cold places will migrate through the wall material. Normal building materials have a very porous structure and offer little resistance to such vapor migration. If condensation occurs within a porous material, the pores may become filled with liquid water, it will cause it physical damage, the thermal insulation qualities of the material are reduced, the wall becomes colder and therefore the condensation increases. If enough quantities of moisture accumulates in the building envelope and cannot escape, it becomes a good environment for mold, mildew, and other moisture-related problems. Different materials have different moisture storage capacity which is a function of time, temperature, and material properties. In reality, multiple moisture sources and transport mechanisms normally act together at one time. Every moisture transport mechanism can cause moisture problems and can help dry building materials and alleviate such problems as well. Therefore, it is not always the best approach to prevent moisture transport mechanisms but rather to control moisture sources, control moisture transport and accumulation mechanisms, and encourage moisture removal (drying) in a building assembly [6]. Significantly more water vapor travels through a wall by air leakage than by diffusion. An often used **rule of thumb** to ensure safe outward diffusion of vapor is that the combination of exterior materials should have total permeance of at least five times the total permeance of the interior vapor retarder plus the interior finish materials. Therefore, if the interior and finish permeance is 1 perm, the total exterior permeance should be 5 perms or more. Conversely, when it is known that vapor resistant finishes such as plywood or hardboard panels will be used on the exterior a more effective retarder and installation method should be used. The integrity and continuity of such a vapor retarder must be insured, as a crack or a puncture may defeat the purpose of the whole detail. Closed cell rigid foam insulation boards do not require added vapor retarder treatment when placed to the interior of masonry

walls. In regions with prevailing hot and humid conditions, on the other hand, moisture is expected to diffuse through the building envelope from outside warmer and humid air to the colder and drier inside conditioned air. Therefore, vapor retarder should generally be placed towards the outside surface of insulation. In mixed climates, where moisture is expected to move both into and out of the space without predominance of either, it is better not to use vapor retarder at all and allow water vapor by diffusion to flow through the building envelope into and out of the space without accumulation.

There are different sources and transport mechanisms of moisture into building assemblies including [6]: Liquid water flow from rain and plumbing leaks; Liquid water movement due to capillarity from the ground through porous materials in the basement foundation, ground floor slab and walls and released moisture which was previously stored in the building structure during slow air drying construction process. Weather-resistive barriers are a part of exterior wall systems that protect building materials from exterior water penetration. They perform like a shell for buildings—liquid water that has penetrated the exterior finish does not pass through, yet water vapor can escape. Weather-resistive barriers make an effective air retardant when all seams and penetrations are fully sealed with an appropriate sealant or tape. By keeping building materials dry, a weather-resistive barrier improves building durability, decreases maintenance costs, and reduces the risk of moisture-related problems such as bugs, mold, mildew, and rot. Some weather-resistive barriers also reduce air infiltration, cutting utility costs and increasing comfort. By code, weather-resistive barriers must be rated at five perms or higher. Higher-perm materials can be desirable to speed the escape of trapped moisture vapor [7].

3.2 Installation Methods for Insulating Materials

Insulation installation depends on the type of structure, the type of insulating material used, and its location in the structure. Besides, there are some principles in terms of vapor diffusion control. For walls, the insulation can be placed to the inside, to the outside or in between (cavity, veneered or sandwich wall). The location of thermal insulation with respect to mass is not critical from thermal resistance point of view. Any building component will have the same overall thermal resistance for the same insulation type and thickness regardless of its placement within the assembly. However, there are other thermal and practical considerations for insulation placement as follows:

3.2.1 Insulation placement to the inside;

- Protected by mass against outside environment and damage. However, the structure will be closer to the outdoor temperature.
- In warm climates and when there is more difference between the daytime and nighttime outdoor temperatures, heat gain in buildings with masonry walls depends on the capacity insulation. The greater the capacity insulation, the lower the heat gain and consequently, the cooler the inside temperatures. They absorb and retain heat during the day and dissipate it to the outside during the cooler hours of the night.
- Expansion/contraction becomes more important.
- More ‘thermal bridges’ due to the unavoidable crossings and penetrations. Therefore, all penetrations and joints must be tightly sealed.
- Minimized potential heating benefits from the mass of the building structure.
- Insulation material should have lower vapor permeability (e.g. XPS) or otherwise the system should be protected from the diffusion of water vapor by means of vapor retarders.
- Board insulation that is not inherently fire resistant (e.g. plastic foam board) should be protected by fire resistant materials like cementitious coatings or gypsum board.

3.2.2 Insulation placement to the outside;

-Support for summer convective cooling and winter passive solar heating.

-Allows mass to store excess solar and internal gains.

