



## To Find out the Feasibility of Ethylene-Tetra-Fluoro-Ethylene (ETFE) in Inflatable Pillow System (IPS) to be Used for Building Facades

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(Received 06 January, 2017 Accepted 29 January, 2017)

(Published by Research Trend, Website: [www.researchtrend.net](http://www.researchtrend.net))

**ABSTRACT:** The increasing energy demand, there have been many research done related with the conservation of energy used in buildings. The systems and materials used in buildings have an important role in consumption of energy. It is been always expected from the building envelope much more than just a skin, building envelope can help to get more efficient environments in terms of quality and energy. Building envelope, which separates indoor and outdoor, altered in the parallel of development on new material and technology. In recent years the technology of producing flexible ETFE films has progressed significantly allowing the production of thin membranes that are stable, durable and can be easily joined. This has given designers a serious alternative to glass for many applications.

This study aims to study construction system; ETFE foil pillow system, which is also known as, Inflatable Pillow System made of ETFE Foil. In the scope of the study, pneumatic pillow system investigated in detail and its performance evaluated on Environmental aspect, Technical aspects, Thermal Behavior (Ecotect analysis), Acoustic performance, Safety, Cleaning, Maintenance etc., which can be compared with other conventional Doubly Glazing Unit (DGU). The results are evaluated with the information gained. The advantages and disadvantages of the system as a glazing are discussed.

**Keywords:** Inflatable Pillow System, Conservation of energy, Pneumatic membrane, Glazing, ETFE foil, Glass, Doubly Glazed Unit (DGU), Building envelope.

### I. INTRODUCTION

New discoveries in polymers, changing trends and rising demand in aesthetics of the building has forced designers to explore new materials. Building envelope, which separates indoor and outdoor, altered in the parallel of development on new material and technology. It is been always expected from the building envelope much more than just a skin, building envelope can help to get more efficient environments in terms of quality and energy. The present study aims to determine Inflatable Pillow System (IPS), which is a new generation construction technique as a building envelope for Pune, Maharashtra, India.

#### 1. WHY ETFE?

Thermoplastic polymers other than ETFE, such as polycarbonates including poly ethyl methacrylate (Plexiglas) and polystyrene or fluorocarbons including polytetrafluoroethylene (PTFE) and polyethylene (PE) have been examined and found unsuitable as a replacement to glazing. (Callister *et al.*, 2011); (Minamisawa *et al.*, 2007) Such alternatives have been rejected as they fail to offer a combination of good

visual performance, energy transmittance and as an adequate engineering material performance (Baille *et al.*, 2006; Callister *et al.*, 2011). ETFE (Ethylene Tetrafluoroethylene) and PTFE (Poly Tetrafluoroethylene) are most common textile materials are used in building construction industry. While ETFE is predominantly applied as Inflated Pillow System (IPS), PTFE is normally used as building shading structure. (Stokes-1998, Robinson *et al.*-2001, G James - 2009, Macleod-2010)

**Understanding ETFE :** ETFE is a thermoplastic copolymer derived from the polymerization of the Ethylene and Tetrafluoroethylene monomers. ETFE can be extruded into large thin sheets, referred to as foils or films. Films are produced in thickness from 0.05mm to 0.3mm. Naturally ETFE films produced clear but can be modified to opaque.

**Understanding IPS (Inflatable Pillow System):** Inflatable Pillow System (IPS) is designed for efficient use of ETFE as covering material. The system also can be used for other polymer materials similar to ETFE.

IPS is a multilayered system that consist of several layers of ETFE foil which is heat sealed and clamped in a frame in order to top up with a small pump intermittently. (Robinson-Gayle ET. AL, 2001) IPS requires other Subsidiary equipments like inflation pumps, air supply ducts with non returning valves, and sensors to complete. The pillow commonly formed in double up to triple layer.

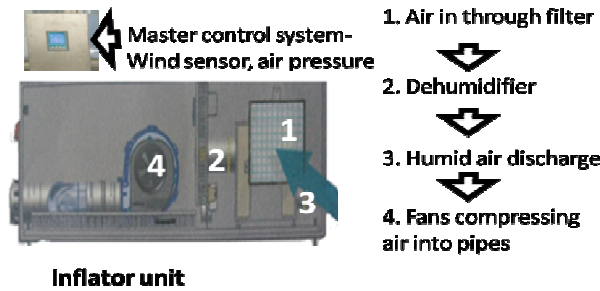


Fig. 1. Working of inflation unit.

