Proceedings of 3rd Conference: ***People and Buildings*** held at Westminster University, School of Architecture and the Built Environment, London, UK, 20th September 2013. Network for Comfort and Energy Use in Buildings: http://www.nceub.org.uk

Optimisation of the edge effect and Life span of a Vacuum Insulation Panel

Lia De Simon[1] and David Tetlow[2]

1 MSc Sustainable Building Technology, University of Nottingham, UK, lia.desimon@gmail.com;
2 Dept of Architecture and Built Environment, University of Nottingham, UK

Abstract
In a context where the Government set high emission reduction targets it is becoming essential to tackle the problem of GHG produced by existing dwellings. The most efficient solution is to improve the efficiency of the building envelope by insulating the edifice. One innovative insulation technology is Vacuum Insulation Panels (VIP). These consist of an evacuated fumed silica core wrapped in an air tight film material that prevents air infiltration. The most efficient barriers are integrated with a layer of aluminium, but as a side effect this produces a thermal bridge. There are still some issues in quantifying the amount of gaseous infiltration. The aim of this paper is to study the thermal bridge effect and combining it with a new model for estimating permeation to individuate the best film that minimizes edge effect but simultaneously maximizes the panel life-span. This will be done using ANSYS for the first part and a Matlab code implementing Random Walk of gaseous particles for the second part.

Keywords: Edge effect, Gas permeation, Random walk, VIP, ANSYS

Introduction
At present, reducing the carbon emissions is a growing concern in many countries all over the world. The UK has both international (Kyoto protocol) and domestic (legislated under the Climate Change Act in 2008) targets to reduce the GHG emissions. The Climate Change Act requires to reduce by 80% the GHG emissions respect to the base year by 2050(Department of Energy and Climate Change 2012). At current state the residential sector is responsible for 15% of the CO_2 emissions, (Department of Energy and Climate Change 2012). One of the most cost effective ways to improve building efficiency is installing insulation (Dowson, Poole et al. (2012)). Vacuum Insulation Panels consist of a core of fumed silica maintained under vacuum conditions wrapped in an airtight material. The coating film is composed by plastic polymers (Polyethylene Terephthalate, Polyethylene, Polypropylene) alternated with metal layers, (Al, Steel, AlO_x, SiO_x) that prevents gaseous penetration inside the core.

VIP present the lowest values for thermal conductivity between the insulating materials currently available on the market, at the centre-of-panel the thermal conductivity can be as low as λ_{cop} = 0.004W/mK.

The downside of VIP is that they present strong in-homogeneities between the thermal conductivity of the core and the coating film materials that gives rise to an

important thermal bridge effect (Hans, Samuel et al. (2005)). The heat transfer into the panel occurs by different transport mechanisms, radiation, solid conduction, gaseous conduction. The dominant component in this process is the gaseous conductivity. Wei, Liu et al. (2012) conducted an experimental investigation aiming to enlighten the behaviour of gaseous thermal conductivity in a porous material in relation to pressure. They proved that due to the high porosity of fumed silica, gaseous conductivity is virtually inexistent at low pressures. For this reason it is essential to maintain low pressure inside the panel.

Membrane Permeability

The permeation model commonly assumed for modelling gas infiltration through VIP envelops is the sorption diffusion model. (Bouquerel, Duforestel et al. (2012)) This model is based on the first and second Fick's lows of diffusion

$$g_i = -D_i \frac{\partial c_i}{\partial x_i}$$

$$\frac{\partial c_i}{\partial t} = D_i \frac{\partial^2 c_i}{\partial^2 x}$$

Equation 1

Where g_i is the mass flow rate, D_i is the diffusion coefficient; c_i is the concentration of the permeant. For Aluminium coated polymers it has been found that permeation occurs through the defects of the metal ply. For macro-defects the permeability has been found to be proportional to the polymer permeability and the expression for the proportionality constant has been proposed for cracks and rectangular holes by Hanika, Langowski et al. (2003) and for circular holes by Rossi and Nulman (1993). Bouquerel, Duforestel et al. (2012) report an approximation proposed by Hanika (2004) for his PhD thesis derived from different numerical simulations to calculate the defect permeability:

$$Pe_{def} = \frac{A_{def} n_0}{1 - e^{-0.507\left(\sqrt{A_{def}}/\eta_{poly}\right)} + 0.01 n_0 A_{def}} Pe_{poly}$$