Passive solar buildings: For heat flow into a building a much larger time lag and reduced decrement factor is achieved by having the main storage mass (capacitive insulation) inside the resistive insulation layer. This would also drastically increase the admittance of the element, leading to a much more stable internal environment.

-In the humid areas the exterior portion of the wall should have a higher vapor resistance than the interior, and when vapor retarders are used they should be on the outside. Water vapor is then directed toward the interior rather than the exterior, as in normal in the cooler climate zones. The vapor inside can be removed by the air conditioning system.

-In winter conditions where vapor moves from warm inside to cold outside, insulation material should have higher vapor permeability or otherwise the system would not breathe.

-There will be no risk of condensation in the element.

-Less durability due to the exposure to outside environmental and damage effects. (XPS has a much lower rate of absorption, which may help reduce loss of insulation effectiveness in the event that condensation does occur)

-Insulation material which is sensitive to daylight must be protected to prevent deterioration.

-Outside-the-wall insulation is often less economical than that inside the wall, because of higher installation and materials costs.

-The finish coats are comparatively brittle and the insulation usually employed (XPS) more rigid than the other insulation materials. Therefore, the finish coats must be divided into control panels by control joints.

3.2.3 Insulation placement in between (cavity wall design);

- A cavity offers two advantages in areas of severe exposure: The continuous air space provides insulation value to the wall and permits insulation to be installed within the wall to further reduce heat transfer and it acts as a barrier to moisture, eliminating the need for furring since significant rain penetration to the interior is practically impossible if proper flashing and weep holes are installed.

For a cavity wall to be installed certain precautions must be observed during its construction. Metal cavity wall ties, designed to resist both tension and compression, should be used to bond the exterior and interior wythes and should be solidly embedded in mortar so that two wythes will together to resist wind and other lateral forces.

-A vapor retarder is unnecessary in a cavity wall, when the cavity is insulated with fill materials that will not retain excessive moisture, such as silicon treated perlite or with rigid board insulations, like XPS, that are at least 2.5 cm less in thickness than the cavity and are installed next to the inner wythe.

-Ventilating exterior wall cavities may provide adequate vapor control in a moderate climate. However wall openings designed to move substantial amounts of air and vapor may waste considerable heat in colder climates. Therefore in walls, as in most other assemblies, vapor retarders are the primary means of vapor control; wall ventilation, when provided, is an adjunct to vapor control with suitable retarders.

-In masonry veneer construction since the veneer is isolated from the back up wall by an air space and exposed to the exterior, severe weathering grade facing brick should be used.

-If there is no air barrier between the insulation and outer wythe of the wall and if the insulation is permeable, than there is a risk of condensation in the cooler side of the thermal insulation material. So, the system should be well protected from condensation if the water vapor retarder is replaced to the inside of the element where there is higher vapor pressure.

4 Thermal Insulation Applications in Turkey

In Turkey, concrete skeleton is the primary structure system and horizontally perforated clay building bricks or gas concrete are used in the non-load bearing walls of the building envelope. As a common method, they are built either as a single wall system insulated either from inside (existing buildings) or outside or double wall system with the insulating material placed in between. However, this system has some disadvantages related to the inadequate construction applications recorded especially right after the big earthquake of 1999. During the application since the wythe of the walls were not connected to each other properly, they easily destroyed ending by terrible injuries.

Insulation placement to the outside of the building is used extensively in the buildings. Polystyrene boards either EPS or XPS are consumed eagerly without considering any environmental affects. Since this insulation material is sold as a system, and the consumers are not conscious and experienced in the insulation subject in general, they do not need to investigate any other alternatives. The system is named as 'COATING' and this makes public awareness by creating an analogy with the fur coat of a human body.

The European market of insulating materials is characterised by the domination of two first two groups of products, namely inorganic fibrous materials, glass wool and stone wool, which account for 62% of the market, and organic foamy materials, EPS and XPS and to a lesser extent polyurethane, which account for some 33% of the market. All other materials accounted for 5% together. In Turkey, although the amount of the material consumed less than the European market the same numbers change 56%, 43% and 1% respectively [8]. According to market survey, the price of XPS insulation board is 10.90 YTL/m² (for 22-31 kg/m³ and 0.05 m) while it is 7.50 YTL/m² for fiberglass board. But it should be pointed out here that XPS is sold as a system as if a ready to use composite material which provides the material adaptive to the available structural system and also expert workmanship can be supplied which makes the product attractive in the market.

