International Journal of Engineering Research And Management (IJERM)
ISSN: 2349- 2058, Special Issue, November 2020

Energy Efficient Building Envelope Design: A Review

Ar. Priyanka Mehta, Dr. Pulkit Gupta

Abstract— **Energy is the most important component of human life. Growing demand of energy due to rapid urbanization has focussed designer, building professionals and researchers to design energy efficient buildings and building envelopes. Energy efficient buildings encompasses various issues regarding energy, water, land and material conservation, together with environmental pollution and the quality of indoor and outdoor environment. Significant energy savings could be achieved through well designed building envelopes. This article strives to make an exhaustive review of the building envelope components and respective improvement from an energy efficiency perspective**

Index Terms— **Energy efficient building, Sustainable building, Building envelope, Thermal insulation, Thermal efficiency of buildings**

I. INTRODUCTION

Building sector accounts for about 30–40% of the total energy consumption in the world and this share is expected to increase to 50% by 2050 [1,2]. Buildings are also responsible for more than 30% of the Green House Gas (GHG) emission, which contributes to global warming, climate change and also leads to irresponsible depletion of natural resources [3]. Residential buildings account for about 1/3rd of the world's total energy usage in building sector and the purpose of about 33% of all energy consumed in buildings is for heating, cooling and air conditioning [4,5]. In the developed countries, Heating Ventilation and Air Conditioning (HVAC) systems are responsible for about 10–20% of total energy consumption in buildings, and in the developing countries this figure reaches to almost 50% [6].

From an economic and environment conservation point of view, it is more beneficial to design buildings with high thermal insulation characteristics than the practice currently followed in the construction of buildings. This will result in long-term benefit of reducing the cost of cooling as well as reducing the pollution of the environment due to heavy use of fuel. Both government and scientific communities across the world have identified the potential and need for energy efficiency in buildings, and initiated several efforts in this direction.

A building envelope is what separates the indoor and outdoor environment of a building. It is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions. Various components such as walls, roofs, fenestration, foundation, thermal insulation, thermal mass, external shading devices etc. make up this important part of any building. Several researchers around the world carried out studies on improvements in the building envelope and their impact on building energy usage. The strategies include various techniques such as adding thermal insulation materials to building envelopes, white washing external walls, reflective coated glass window glazing, green roof , thermal insulating plasters etc.

II. BUILDING ENVELOPE AND IT'S COMPONENT

Cleveland and Morris (2009) created a good working definition of building envelope as "the collective term for all the components of a building that enclose its conditioned space and separate the conditioned space from the unconditioned spaces". [7].The basic components of a building envelope include walls, roofs, floors, doors and windows and foundation. The building envelope is the initial and primary means to conserve energy and control occupant comfort. An energy efficient building envelope can maximize occupant comfort, including thermal control, air quality, daylight, humidity, acoustics and security; while minimizing running costs through the use of solar, wind and daily temperature variations.

III. THERMAL PARAMETERS

The U-value represents the amount of heat transfer through the element of a building. The lower the U-value, better the effectiveness of the thermal insulation in the building envelope. Insulation is rated in terms of thermal resistance, called R-value, R-value is the reciprocal of the time rate of heat flow through a unit area induced by a unit temperature difference between two defined surfaces of material or construction under steady-state conditions. R-value is expressed in m^2 K/W. Thermal diffusivity relates to the propagation of speed of transfer of heat through a material. Thermal Effusivity (heat penetration coefficient) is the rate at which a material can absorb heat. The lower the diffusivity of the material, absorption of the heat will be lower from one layer to another layer in the building envelope. Thus, for better insulation purpose the thermal diffusivity should be as low as possible.

IV. THERMAL INSULATION MATERIALS FOR BUILDINGS

By definition, a thermal insulation material is a material that restricts the transfer of heat. This kind of definition allows any material to pretend as a thermal insulation material. However, when building materials are considered, only materials that provide a significantly better resistance to heat flow than common materials used for the building fabric (stone, concrete, hollow and plain bricks or concrete blocks) can be considered as thermal insulation materials. So, a thermal insulating material is a material that, at relatively small thickness, presents a thermal resistance large enough for the envisaged purpose. [8] The physical principles used in insulating materials are the following:

- To reduce conduction by reducing as much as possible the amount of matter, and use low-conductivity materials. Most of the volume of an insulating material is air or, in a few cases, other gases of even vacuum. Thermal insulation materials are, therefore, all lightweight.