Equation 2

Random Walk

Gaseous particles movement is the result of collisions between molecules and boundaries. This results in a motion called random walk. There are many examples that describe random walk and as a starting point let's consider a one dimension model:

- A particle can move only backward and forward along one line.
- The step size is +1 if moving forward or -1 if moving backwards
- The probability of going forward or backward is 50%

With some calculation it can be shown that the displacement of the particles from the starting point is proportional to the square root of the number of steps performed. The number of steps is proportional to the time elapsed therefore the spreading goes like the square root of the time (Rochester). Random walk can be applied to diffusion, particle movement in concentration gradients (MIT) and Vanderroost, Ronsse et al.

(2012) implemented a model to describe the random walk of particles in an Hexagonal Closed Packing Lattice showing that it was possible to achieve a realistic distribution of real particles implementing this method. In this paper it will be used to understand the particle motion between the barrier layers in the envelope material.

Methodology

Thermal conductivity

In order to compare the edge effect of different envelope types it was chosen to calculate an overall thermal conductivity for 5 different film types, three Metallized Foils and two Aluminium Film envelopes. The simulations were carried out making use of ANSYS 14.5. The aim was to calculate an overall thermal conductivity to compare the thermal bridge effect. Different simulations were carried out to calculate the thermal conductivity along two perpendicular directions of the film since the material is not isotropic.

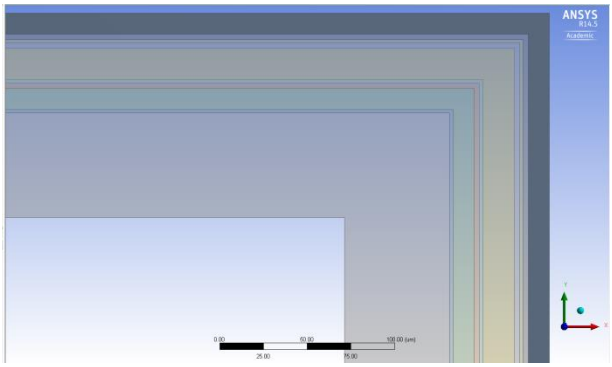

Figure 1 Details of Geometry for MF1

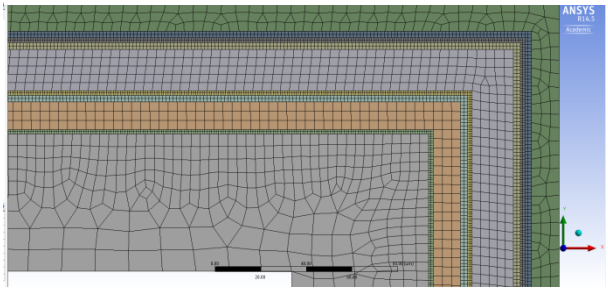

Figure 2 Details of mesh for MF1

It was chosen to design a 2D geometry in order to simplify the problem and reduce the computational time. The values relative to the Thermal conductivity of each component were retrieved from the literature and the details of the film structure were taken from Hans, Samuel et al. (2005). It was very important to produce a refined mesh on the boundaries between materials with different thermal conductivities. The boundary conditions set a temperature gradient of 10°C between opposite faces. **Error! Reference source not found.** shows details of the geometry for the first metallized foil, **Error! Reference source not found.** shows the details of the mesh for the same envelope. In the case of the calculation of the perpendicular thermal conductivity, the geometry was further simplified and reduced to a rectangle. The temperature gradient was set across the top and bottom layer, simulating the case where the heat was flowing perpendicularly from the Aluminium direction. In all simulations the heat flux though each layer was monitored. From this, the single element thermal conductivity and the geometrical parameters, the heat flow and the absolute resistance for each layer were calculated allowing to find the film overall thermal conductivity.

