Passive Collecting of Solar Radiation Energy using Transparent Thermal Insulators, Energetic Efficiency of Transparent Thermal Insulators

Smajo Sulejmanović [1], Suad Kunosić [1], Ema Hankić [1]

[1] Department of Physics Faculty of mathematics and natural sciences
University in Tuzla Bosnia and Herzegovina

Abstract: **This paper explains passive collection of solar radiation energy using transparent thermal insulators. Transparent thermal insulators are transparent for sunlight, at the same time those are very good thermal insulators. Transparent thermal insulators can be placed instead of standard conventional thermal insulators and additionally transparent insulators can capture solar radiation, transform it into heat and save heat just as standard insulators. Using transparent insulators would lead to reduce in usage of fossil fuels and would help protection of an environment and reduce effects of global warming, etc.**

Keywords: transparent thermal insulators, conventional thermal insulators, solar radiation energy, passive collection of solar radiation, efficiency coefficient of thermal insulators

Introduction

Nowadays, people produce a lot of different products in large amounts. A special attention is paid to product packages. Mainly products and packages are used only once and then are stored somewhere on landfills. Keeping up with such a huge amounts of landfills becomes really problematic.
Production processes require a lot of energy. Mainly fossil fuels are used as energy sources; coal, oil, gas, etc. Amounts of those energy sources are limited in nature. Each day there is less and less of them and in the future it would cause a lot of problems to handle all the needs with limited energy resources. Usage of fossil fuels is one of the main reasons for catastrophic effects of global warming.
Globally, countries are trying to handle the problem of global warming by reducing the usage of fossil fuels. During the last 100 years, usage of energy in world has increased 12 times. During this period population on Earth has only tripled, what means that the usage of energy per person has increased four times.
Many huge countries, such as India and China are planning industrial development based on coal, and the USA use mainly oil as energy resource. European countries are using natural gas and renewable energy resources.
This paper gives practical proposal for solution of this global problem. As we know packages of different products are mainly similar; transparent, light, but extremely durable in nature. Those materials are cellophane, nylon, PET, transparent plastics, glass. These materials could be used for mass production of transparent thermal insulators. These insulators are good thermal insulators, transparent to sunlight. [3]
One of the basic facts by building new facilities is the energy efficiency of objects and thermal insulation of the objects. Usually as thermal insulators we use standard conventional insulators (Styrofoam, glass wool, etc.). [1], [2], [3], [4] and [5]
Transparent thermal insulators which are placed on outer walls of buildings can passively capture solar radiation energy, collect this energy and transform it into heat. [3]

Theoretical part

Heat transfer through solid objects is implemented by conduction and is explained by Fourier's empirical law, as follows (1): [1], [2], [4] and [9]

$$Q = \lambda \frac{S}{d} \tau \Delta T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Q - heat quantity which passes through thermal insulator
S – transparent thermal insulators surface through which heat passes
d – thickness of transparent thermal insulator
τ - duration of heat transfer
ΔT – temperature difference between surfaces of transparent thermal insulator
λ - coefficient of heat transfer through transparent thermal insulator

$$\frac{Q}{S\tau} = \frac{\lambda}{d}\Delta T \quad \ldots\ldots (2)$$

$$q = k\Delta T \quad \ldots\ldots (3)$$

$$q = \frac{Q}{S\tau} \quad \ldots\ldots (4)$$

$$k_u = \frac{\lambda}{d}, \text{ or } k_u = \frac{q}{\Delta T} \quad \ldots\ldots (5)$$

q – thermal flux

k_u – coefficient of heat transfer through sample

Resistance to heat transfer through heat insulator is given by (6): [4]

$$R_u = \frac{1}{k_u S} \quad \ldots\ldots (6)$$

Heat is transferred by conduction through small air layer, from thermal chamber directly to the surface of transparent thermal insulator, equation (7), equation (8): [4] and [9]

$$Q = \alpha_{in} S\tau \, \Delta T_{in} \quad \ldots\ldots (7)$$

$$q = \alpha_{in} \Delta T_{in} \quad \ldots\ldots (8)$$

α_{in} - coefficient of heat transfer from thermal chamber to the surface of transparent insulator

