PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 18 No. 1 March 2014 pp: 171 - 179

Improve Energy Efficiency through Nano Pore Vacuum Insulation Panels "Vips"

Mustafa M. Abd El-Hafez[1], Ashraf El-Mokadem[2] and Noha M. Abu-Samra[3]

Abstract

Energy efficiency of the built environment greatly depends on the performance of the insulating materials used in the building envelope construction. Vacuum insulation panels (VIPs) offer excellent thermal resistance properties that can enhance the energy efficiency of the insulating systems and provide savings in energy consumption. However, VIP systems are virtually unknown and rarely used for building construction. There is a need to investigate the use of VIPs in various components of building envelopes (walls – roofs) and their long-term function and performance.

1. ENERGY EFFICIENCY

Energy Efficiency is the capacity to produce results with a minimum overall expenditure of energy, human effort, materials and capital. Because the cost and availability of these resources differ, efficiency is relative to time and place. This means that countries have different perspective and limitations on efficiency, but share the same aim of minimizing expenditure of resources for the tasks at hand [1].

Energy efficiency is the capacity to produce results with a minimum expenditure of energy inputs. Waste energy is any energy in a system which is not directly serving the systems function. A system is thought of energy-efficient if its requirements are low in relation to the results produced, and if energy is not wasted [2].

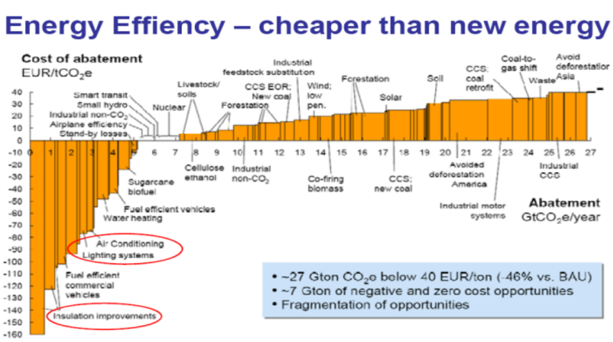


Figure (1): Energy efficiency cheaper than new energy (Cost for various GHG measures in 2030)

Source: Anne Grete Hestnes and Marit Thyholt, **Zero Emission Buildings (ZEB)**, The Research Centre on Zero Emission Buildings, February 2009, www.zeb.no

[1] *Architecture and Urban Planning Department, Faculty of Engineering, Port Said University, Port Said, Egypt, E-mail: whitehouse.egy51@yahoo.com*
[2] *Architecture and Urban Planning Department, Faculty of Engineering, Port Said University, Port Said, Egypt, E-mail: elmokadem1@gmail.com*
[3] *Architecture and Urban Planning Department, Faculty of Engineering, Port Said University, Port Said, Egypt, E-mail: abosamranoha@yahoo.com*

2. VACUUM INSULATION PANELS (VIP)

And thus, we can define energy efficiency as "the ability to provide the best results at the lowest possible energy sparingly, without prejudice to the job"
Minimum Inputs Energy + Minimum Waste Energy = Energy Efficiency

VIP are regarded as one of the most promising high performance thermal insulation solutions on the market today, Thermal performances five to ten times better than conventional insulation of the same thickness.

2.1. Definition of VIPs

A vacuum insulation panel is composed of two components: a micro- to nano- porous material called the "core" that is evacuated, and sealed using a thin membrane called the "foil" [3]. Vacuum insulation panels are defined as: "An evacuated foil-encapsulated open porous material as a high performance thermal insulating material" [4].

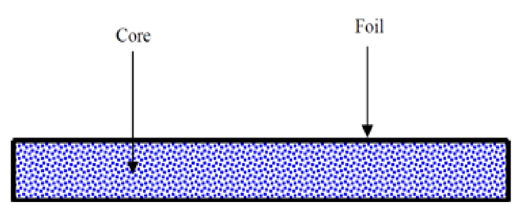


Figure (2): schematic representation of a vacuum insulation panel

Source: Mukhopadhyaya, P., High-performance insulation materials, National Research, Council Canada, September 2004.