## II. ANALYSIS FOR THERMAL BEHAVIOR OF FAÇADE ASSEMBLY IN ECOTECT.

To understand how the two assemblies create heating and cooling load on building. A hypothetical building case with certain parameters is simulated for thermal behavior of the façade assembly by using Ecotect

software. Data is collected for following two façade assemblies -

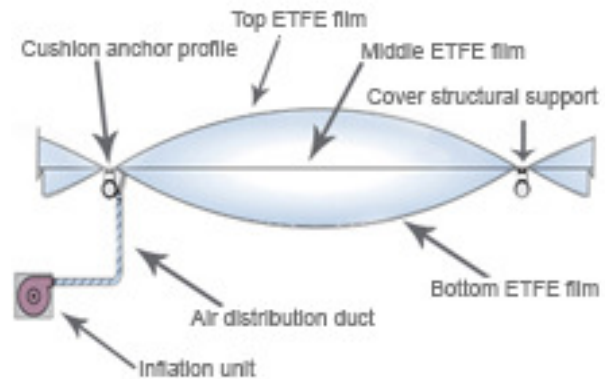


Fig. 2. IPS with three layers of ETFE film.

- Case 1- IPS (0.2mm thk. ETFE film+300mm air gap +0.2mm thk. ETFE film)
- Case 2- DGU (6mm thk. Clear glass+12mm air gap +6mm thk. Clear glass)

A ten floor building located in Pune, Maharashtra which has moderate climate having floor plate of 25mx25m, clear floor height of 3.6m, total height of building is 40m, each floor area 625sqm and total area of building is 6250 sqm.

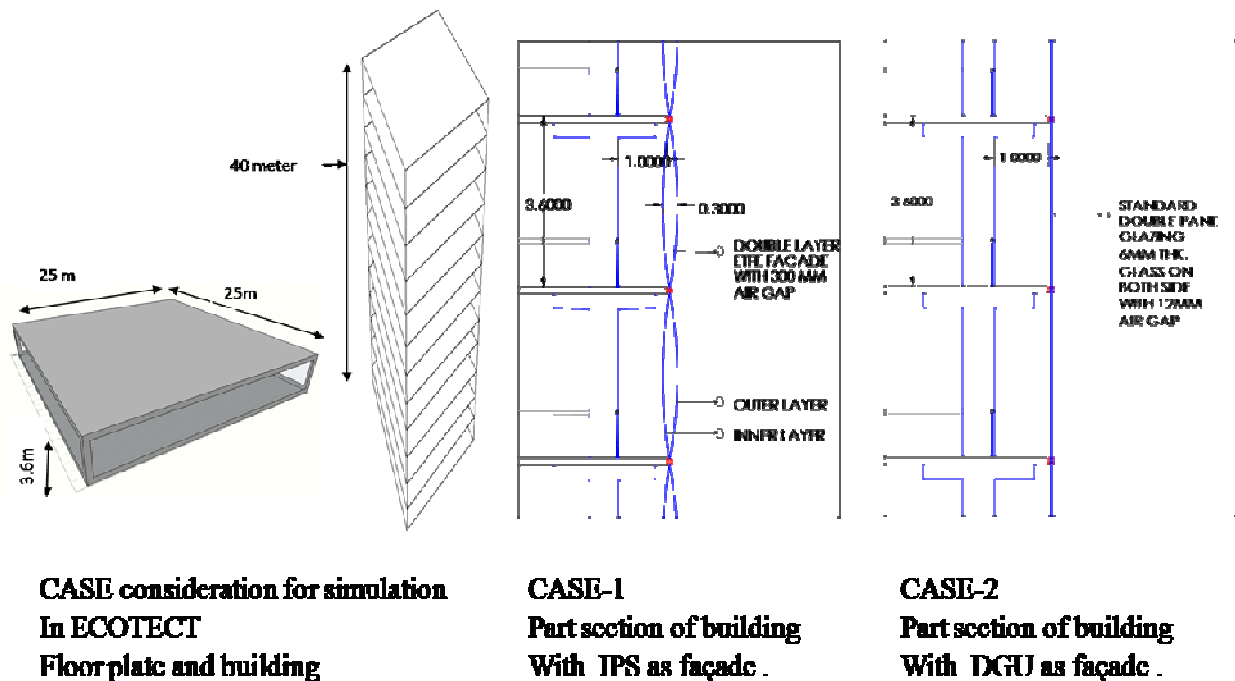


Fig. 3. Building details and part sections of façade for simulation of IPS and DGU.