4.1 Suitable insulation materials for Turkey, WHY?

Boron minerals and refined boron products are extensively used in various applications. 20% of boron consumption of the world is used in glass fiber sector and the other 80% is consumed in other sectors [9]. Boron improves the flexibility of fiberglass and the energy efficiency of manufacture. Fiberglass insulation is approximately 6-8% boron oxide (B₂O₃) by weight. 72.2% of the world boron reserves are in Turkey and the world total B₂O₃ consumption is 1.5 million tones/year [9]. Turkey has the potential that can compensate the world demand for 567 years. The glass market accounted for around 44% of all world boron consumption in 2001. In Western Europe, B₂O₃ used in insulation grade fiberglass production is 100.000 ton/year in 2001. This quantity is 14% of total boron consumption in Western Europe [9]. Insulation grade fiber glass is also the largest end use for boron compounds in the US glass industry, accounting for 66% of the total [10]. In 2004 concentrated boron ore production of Turkey is 1.697.000 ton and market value of fiberglass insulation in the world is approximately 4.4 billion Euro. Turkey has the lowest share in the market with the share of only 0.6 % [11]. It is clear that our country which develops the boron industry of other countries by exporting the mineral needs to develop its own boron based industrial sectors. The production of glass fiber insulation materials in order to enhance the insulation sector based on local resources needs to be pervaded [12]. Boron is also used as the flame retardant in the cellulose based insulation material.

On the other hand, Perlite, as a naturally occurring siliceous rock has the unusual characteristic of expanding to about 20 times its original volume upon heating within its softening temperature range of

760 to 1090 °C. The resultant expanded product finds a variety of industrial and constructional applications owing to the low density of the material with attendant properties of low thermal conductivity, and high sound absorption. World total perlite reserve is 7.700 million tones. Turkey is the leading country with its capacity of 5.700 million tones (74%) [13]. In the year 2003, 1.63 million tones perlite is produced in the world and the average perlite production of Turkey is 150.000 tones /year. Turkey is the third country in perlite production after USA, Greece and Japan. 80% of perlite produced in Turkey is used in the production of sound and thermal insulation products. 43% of the world perlite is consumed in USA, and in 2003, 64% of the perlite is consumed as construction products. 70% of perlite based construction products are in board form in the world. Turkey has the advantage of having abundant perlite resources that can be utilized in the production of insulation materials. Although 74% of the world perlite reserves are in Turkey, its average perlite production is only 9 % of the world total.

According to [14], for a typical residential multistory building in Istanbul, annual heat loss of the wall which is insulated by a perlite board applied to the exterior side and the lightweight perlite-gypsum plaster applied to the interior side is 19.553 M Wh. On the other hand, when the walls of the same building are insulated by EPS externally, the annual heat loss from the walls is 17.754 M Wh. There is only 9.20% reduction is gained in the annual heat loss when the walls insulated by EPS. Fiberglass has very close R value to expanded perlite that no apparent difference could be achieved. When the potential resources are taken into consideration the suitable insulation materials for Turkey seems to be perlite and fiberglass.

4.2 Environmental Comparisons of Perlite, Fiberglass and XPS

4.2.1 Raw Material Acquisition, Processing and Manufacture, Transportation

Fossil fuels are used in the production of foam plastic insulation. Fossil fuels are not going to run out any time soon, but the reserves are finite. There are various environmental impacts associated with extraction, shipping, and processing crude oil and natural gas. The most significant pollutants found in insulation materials are chlorine-based chemicals that destroy the earth's protective ozone layer. In XPS, originally CFC-12 was used as the blowing agent. The use of CFCs in cellular plastics was phased out in the developed world in 1995 (though they are still used in some parts of the world). In Europe the transitional HCFC, which has a much lower ODP, was also phased out in insulation boards in 2002 - 2004, and in other parts of the world to a 65% reduction by 2010 and total elimination by 2030. Since the CFC phase-out, HCFC-142b has been used. The most viable non-ozone depleting alternatives are HFC-134a and CO₂. XPS would be processed the same way with either of these alternatives. While fiberglass and perlite are not made from petrochemical feedstock, they require fossil fuel energy for mining, manufacture and transport, so they lead indirectly to fossil fuel depletion. Primary environmental impacts for perlite result from mining the volcanic rock and operating furnaces to expand it. 74% of the world perlite deposits are in Turkey. Fiberglass insulation is the number one end use of boron, most of which comes from two primary deposits, USA and Turkey.

Perlite is expanded in a furnace at 800-1200 C. XPS is among the highest embodied energy of any insulation material. The embodied energy per insulating unit would be higher than for either EPS or polyisocyanurate. Fiberglass has medium energy intensity compared with other insulation materials. Fiberglass insulation takes an estimated 27.9 MJ/kg to produce; including transportation. All insulation materials have a wide range in density which will affect shipping costs/impacts. The minimum recycled content percent by weight of fiberglass is 20-25 % cullet (post-industrial or post consumer glass) Recycled plastic resin is used in some XPS and EPS. Perlite is reusable. Could be recycled as an aggregate in gypsum and cement mortar.