2.2. Components of VIPs

VIP has three major components [5]:

- Core Material: imparts mechanical strength and thermal insulating capacity by preventing the free flow of the gas/air molecules thereby reducing the ability of heat transfer through air conduction, (e.g. fumed silica, aerogel, glass fiber or foams). Ideal core materials should have an open cell structure, very small pore diameter, resistance to compression due to atmospheric pressure and very high resistance to infrared radiation.

- Gas Barrier / Facer Foil: provides the air and vapour-tight enclosure for the core material. The long-term performance of the VIPs is very much dependent on the performance of the gas barrier of facer foil.
- Getter / Desiccant: is added inside the core material to adsorb residual or permeating atmospheric gases or water vapour in the VIP enclosure. The addition of getter/desiccant increases the performance and longevity of VIPs.
-

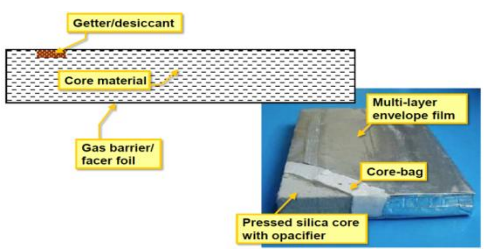


Figure (3): Components of "VIP"

Source: Dr. Phalguni Mukhopadhyaya, **High-Performance Vacuum Insulation Panel in Building Envelope Construction**, National Research, Council Canada, 2010 AMTS Technical Committee Meeting, 06 October 2010. www.nrc-cnrc.gc.ca/irc

There are many various shapes possible of VIP, in particular for technical applications, which give vacuum insulation very good value.

Figure (4): Different shapes of vacuum insulation panels

Source: Mukhopadhyaya, P., **High-performance insulation materials**, National Research, Council Canada, September 2004.

The thermal resistance of VIPs is several times (up to 10 times) higher than conventional insulating materials, therefore Thermal conductivity of VIPs is several times (up to 10 times) lower than conventional insulating materials.

Table 1: Thermal conductivity for different Insulator

Insulation Methods	Thermal conductivity
Traditional Insulation	36 mW/(mK)
Vacuum Insulation Panels (VIP)	4 mW/(mK) fresh 8 mW/(mK) 25 years 20 mW/(mK) perforated
Gas-Filled Panels (GFP)	40 mW/(mK
Aerogels	13 mW/(mK)

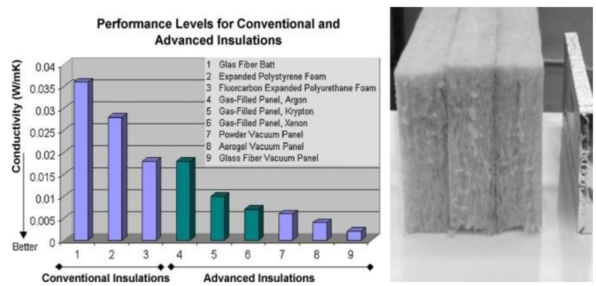


Figure (5): [left] the thermal conductivities of conventional and advanced insulation materials and solutions and [right] the required thicknesses for conventional insulation (e.g. glass wool) and a VIP

Source: va-Q-tec c, Vacuum Insulation Panels (VIPs), June 2011, www.va-Q-tec.com

2.5. Advantages of VIPs

VIPs is considered the best solution today and in the near future. VIPs Advantages are:

- Higher thermal resistance.
- Reduced thickness of the component.
- Recyclable.
- High performance thermal insulating.
- Increased floor area.
- Appropriate refurbishing of existing buildings with high restrictions.
- Lower operating temperature increases thermal.

