An Active Thermal Wall Based on Thermoelectricity

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Abstract

This paper describes the basic principles of a new concept for an active thermal wall able to improve the current practice of design and installation of air conditioning for enclosed spaces. The wall is a translucent or transparent flat wall which separates two environments (indoor and outdoor environments) at different temperatures allowing for the control of the desired temperature in one of these environments. This objective is reached using thermoelectric modules imbibed between translucent or transparent materials, such as glass windows, allowing for the transport of heat between the two environments at different temperatures. The most important applications to which the new active wall would be aimed are included within the sector of the thermal conditioning of spaces and heat transmission controlled in industrial machines or environments, substituting the usual installations.

Introduction

The house of the future is a concept on the minds of many researchers from different technological fields in order to improve the quality of life and the services of existing houses. One of the main topics of these investigations is energy use and management in the house of the future. The temperature in a room is an important factor to control in order to guarantee a comfortable atmosphere [1],[2]. The increasing use of electricity for air conditioning demonstrates this assertion.

This paper describes the basic principles of a new concept of an active wall for the house of the future able to improve the current practice of air conditioning design. This active wall is the object of a registered patent of the authors. The wall is a translucent or transparent flat wall which separates two environments (indoor and outdoor environments) at different temperatures allowing for the control of the desired temperature in one of these environments. This objective is reached using the active wall as a heat pump using the Peltier effect through thermoelectric modules [3] included between translucent or transparent materials, such as glass windows, allowing for the transport of heat between the two environments at different temperatures. The thermoelectric elements have to be supplied by a continuous electric current which can be obtained from conventional sources of electricity or from photovoltaic panels.

The most important applications to which the new active wall would be aimed are included within the sector of the thermal conditioning of spaces and heat transmission controlled in industrial machines or environments, substituting the usual installations.

This paper is organised as follows. First, a description about the active wall is presented. Next, its theoretical performance is analysed using finite element techniques. Finally, some experimental results are included.

Description of the active thermal wall

The active thermal wall consists of two main components:

- The thermoelectric chains
- The material where the thermoelectric chains are imbibed

One thermoelectric chain is a set of aligned thermoelectric pairs connected electrically in series and thermally in parallel.

The electrical connections between the thermoelectric chains can be in series or in parallel. In this last case, the electrical bridges have to have special dimensions in order to improve not only the heat absorption at the cool side and the heat dissipation at the hot side of the thermoelectric pair, but also to uniform the temperatures on both sides of the active thermal wall.

In order to obtain a suitable structural integrity of the active thermal wall, these chains have to be integrated in an imbibing material where the following two different configurations are possible:

- Configuration (a) in fig. 1. In this case the thermoelectric chains have some material imbibed which are the electrical bridges of the chains in direct contact with the environment.

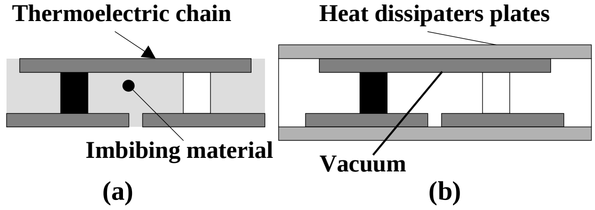


Figure 1. Cross section of a thermoelectric chain

- Configuration (b) in fig. 2. In this case the thermoelectric chains are located between two heat dissipater plates. The external dissipaters form a thermal resistance and diminish the thermal power pumped, so it would be necessary to increase the effective surface of the pump created by the thermoelectric chains, but in contrast, the robustness of the system is improved.

The active thermal wall described in this article is exclusively based on the configuration (b). This configuration is very simple, and furthermore it is very flexible to build many different models of active thermal walls as thermoelectric heat pumps.

One of the main applications of this active thermal wall is the air-conditioning of enclosed spaces where the temperatures to be controlled are different from those of their outer environments. Rooms of houses are a typical case where the active thermal wall can be applied. Their windows can be used to integrate inside them a set of thermoelectric chains such as in configuration (b) in fig. 1. The objective would be to control the indoor temperature of a room according to the outdoor temperature and the requirements of the user.

In order to integrate the opaque thermoelectric chains into a transparent window, it is necessary to keep an amount of surface without being covered by them. In order to do this, a distance is required between the chains to guarantee the transparency of the window. Moreover, the external dissipaters and the imbibed materials have to be translucent. Fig. 2 shows how to build an active thermal wall in a window. This figure represents rows of parallel thermoelectric chains between two glasses or translucent materials. Inside the active wall there would be air, although it would be useful to make a vacuum to obtain a better thermal insulation. It is also possible to see some metallic extension plates in order to facilitate the electrical connections between the chains and also, the DC current source.