- To avoid convection by locking air (or another gases) between fibres that strongly hinder the air movement, or in foam bubbles that completely suppress air movement.
- To avoid radiation by using opaque or even reflecting materials. Glassy and plastic materials used for fibres and foam walls are not transparent to thermal radiation. Thermal insulation materials could be transparent or translucent to light, but should not transmit the infrared radiation linked to surrounding temperatures.
- To avoid evaporation-condensation by maintaining the product dry. When wet, an insulating material loses a large part of its thermal resistance.

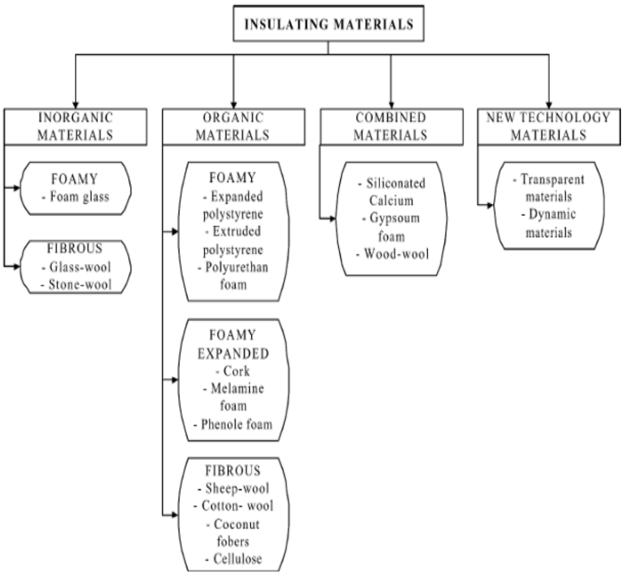

Fig. 1 Different thermal insulation materials

A. Autoclaved Aerated Concrete (AAC) blocks

AAC blocks are produced using materials including silica sand, lime, cement, gypsum, water, fly-ash and aluminium powder. The special combination of these substances yields a material with excellent construction properties such as thermal insulation, structural strength, density and fire resistance.

Fig. 2 AAC Blocks (Solid & Hollow0

B. Extruded polystyrene (XPS)

XPS is a type of insulation material with a high R-value, good moisture resistance, high structural strength and low weight. Extruded polystyrene is used extensively as thermal insulation in industrial, commercial and residential construction. It is commonly used in wall and roof applications[9].

Fig. 3 Extruded Polystyrene (XPS)

C. Expanded polystyrene (EPS)

It is a type of insulation that provides thermal and acoustical insulation with characteristics such as low weight, high moisture resistance and high structural strength. Expanded polystyrene can be used to insulate the walls and roofs. Commercially this is often referred to as thermocol insulation. [10]

Fig.4 Expanded Polystyrene

It is light in weight and provides good acoustic insulation also. It is commonly used for duct and wall thermal insulation.

Fig.5 Glass Wool

E. Stone Wool

Stone wool consists of the same basic materials as glass wool. Its main differences concern the higher melting temperatures during the production process and the different size of the fibres. These differences make stone wool heavier, with a higher melting point and hence better suited for high temperature applications.

Fig.6 Stone Wool

F. Polyurethane Foam

Polyurethane foam is based on poly-isocyanic associations. The propellant gas used initially was R11, which was forbidden in the late 1980s and was substituted by carbon dioxide or pentane. This modification lead to an increase ofthe thermal conductivity of polyurethane foam.

Fig.7 Polyurethane Foam

G. Thermal Insulating Plasters

Bims granule plaster has good thermal insulation properties comparable with typical thermal insulation materials (thermal conductivity equals 0.068 W/mK). It causes thus an improvement of the thermal insulation properties of walls and the reduction of energy consumption to heat in the thermal phase of the building usage. It brings both certain economic and ecological benefits.