2.6. Disadvantages of VIPs

Although VIPs has many Advantages, there are many Disadvantages,

- Any damage in the vacuum system (even a small pinhole) will severely destroy the thermal insulating capacity of VIPs.
- Very fragile and protection for puncture of the foil is necessary.
- Reducing thermal performances through time.
- Limited service life may require replacement.
- Less suitable for traditional timber wall structures.
- Production inaccuracy of the panel sizes.
- Inflexible: Can not be cut or adapted at building site.
-

2.7. Challenges and solution of VIPs

Challenges	solution
Cost (relatively expensive)	- Like many other nanomaterials cost effective, high quality and large volume production of nanoporous insulating materials is important for their widespread applications.
Aging and durability	- Manufacturing - Properties of core materials - Handling and exposure
Thermal bridge effects at edges	- Use large panels - Overlap panels - Fill gaps at edges with insulating materials
Condensation	- VIP is an absolute vapour barrier - Avoid damp construction materials - Consequences of vacuum failure

2.8. Lifespan of VIPs

The life expectancy of a vacuum insulation panel is determined by a number of factors. Specifically, these are;

- The initial vacuum level of the panel.
- The permeation rate of the membrane film.
- The out-gassing (if any) of the core material and membrane film.
- The permeation rate of the membrane sealing edge
- The quantity and effectiveness of the getter and desiccant.
- The effect of pressure rise on the specific core material.
- Minimum Performance Requirements
- Panel Size
- Fabrication Quality
- VIP Component Choices
- Use Conditions.

The two primary factors that determine the long-term thermal performance of the vacuum insulation panel are:

- Effectiveness of gas barrier, and
- Performance of core material.

2.9. Recommendations to Usages of VIPs

To raise the confidence in VIP-technology and their use in building applications the following recommendations should be taken [6]:

- Industrial processing: integration of VIP in prefabricated building systems and components.
- Information and consulting: all concerned be informed, advised as early as possible and be supported by a specialist during the entire planning and installation process (preferably by the VIP supplier). Warning label "VIP inside".
- Handling: VIP must be handled with care and suitable protective measures and tools employed (protective mats, felt shoes, etc.).
- Detailing: VIP must be well protected from mechanical damage. This applies to functional loading (e.g. from the floor). Inadvertent loading (e.g. dilatation) and subsequent manipulations (e.g. nailing). One must pay special attention to various joint details, since protecting components (e.g. angle brackets for window attachment, guide rails, frames) may damage the VIP.
- Reducing the edge effect: select panels that are as square and large as possible (min. 0.5×0.5 m^2). Panel with an aluminum foil envelope (only rarely nowadays), lay the panels in a double layer, overlapping by at least 5 cm.
- Water vapour diffusion: VIP are vapour-tight insulation systems, which has to be taken into account in planning the order and thickness of the layers. Furthermore, special attention must be given to the joints between the panels.
- Inspection of the VIP: installation of the VIP in such a way that inspection of their correct functioning can be made (sensor or thermograph).
- Replace-ability: it would be desirable, that the VIP are embedded in the construction such that they can be replaced without undue effort in preparation or as a result (e.g. mechanically fixed covers). Otherwise deterioration in the U-value has to be accepted and it must be assured that on loss of vacuum, there is no risk of loss of condensation and mould at the inside of the walls.

Figure (6): Draft sketch for an adhesive warning label to mark VIP panels and building components containing VIP
Source: Prof. Armin Binz, Gregor Steinke, **Applications of Vacuum Insulation in the Building Sector**, 7th International Vacuum Insulation Symposium, Empa, Duebendorf / Zurich, Switzerland, September 28-29, 2005.

2.10. Development of VIPs

- **Before 2005,** VIP has only limited use, mainly in top models home refrigerators/freezers and cold shipping boxes. Japan controls more than 50% of the small global VIP market with several million panels per year. The VIP market in Japan is fast growing. The common core materials are fumed and precipitated silica.

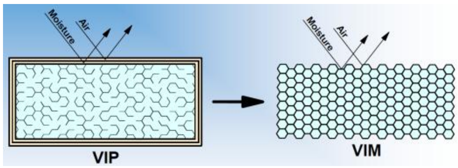


Figure (7): vacuum insulation panels before 2005
Source: Bjørn Petter Jelleab and Arild Gustavsenc, **Advanced Thermal Building Insulation (From Vacuum Insulation Panels to Nano Insulation Materials)**, Trondheim, Norway, 9th of September, 2010.

