Building Physics

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Abstract

No one sets out to make a plastic building. Having worked on designs for the Watercube, Clarke Quay and now Highpoint shopping centre using lightweight materials we are building up a better affinity with lightweight plastic products have acronyms such as ETFE and PTFE. This presentation discusses how these materials are used to moderate the environment to obtain desired internal conditions. These products have unique solar and thermal properties that need to be manipulated to achieve desired effects. Arup uses building physics tools to help analyse how these materials interplay with conditioning strategies to provide overall energy and comfort solutions.

Paper

No one sets out to make a plastic building. I've been trained not to like plastic. We are to like granite or concrete or heavy timbers. In this age, we must like glass and steel.

The use of plastic wasn't apparent to us when we started work on the National Swimming Centre in Beijing, otherwise known as the 'Water Cube.' The idea of using the plastic 'pillows' made of ethylene-tetrafluoroethylene, otherwise known as ETFE, emerged from some early thoughts on the Eden Project, which may be the best example of large-scale ETFE use on a building. The Eden Project is a true greenhouse, in both design and building typology, and its honeycomb structural system and ETFE pillows have clearly demonstrated that such systems can work well. The Water Cube design team felt it was a great aesthetic fit with a building the architects envisioned as a meditation on water—and it certainly became the preferred material once the concept of the box of bubbles was generated.

Selecting ETFE

Aside from the Water Cube and Eden, in 2006 we used ETFE for an exterior pedestrian mall at Clarke Quay, in Singapore, which has proven quite effective. At Clarke, an ETFE canopy helped to regulate outdoor air temperatures to create an acceptable micro-climate for an urban corridor in a relatively hot, humid city.

However, the design constraints of an indoor public garden or an outdoor shopping centre are certainly less restrictive than those for an Olympic swimming centre meant to contain 20,000 people at any one time

Tuning ETFE

Part of a lightweight cladding systems design requirements is to achieve designed thermal and daylight performance. This thermal performance is achieved through a combination of U value, solar radiation and visible light transmission. Literature on ETFE often promotes its use due to its high light transmission and low U value. In reality a single cushions properties are not as good as a reasonably performing double glazed unit. Typical U-values and Shading Coefficients for different systems can be found in the Figure 1.

Description	**U-Value W/m²K**	**Shading Coefficient**
6mm Monolithic Glass	5.9	0.95
6-12-6 DGU	2.8	0.83
6-12-6 Performance DGU	2.0	0.35
2 Layer Cushion	2.9	0.71-0.22 (with frit)
3 Layer Cushion	1.9	0.71-0.22 (with frit)
4 Layer Cushion	1.4	0.71-0.22 (with frit)

Figure 1: ETFE thermal and optical properties

The major benefit of an ETFE cushion system in terms of thermal and optical properties is the flexibility/alterability that can be designed into the system. The thermal and optical properties are altered quite significantly depending on the coatings, prints and cushion geometry and configuration used. By tuning the Water Cube with the following approaches, energy consumption of the main swimming pool hall could be reduced by 30 percent.

With two outer layers to form each pillow, three-dimensional space was introduced to the façade. This added dimension meant we could play around with the properties of each pillow—visible light transmittances, colours, solar shading and heat gain. By adding a layer of frit to the surface of the ETFE, We could reduce the solar heat gain through the façade and reduce cooling loads for the interior. By working with our prototype, we found we could use the three-dimensional quality of the pillow to position the frit in areas that would only block summertime sun, allowing the winter sun to shine through and passively heat the building. Our computer modelling indicated that the frit patterns resulted in an effective shading coefficient of 0.2 in summer and between 0.3 and 0.35 in winter. While a glass curtain wall façade can be designed to achieve much the same performance characteristics, exterior sun shade devices would be needed in order to vary the shading coefficients between seasons. With the bulbous ETFE pillows, this varied condition was achieved without sacrificing the appearance of a smooth, rectilinear façade.

We also added a third layer to the pillows, which provided more depth of colour and reduced the U-Value of the façade, resulting in better thermal performance. These multiple layers could also be formed by different colours of ETFE, such as blue on the exterior and whiter for the interior. This resulted in the façade taking on depth with a striking watery effect, which the architects clearly appreciated. The two layers of ETFE pillows also created a cavity, which could then be mechanically vented, pulling hot air out and into the swimming hall during winter months and exhausting the hot air through the roof during summer months (see Figure 2).