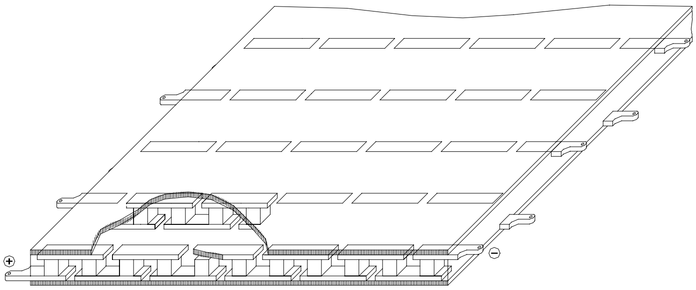


Figure 2. Scheme of the active thermal wall

If the reception of light is not required, the thermoelectric chains could cover all the surface of the active thermal wall imbibed in an opaque material.

Even taking into account the disadvantage of losing illumination inside the room, this system has some important advantages inherent to the use of thermoelectricity which balance the problem:

- Rational use of energy.
- Whether it is used as a window or as a wall, it has a natural adaptability to the environment.
- Better use of the space available. It has a reduced size and weight in comparison to traditional heat pumps which require a considerable space (condenser, evaporator, compressor...). The thermoelectric active wall only needs an electrical DC current source, and it has only some millimetres of thickness.
- A relatively simple construction.
- A system free of moving parts.
- High reliability combined with a long life time.
- A reversible system, where it is possible to heat or cool by changing the polarity of the DC source.
- Precision temperature control capability.
- Absence of refrigerant fluids. This makes this heat pump environmentally friendly which is an important step towards the objective of reducing the use of chlorofluorocarbons (CFC).

Tridimensional analysis of the active thermal wall using finite element techniques

An analysis of the active thermal wall was performed before building a prototype creating a model using finite element techniques. It allows for the prediction of the possible behaviour of this prototype and for an estimation of the influence of different geometrical and physical parameters. A programme was developed using the commercial software tool named ANSYS based on the results obtained in [4]. This programme was performed using elements in three dimensions and a specific subroutine developed in order to apply the Peltier effect in the model. Furthermore, the software developed allows for the introduction of parametric models and the performance of simulations with a great deal of loads and boundary conditions.

Components and materials modelled

The model created by finite element techniques corresponding to one element of the thermoelectric chain in the active thermal wall is shown in fig. 3.

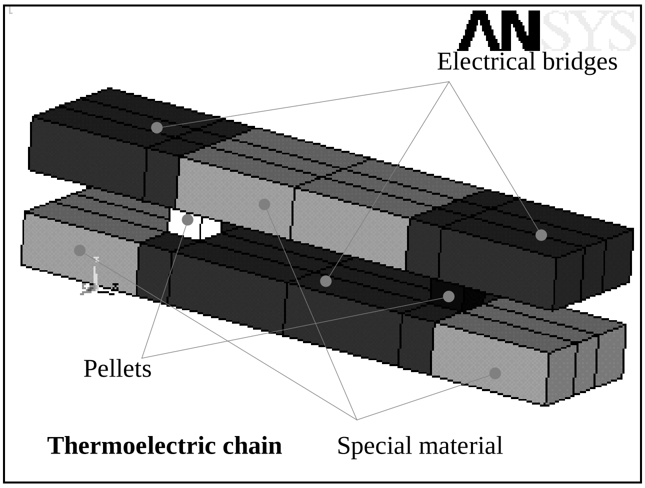


Figure 3. Scheme of one element of the thermoelectric chain

Fig. 4 shows the model of the heat exchangers (thermoelectric chain imbibed between two glass surfaces) put on both sides of the thermoelectric chain. The whole model of the active thermal wall contains the thermoelements, the electrical bridges and the glasses, but without welding the different elements together.

A new material was introduced in order to simplify the model (reducing the number of volumes). It has the same thermal conductivity as copper, but it is practically a perfect electric insulant. The main idea is to highly simulate the heat transmission in accordance with the real geometry of a prototype. It does not matter if the electrical model is not so exact because the electrical continuity is assured.

The next paragraphs describe more details about the components of the active thermal wall modelled.

Electrical bridges

The electrical bridges are made of copper. The surface occupied by the thermoelectric chains has to be a compromise between the biggest in order to maximise the thermal flux and the smallest in order to minimise the opaque area of the window. A good compromise could be that only one third of the total surface is occupied by the thermoelectric chains.