- **After 2005,** Nano Insulation Material (NIM): A basically homogeneous material with a closed or open small nano pore structure with an overall thermal conductivity of less than 4 mW/(mK) in the pristine condition [4].

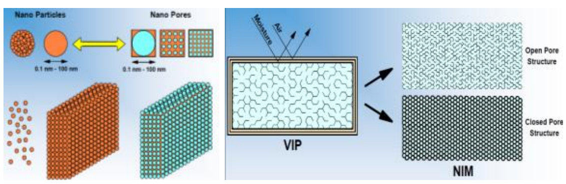


Figure (8): vacuum insulation panels after 2005
Source: Bjørn Petter Jelleab and Arild Gustavsenc, **Advanced Thermal Building Insulation (From Vacuum Insulation Panels to Nano Insulation Materials)**, Trondheim, Norway, 9th of September, 2010.

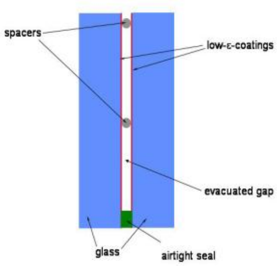


Figure (9): Principle of a Vacuum Insulation Glass
Source: H. Weinlader, H.-P. Ebert, J. Fricke, **VIG - Vacuum Insulation Glass**, Bavarian Center for Applied Energy Research (ZAE Bayern), Am Hubland, D-97074 Wurzburg.

- **In the near future,** Vacuum Insulation Glass (VIG): VIG is a double glazing with a vacuum between the panels of glass. This means that slim systems less than 10 mm thick can be realized with heat transfer coefficients of U ≈ 0.5 W/ (m²K). Triple glazing, used, for instance, in passive houses, achieves a typical U-value of 0.6 - 0.7 W/(m²K) at a thickness of 28 - 44 mm, but is 50 % heavier. VIG with a U-value of ≈ 0, 5 W/ (m²K) is not yet available on the market [7].

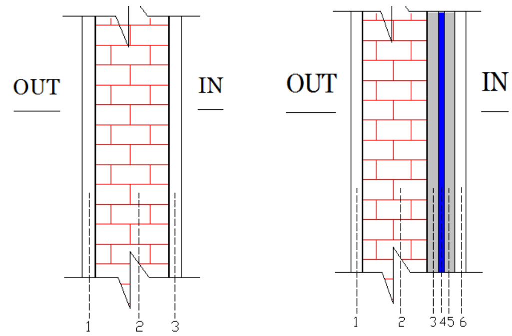
3. IMPROVE ENERGY EFFICIENCY THROUGH NANO PORE VACUUM INSULATION PANELS "VIP"

We can improve energy efficiency through opaque parts (wall sections) used nano insulation materials (nano pore vacuum insulation panels "VIP").

3.1. Wall Sections Shape

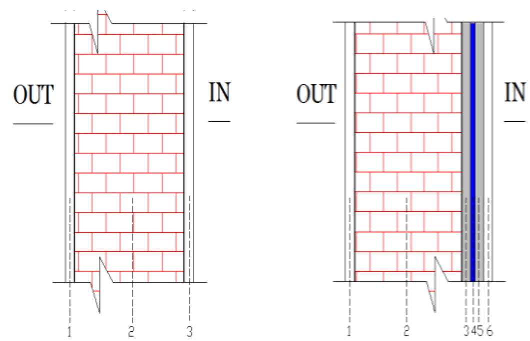
Wall Section Shape is divided into:

Solid Wall Section (20mm – 120mm – 20mm)



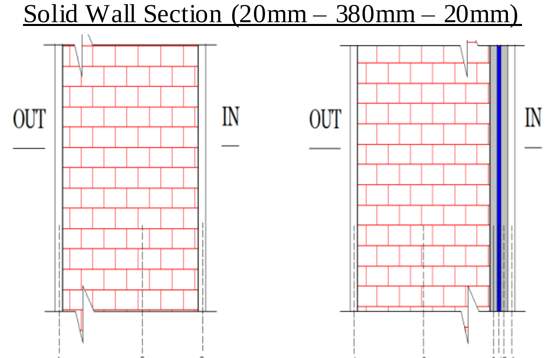
Without Insulation **With (VIP) Insulation**

