Heat Loss Reduction Analysis of 2-Layer ETFE Foil by Dymola Simulation

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***Abstract*—ETFE (Ethylene Tetra Fluoro Ethylene) is a light weight foil with architectural beauty which is commonly used as building material. However to improve the poor heat insulation, deposition of multiple layers of *low-emissive* coating is necessary. During winter large amount of heat can be trapped since the property of low-e coating includes reduction of radiative part of heat loss with the increase in infrared reflection and decrease in infrared emission. Thus the reflective property stops emission of radiant heat outside, keeping the produced radiant heat inside. The simulation of 2 layer ETFE pillows is performed using Dymola Simulation software with and without low-e coating. The simulation showed a significant reduction in U value from 2.6 to 1.7.**

***Index Terms*—ETFE, DYMOLA, LOW-E**

I. Introduction

The incredible features of ETFEs like lightweight, flexibility, high sunlight transmittance capability and its durability makes it an extra-ordinary building material with architectural beauty. The main drawback of ETFE is the lack of good heat insulation increasing the building energy required for warming during winter and cooling during summer. The solution is to use layers of low emissive coating on top of the foil to reduce the energy consumption. The emission of heat by the ETFE pillows is minimized due to the lower radiation of heat from Low-e coatings.

Our research was based on simulation with the parameters: infrared emittance set to 30% and visible transmittance set to 50%. The entire work was based on a concept which already exists for glass (e.g. glass windows). The objective of the research was to find out the feasibility of introducing the Low-e coatings on ETFE foil.

II. Mathematical Model

This is an analytical model which can be used to improve the heat insulation of ETFE pillows by introducing a low-e coating [1] on one or more ETFE foils. Different types of heat transfer mechanism, the solar spectrum and low-emissive layers are observed to get the desired result. The empirical correlations for the convective heat loss in parallel layers can be obtained via dimensionless numbers. The convective heat transfer [2] can be calculated by Newton's law of cooling, which states that the rate of heat loss is proportional to the temperature difference between a body and its surroundings:

$$q''=h.A.\left(T(t)-T_{env}\right) = h.A.\Delta T(t) \tag{1}$$

Here, q'' is the heat flux which is equal to the heat transfer rate (W), h is the heat transfer coefficient (W/m^2K), A is the surface area of the heat being transferred (m^2), T is the temperature of the object's surface and interior (K), T_{env} is the temperature of the environment (K) and ΔT is the time-dependent thermal gradient between environment and object (K).

The radiative heat losses [3] can be calculated for parallel layers and can be found by,

$$\frac{Q}{A} = \frac{\sigma\left(T_2^4-T_1^4\right)}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1} \tag{2}$$

Here, A is the area of parallel plates, Q is heat radiation. T_1 and T_2 are the high and low temperatures respectively. σ is Stefan–Boltzmann constant which is equal to $5.67x10^{-8}$ W/m^2K^4 and ε_1 and ε_2 are emission coefficients.

The interplay of energy exchange by thermal radiation is characterized by,

$$\alpha+r+\tau = 1 \tag{3}$$

Here, $\boldsymbol{\alpha}$ is the ratio of the radiant energy absorbed by a body to the total amount of radiation incident upon it, **r** is the ratio of the total amount of radiation reflected by a surface to the total amount of radiation incident on the surface and known as reflectance. τ is the fraction of incident light (electromagnetic radiation), that passes through a sample or glazing. According to Kirchhoff's law of thermal radiation, for thermal equilibrium for a particular surface, the monochromatic emissivity equals the monochromatic absorptivity,

$$\text{absorption } (\alpha) = \text{emissivity } (\varepsilon) \tag{4}$$

So the Eq. 3 can be re-written as:

$$\varepsilon+r+\tau = 1 \tag{5}$$

The U-value [2] which is rate of heat flow passing through a square meter of the material in a unit time for every degree kelvin temperature difference across the