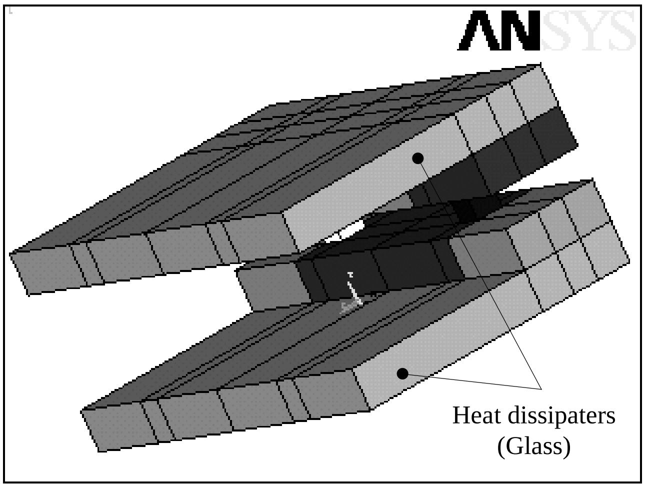


Figure 4. Thermoelectric chain model between two glasses

Heat dissipaters

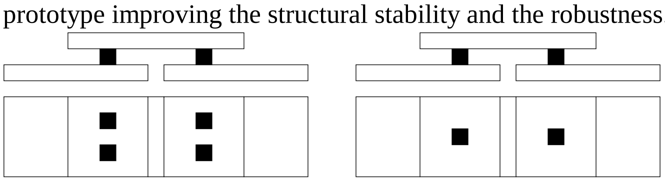
The external glasses are the heat exchangers of the heat pump. In general, glass does not have good thermal properties and this particularly diminishes the heat power which is possible to absorb at the cold side or reject at the hot side. The thickness considered for the glasses is 2 mm.

Thermoelements

The pellets used in the model have the following dimensions 1.4x1.4x1.6 mm and are made of bismuth telluride. This is a common size working at temperatures relatively close to the ambient temperature.

The software developed allows for the modification of the number of thermoelements in each thermoelectric pair.

The configuration in fig. 5a is better in order to build a prototype improving the structural stability and the robustness.



(a) **(b)**

Figure 5. Models with different a number of pellets in parallel

The variation with the temperature of the thermoelement and copper properties has been taken into account.

Symmetry of the model used

Because of the configuration of the thermoelectric chains inside the window, see fig. 6, there is a geometric and physical symmetry. If the border effects are considered negligible, this symmetry allows the model analysis by finite element techniques only in a thermoelectric pair and in the glass area of the window associated with it. This allows for the refining of the mesh in a specific area. The main dimensions of the model are shown in fig. 7.

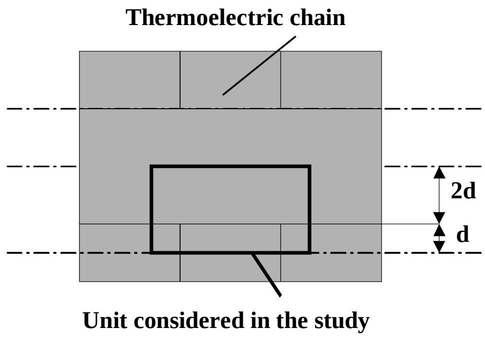


Figure 6. Unit considered in the model

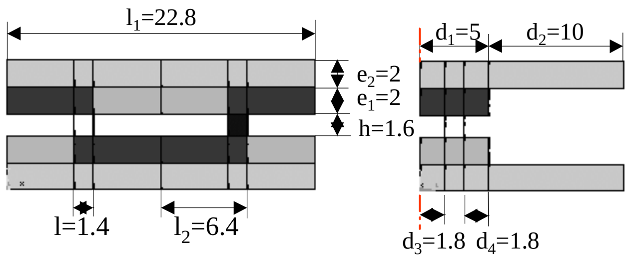


Figure 7. Main dimensions of the model (mm)

Loads and boundary conditions used in the model

As shown in fig. 8, a uniform electrical current density is applied to one of the ends of the electrical bridges while on the other end a reference voltage is fixed.

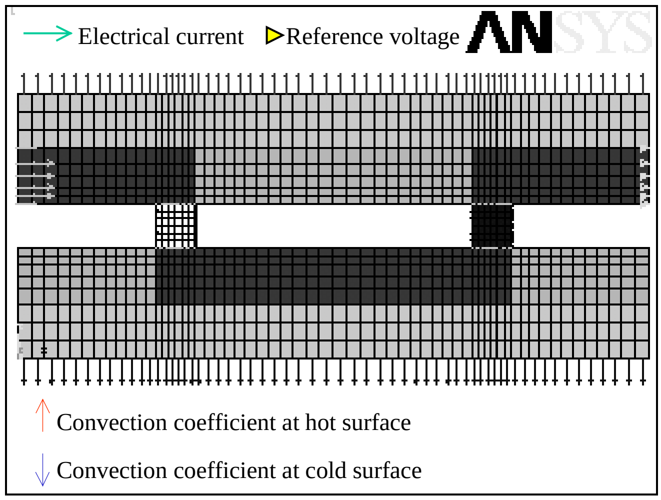


Figure 8. Boundary conditions in the model

Thermal boundary conditions in the model are flexible, so it is possible to fix the temperature in both external surfaces or apply a convection coefficient (this is a more real situation).

A perfect vacuum is considered inside the model being the model adiabatic, but it is also possible to consider air or another imbibing material. In fig. 8, the mesh of the model can be seen. Note that it is smaller in the influence area of thermoelements and inside the pellets.