Solid Wall Section (20mm – 250mm – 20mm)



Without Insulation **With (VIP) Insulation**

Solid Wall Section (20mm – 380mm – 20mm)

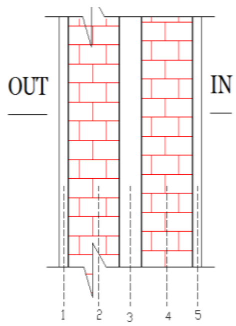


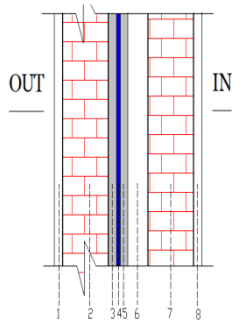
Without Insulation **With (VIP) Insulation**

1- External Plaster
2- Bricks
3- Internal Plaster

1- External Plaster
2- Bricks
3- Protective layer (Expanded Polystyrene)
4- Vacuum Insulation Panels
5- Protective layer (Expanded Polystyrene)
6- Internal Plaster

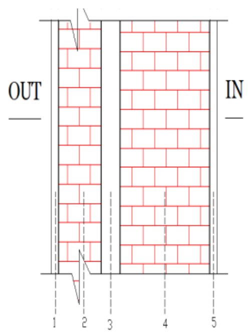
Cavity Wall Section with 50mm Air Space
(20mm – 120mm – 50mm – 120mm – 20mm)

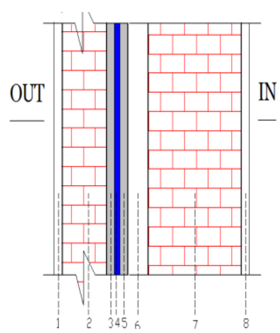




Without Insulation **With (VIP) Insulation**

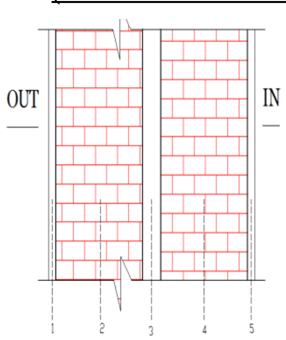
Cavity Wall Section with 50mm Air Space
(20mm – 120mm – 50mm – 250mm – 20mm)

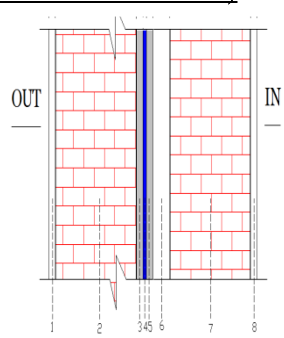




Without Insulation **With (VIP) Insulation**

Cavity Wall Section with 50mm Air Space
(20mm – 250mm – 50mm – 250mm – 20mm)





Without Insulation

1- External Plaster
2- Bricks
3- Air Space
4- Bricks
5- Internal Plaster

With (VIP) Insulation

1- External Plaster
2- Bricks
3- Protective layer (Expanded Polystyrene)
4- Vacuum Insulation Panels
5- Protective layer (Expanded Polystyrene)6- Air Space
7- Bricks
8- Internal Plaster

3.2. Thermal Properties of wall section as layers

Material		Thermal Properties as layers	
Name	**Thickness** (L) - (mm)	**Thermal Resistance** (R-value) - (m^2.c°/watt)	**Thermal Transmittance** (U-value) - (watt/m^2.c°)
External Plaster	20	0.02	50
Internal Plaster	20	0.02	50
Air space	50	0.153	6.53
Hollow Cement Bricks	120	0.07	14.2
	250	0.16	6.25
	380	0.24	4.16
Protective layer (Expanded Polystyrene)	20	0.54	1.85
	30	0.81	1.23
	50	1.35	0.74
Vacuum Insulation Panels (VIP)	10	2	0.5
	15	3	0.33
	20	4	0.25
	25	5	0.2
	30	6	0.16
	40	8	0.125