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material (W/m^2K). Heat transfer across a material can be expressed in electrical terms by the individual thermal resistance (R) values of the layers and the air on either side of the material. Then it's needed to take the reciprocal of the total R-value (R_{tot}) to get the total U-value of the material. The thermal resistance is a measurement of a temperature difference by which an object or material resists a heat flow. There exist an analogy between the diffusion of heat and electrical charges with the assumption of heat flow Q' as current and temperature difference between two surfaces, T_1-T_2 as voltage difference and the equation can be written as:

$$R = \frac{T_1 - T_2}{q''} \tag{6}$$

The total U-value, which is reciprocal of total thermal resistance (R_{tot}) would be,

$$U_{tot} = \frac{1}{R_{tot}} \ (W/m^2K) \tag{7}$$

By analyzing equation 7, it can be seen that the higher the U-value, the lower the thermal resistance, namely more heat flows through and the heat insulation is very low. In general a good U-value is a low one as it is expected to keep heat inside the building when it is cold outside; or outside the building when one wants to keep the temperature low within the building, depending on the climate. Consequently, a house with low U-value will use less energy.

III. Results and Discussion

At first, a 2–layer uncoated and parallel pillow is considered as shown in Fig. 1. There are only 2 layers, where layer 1 and layer 2 is in contact with the outside and inside atmosphere respectively. Thermal resistance analogy of the model in terms of convection and radiation heat transfer coefficient is shown in Fig. 2

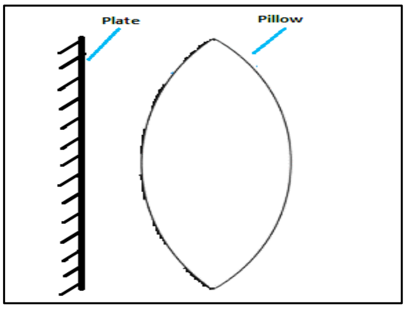

Figure 1. 2–layer ETFE pillow.

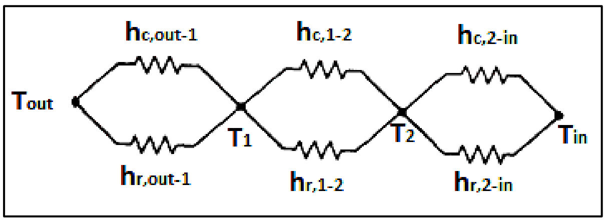

Figure 2. Thermal resistance network of 2–layer ETFE pillow.

For this example, the following input parameter values were taken from Table I.

TABLE I. Input Parameters for Simulation of an Uncoated 2-Layer ETFE.

Irradiation	1000 W/m^2	Tin	293.15 K (20 ℃)
Pressure	100000 Pa	Tout	283.15 K (10 ℃)
h_w (wind heat transfer coefficient)	10 W/m^2K	T_p (average plate temperature)	293.15 K (20 ℃)
Foil transmittance (τ_1, τ_2)	0.9246	Foil reflectance (r_1, r_2)	0.07175
Foil emittance (ε_1, ε_2)	0.788	d (layer distance)	0.025 m
Area	1 m^2	γ (inclination angle)	45 °

By using the parameter values, a simulation has been done by Dymola [4] considering a 2-layer ETFE pillow. For the simplification of the calculation, the outside and the inside heat coefficient ($h_{outside}$ & h_{inside}) was assumed as 23W/m^2K and 8W/m^2K respectively, according to the universal standards [5]. The model and thermal resistance analogy is shown in Fig. 3.

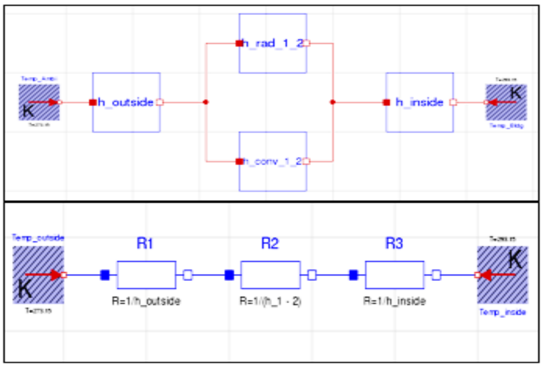

Figure 3. Thermal representation of 2-layer ETFE pillow model.