4.2.2 Durability

Foam insulation materials are prone to infestation of wood-boring insects, such as carpenter ants. To address this concern, EPS manufacturers incorporate a borate additive into EPS foam-core panels. XPS has a closed cell structure also means that it is more resistant to moisture absorption, and less permeable to water vapor than perlite and fiberglass. They are sensitive to daylight and will deteriorate after prolonged exposure. They will give off carbon monoxide gas while burning. They do not however smolder or add a significant amount of fuel to a fire. XPS has flame retardant, hexabromocyclododecane is typically added as a fire retardant, but it cannot meet fire code requirements with a hydrocarbon blowing agent. Because of that reason mineral wool insulation will benefit from concerns about fire safety in Western Europe [15]. On the other hand blown cellular plastics are known to age in the first years of their life through a process of gas exchange diffusion between CO₂ in the cells and the ambient air relates to increased thermal conductivity. This is taken into account in manufacturer's quoted conductivity values which should be declared according to the European Standard (EN 13165 for rigid polyurethane insulation) to represent the aged -i.e. long-term - value.

Unlike the cellular plastics, however perlite and fiberglass boards are inorganic and will not burn or smolder. As long as the Fiberglass and perlite are kept dry it remains effective during the whole life of the building. No maintenance is required after installation. Although perlite can become water saturated it is a durable material having resistance to rot, vermin and termites. It doesn't require any maintenance if properly installed and protected from nature.

4.2.3 Health and Welfare

For perlite dust is a possible concern. Off-gassing is not believed to be a problem. Other environmental characteristics are unknown. For XPS benzene is a suspected carcinogen. Building occupants suffering from acute chemical sensitivity could be sensitive to emissions from XPS. There is a potential emission of toxics in communities with styrene manufacturing plants. Fiberglass has the significant concern over occupational exposure to respirable fibers. Fiberglass designated as 'possibly carcinogenic to humans' by International Agency for Research on Cancer. For the building occupants it has minimum concern as long as there is a barrier between the fiberglass and occupied space, there should be little if any risk. Most fiberglass is produced using a phenol formaldehyde (PF) binder to hold the fibers together. During manufacturing, most of the binder apparently dissipates and is captured with pollution control equipment, according to several industry sources. A new type of fiberglass does not require a binder was introduced in 1999, so pollution control emissions during manufacturing is much less of a concern. In fiberglass manufacture, air pollution emissions result from fuel combustion by the furnaces.

5 Concluding Remarks

- Reducing the operating energy requirements of a building is usually the single most important strategy for reducing the building's overall environmental impact.
- Use the capacitive insulation principles in order to reduce energy requirements for both heating and cooling loads.
- The choice of insulation material per se has very little impact on the total environmental impact of the building. What is most significant is the thermal design and specification: the overall design strategy and the particular U-value of components, which can be achieved with a variety of different materials at different thicknesses.

- If used appropriately, all insulation materials play a crucially important role in reducing the operating energy use in buildings.
- In situations where the structural framing material has high thermal conductivity, cavity-fill insulation alone is rarely adequate. Specify a layer of rigid insulation to cover the framing and reduce thermal bridging. Because even the best cavity-fill insulation's performance will be compromised by the framing, use an inexpensive cavity-fill insulation, and invest more of the insulation budget in the rigid insulation.
- Specialized reflective films or coatings can be employed in some situations to help reduce heat loss and/or heat gain.
- Choose a material with long life, sufficient durability and minimum failure risk (to maximize energy and carbon benefits). Once low U-values have been achieved, the most important issue in choosing insulants is longevity of thermal performance. The biggest risk factor is perhaps moisture build-(whatever the cause), which will increase thermal conductivity—and some cases damage the fabric of the insulant. Other risk factors include settlement—which some may be susceptible to; air movement at surface, leakiness, and attack by vermin and/or rot.
- To reduce atmospheric impacts from foam insulation, specify material that is not produced with ozone-depleting HCFC blowing agents
- Fiberglass and perlite based insulation materials generally have lower environmental impacts associated with their manufacture than foam plastic insulation materials, although they usually do not offer as high R-values, arrange the insulation thickness.
- Look for high recycled content in all insulation materials. Fiberglass generally offer the highest recycled content, followed by perlite.
- Building materials that are produced from locally available materials will avoid the environmental burdens associated also with transportation factors. Perlite and boron resources of Turkey is available in sufficient quantity to support the extensive production of insulation materials out of them.
- The high insulation values for a given thickness make foamed plastics appropriate for use in insulation of a wide variety of construction, including stone, brick and masonry. Since it is sold as a system and as a part of the exterior wall, it is accepted as a more convenient system which is widely used
- There is a need to produce insulation materials from perlite and fiberglass that can compete with the XPS market, so special attention should be given to easiness of application and workmanship factors.

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