3.3. Thermal Properties of wall section as whole

We can calculate (Thermal Resistance **(R-Value)** - Thermal Transmittance **(U-Value)**) from the two equation:

$$R\text{-Value} = 1/h_{ao} + \sum R_i + 1/h_{ai} = \ \ldots \ m^2.c°/watt \quad (8)$$

Where:

$$1/h_{ao} + 1/h_{ai} = 0.178 \ m^2.c°/watt$$

$$\sum R_i = \sum R \text{ for each layer} \ m^2.c°/watt$$

$$U\text{-Value} = 1 / R\text{-Value} = \ \ldots\ldots \ watt/m^2.c° \quad (9)$$

Where:

$$R\text{-Value} = \ \ldots\ldots\ldots\ldots \ m^2.c°/watt$$

Section		Thermal Properties as whole	
Name	**Insulation**	**Thermal Resistance** (R-value) - (m^2.c°/watt)	**Thermal Transmittance** (U-value) - (watt/m^2.c°)
1- Solid Wall Section (20mm – 120mm – 20mm) with 10mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.28	3.57
	With VIP	3.36	0.30
2- Solid Wall Section (20mm – 120mm – 20mm) with 15mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.28	3.57
	With VIP	4.36	0.23

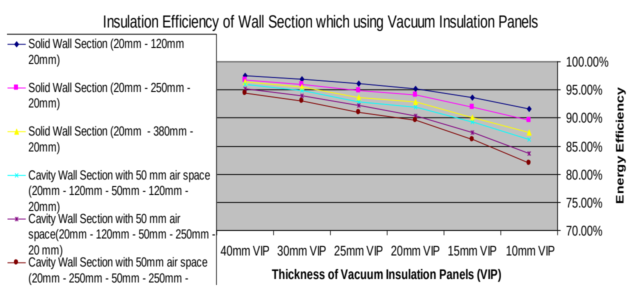
3- Solid Wall Section (20mm – 120mm – 20mm) with 20mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.28	3.57
	With VIP	5.90	0.17
4- Solid Wall Section (20mm – 120mm – 20mm) with 25mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.28	3.57
	With VIP	6.90	0.14
5- Solid Wall Section (20mm – 120mm – 20mm) with 30mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.28	3.57
	With VIP	8.98	0.11
6- Solid Wall Section (20mm – 120mm – 20mm) with 40mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.28	3.57
	With VIP	10.98	0.09
7- Solid Wall Section (20mm – 250mm – 20mm) with 10mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.37	2.70
	With VIP	3.45	0.28
8- Solid Wall Section (20mm – 250mm – 20mm) with 15mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.37	2.70
	With VIP	4.45	0.22
9- Solid Wall Section (20mm – 250mm – 20mm) with 20mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.37	2.70
	With VIP	5.99	0.16
10- Solid Wall Section (20mm – 250mm – 20mm) with 25mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.37	2.70
	With VIP	6.99	0.14
11- Solid Wall Section (20mm – 250mm – 20mm) with 30mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.37	2.70
	With VIP	9.07	0.11
12- Solid Wall Section (20mm – 250mm – 20mm) with 40mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.37	2.70
	With VIP	11.07	0.09
13- Solid Wall Section (20mm – 380mm – 20mm) with 10mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.45	2.22
	With VIP	3.53	0.28
14- Solid Wall Section (20mm – 380mm – 20mm) with 15mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.45	2.22
	With VIP	4.53	0.22
15- Solid Wall Section (20mm – 380mm – 20mm) with 20mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.45	2.22
	With VIP	6.07	0.16
16- Solid Wall Section (20mm – 380mm – 20mm) with 25mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.45	2.22
	With VIP	7.07	0.14
17- Solid Wall Section (20mm – 380mm – 20mm) with 30mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.45	2.22
	With VIP	9.15	0.10
18- Solid Wall Section (20mm – 380mm – 20mm) with 40mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.45	2.22
	With VIP	11.15	0.08
19- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 120mm – 20mm) with 10mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.51	1.96
	With VIP	3.59	0.27
20- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 120mm – 20mm) with 15mm	Without VIP	0.51	1.96
	With VIP	4.59	0.21