Results of the programme developed

The main numeric results obtained by the programme developed are the following:

$\dot{Q}_c$: thermal flux absorbed at cold side per surface unit [W/m^2]

$\dot{Q}_h$: thermal flux rejected at hot side per surface unit [W/m^2]

W_e : input electrical power per surface unit [W/m^2]

η_c : cooling efficiency obtained as $\dot{Q}_c / W_e$

COP: coefficient of performance obtained as $\dot{Q}_h / W_e$

It is also possible to obtain graphical results such as thermal maps and thermal and electrical fluxes distribution in some specific sections or lines.

Main results of the model simulated

No study was done to establish the optimal dimensions of the copper plates and the heat dissipaters. A thickness of 2 mm was used for the glass because it is commercial and offers a sufficient structural stability to the model of the active thermal wall. The length of the electrical bridges of the thermoelectric pairs in all simulations was 23 mm.

The best results were obtained with a width of the thermoelectric chains of 10 mm. This result must only be considered as an approximation because it was obtained probing different widths under only one condition of work, this is, using only one value of temperature difference and one value of electrical current. An exhaustive study will be done in the future in order to optimise the dimensions of all components.

The simulations were divided into two groups. In the first one, the behaviour of the model working under summer climatic conditions was investigated trying to achieve considerable cooling powers with a reasonable cooling efficiency. The ambient temperature was set at 34ºC, and wishing for 24ºC inside the room as the temperature for obtaining an acceptable level of comfort. In the second group the behaviour of the same model was analysed under winter conditions. The ambient temperature was set at –3ºC and the temperature of a suitable level of comfort was fixed at 22ºC.

The main parameters used by the model simulated were:

Thickness of electrical bridges (e_1)	2 mm
Thickness of heat dissipaters (e_2)	2 mm
Height of thermoelements (h)	1.6 mm
Side of thermoelements (l)	1.4 mm
Distance between thermoelements in parallel ($2d_3$)	3.6 mm
Distance between thermoelements in series ($2l_2$-l)	10 mm
Lateral extension of electrical bridges (d_4)	1.8 mm
Surface ratio between glass/thermoelectric chains	2/3
Number of thermoelements in parallel	2
Convection coefficient at cold and hot sides	82.5 W/m^{2}K

The electrical current expressed in all graphics and tables is the total current which flows through a thermoelectric chain, although only one half is applied in the model because of the symmetry of the problem.

All the following graphics show results of the simulation considering the summer conditions described and applying an electrical current of 4 A.

As shown in fig. 9, the external hot side of the glass achieves a maximum temperature of 316.9 K and a minimum one of 310.8 K. The temperature is practically constant in the zone of the glass in contact with the thermoelectric chain and diminishes in an exponential way in the free surface.

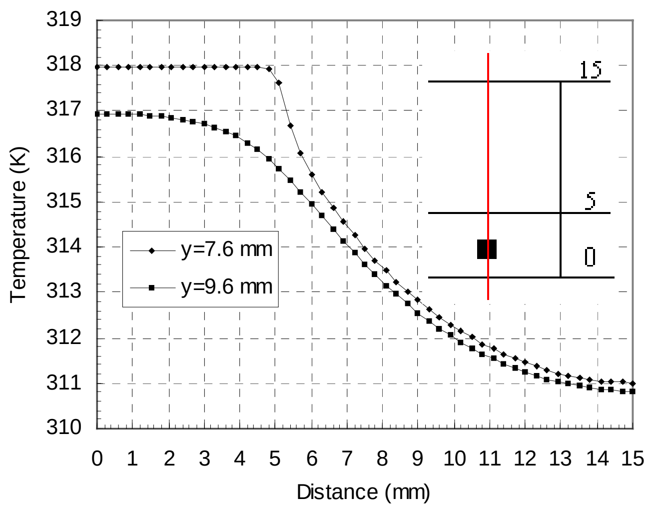


Figure 9. Temperature distribution in the model at the hot dissipater. I=4 A, summer conditions

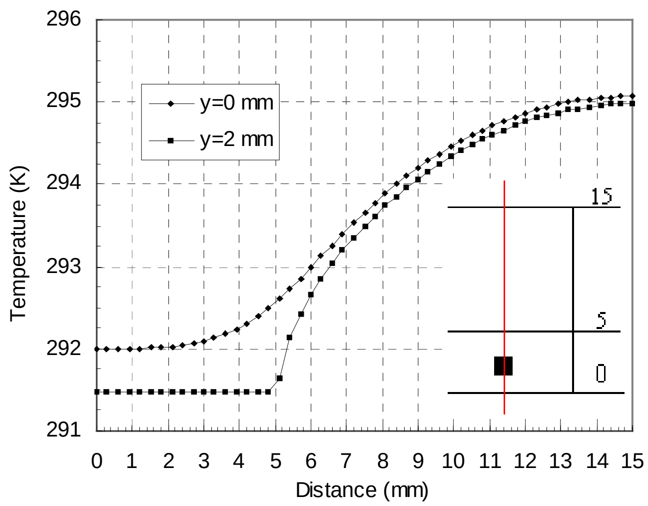


Figure 10. Temperature distribution in the model at the cold dissipater. I=4 A, summer conditions