Max Heating: 18197 W at 05:00 on 21st January  
Max Cooling: 53702 W at 14:00 on 8th May

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	128142	2689924	2818067
Feb	0	4653438	4653438
Mar	0	7808730	7808730
Apr	0	8018959	8018959
May	0	7610922	7610922
Jun	0	4777338	4777338
Jul	0	3787060	3787060
Aug	0	3405022	3405022
Sep	0	4295992	4295992
Oct	0	4440174	4440174
Nov	0	3306690	3306690
Dec	93827	2444720	2538546
<b>TOTAL</b>	<b>221969</b>	<b>57238968</b>	<b>57460936</b>
<b>PER M<sup>2</sup></b>	<b>355</b>	<b>91582</b>	<b>91938</b>
<b>Floor Area:</b>	<b>625.000 m<sup>2</sup></b>		

- **CASE 1**
- Heating and Cooling load – 91 KWh/sq.m
- Total heating and cooling load –  
 $6250 \text{ sqm} \times 91 \text{ KWh/sq.m} = 5,68,750 \text{ kwh}$

Max Heating: 18575 W at 05:00 on 21st January  
Max Cooling: 55123 W at 14:00 on 8th May

	HEATING	COOLING	TOTAL
MONTH	(Wh)	(Wh)	(Wh)
Jan	112676	2520453	2633129
Feb	0	4627295	4627295
Mar	0	8074392	8074392
Apr	0	8290151	8290151
May	0	7922724	7922724
Jun	0	5093249	5093249
Jul	0	4116892	4116892
Aug	0	3709754	3709754
Sep	0	4631471	4631471
Oct	0	4765318	4765318
Nov	0	3391005	3391005
Dec	63282	2106492	2169773
<b>TOTAL</b>	<b>175958</b>	<b>59249200</b>	<b>59425156</b>
<b>PER M<sup>2</sup></b>	<b>282</b>	<b>94799</b>	<b>95080</b>
<b>Floor Area:</b>	<b>625.000 m<sup>2</sup></b>		

- **CASE-2**
- Heating and Cooling load –  
**95.08 KWh/sq.m**
- Total heating and cooling load –  
 $6250 \text{ sqm} \times 95.08 \text{ KWh/sq.m}$   
 $= 5,94,250 \text{ kwh}$

Fig. 4. Ecotect Simulation results-Thermal Analysis of Double layer ETFE .Case 1 and Doubly Glazed Unit. Case 2.

### III. COST of ETFE based IPS and DGU

Cost of DGU (6mm thk. Toughened glass+12mm air gap +6mm thk. Toughened Glass) rates taken from-GFS Fabricators, Mumbai = 8987 Rs/sqm = 835 Rs/sqft

Cost of IPS (0.2mm thk. ETFE foil + 300mm air gap + 0.2 mm thk. ETFE foil) = 19,798.5 Rs/sqm = 1840 Rs/sqft. RATES FROM – KDMEM, CHINA. 1 US \$ = 67 Rs. considered

Table 1: Cost breakup of IPS.

	Rates in Dollar	Cost in Rupees
Membrane Material cost	140 USD/sqm	9380 Rs/sqm
Supporting Steel	45 USD/sqm	3015 Rs./sqm
Aluminium profile	26 USD/sqm	1742 Rs./sqm
Supply Tubes and tapes	13 USD/sqm	871 Rs./sqm
Inflator unit	14 USD/sqm	938 Rs./sqm
Shelf fee	4.5 USD /sqm	301.5 Rs./sqm
Lift charges	5.0 USD/sqm	335 Rs./sqm
Labour	48 USD/sqm	3216 Rs./sqm
<b>Total</b>	<b>295.5 USD/sqm</b>	<b>19,798.5 Rs./sqm</b>

Table 2: Cost breakup of DGU.