New solutions, such as nanotechnology or aerogel based plasters, could also make a significant contribution in energy efficiency issues of buildings by using higher level of thermal performance and reducing needed thickness. They have the following advantages:

-low thickness of application with equal thermal insulation;

- fast installation and application by machine;

-application in different fields: new or old buildings, civil or industrial constructions, different supports (e.g. brick, concrete, mixed masonry bricks/stones, etc.);

- versatility of use in both indoor and outdoor.[11]

Fig.8 Thermal Insulating Plaster

V. THERMAL INSULATION SELECTION

Many parameters should be considered when selecting thermal insulation, including durability, cost, compressive strength, water vapor absorption and transmission, fire resistance, ease of application, and thermal conductivity. However, the thermal resistance of insulation materials is the most important property that is of interest when considering thermal performance and energy conservation issues. The factors that impact the choice of insulating materials can be summarized as
follows [12]:

1. Thermal performance
_ Thermal resistance
_ High R-value insulation material (e.g., fiberglass,
rock wool, polystyrene, polyethylene, polyurethane,
...).
_ Material thickness vs. thermal resistance.
_ Material density vs. thermal resistance.
_ Operating temperature range vs. thermal resistance.
_ Thermal bridging
_ Continuity of thermal insulation around walls/
roof.
_ No/minimum framing.
_ Thermal storage
_ Thermal storage benefits from massive walls
(e.g., concrete, adobe).
_ Time lag capabilities.
2. Cost
_ Extra cost of insulation (cost per R-value).
_ Extra cost of quality materials and workmanship.
_ Impact on labor cost.
_ Impact on air-conditioning equipment size and
initial cost.
_ Impact on energy/operating cost.
3. Ease of construction
_ Impact on workmanship requirements.
_ Impact on ease/speed of construction.
_ Impact on ease of operation, maintenance and
replacement.
4. Building codes requirements (safety and health issues)
_ Fire resistance capabilities.
_ Health hazards (toxic or irritating fumes).
_ Structural stability (load bearing vs. non load
bearing, compressive strength).
_ Odor and skin/eye irritation.
5. Durability
_ R-value change over time (e.g., foams filled with
gases heavier than air, that diffuse over time).
_ Water and moisture effects (absorption and
permeability).
_ Dimensional stability (thermal expansion and
contraction).
_ Settling over time.
_ Strength (compressive, flexural, and tensile).
_ Chemicals and other corroding agents.
_ Biological agents (dry rot and fungal growths).
6. Acoustical performance
_ Sound absorption.
_ Sound insulation.
7. Air tightness
_ Vapor/infiltration barrier.
_ Wall/roof construction quality.
ARTICLE IN PRESS
360 M.S. Al-Homoud / Building and Environment 40 (2005)
353–366
_ Sealed penetrations.
_ No cracks.
_ Good weather stripping.
8. Environmental impact
9. Availability

VI. ENERGY EFFICIENT BUILDING ENVELOPE DESIGN

A. Wall

Walls are a predominant fraction of a building envelope and are expected to provide thermal and acoustic comfort within a building without compromising the aesthetic of the building.

1. Thermal Mass Wall

Thermal mass wall can reduce cooling requirements and air temperature elevation by slowing down the heat transfer though the envelope and absorb heat generated internally .According to Alaidroos & Krarti (2015), heat avoidance is the first approach to building design in order to minimize heat gains associated with direct solar radiation and high outdoor temperatures. One measure that can minimize heat gains is the heat storage capability of building envelope components that can help in controlling the indoor temperatures and lowering the need of mechanical air-conditioning[13].

2. Ventilated or double skin walls

An air gap between two layers of masonry wall braced with metal ties constitutes a ventilated or double skin wall. They are also called cavity walls. There are two basic kinds of ventilated walls, one with forced ventilation in the cavity, and the other with natural ventilation (stack effect). Most commonly, ventilated walls are used to enhance the passive cooling of buildings. Ciampi et al. [14] developed a mathematical model to evaluate the energy performance of a ventilated wall. They validated this model for 6 different ventilated wall designs.