Random Walk

The aim of this section was to investigate whether different dispositions of the metal coatings inside the film material would affect permeation through the film. This was done simulating the Random Walk with a Matlab code, assuming that the gas particles could move left or right or up or down with 50% probability. Simulations with different step size were carried on. It was assumed that the step size should match the length of the mean free path in the PET material calculated according to the formula proposed by Zeng, Hunt et al. (1995). To consider all the possibilities five different step sizes were simulated (0.6µm, 0.4 µm, 0.2µm, 0.1µm and 0.05 µm) and for each case the distance between the two metal layers was set at first at 12µm and then at 2µm. It was assumed that the particles weren't allowed to exit the domain once entered. For each case, the final x position of the molecules was registered when the particle hit the second AL stratum. This allowed calculating the mean and standard deviation of the distribution followed by the particles in each scenario. The number of particles performing the Random Walk in each case was set to 500.

Results

Table 1 Reports shows the figures obtained for the overall thermal conductivity of all Film types. For each layer the Absolute thermal resistance was calculated. For the MF films, in the barrier layers, this was of the same order of magnitude as for the polymer layers ~10^{12}K/W while for the AF Foils this was two orders of magnitude lower ~10^{10}K/W.

Table 1 Perpendicular and Parallel thermal conductivity for all films

	λ [W/(m K)]	
	Parallel	Perpendicular
AF1	27.610	0.289
AF2	18.460	0.276
MF1	0.425	0.212
MF2	0.925	0.252
MF3	0.441	0.266

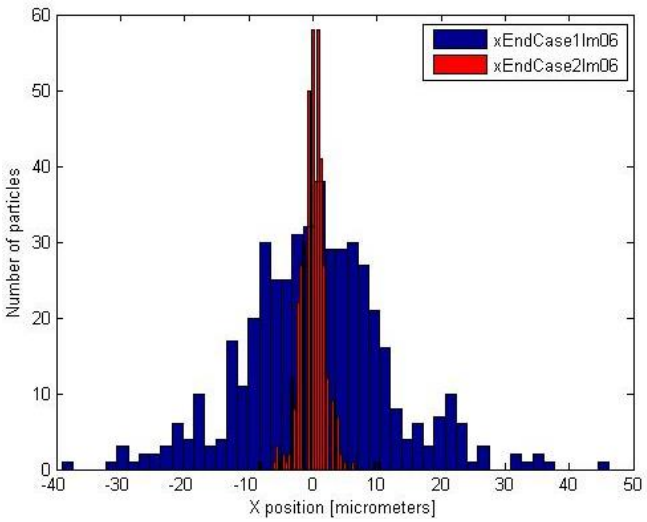

Figure 3: final position of Particles for lm 0.6µm

Figure 3 shows the comparison between the final positions of the gas particles in the 2µm and 12µm domain for mean free path length 0.6µm. Similar results were achieved for all the other mean free path lengths. The table below instead presents the figures relative to the mean and variance of the distributions obtained interpolating the results with a Gaussian fit. Case1

corresponds to the 12µm domain, while Case 2 stands for the 2µm domain.

Table 2: First and seconf moment of the distributions

Case	Mean µ	Variance σ
Case 1 lm 0.6	-0.391	10.303
Case 2 lm 0.6	0.094	1.955
Case 1 lm 0.4	-0.146	11.547
Case 2 lm 0.4	-0.067	1.945
Case 1 lm 0.2	-0.756	10.916
Case 2 lm 0.2	0.0003	2.090
Case 1 lm 0.1	0.539	11.783
Case 2 lm 0.1	0.040	2.049
Case 1 lm 0.05	0.350	11.482
Case 2 lm 0.05	0.247	2.140

Discussion

The results obtained clearly mark the difference in thermal conductivity between the two families of envelopes. Such low values in thermal conductivity for the MF films are achievable thanks to the reduction in the thickness of the Aluminium strata. The high resistivity thus obtained means that the heat flow through the barrier layers is of comparable magnitude as the flow in the plastic plies. This doesn't happen in the AF films. These results can be employed for whole panel simulations where the envelope can be simulated as a unique material of equivalent thermal conductivity. According to the heat flux direction one needs to use the parallel or perpendicular conductivity.