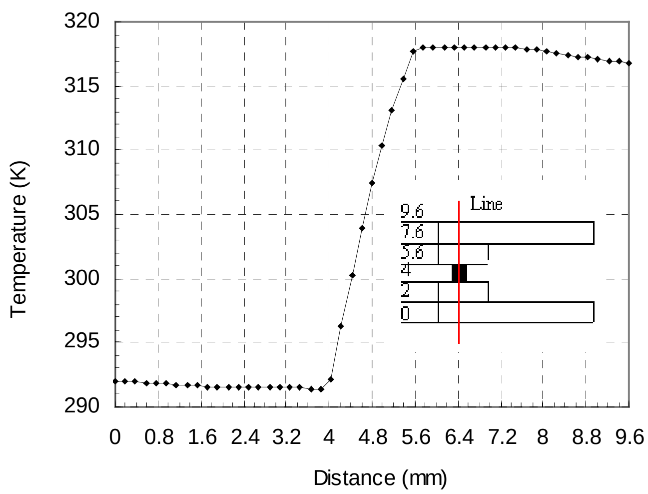


Figure 11. Temperature distribution across a line of the model. I=4 A, summer conditions

The same behaviour is appreciated in fig. 10 at the cold side, the minimum temperature is achieved at the area in contact with the thermoelectric chain (291.9 K), and the maximum temperature at the opposite end (295.1 K). Note that the temperature is lower than the indoor ambient temperature (24ºC) in all the external glass surface.

Fig. 11 shows the temperature evolution from the cold to the hot side in a line of the model which crosses a thermoelement. The temperature diminishes slightly in the dissipater in contact with the cool ambient and remains approximately constant at the electrical bridge. The main temperature difference is established in the thermoelement. The temperature once again remains constant inside the hot electrical bridge and decreases slightly in the hot dissipater.

The following tables show some quantitative results obtained from the simulation of the model in summer and in winter conditions. Also, two models of the active thermal wall were tested. Model 1 contains 1/3 of the transparent window covered by opaque thermoelectric chains and Model 2 has 1/2 of its surface covered.

Model 1. (1/3 of the surface covered by thermoelectric chains)

I (A)	$\dot{Q}_h$ (W/m²)	$\dot{Q}_c$ (W/m²)	W_e (W/m²)	η_c
1	66.8	44.4	22.4	1.98
1.5	139.4	93.8	45.6	2.06
2	216.4	139.4	77.0	1.81
2.5	297.9	181.3	116.6	1.55
3	383.9	219.7	164.2	1.34
3.5	474.5	254.5	220.0	1.16
4	569.9	286.1	283.8	1.01
5	783.6	333.3	450.3	0.74
6	1020.3	367.8	652.5	0.56
8	1586.9	384.7	1202.2	0.32
10	2355.4	315	2040.4	0.15

Table 1. Summer conditions: Th=34 ºC Tc=24 ºC

Table 1 shows that the cooling efficiency starts to diminish when the model works with electrical currents up to 1.5 A. However, it is necessary to work with higher electrical currents in order to obtain good values of cooling powers. The cooling power is acceptable using 4 A, but the cooling efficiency is only 1. It would be necessary to improve the efficiency of the system because traditional heat pumps work with higher efficiencies (more than double).

Table 2 shows the same model working in winter conditions. It does not have satisfactory results due to the fact that the temperature difference is higher. Although heating powers are high enough, the coefficient of performance is very low in all cases, always under 1.5 and very far from the values of commercial heat pumps. With these results, it would be more appropriate to use this system combined with traditional heating systems, using the thermoelectric one when the ambient temperature was higher.

I (A)	$\dot{Q}_h$ (W/m²)	$\dot{Q}_c$ (W/m²)	W_e (W/m²)	*COP*
3	250.2	70.9	179.3	1.40
4	424.6	126.4	298.2	1.42
5	622.5	165.5	457	1.36
6	839.8	192.9	646.9	1.30

Table 2. Winter conditions: Th=22 ºC Tc=-3 ºC

The behaviour of the model improves considerably using an ambient temperature of 7ºC, as shown in table 3. It would be possible to obtain a heating power between 250 and 300 W/m² working with a coefficient of performance close to 1.

I (A)	$\dot{Q}_h$ (W/m²)	$\dot{Q}_c$ (W/m²)	W_e (W/m²)	*COP*
2	164.4	85.2	79.2	2.08
2.5	241.5	123.4	118.1	2.04
3	322.8	158.3	164.5	1.96
4	498.5	218.5	280	1.78
5	698.3	261.4	436.9	1.60
6	917.9	292.5	625.4	1.47

Table 3. Winter conditions: Th=22 ºC Tc=7 ºC

Model 2. (1/2 of the surface covered by thermoelectric chains)

In order to obtain higher cooling heating powers, a new model has been simulated. The only difference with model 1 is that the ratio between the opaque and translucent part of the active thermal wall is 1/2. Here the results are better.