	Rates	Average Cost
Material cost	2368 -3767 Rs. /sqm.	3067 Rs/sqm
Installation cost inclusive structural supports.	4305 - 7534 Rs./sqm	5920 Rs/sqm
<b>TOTAL</b>		<b>8987 Rs/sqm.</b>

### IV. COMPARISON OF IPS AND DGU PROPERTIES

Light transmission and vision: It is found from the study that IPS with two layers ETFE has good (83%) light transmission value where as DGU has 79%, which can be utilized to enhance the light quality within the

building. The ETFE film can be modified to control its light transmission, which may give a scope to use it as per climate requirement so as to enhance inner comfort of building. Soft nature of cushion does not create glare on surrounding gives soothing vision to outsider. The building façade can act as interactive skin by using ETFE based IPS.

**Weight.** It is found from the study that two layer ETFE (0.7 kg/sqm) is 97 % light in weight as compared to DGU of 6mm thk. Glass (30kg/sqm) with 12mm air gap .Due to less weight IPS will create less load on structure resulting in reducing steel consumption and cost. Due to light weight and fabric nature it is easy to transport and also reduces the risk of hazard during transport and installation as compared to DGU.

**Span and supporting structure.** ETFE manufactured in foil form which makes it possible to produce it in limitless length the easy welding property makes it possible for larger width. Requires minimum light weight supporting members less obstruction for view of supporting members from inside

**Cushions.** IPS will prove to be good system in earthquake prone zones because of its cushioning nature it provide structural stability against lateral forces. Buildings with IPS as façade are safer, as Pillow absorbs some of the pressure of wind and therefore transmits less forces to the main structure of the building. Flexibility of the membrane itself also absorbs the movements and reduces the need for the movement joints.

**Fire performance.** ETFE foil prevents flames to spread, which delays the structure of the building to collapse and proves high fire safety compared to the glass glazing system. Self extinguishing property and does not drip molds. IPS does not have fragile structure like glass hence minimizes risk in case of explosion

#### **Acoustics**

It is learnt from the study that IPS shows poor (12.4db) acoustical performance compared to glass glazing system (39.2db) Major disadvantage where silent spaces are preferable like libraries, meditation centers

#### **Embodied energy**

ETFE is a recyclable material which has lower embodied value per sqm as compared to DGU. IPS requires less embodied energy for maintenance and refurbishment .This makes ETFE as environment friendly material.

#### **Cleaning and maintenance**

IPS requires less cleaning and maintenance as compared to glass glazing system.

#### **Subsidiary equipments**

IPS system requires constant air pressure inside pillow which requires the air pumps working intermittently to maintain the air pressure.

### **V. NORMS FOR GLAZING U- VALUE IN INDIAN CONTEXT.**

As per Indian Green Building Council, Manual IGBC, Sept. 2014 preferred U-value of glazing material in

temperate climate is 5.7W/m<sup>2</sup>K.and as per Ministry of Environmental and Forests (MoEF) 2010. Government of India prescribed U-value of glazing material in moderate climate is 6.9227W/m<sup>2</sup>K. U-Value DGU (6mm thk. Clear glass+12mm air gap +6mm thk. Clear glass) is 3.3 W/sq.m K .U-Value IPS (0.2mm thk. ETFE film+300mm air gap +0.2mm thk. ETFE film) is 2.6 W/sq.m K

### **VI. MERITS AND DEMERITS OF IPS**

The Inflatable Pillow System (IPS), which is materialized by ETFE, is used as alternative to glass glazing system in recent architectural applications because of its flexibility, light weight, better thermal performance, low maintenance and embodied energy, ability to give dramatic effect, ability to act as interactive skin. It is been observed through the study that IPS is used more to public buildings where there is less concern about acoustic like sports hall, shopping center, art gallery, museum, railway stations and entertainment centers etc. The poor acoustic performance makes ETFE based IPS undesirable solution as main building façade material. It will not be advisable to use it as façade system for buildings located in busy and crowded areas. Availability of the material, skilled labor and the higher cost in present scenario will again create limitations on its type of user.