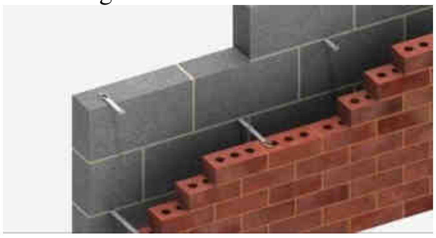

Fig.9 Cavity Wall

Although, energy savings for all the wall designs increase with the increase in width of the air gap, however, further increase over 0.15m yielded only diminishing returns. A typical summer cooling energy savings of 40% can be achieved with a carefully designed ventilated wall. However, poor construction quality can introduce thermal bridge issues. Also, the parameters such as the thermal resistance of the exterior wall and relative roughness of the slabs delimiting the air duct are important .

3.Green Walls

Rapid urbanization brought about the problems of increased building energy consumption and decreased area of green space as well as poor air quality and heat island effect. Building envelope integrated green plants (BIGP), which is also called as vertical greening, is regarded as the potential solution to the energy and environmental issues. The energy saving potential of BIGP was analysed in China's hot summer and cold winter regions through comparative experiments between a vertical greening room and a reference room. It was observed that during winter, the heat flux density of the exterior wall is reduced by 3.11 W/m² with BIGP, and the hourly power consumption of the reference room is 1.22 times that of the room with BIGP. The energy saving rate of BIGP is approximately 18%. During summer, the heat flux density of the exterior wall of the reference room is 4.15 W/m² larger than that of the vertical green room and the hourly power consumption is 1.33 times that of the vertical greening room. The energy saving rate of BIGP is about 25% [15].

Fig.10 Green Wall

4.Polystyrene Insulated Cement Block Walls

Polystyrene insulated cement blocks emerged recently as an energy saving building material in construction practice. Expanded polystyrene of 5cm thickness or more is introduced as a middle fill layer within the cement block in order to improve the thermal properties of walls. Two chambers were constructed, each is built in the form of four block walls 20cm in thickness, one meter wide and one meter high. 5TE sensors and a data logger were used to record ambient temperature and temperature inside each chamber. It was found that the improvement provided by the polystyrene cement blocks is less efficient in hot temperature than in moderate temperature. The insulation provided by the blocks as constructed is very poor and heat transfer is enabled through mortar filled gaps and joints. The temperature gradient has influence on the polystyrene insulation material [16].

	
a-V- groove polystyrene filled.	b- Cuboid filled cavity

Fig. 11Polystyrene Insulated Cement Block

B.Roof

Roofs are a critical part of the building envelope that are highly susceptible to solar radiation and other environmental changes, thereby, influencing the indoor comfort conditions for the occupants. Roofs account for large amount of heat gain/loss, especially, in buildings with large roof area such as sports complexes, auditoriums, exhibition halls etc. The roof thickness and combination of insulation layers proves to be crucial factor in reducing effects of direct solar irradiation. The modification in roof architecture is one of the passive cooling techniques used in green building constructions.

1.Lightweight roofs

Lightweight aluminum standing seam roofing systems (LASRS) are popularly used on commercial and government buildings as they are economical. Two easy ways to improve thermal characteristics of these roofs are by adding thermal insulation and using light colored roof paint. It was determined that the lighter colored surfaces such as white,off-white, brown and green yielded 9.3%, 8.8%, 2.5% and 1.3% reduction in cooling loads compared to an black-painted LASRS surface [17]. Alternative thermal insulation materials such as polyurethane, polystyrene or a combination of these have been evaluated[17] .These roofing systems, modeled and tested on an indoor stadium with a large roof surface area of 51m×41 m, indicated that roof structure with polyurethane insulation and white painted top surface performed better and saved 53.8% of the peak cooling load compared to a dark painted roof with glass wool insulation [17].

Fig. 12 Lightweight Roof

2.Vaulted and domed roofs

Such roofs are quite popular in the vernacular architecture of the Middle East where the climatic conditions are hot and arid. Tang et al. [18] performed detailed finite element modelling of both vaulted roof (VR) and flat roof to compare their thermal performance in various climatic conditions. The half rim angle of a VR should be greater than 50◦ for it to show favourable influence on the indoor thermal conditions. South–north orientation of VR is more advantageous than east–west orientation. Also, they are only suitable for hot and dry climates, due to the presence of larger beam component of the solar radiation which is effectively reflected by the curved roof surface, and not so much for hot and humid climates [18]. Although VRs absorb more heat during the daytime than flat roofs, they also dissipate more heat through natural convection and re-radiation. Also, during night times, typical desert climate experiences colder ambient temperatures causing the VRs to dissipate heat even faster. High thermal stratification occurs inside VR buildings, with almost 75% of the stratification taking place in the volume under the vault, keeping the lower part of the building space cool. The hot air can be exhausted near the top of the gable walls of vaults [18].