From the simulation, radiation heat transfer coefficient between layer 1 & 2, $h_{rad,1\text{-}2}$ is 3.27 W/m^2K, convection heat transfer coefficient between layer 1 & 2, $h_{conv,1\text{-}2}$ is 1.43 W/m^2K, temperature of layer 1, T_1 is 275.45 K or 2.3 ℃, temperature of layer 2, T_2 is 286.59 K or 13.44 ℃ and the U- Value is 2.6 W/m^2K.

It is observed that the conduction heat transfer coefficient in layer 1 and layer 2 is h_{cond} is 0.025 W/m-K, which is smaller than the conduction and radiation heat transfer coefficients and almost negligible. So, the heat transfer by conduction is so negligible and can be left alone.

The schematic of thermal resistances and the approximations are same as shown in previous section while considering single or multi-layer low-e coating on 2-layer ETFE pillow. The changed parameter values are given in Table II.

TABLE II. PARAMETERS FOR SIMULATION OF A COATED 2-LAYER

Irradiation	1000 W/m^2
Pressure	100000 Pa
Transmittance, τ *(uncoated)*	0.9246
Transmittance, τ *(coated)*	0.50
Emittance, ε *(uncoated)*	0.788
Emittance, ε *(coated)*	0.30
h_outside	23 W/m^{2}K
T_{in}	293.15K (20 ℃)
T_{out}	273.15K (0 ℃)
Reflectance, r *(uncoated)*	0.07175
Reflectance, r *(coated)*	0.15
ɣ (inclination angle)	45 °
d (layer distance)	0.2 m
h_inside	8 W/m^{2}K

There are four different positions to apply low-e coating on a 2-layer ETFE pillow as can be seen in Fig. 4. Simulating the low-e for different positions and using the input parameters above, the following U- values and layer temperatures are found from Table III.

TABLE III. SIMULATION RESULTS FOR A 2-LAYER ETFE.

Positions	U-value (W/m^{2}K)	T_1 (layer 1 temp.)		T_2 (layer 2 temp.)	
		℃	K	℃	K
1	2.62	2.28	275.43	13.44	286.59
2	1.95	1.69	274.84	15.12	288.27
3	1.95	1.69	274.84	15.12	288.27
4	2.62	1.5	274.65	13.44	286.59
2+3	1.72	1.5	274.65	15.7	288.85

From the simulation results in Table III, it is observed that there is a significant decrease in U-value for a low-e coating on the inner positions (position 2 & 3). Even better is a multiple layer coating on positions 2 & 3. The temperature of the two layers (T_1 & T_2) stays almost constant, which means the low-e layers on a 2-layer ETFE, have no significant effect on the temperature of the ETFE layers. Also no change in U-value can be found for low-e in layers 1 and 4. The reason is that by applying low-e layers in outside (position 1) and inside (position 4) atmosphere, the atmospheric incidents like wind, humidity, and rain prevents the low-e to work efficiently.

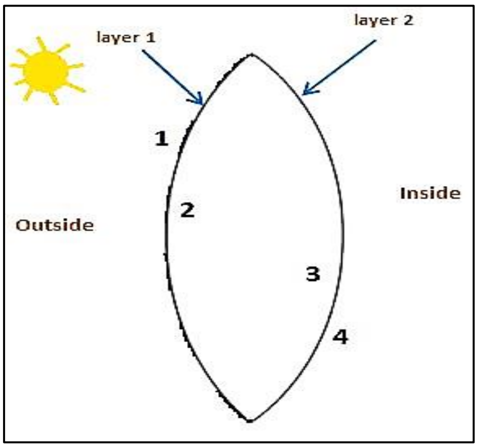

Figure 4. U-value for low-e in different positions of a 2-layer ETFE pillow.

The simulation results of the low-e coating in different position of a 2-layer ETFE pillow are also given in Table III.

IV. CONCLUSION

The ultimate goal of this research work was to simulate the results of a potential addition of low-e coating on the ETFE foil and to verify if this aids to reduce radiative heat losses, as the low-e coating would have a lower emissivity which will reduce heat emission and reduce heat losses. The results showed about 34% improvement in heat insulation for a double-side coated 2-layer ETFE pillow compared to an uncoated one.

However, these are all preliminary results and it might take some time to get this concept the required exposure in the real world. In our opinion, by taking required measures it is possible to introduce low-e coatings on ETFE foils in energy saving purpose, which is already been used in the glass industries for the same purpose.

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