I (A)	$\dot{Q}_h$ (W/m²)	$\dot{Q}_c$ (W/m²)	W_e (W/m²)	η_c
2	229.0	140.1	88.9	1.58
3	436.0	247.6	188.4	1.31
4	664.2	339.1	325.1	1.04
5	915.0	415.2	499.8	0.83
6	1202.1	468.1	734.0	0.64

Table 4. Summer conditions: Th=34 ºC Tc=24 ºC

I (A)	$\dot{Q}_h$ (W/m²)	$\dot{Q}_c$ (W/m²)	W_e (W/m²)	*COP*
3.5	298.1	28.8	269.3	1.11
4	405.8	64.8	341.0	1.19
4.5	518.5	97.6	420.9	1.23
6	887.7	176.1	711.6	1.25

Table 5. Winter conditions: Th=22 ºC Tc=-3 ºC

I (A)	$\dot{Q}_h$ (W/m²)	$\dot{Q}_c$ (W/m²)	W_e (W/m²)	*COP*
3	263.1	66.5	196.6	1.34
4	474.6	145.2	329.4	1.44
5	706.2	210.3	495.9	1.42
6	906.4	254.9	651.5	1.39

Table 6. Winter conditions: Th=22 ºC Tc=2 ºC

I (A)	$\dot{Q}_h$ (W/m²)	$\dot{Q}_c$ (W/m²)	W_e (W/m²)	*COP*
2	137.3	46.6	90.7	1.51
2.5	231.3	96.7	134.6	1.72
3	330.2	143	187.2	1.76
4	542.5	225.1	317.4	1.71
4.5	656.2	260.7	395.5	1.66
5	774.9	292.9	482	1.61
6	1035.8	339.8	696	1.49

Table 7. Winter conditions: Th=22 ºC Tc=7 ºC

Prototype

A prototype was built using the results obtained by the simulation of the active thermal wall model.

The main dimensions of the thermoelectric chain are shown in fig. 12. Due to the fact that the surface of copper bridges is much higher than the cross sections of pellets, an adhesive was applied at points far away from the unions between pellets and electrical bridges in order to obtain a good structural stability in the chains.

Each thermoelectric chain has seven thermoelectric pairs. The whole prototype built has 8 thermoelectric chains. The dimensions of the prototype are shown in fig. 13 in cm. The first thermoelectric chain is located 53 mm up to the lower end of the glass in order to join the prototype to the support which allows for applying an air flow to the model. The model joined to the test bench is shown in figures 14 and 15.

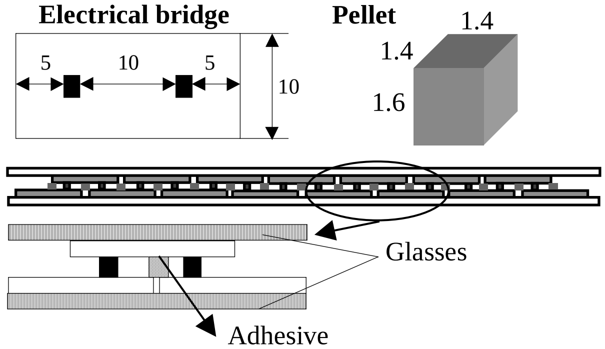


Figure 12. Components of the prototype of active thermal wall, dimensions in mm

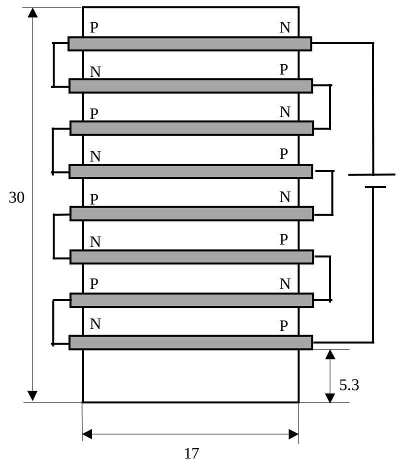


Figure 13. Dimensions of the active thermal wall prototype

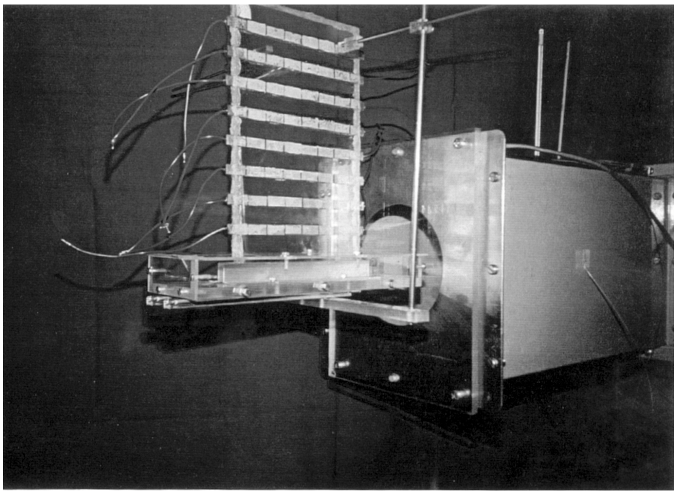


Figure 14. Test bench of the prototype of active thermal wall-1

<u>Tests performed</u>

The first experiment concerning the behaviour of the prototype built was performed under natural convection conditions. The electrical current applied was 0.45 A and the ambient temperature 21ºC.