Fig.13 Vaulted Roof

Fig.14 Domed Roof

3. Solar reflective roof /Cool Roof

As defined by the Cool Roof Rating Council, a cool roof reflects and emits the sun's heat back to the sky instead of transferring it to the building. The coolness of the roof is measure of two properties: solar reflectance and thermal emittance. Both the properties are measured from 0 to 1 and the higher the value, the cooler the roof.

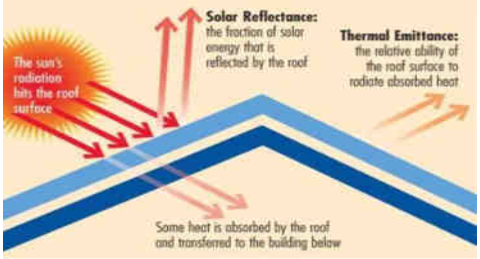

Fig.15 Cool Roof Working

Cool roofs can be selected from a wide variety of materials and colors, and can be advantageously applied to almost any building or roof type, and in most locations. Moreover, cool roofs are a viable option for both new and existing building applications. However, the extent of the benefits will correlate to the location of the building (i.e., climate), type and use, as well as to the specific thermal properties of the selected roofing product. For new buildings and even for existing buildings too, the additional expenses may be insignificant if the retrofit is properly integrated with the reroofing schedule. Conventional materials for standard roofing are now available with their cool roof counterparts. Table 1 lists the SRI for common roofing materials. White roofs are characterized by a high SRI [19].

TABLE 1
Solar Reflective Index (SRI) for common roofing materials

Example SRI Values for Generic Roof Materials	**Solar Reflectance**	**Infrared Emittance**	**Temp Rise (C-Deg)**	**(C Deg) SRI**
Gray EPDM	0.23	0.87	38	21
Gray Asphalt Shingle	0.22	0.91	37	22
Unpainted Cement Tile	0.25	0.90	36	25
White Granular Surface Bitumen	0.26	0.92	35	28
Red Clay Tile	0.33	0.90	32	36
Light Gravel on Built-up Roof	0.34	0.90	32	37
Aluminum	0.61	0.25	27	56
White Coated Gravel on Built-up Roofing	0.65	0.90	16	79
White Coating on Metal Roof	0.67	0.85	16	82
White EPDM	0.69	0.87	14	84
White Cement Tile	0.73	0.90	12	90
White Coating – 1 coat8 mils	0.80	0.91	8	100
PVC White	0.83	0.92	6	104
White Coating – 1 coat20 mils	0.85	0.91	5	107

3.Green Roof

Green roof strategy not only provides heat island amelioration and thermal comfort for occupants but also reduces energy consumption of buildings as well as add aesthetic values to the environment.

A model of green roof thermal behaviour was coupled with a building code to allow the evaluation of green roof foliage and soil surface temperatures. Simulations were conducted for a single-family house with conventional and green roofs in a temperate French climate. With a green roof, the summer indoor air temperature was decreased by 2 °C, and the annual energy demand was reduced by 6%. A green roof system incurs higher annual savings when installed on a well insulated roof [20].