Vacuum Insulation Panels (VIP) used Hollow Cement Bricks			
21- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 120mm – 20mm) with 20mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.51	1.96
	With VIP	6.13	0.16
22- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 120mm – 20mm) with 25mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.51	1.96
	With VIP	7.13	0.14
23- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 120mm – 20mm) with 30mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.51	1.96
	With VIP	9.21	0.10
24- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 120mm – 20mm) with 40mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.51	1.96
	With VIP	11.21	0.08
25- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 250mm – 20mm) with 10mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.60	1.66
	With VIP	3.68	0.27
26- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 250mm – 20mm) with 15mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.60	1.66
	With VIP	6.22	0.16
27- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 250mm – 20mm) with 20mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.60	1.66
	With VIP	6.13	0.16
28- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 250mm – 20mm) with 25mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.60	1.66
	With VIP	7.13	0.14
29- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 250mm – 20mm) with 30mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.60	1.66
	With VIP	9.21	0.10
30- Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 250mm – 20mm) with 40mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.60	1.66
	With VIP	11.21	0.08
31- Cavity Wall Section with 50mm Air Space (20mm – 250mm – 50mm – 250mm – 20mm) with 10mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.69	1.44
	With VIP	3.77	0.26
32- Cavity Wall Section with 50mm Air Space (20mm – 250mm – 50mm – 250mm – 20mm) with 15mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.69	1.44
	With VIP	4.77	0.20
33- Cavity Wall Section with 50mm Air Space (20mm – 250mm – 50mm – 250mm – 20mm) with 20mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.69	1.44
	With VIP	6.31	0.15
34- Cavity Wall Section with 50mm Air Space (20mm – 250mm – 50mm – 250mm – 20mm) with 25mm Vacuum Insulation Panels (VIP) used	Without VIP	0.69	1.44
	With VIP	7.31	0.13

Hollow Cement Bricks			
35- Cavity Wall Section with 50mm Air Space (20mm – 250mm – 50mm – 250mm – 20mm) with 30mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.69	1.44
	With VIP	9.39	0.10
36- Cavity Wall Section with 50mm Air Space (20mm – 250mm – 50mm – 250mm – 20mm) with 40mm Vacuum Insulation Panels (VIP) used Hollow Cement Bricks	Without VIP	0.69	1.44
	With VIP	11.39	0.08

4. DISCUSSION

- Insulation Efficiency of solid wall section (20mm – 120mm – 20mm) is average <u>91.60 %</u> **:** <u>97.48 %</u>
- Insulation Efficiency of solid wall section (20mm – 250mm – 20mm) is average <u>89.63 %</u> **:** <u>96.67 %</u>
- Insulation Efficiency of solid wall section (20mm – 380mm – 20mm) is average <u>87.39 %</u> **:** <u>96.40 %</u>
- Insulation Efficiency of cavity wall section with 50mm air space (20mm – 120mm – 50mm – 120mm – 20mm) is average <u>86.22 %</u> **:** <u>95.92 %</u>
- Insulation Efficiency of cavity wall section with 50mm air space (20mm – 120mm – 50mm – 250mm – 20mm) is average <u>83.73 %</u> **:** <u>95.18 %</u>
- Insulation Efficiency of cavity wall section with 50mm air space (20mm – 250mm – 50mm – 250mm – 20mm) is average <u>81.94 %</u> **:** <u>94.44 %</u>



5. CONCLUSION

In less than a century, human has led mankind to unexpected heights in human and technical domains. But in the same time, a small part of mankind has:

- Forever consumed some major natural resources.
- Altered the thermal equilibrium of the planet.

We should now find efficient ways to: Build sustainable development and solve the energy equation for more than 6 billion people.