ΔT_{in} - temperature difference between surface of transparent insulator and air inside of thermal chamber

Resistance to heat transfer from thermal chamber to the surface of transparent insulator is given by (9):

$$R_{in} = \frac{1}{\alpha_{in} S} \quad \ldots\ldots (9)$$

Heat transfer from outer surface of transparent insulator to air around insulator is done by the process of conduction through small air layer and is explained by equation (10), and equation (11): [6]

$$Q = \alpha_{ex} S\tau\Delta T_{ex} \quad \ldots\ldots (10)$$

$$q = \alpha_{ex} \Delta T_{ex} \quad \ldots\ldots (11)$$

α_{ex} - coefficient of heat transfer from surface of transparent insulator to air surrounding transparent thermal insulator

ΔT_{ex} - temperature difference between outer surface of transparent insulator and air in environment around transparent thermal insulator

Resistance to heat transfer from surface of transparent thermal insulator to air in environment around transparent insulator is given by equation (12):

$$R_{ex} = \frac{1}{\alpha_{ex} S} \quad \ldots\ldots (12)$$

Resistance of heat transfer from thermal chamber to the environment, through transparent thermal insulator is given by equation (13): [4]

$$R = R_{in} + R_{ex} + R_u \quad \ldots\ldots (13)$$

From (13), we can obtain (14):

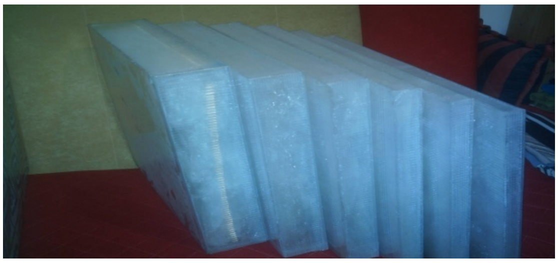
$$\frac{1}{k} = \frac{1}{\alpha_{in}} + \frac{1}{\alpha_{ex}} + \frac{1}{k_u} \quad \ldots\ldots (14)$$

k – coefficient of heat transfer from thermal chamber to environment through transparent thermal insulator

Experimental part

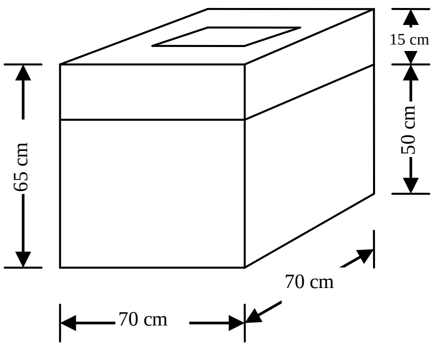
In order to define coefficient of thermal conductivity, coefficient of heat transfer through, coefficient of heat transfer from/to, transparency coefficient of transparent thermal insulators; for experimental purposes 6 samples of transparent thermal insulators have been made. Samples have been produced from polycarbonate panels which are 6mm thick.

Dimensions of samples are; length 50 cm, width 50 cm, thickness 12 mm, 27 mm, 58 mm, 77 mm, 112 mm, picture 1. Samples are filled with nylon, cellophane which is gathered from many different types of product packages, picture 2.

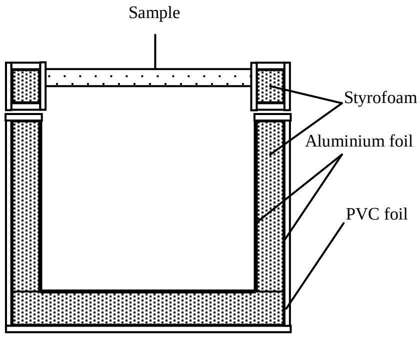


Picture 1. Experimental samples [8]