The results were not satisfactory and were not in agreement with the results of a simulation of the model under the same conditions. The temperature in the hot glass was between 24ºC and 28ºC with the exception of two points where the temperature was higher than 30ºC. However the main problem was that the cold glass temperature was always up to the ambient temperature. One of the possible reasons for this could be that at the hot side the dissipation of heat was not high enough and also the Fourier effect was higher than the Peltier effect, taking into account that the vacuum had not been made inside the prototype.

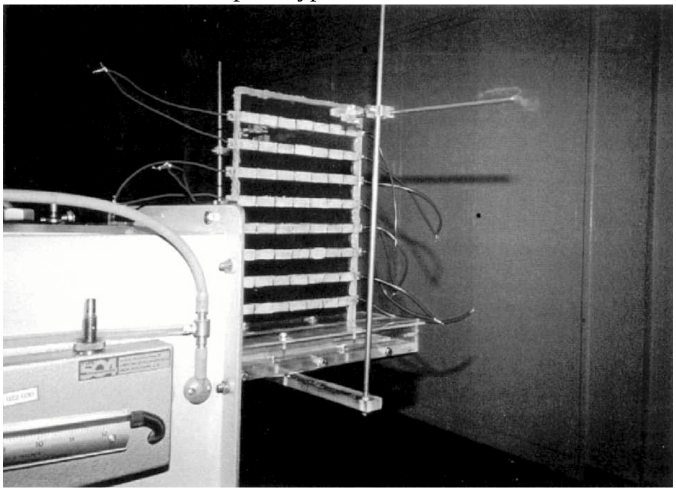


Figure 15. Test bench of the prototype of active thermal wall-2

It is possible to maintain a temperature difference between 2ºC and 4ºC in most of the area of a window while the results with finite element techniques show that with this value of electrical current and with a temperature at the cold side between 22ºC and 24ºC the maximum temperature difference could be about 5ºC. Another important aspect is the high values of the temperature measured at some points on both sides of the prototype. The reason for this fact is the existence of high electrical resistance at some unions as a consequence of bad weldings. These high values implicate a higher heat by Joule effect, and therefore, an increment of temperature.

The same experiment under forced convection was carried out. The temperature at the hot side was between 23-24ºC and the same hot points were appreciated, which confirmed the high electrical resistance at those points. The average temperature on the cold side was 22.5ºC. Comparing the results with the natural convection case, the temperature diminished 3ºC on the average on the hot side and 1.5ºC on the cold side, but the temperature difference was between 1ºC and 2ºC and the temperature on the cold side continued up to the ambient temperature.

The main reasons for the bad behaviour of this prototype, so far from the theoretic results, are explained in the construction of the prototype, and more specifically in the unions between pellets and electrical bridges and between thermoelectric chains and glasses. This suggests a better construction of another prototype to be carried out in another step of the investigation.

Examples of possible applications of the active thermal wall

This section includes two examples of possible applications of active thermal walls. They are included to demonstrate the important possibilities for this use of thermoelectricity. They are theroretical simulations based on real measurements.

Air conditioning of a greenhouse

Two main characteristics make the active thermal wall interesting. The greenhouses need an air-conditioning system in order to maintain a certain thermal level inside it and on the other hand the material of construction has to be translucent. The use of glass or some type of plastic such as polycarbonate, polyethilene, metacrylate, or PVC (the most important plastic used in this type of construction) make it possible to imbibe the thermoelectric heat pump inside it.

The greenhouse air-conditioning system has to regulate many climatic parameters such as temperature, light, grade of humidity and the concentration of CO_2. The thermoelectric heat pump would only control the temperature, reducing the oscillations of temperature between day and night. The rest of the parameters cannot be controlled with this system, so it is necessary to use auxiliary equipment.

The ideal place to locate the active thermal wall would be in the inferior part of the walls because this is the area where the influence of a decrease of light (one third would be opaque) is not so important taking into account that the most part of the solar radiation goes through the roof of the greenhouse. In this area, the incidence angle of solar rays is practically null and the translucent material reflects approximately only 20% of solar radiation. A greater fraction of solar radiation reflected corresponds to a higher incidence angle. So, the location of panels in this part of the greenhouse does not damage its illumination.