The main result obtained from the Random Walk simulation is that, in the case of short distance between the metal layers, the spreading of the particles is restricted. The model cannot be applied directly to calculate permeation since it would give a tautological result: the permeation would be proportional to the probability of finding a pinhole, which depends on the pinhole distribution, a property of the metal coating itself. The following consideration could be made instead: from the particles point of view, the pinholes laying outside the width of the spreading on the second boundary are unreachable. This means that only the defects contained within the boundaries of the distribution count as possible openings for permeation and the aluminium outside these margins is as if it was a perfect coating because the particles cannot pass through these regions. This means that, in the second case, the number of pinholes involved in the permeation through the second Aluminium ply is less than in the first case. This factor could be counted as a reduction in the "overall density of defects" of the second barrier layer and according to Equation 2 it could account for a reduction in the permeability of the metal layer.

Conclusions

The thermal analysis shows the advantage of MF films in reducing the edge effect of VIPs compared to the AF films. The analysis carried out on the random walk suggests

that the disposition of the layers could improve the barrier capacity of an MF film without affecting the thermal efficiency. A metallized foil film with closer barrier layers could be more efficient from a permeation point of view without paying the price in terms of thermal bridge effect.

References

Bouquerel, M., T. Duforestel, D. Baillis and G. Rusaouen (2012). "Mass transfer modeling in gas barrier envelopes for vacuum insulation panels: A review." Energy and Buildings **55**: 903-920.

Department of Energy and Climate Change (2012). Uk Greenhouse Gas Emissions: Performance Against Emissions Reduction Targets -2011 Provisional Figures.

Dowson, M., A. Poole, D. Harrison and G. Susman (2012). "Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal." Energy Policy **50**(0): 294-305.

Hanika, M. (2004). Ph.D, TU Munchen.

Hanika, M., H. C. Langowski, U. Moosheimer and W. Peukert (2003). "Inorganic Layers on Polymeric Films – Influence of Defects and Morphology on Barrier Properties." Chemical Engineering & Technology **26**(5): 605-614.

Hans, S., B. Samuel, H. Ulrich, S. Hubert, K. Kumar, M. Phalguni, Q. Daniel, S. Hébert, N. Klaus, K.-N. Esra, S. Cornelia, T. Martin, C. Hans and E. Markus (2005). Study on VIP-components and Panels for Service Life Prediction of VIP in Building Applications (Subtask A). IEA/ECBCS Annex 39, EMPA: Swiss Federal Laboratories for Materials Testing and Research (Switzerland), ZAE-Bayern: Bavarian Centre for Applied Energy Research (Germany), NRC-IRC: National Research Council - Institute for Research in Construction (Canada), CSTB: Scientific and Technical Centre for Construction (France), Fraunhofer IVV: Institute for Process Engineering and Packaging (Germany), TU Delft Technical University of Delft (Netherlands), Dr.Eicher+Pauli AG (Switzerland).

MIT, M. I. o. T. "Random Walks, The mathematics in one dimension." Retrieved 05/08, 2013, from http://www.mit.edu/~kardar/teaching/projects/chemotaxis(AndreaSchmidt)/random.htm.

Rochester, U. o. "Diffusion in a Gas The Speed of Molecular Motion " Retrieved 30/08, 2013, from http://www.pas.rochester.edu/~stte/phy104-F00/n9/notes-9b.html.

Rossi, G. and M. Nulman (1993). "Effect of local flaws in polymeric permeation reducing barriers." Journal of Applied Physics **74**(9): 5471-5475.

Vanderroost, M., F. Ronsse, K. Dewettinck and J. G. Pieters (2012). "Modelling particle random walk in a confined environment for inclusion in fluidised bed applications." Powder Technology **221**: 155-163.

Wei, G., Y. Liu, X. Du and X. Zhang (2012). "Gaseous Conductivity Study on Silica Aerogel and Its Composite Insulation Materials." Journal of Heat Transfer **134**(4): 041301.

Zeng, S. Q., A. Hunt and R. Greif (1995). "Mean free path and apparent thermal conductivity of a gas in a porous medium." Journal Name: Journal of Heat Transfer; Journal Volume: 117; Journal Issue: 3; Other Information: PBD: Aug 1995: Medium: X; Size: pp. 758-761.