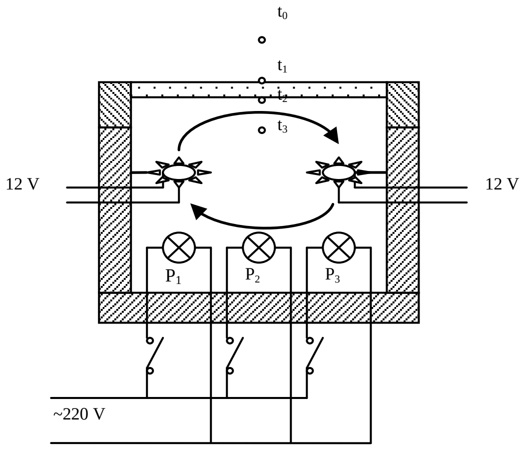
Picture 2. Experimental sample [8]



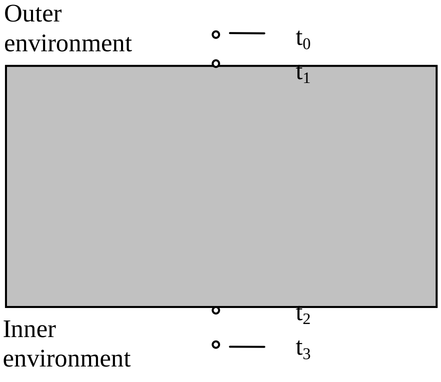
Picture 3. Outer dimensions of thermal chamber [8]



Picture 4. Cross-section of thermal Chamber [8]



Picture 5. Electrical scheme [8]



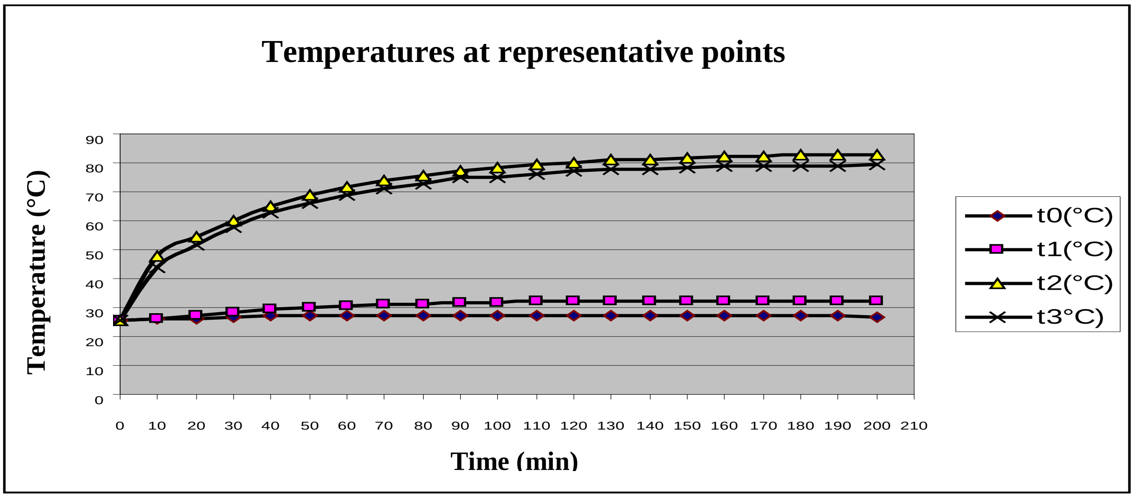
Picture 6. Points of interest on sample [8]

Coefficient of heat transfer through and coefficient of heat transfer from/to are defined using thermal chamber and experimental measurements on samples. Thermal chamber is presented on picture 3. and picture 4. As a heat source in thermal chamber, electrical bulb with standardized power has been used, picture 5. Air fans are used to mix air inside of the thermal chamber. Temperatures are measured with digital thermometer and thermo pair wires in special representative points of interest, picture 6. Measured temperatures in representative points are shown in table 1. And are represented graphically, picture 7. In table 2 are represented all thermal parameters which have been defined due to experimental measurement on thermal chambers and samples. [8]

Results of experimental measurements

Table 1. Temperatures in representative points of interest [7].