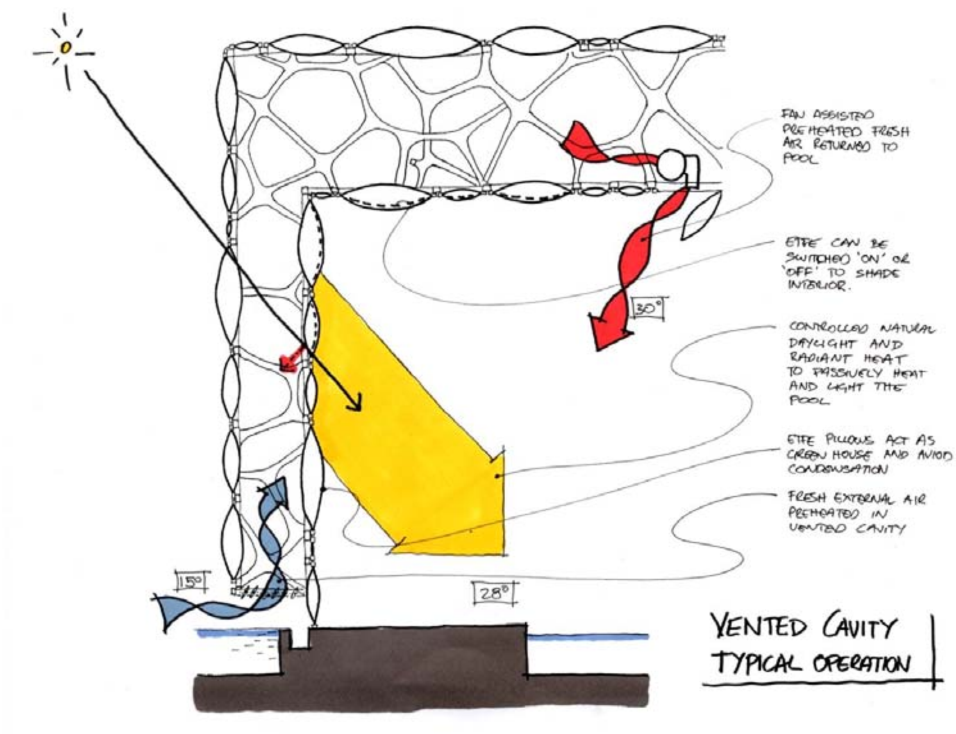

Figure 2: Vented Cavity Typical Operation

An interesting feature of ETFE is that it is transparent to longer wavelengths than glass. Figure 3 is a graph of transmission versus wavelength for a sheet of ETFE and a clear 6mm sheet of glass.

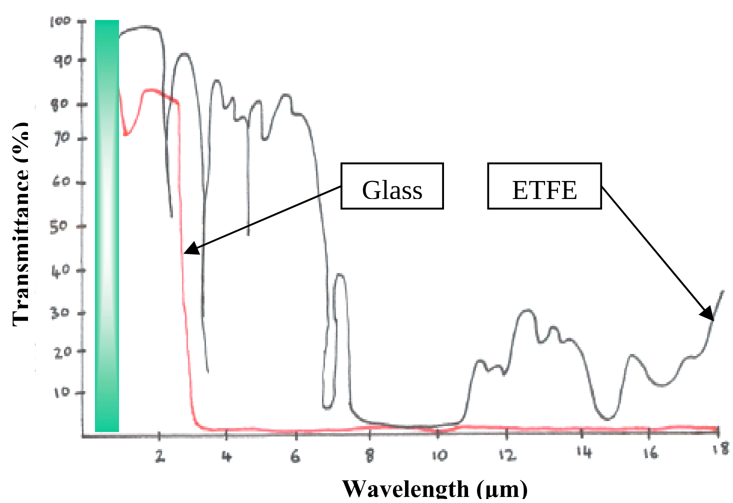

Figure 3: Transmittance of ETFE & Glass

U-Value

ETFE cushions are typically comprised of two or three air chambers where the principal means of heat transfer is through convection. A two layer cushion exhibits comparable U-values to a low performance double glazed unit. The transparency of ETFE at long wave lengths should affect this U value especially during cold nights.

PTFE Alternatives

Due to its flexibility in adding different performance coating ETFE is a excellent product to use in light weight structures as appropriate performance can be obtained by appropriate product selection from number of layers to density of frit and colour. The alternative in lightweight structures is to use PTFE with nanogel insulation. This product is capable of providing a degree of insulation and reduced reradiated solar load through the insulation value of the nanogel. It does however come at a cost of visible light transmission as demonstrated in the graph of U value versus VLT in figure 4.

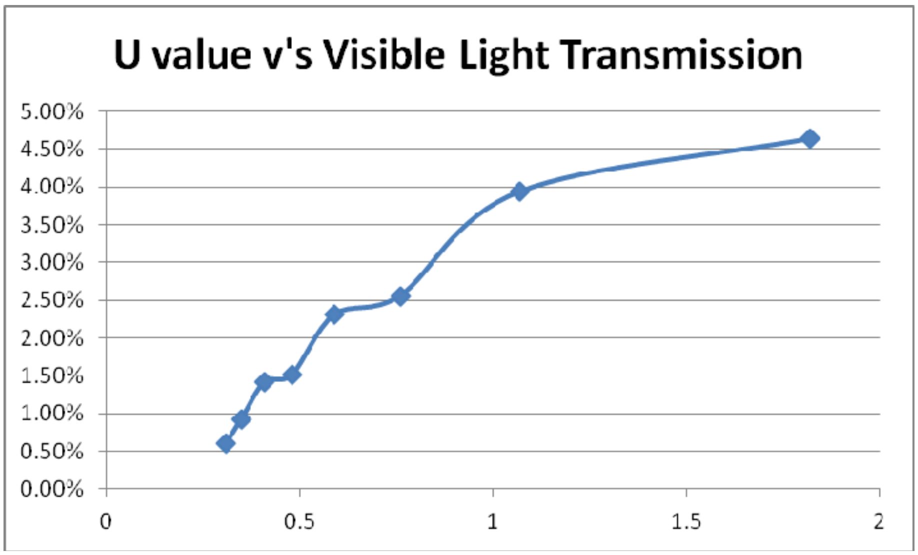

Figure 4: Vented Cavity Typical Operation

Further refinements of this concept may include the use of phase change materials to draw down peak radiant temperatures.

Conclusion

There are many ways to achieve thermal and daylight performance out of lightweight structures. It is important to set appropriate performance requirements of the covered space and then select appropriate technologies to augment the proposed cladding. Although there is more flexibility using ETFE to achieve desired thermal and daylight performance, PTFE also has several innovations that help it to deliver specific performance. Each product needs to be considered in detail as each products has different solar , thermal and light performance which needs to be designed for the space that the product covers.