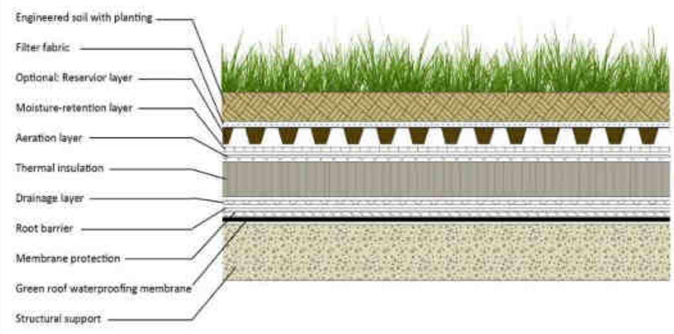

Fig.15 Green Roof Detail

5.Roof Insulation

The effects of combination of roof insulation was studied at Hyderabad region, India having arid climatic conditions. Various materials have been identified which are used as building insulation materials to lower the heat transfer through building envelope components. The materials for the study were Suspended ceilings (rock wool), Fiber Glass, Gypsum board, PVC Mesh – Polyurethane (insulation) layer. Using all these materials, roof slabs were modelled for the study to understand the effects on insulation layers on building energy system. The research successfully suggests the value-added function of insulation layers not only to provide thermal indoor air comfort by restricting the dissipation of heat through the exposed roof surface but also proves to be energy efficient for building envelope [21]. The analysis points out that expanded polystyrene and Rock wool proves to be energy efficient and economical but has high embodied energy. Thus, it is suggested that the focus should be on adopting materials having low overall energy consumption i.e. embodied energy and operational energy, which should be consider while designing and selection of building materials. The possibility of insulating material has been explored to provide overall sustainability during its life cycle. The low U-value roof system proves to be having long term economic benefits over the conventional roof system for building envelope.

C.Doors and Windows

Doors and Windows, referred as fenestrations are very important component of the building envelope. Solar radiation coming in through windows provide natural lighting, natural air and heat gain to the space inside, thus significantly impacting the energy usage of the building. Size, shape and orientation of openings moderate air velocity and flow in the room, a small inlet and a large outlet increase the velocity and distribution of air flow through the room. There should be sufficient air motion in hot-humid and warm-humid climates. Natural light is also admitted into a building through glazed openings. Thus, fenestrations design is primarily governed by requirements of heat gain and losses, ventilation and day lighting. The important components of a window are the glazing systems and shading devices.

1.Glazing types and Materials

Until recently, single pane clear glass was the primary glazing material used in windows. The past few decades have seen immense changes in glazing technology. Several types of advanced glazing systems are available to help control heat loss or gain. The advanced glazing include double and triple pane windows with coating such as low-e (low-emissivity)/

spectrally selective, heat absorbing (tinted), or reflective, gas filled windows and windows based on combination of these options.

Substantial improvements in glazing performance are expected from new materials and techniques. The creation of vacuum or partial vacuum in the cavity of a double glazed unit and the use of aerogel to fill the cavity can lower the U-value considerably. Air spaces between glass layers Thermal resistance provided by the air cavity between glass layers increases with increase in cavity width up to 12mm. Convection currents, which form in wider cavities, lead to drop in thermal resistance.

2.Building integrated photovoltaic glazing

The last generation of energy efficient fenestration is one that generates its own renewable energy, effectively reducing the total building consumption. Generation 3 fenestration products are commonly known as building integrated photo voltaic (BIPV) .Third generation BIPV will come in two main forms: partially opaque/light transmitting; and transparent. As implemented today, light transmitting BIPV consists of solar cells made from thick crystalline silicon either as single or poly-crystalline wafers . These deliver about 10 to 12 Watts per ft² of PV array (under full sun). Such technology is best suited for areas with no light transmission requirements (e.g. spandrels) or shading areas such as overhangs and sunshades [22].

Fig 16: Image of a commercially available ―light thru‖ BIPV Product.

Fig 17: Image of a commercially available ―see through.

D. Future Building Insulations

This section provides a brief description of the building insulations that might be used in the near future:

1.Vacuum insulation materials (VIM)

A vacuum insulation material (VIM) is basically a homogeneous material with a closed small pore structure filled with vacuum with an overall thermal conductivity of less than 4mW/(mK) in pristine condition.. Perforating the VIM with a nail or similar would only result in a local heat bridge, i.e. no loss of low thermal conductivity. For further details on VIMs it is referred to [23].

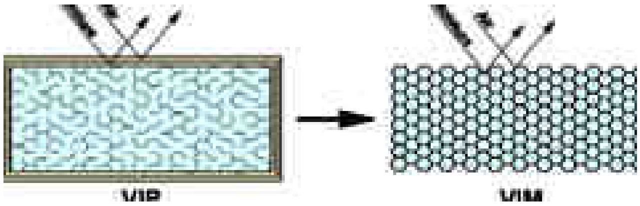

Fig 18: The development from VIPs to NIMs

3.Nano insulation materials

The development from VIPs to nano insulation materials (NIM) is depicted in . In the NIM the pore size within the material is decreased below a certain level, i.e. 40nm or below for air, in order to achieve an overall thermal conductivity of less than 4mW/(mK) in the pristine condition. That is, a NIM is basically a homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4mW/(mK) in the pristine condition.