t(min.)	t_0(°C)	t_1(°C)	t_2(°C)	t_3(°C)
0	25,4	25,4	25,3	25,3
10	25,9	26,3	47,7	43,9
20	26,1	27,3	54,6	51,4
30	26,5	28,6	60,1	57,6
40	27,1	29,4	65,2	62,8
50	27,1	30,1	68,7	66,3
60	27,3	30,7	71,8	69,0
70	27,1	31,1	73,9	71,2
80	27,2	31,3	75,8	73,0
90	27,4	31,6	77,2	74,8
100	27,1	31,8	78,6	75,2
110	27,5	32,0	79,2	76,3
120	27,0	32,1	80,2	77,0
130	27,2	32,2	81,0	77,7
140	27,5	32,3	81,2	78,0
150	27,1	32,4	81,8	78,5
160	27,2	32,3	82,0	78,7
170	27,0	32,2	82,4	78,8
180	27,1	32,4	82,6	78,9
190	27,2	32,2	82,7	79,0
200	26,8	32,3	82,7	79,3



t_0(°C) – outer air temperature
t_1(°C) – temperature on outer surface of sample
t_2(°C) - temperature on inner surface of sample
t_3(°C) – inner air temperature

Picture 7. Graph of temperatures in representative points of interest on transparent thermal insulator [8].

Table 2. Results of experimental measurements [8].

No.	Parameter	Value
1.	Max. temperature in thermal chamber	t_{3k} = 79,3 °C
2.	Max. temperature at the surface of a sample faced to inside of chamber	t_{2k} = 82,7 °C
3.	Max. temperature at the surface of a sample faced to outer environment	t_{1k} = 32,3 °C
4.	Air temperature in outer environment	t_0 = 26,8 °C
5.	Max. temperature difference between max. temperature of an air in thermal chamber and max. temperature at the surface of a sample facing inside of thermal chamber	Δt_{in} = -3,4 °C
6.	Max. temperature difference between samples surface temperatures	Δt_{uk} = 50,4 °C
7.	Temperature difference between max. temperature at the surface of a sample facing outer environment and air temperature in outer environment	Δt_{ex} = 5,5 °C
8.	Coefficient of heat transfer from thermal chamber to the wall of a sample	α_{in} = -58,82 W/(m²K)
9.	Coefficient of heat transfer through sample	k_u = 3,97 W/(m²K)
10.	Coefficient of heat conductivity	λ_u = 0,445 W/(mK)
11.	Coefficient of heat transfer from the surface of a sample to an air in outer environment	α_{ex} = 36,36 W/(m²K)
12.	Resistance to heat transfer from air in thermal chamber to a surface of a sample	R_{in} = -0,017 m^2K/W
13.	Resistance of heat transfer through sample	R_u = 0,252 m²K/W
14.	Resistance of heat transfer from surface of a sample to an air in outer environment	R_{ex} = 0,028 m²K/W
15.	Resistance to heat transfer from thermal chamber to an air in outer environment	R = 0,263 m^2K/W

Defining transparency coefficient of transparent thermal insulators

Transparent thermal insulators are reflecting, absorbing and transferring sunlight. Transparency coefficient is relation between intensity of light which passes through transparent thermal insulator I and intensity of received sunlight I_0 at the surface of transparent thermal insulator, equation (15): [6]