<u>Energy Efficient Buildings are a part of the solution</u>

<u>Insulation Efficiency can be calculate through equation:</u>

$$\text{Insulation Efficiency} = \frac{(\text{U-value})\ \text{Without VIP} - (\text{U-value})\ \text{With VIP}}{(\text{U-value})\ \text{Without VIP}} * 100$$

Sections			Insulation Efficiency
Solid Wall Section (20mm – 120mm – 20mm)	1	with 10mm VIP	91.60 %
	2	with 15mm VIP	93.56 %
	3	with 20mm VIP	95.24 %
	4	with 25mm VIP	96.08 %
	5	with 30mm VIP	96.92 %
	6	with 40mm VIP	97.48 %
Solid Wall Section (20mm – 250mm – 20mm)	7	with 10mm VIP	89.63 %
	8	with 15mm VIP	91.85 %
	9	with 20mm VIP	94.07 %
	10	with 25mm VIP	94.81 %
	11	with 30mm VIP	95.93 %
	12	with 40mm VIP	96.67 %
Solid Wall Section (20mm – 380mm – 20mm)	13	with 10mm VIP	87.39 %
	14	with 15mm VIP	90.09 %
	15	with 20mm VIP	92.79 %
	16	with 25mm VIP	93.69 %
	17	with 30mm VIP	95.50 %
	18	with 40mm VIP	96.40 %
Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 120mm – 20mm)	19	with 10mm VIP	86.22 %
	20	with 15mm VIP	89.29 %
	21	with 20mm VIP	91.84 %
	22	with 25mm VIP	92.86 %
	23	with 30mm VIP	94.90 %
	24	with 40mm VIP	95.92 %
Cavity Wall Section with 50mm Air Space (20mm – 120mm – 50mm – 250mm – 20mm)	25	with 10mm VIP	83.73 %
	26	with 15mm VIP	87.35 %
	27	with 20mm VIP	90.36 %
	28	with 25mm VIP	92.17 %
	29	with 30mm VIP	93.98 %
	30	with 40mm VIP	95.18 %
Cavity Wall Section with 50mm Air Space (20mm – 250mm – 50mm – 250mm – 20mm)	31	with 10mm VIP	81.94 %
	32	with 15mm VIP	86.11 %
	33	with 20mm VIP	89.58 %
	34	with 25mm VIP	90.97 %
	35	with 30mm VIP	93.06 %
	36	with 40mm VIP	94.44 %

6. REFERENCES

[1] Ahmed Sobhy Foda, "Energy Code and Building Envelope", Master of Science in Architecture, Department of Architecture, Faculty of Engineering, University of Cairo, Giza, 2005.

[2] Anne Grete Hestnes and Marit Thyholt, "Zero Emission Buildings (ZEB)", The Research Centre on Zero Emission Buildings, February 2009.

[3] Phalguni Mukhopadhyaya, "High-performance insulation materials", National Research, Council Canada, September 2004.

[4] Bjørn Petter Jelleab and Arild Gustavsenc, "Advanced Thermal Building Insulation (From Vacuum Insulation Panels to Nano Insulation Materials)", SFFE

Lunch Lecture, Trondheim, Norway, 9th of September, 2010.
[5] Phalguni Mukhopadhyaya, "High-Performance Vacuum Insulation Panel in Building Envelope Construction", National Research, Council Canada, 2010 AMTS Technical Committee Meeting, 06 October 2010.
[6] Prof. Armin Binz, Gregor Steinke, "Applications of Vacuum Insulation in the Building Sector", 7th International Vacuum Insulation Symposium, Empa, Duebendorf / Zurich, Switzerland, September 28-29, 2005.
[7] H. Weinlader, H.-P. Ebert, J. Fricke, "VIG - Vacuum Insulation Glass", Bavarian Center for Applied Energy Research (ZAE Bayern), Am Hubland, D-97074 Wurzburg.
[8-9] Rasha Mohamed Sleem, **Impact of Building Technology used in Building Envelope on Energy Reduction in Buildings**, Master of Science in Architecture, Department of Architecture, Faculty of Engineering, University of Cairo, Giza, 2003