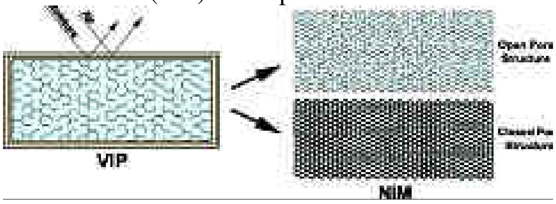

Fig. 19: The development from VIPs to NIMs

2.Dynamic insulation materials (DIM)

A dynamic insulation material (DIM) is a material where the thermal conductivity can be controlled within a desirable range. The thermal conductivity control may be achieved by being able to change in a controlled manner:

-The inner pore gas content or concentration including the mean free path of the gas molecules and the gas-surface interaction.

-The emissivity of the inner surfaces of the pores.

- The solid state thermal conductivity of the lattice.

The thermal insulation regulating abilities of DIMs give these conceptual materials a great potential. However, first it has to be demonstrated that such robust and practical DIMs can be manufactured. It is referred to (Aspen Aerogels, 2008) for further details and elaborations concerning DIMs [24].

VII. CONCLUSION

This paper presented an overview of the performance characteristics and the main features of common building thermal insulating materials and their applications into concrete building structures in a comprehensive and practical way for the practicing engineer and/or building owner. The recommendations can be summarized below:

1. Proper treatment of building envelopes can significantly improve thermal performance especially for envelope-load dominated buildings, such as residences. Therefore, the proper selection and treatment of the building envelope components can significantly improve its thermal performance.
2. Wall and roof insulation are recommended for buildings in all climates for more thermally comfortable space and, therefore, less energy requirements. Insulation helps in reducing conduction losses through all components of the building envelope. However, roof insulation is generally more critical than walls and should be given more attention.
3. Thermal bridges is one of the sources for energy losses during the heating and cooling season in a building. It can also

contribute to other problems such as interior surface condensation problems. Thermal bridges can usually occur in window-to-wall, roof-to-wall, wall-to-balcony slab and wall-to-wall interface. This geometric connections between elements of a building cause energy losses and must be reduced or eliminated as much as possible.

4. Moisture penetration and condensation could use a lot of physical damage and health problems. It could also deteriorate the performance of thermal insulation over time. Therefore, it is important to control moisture in buildings through adequate ventilation, infiltration control and the proper use and location of moister retarders in the building envelope.

6. Infiltration is the most difficult variable to measure and its losses are the most difficult to control. Additionally, due to frequent opening of doors and windows in residences, infiltration rates are expected to be generally higher than anticipated. Therefore, careful treatment of cracks and leaks should be implemented.

7. It is important to provide adequate ventilation in order to insure proper indoor air quality and moisture control, especially in well-insulated buildings .

8. Assessing the thermal performance of the building envelope involves three considerations: the quantity of heat transferred through the walls, windows and other elements of the building envelope -the conductive heats transfer; the quantity of heat needed to bring the temperature of the outdoor air to that of the indoor air, the air-leakage characteristics or air exchange rate; the differences in temperatures on the inner surface of the building envelope - the mould and mildew control points. However, more accurate results were obtained with numerical and analytical methods considering the transient thermal behaviour of the building envelope, while some authors used a dynamic time dependent method based on the finite volume implicit procedure to compute the yearly transmission loads through the wall under steady periodic conditions.

REFERENCES

[1] Marin P, Saffari M, de Gracia A, Zhu X, Farid MM, Cabeza LF, Ushak S. Energy savings due to the use of PCM for relocatable lightweight buildings passive heating and cooling in different weather conditions. Energy Build 2016;129:274–83.

[2] Pérez-Lombard L, Ortiz J, Pout C. A review on buildings energy consumption information. Energy Build 2008;40:394–8.

[3] Wang T, Seo S, Liao P-C, Fang D. GHG emission reduction performance of stateof-the-art green buildings: review of two case studies. Renew Sustain Energy Rev 2016;56:484–93.