$$\tau = \frac{I}{I_0} \quad (15)$$

$$I = I_0 \tau \quad (16)$$

$$I = I_0 e^{-\mu d} \quad (17)$$

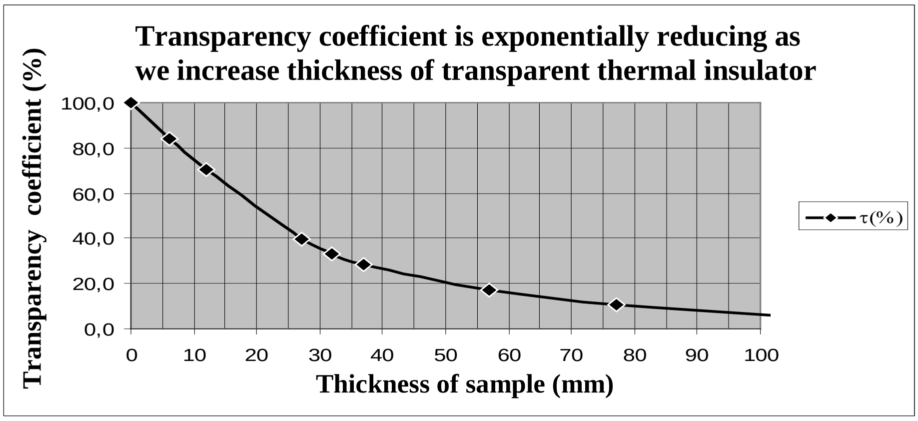
$$\tau = e^{-\mu d} \quad (18)$$

I_0 – intensity of received sunlight at the surface of thermal insulator
I – intensity of transferred sunlight through transparent thermal insulator
τ - transparency coefficient on transparent thermal insulators
μ -absorption coefficient on transparent thermal insulators
d – thickness of transparent thermal insulator

In table 3 are shown results of measurements of sunlight intensity. Relation between transparency coefficient and thickness of transparent thermal insulator are given graphically on picture 8.

Table 3. Relation of transparency coefficient and thickness of transparent thermal insulator [8]

d(mm)	I(W/m^2)	τ (%)
0	304	100,0
6	256	84,2
12	214	70,4
27	120	39,5
32	100	32,9
37	86	28,3
58	52	17,1
77	32	10,5
102	18	5,9



Picture 8. Graphical display of relation between transparency coefficient and thickness of a transparent thermal insulator [8]

Passive collecting of solar radiation using transparent thermal insulators

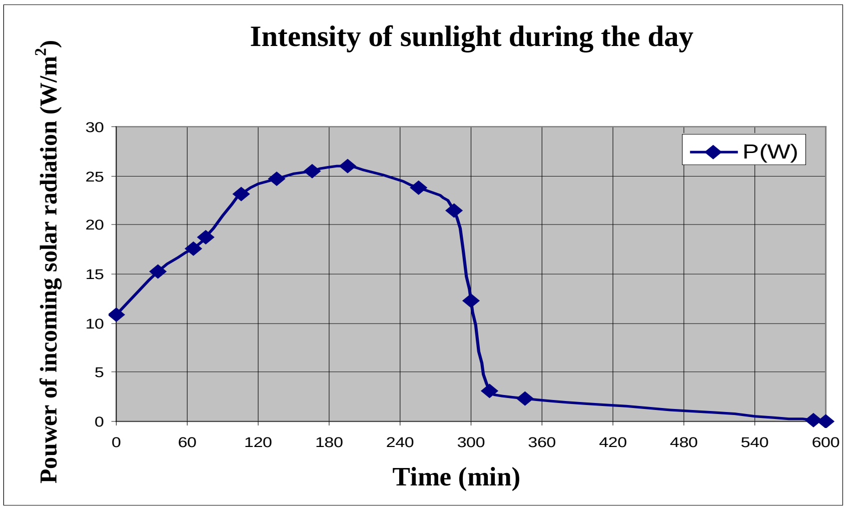
In order to experimentally test passive collection of solar radiation using transparent thermal insulators; two completely identical experimental thermal chambers have been made, picture 9.
Outer dimensions of chambers are 25 cm x 25 cm x 45 cm. Chambers have openings from the front side. Dimensions of inner space in chambers are 15 cm in width, 20 cm in depth, and 35 cm in height. Inside of chambers are placed water canisters of 5 liters, with dimensions: 14 cm x 14 cm x 26 cm, and mass of 5kg. One chamber is closed with conventional thermal insulator, Styrofoam, with a width of 15 cm, height 35 cm and thickness 1,3 cm. Other chamber is closed with transparent thermal insulator, with dimensions of 15 cm in width, 15 cm in height and thickness of 5,8 cm, picture 10.