### **VII. DESIGNED SOLUTION FOR EFFECTIVE USE OF IPS AS BUILDING FACADE**

A case is been discussed so as to overcome the drawback of acoustics when ETFE based IPS is used as building façade assembly. In this Case 3 a single layer of 6mm thk. glass as window is introduced at 1000mm distance from outer façade assembly of ETFE based IPS. This case 3 is simulated for thermal behavior to calculate heating and cooling load on building. It can be derived from the above chart showing comparison of heating and cooling load per sqm and total annual heating and cooling load that Case 3 creates remarkably low heating and cooling load on building. It creates 40.90 kwh/sqm less heating and cooling load. The total load reduced to 2, 55,625 kWh annually as compared to Case 1 which is of Double layer ETFE based IPS. It creates 44.98 kwh/sqm less heating and cooling load. The total load reduced to 2, 81,125 kwh annually as compared to Case 2 which is of DGU. So it can be concluded from the above thermal analysis that by introduction of single pane of 6mm thick clear glass or window the thermal performance of double layer ETFE based IPS can be improved.

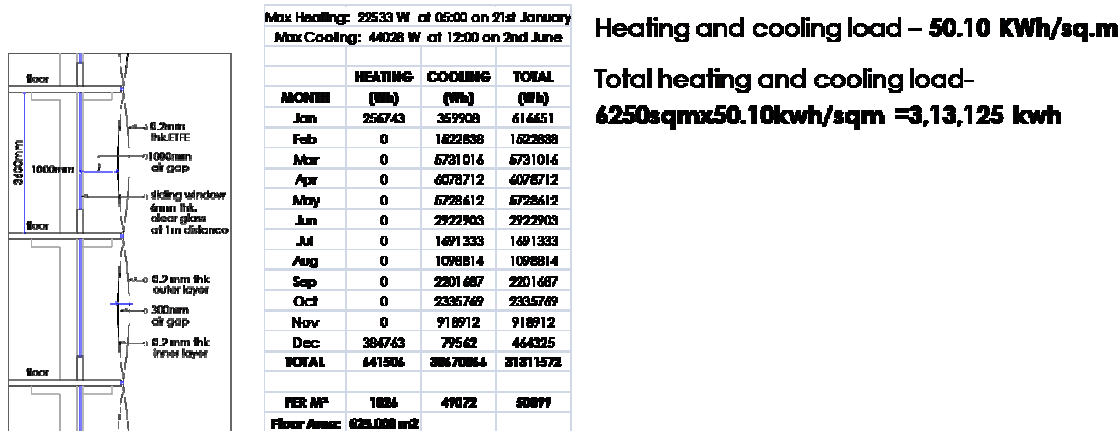


Fig. 5. ECOTECT simulation results for Double layer ETFE with sliding window of 6mm thk. Clear Glass at 1m distance.

Table 3: Comparison of Heating and Cooling load of Case 1, Case2, and Case3.

	Case 1	Case 2	Case3- design case
	Double skin ETFE	Double glazed unit	single layer Glass + Double skin ETFE
Annual heating and cooling load per sqm	91.00 kwh/sqm	95.08 kwh/sqm	50.10 kwh/sqm
Annual heating and cooling load of building	$6250\text{sqm} \times 91.00\text{ kwh/sqm} = 5,68,750\text{ kwh}$	$6250\text{sqm} \times 95.08\text{ kwh/sqm} = 5,94,250\text{ kwh}$	$6250\text{ sqm} \times 50.10\text{ kwh/sqm} = 3,13,125\text{ kwh}$

#### Effect on other properties for designed case

Table 4: Effect on other properties of Case 3.

Property	Effect
Light transmission	Will not get affected.
Weight	Load of 15kg / sqm of 6mm thk. Glass will be added to building.
flexibility	Will not get affected.
Fire performance	Will provide additional safety.
Span and supporting structure	Will not affect façade supporting structure.
Reflective index	Will remain same, no glare from façade.
Acoustical performance	Will improve the acoustical performance by obstructing outside sound.
Safety and security	More safe and secured condition.
Cost	Nominal increase in the cost due to glass window.

## VIII. CONCLUSION

It can be commented from above designed case discussion that ETFE based IPS used in combination of inner skin like glass layer as discussed in Case 3 will enhance the performance of IPS by minimizing its limitations and will enhance buildings aesthetical and environmental value. It may not fully occupy the place

of conventional glass glazing system, but definitely give designers a new perspective to look at building façade, which is more futuristic, dramatic in form. More such designed case alternatives to be worked out to enhance the performance of ETFE based IPS. Further study should be done to enhance use of ETFE based IPS as building envelope for residential use.

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