[4] Nejat P, Jomehzadeh F, Taheri MM, Gohari M, Majid MZA. A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renew Sustain Energy Rev 2015;43:843–62.

[5] Whiffen TR, Naylor S, Hill J, Smith L, Callan PA, Gillott M, Wood CJ, Riffat SB. A concept review of power line communication in building energy management systems for the small to medium sized non-domestic built environment. Renew Sustain Energy Rev 2016;64:618–33.

[6] Kojok F, Fardoun F, Younes R, Out bib R. Hybrid cooling systems: a review and an optimized selection scheme. Renew Sustain Energy Rev 2016;65:57–80.

[7] Cleveland, Cutler J., and Christopher G. Morris.(2009)"Building envelopergy. Expanded Edition.Burlington:Elsevier,2009.

[8] A.M. Papadopoulos, et al., Design and Development of Innovative Stone-wool Products for the Energy Upgrading of Existing and New Buildings, Project Interim Report, Thessaloniki, 2004 (in Greek).

[9] EN 13164, Thermal insulation products for buildings, factory made products of extruded posystyrene (XPS), Specification, DIN, Berlin,2001.

[10] Data from publications and the web-site of the European association of extruded and expanded polystyrene, EUMEPS, 2003.http://www.eumeps.org/.

[11] Adamczyk, J., Springer, M., 2010. A comparative analysis of cement plaster and thermal insulating plaster e thermopor in the context of the impact on the environment. Przegla̧d Bud. Build. Rev. 7-8, 47e50 (in Polish).

[12] Budaiwi IM, Abdou AA, Al-Homoud MS. Variations of thermal conductivity of insulation materials under different operating temperatures: impact on envelope induced cooling load. Journal of Architectural Engineering 2002;8(4):125–32.

[13] Alaa Aaidroos,Moncey Krati, Impact of Passive Cooling Strategies on Energy Consumption reduction of residentialbuilding in the kingdom of Saudi Arabia,Conference paper in Journal of Solar Energy Engineering,June 2015.

[14] Ciampi M, Leccese F, Tuoni G. Ventilated facades energy performance in summer cooling of buildings. Solar Energy 2003;75(6):491–502.

[15] Jiayu Li 1,, Bohong Zheng 1, Wenquan Shen 1, Yanfen Xiang 1, Xiao Chen 2 and Zhiyong Qi 1,Cooling and Energy-Saving Performance of Different Green Wall Design: A Simulation Study of a Block,Journals/Energies/Volume 12/Issue 15.

[16] Muawia A Dafalla and Mohammed I. Al Shuraim, Efficiency of Polystyrene Iinsulated Cement Blocks,International Journal of GEOMATE, Aug, 2017, Vol.13, Issue 36, pp.35-38.

[17] Han J, Lu L, Yang H. Investigation on the thermal performance of different lightweight roofing structures and its effect on space cooling load. Applied Thermal Engineering 2009;29(11–12):2491–9.

[18] Tang R, Meir IA, Wu T. Thermal performance of non air-conditioned buildings with vaulted roofs in comparison with flat roofs. Building and Environment 2006;41(3):268–76.

[19] Liu KKY. Green, reflective, and photovoltaic roofs. Construction Canada 2006;48(5):44.

[20] Castleton HF, Stovin V, Beck SBM, Davison JB. Green roofs: building energy savings and the potential for retrofit. Energy and Buildings 2010;42(10):1582–91.

[21] A Raut , S Khatoon and P Goud,A comparative study on effects of various insulating layers of roof sustem on energy usage of building envelope,2019 International Conference on New Energy and Future Energy System.

[22] Tinianov Brandon(2010),‖Developing The Next Three Generation of Zero Energy Windows‖,BEST2-Fenestration 1,Session WB9-4.

[23] WeggerE., JelleB.P., SveipeE., GrynningS., GustavsenA., BaetensR. and ThueJ.V., ―Aging effects on thermal properties and service life of vacuum insulation panels‖, Journal of Building Physics, in press.

[24] HostlerS.R., Abramson A.R, GawrylaM.D., BandiS.A., SchiraldiD.A. (2008),‖Thermal conductivity of a clay-based aerogel‖, International Journal of Heat and Mass Transfer, Volume 52, pp.665–669.