Picture 9. Experimental chambers [8]

Picture 10. Experimental measurements (equipment) [8]

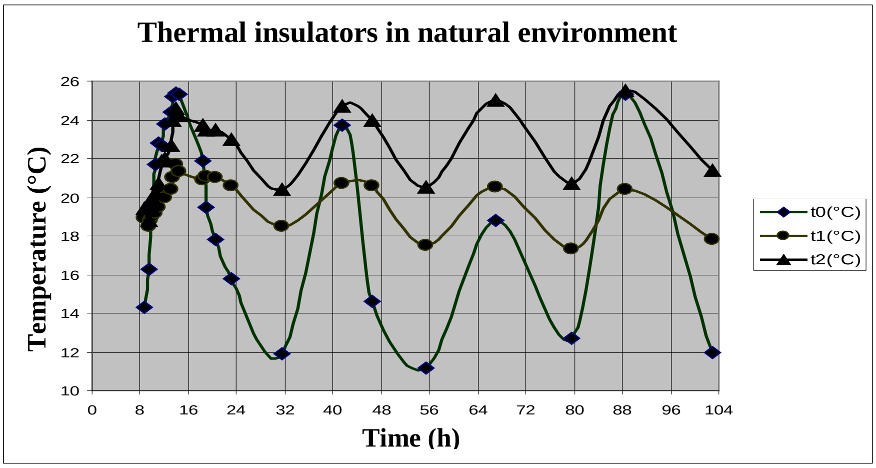
Transparent thermal insulator sample and sample of a conventional thermal insulator have same coefficients of heat transfer through, k = 3,31 W/(m^{2}K). Coefficient of heat conductivity for transparent thermal insulator is λ = 0,19 W/(mK), and for conventional thermal insulator λ = 0,043 W/(mK). [7]
Initial water temperatures inside canisters are equal and are 19 °C. Both thermal chambers are under same weather conditions, at the same time exposed to sunlight in morning hours, at 8:00 h.
Outer air temperature, temperature of water under conventional thermal insulator and water temperature under transparent thermal insulator are measured. Measurements have taken place between 8:00 and 18:00 h. Outer air temperature was changing constantly. Average outer air temperature is 21°C. Water temperature under conventional thermal insulator at 23:00 h was 20 °C, and under transparent thermal insulator at the same time of the day was 22 °C.
Water under conventional thermal insulator increased temperature for 1 °C, and the one under transparent thermal insulator increased temperature for 3 °C during the day. Water under conventional thermal insulator has gained 21 kJ of heat and under transparent thermal insulator 63 kJ.

On picture 11, graphically are presented results of measurements of sunlight radiation power at the surface of transparent thermal insulators.



Picture 11. Power of incoming solar radiation at the surface of thermal insulators [7].

Transparency coefficient of transparent thermal insulator is 0,175. Due to the graph it is possible to calculate incoming solar radiation power at the surface of transparent and conventional thermal insulators. This power is 360 kJ. Heat which is gained by water under transparent thermal insulator is 63 kJ. Relation between water heat quantity and incoming solar radiation energy at the surface of transparent thermal insulator is 0,175.
In this manner it is proved that transparent thermal insulators are able to collect energy of solar radiation and transform this energy into heat.
The apparatus was executing measurements for 4 consecutive days in order to see how transparent thermal insulators behave over long period of time, especially during night when there is no sunlight.
The results are shown in picture 12. From the graph it is obvious that during 4 days water temperature under transparent thermal insulator is always higher than the water temperature under conventional thermal insulators. Maximum and minimum temperatures after first, second and third day have continually raised under transparent thermal insulator. Under conventional thermal insulator it was the opposite, temperature was falling down after first, second, third day.



t_0 (°C) – *outer air temperature*
t_1 (°C) – *water temperature under conventional thermal insulator*
t_2 (°C) – *water temperature under transparent thermal insulator*

Picture 12. Outer and inner temperatures under conventional and transparent thermal insulators [8]

Heat conductivity coefficient of water is λ = 0,6 W/(mK), and coefficient of heat transfer through 14 cm thick wall is k_z = 4,29 W/(m^{2}K). Sunlight absorption coefficient in water is $\alpha \approx 1$. Coefficient of heat conductivity for Styrofoam is λ = 0,043 W/(mK), and coefficient of heat transfer through 1,3 cm thick Styrofoam is k_i = 3,31 W/(m^{2}K). [7]

Efficiency coefficient of conventional thermal insulator is:

$$\eta_k = \frac{1}{1+\frac{k_i}{k_z}} = \frac{1}{1+\frac{3,31}{4,29}} = \frac{1}{1,772} = 0,56 \text{......... (19)}$$

Efficiency coefficient of Styrofoam is 56,4 %.

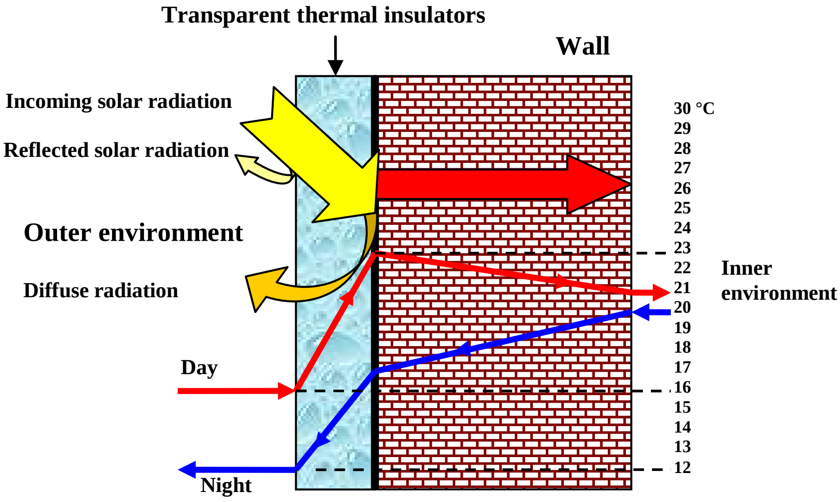
Efficiency coefficient of transparent thermal insulator is:

$$\eta_p = \frac{1+\alpha\tau}{1+\frac{k_i}{k_z}} = \frac{1+1\cdot 0,175}{1+\frac{3,31}{4,29}} = \frac{1,175}{1,772} = 0,66 \text{... (20)}$$

Efficiency coefficient of transparent thermal insulator is 66 %. [8]
From relation (19) and (20) it is obvious that efficiency coefficient of transparent thermal insulator is greater for about 10 % than the one of conventional thermal insulator.
Transparent thermal insulator is able to collect 17,5 % of incoming solar radiation energy, transform it into heat and capture 56 % of that energy. [8]
Finally transparent thermal insulator is able to passively collect, transform into heat and capture energy which is coming directly from incoming solar radiation at the surface of transparent thermal insulator itself. [3]
Let's say that one living facility needs about 10tons of coal during the year, after it is isolated with conventional insulators facility it will need about 4,4 tons, and with the usage of a transparent thermal insulator it will need only 3,4 tons of coal during year. It means that using transparent instead of conventional thermal insulators at the walls of the facility will save 1 ton of coal per year. For 1 ton of coal, 2,67 tons of oxygen are needed. Burning 1 ton of coal produces about 3,67 tons of carbon dioxide, clinker, carbon dust, smoke, etc.

Discussion

By installing transparent thermal insulators at outer walls of the living facilities, we can passively collect solar radiation energy, transform it into heat and capture inside of the walls and object itself. [3]



Picture 13. Passive collecting of solar radiation energy [7]

Conclusion

Using transparent material from different product packages we can produce transparent thermal insulators.

Transparent thermal insulators are able to passively collect energy of solar radiation, transform it into heat and capture this heat.

Using transparent thermal insulators in daily life would help solving the problem of global warming, reduce the usage of fossil fuels, organization of landfill, climate changes, etc. [5]

Transparent thermal insulators could make our environment better for our future generations.

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Corresponding author: Smajo Sulejmanović
Institution: University in Tuzla, Faculty of mathematics and natural sciences, Bosnia and Herzegovina
E-mail: smajo.sulejmanovic@untz.ba