Another advantage of this location is that it assures a direct effect on the zone where plants and flowers normally are located. With some types of crops, it is necessary to increase the temperature of the ground. In this case, two options would be possible: the first one would be the use of active thermal panels buried, maintaining the temperature of the ground controlled. The second one would be the use of the air which circulates over the surfaces of the walls and returns back through pipes in the ground.

The environmental character of the thermoelectric wall is also important because emissions of CO, CO_2, and sulphur oxides of fuel combustion are eliminated and no refrigerant fluid is used. The active thermal wall allows for the use of total interior space of the greenhouse because the heat pump is integrated into the walls.

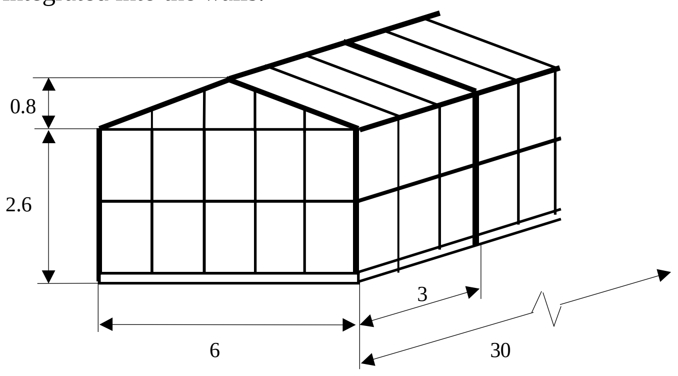


Figure 19. Scheme of the greenhouse, dimensions in m

An application of the active thermal wall is possible for the air-conditioning of a greenhouse in a sunny region of Spain used for growing tomatoes. The average summer conditions in this zone are 30ºC with a relative humidity of 70% and the average temperature in winter is 5ºC.

The greenhouse is made using glass walls and a steel structure. A small sketch is shown in fig. 19. It is east-west oriented, an orientation that is recommended for a greenhouse of only one bay.

The optimal conditions for growing tomatoes are fixed between 13ºC to 16ºC at night and from 22ºC to 26ºC during the day. The maximum and minimum biological temperatures are 30ºC and 2ºC respectively and the optimum relative humidity is between 55% and 60%.

In order to calculate the thermal loads which the thermal wall has to balance in winter and in summer, a temperature of 24ºC during the day and 14ºC at night should be used, selecting the more unfavourable conditions: nocturnal period in winter and diurnal in summer.

In summer, it is necessary to use some specific protection to shade the crop and reduce the thermal loads because of the solar radiation during this season.

The energy interchange between the inside of the greenhouse and the ambient is complex due to the different forms of heat transmission which take place: radiation, convection and conduction.

In winter, interchanges by radiation: coming from the ground, the inner ambient, the atmosphere and the vegetation, and emitted to the ambient from the metallic structure and the translucent cover, were calculated using Chiapale's methodology (1981). Interchanges by convection with the outer and inner ambient, and the ground, and conduction loads through the ground and the walls of the green house were calculated using Bianchi's method (1982).

In summer, outer loads: solar gain, heat transmission through the translucent glasses, air ventilation, and inner loads: occupation, artificial illumination and other equipment were calculated using the guide of Carrier company [1].

In both cases, the influence of the energy used by plants in photosynthesis and the heat supplied by the transpiration of the crops were considered to be negligible.

The thermal load to balance in winter was 48250 W and 40360 W in summer, the last one being the critical load. No more details were included because it is not the main goal of this article and furthermore, there is a great deal of commercial information to calculate this type of loads.

Using the results obtained in the simulations of model 1, if the thermal wall works with an electrical current of 3 A, the total surface will be of 105.1 m^2 with a height of 1.5 m approximately. The height can be reduced to 0.8 m with the use of dark sunblinds to decrease the solar radiation.

Air conditioning of a student residence building

A study of the thermal loads in a student residence building in Madrid was done in order to know the viability of the active thermal wall. Once again the main goal was to maintain comfortable temperature conditions in all rooms taking into account the available glazed surface of each one. The maintenance of the relative humidity and the renewal of air was not analysed because these goals rest with other auxiliary equipment.

The levels of comfort considered were 24ºC in summer and 22ºC in winter with an ambient temperature of 34ºC and –3ºC respectively.

The outer loads were the heat transmission by conduction through the walls and the solar radiation through the windows. The inner loads were occupation (very important in some specific rooms), and equipment which dissipate heat and artificial illumination. Notice that in winter, only the heat transmission by conduction represents a thermal load. All calculations were done using the Carrier guide.

A summary of the average results in some parts of the student residence building is presented in tables 7 and 8 to have an idea of the magnitude of the thermal loads. Specific values have not been shown because the thermal loads in each room depend on many parameters such as the size of the room, the glazed surface, the orientation and the location inside the building. Furthermore, the number of different rooms is considerable.

The kitchen, the pantry and the bathrooms were not air conditioned. It would be necessary to use traditional systems in the assembly room because of the absence of windows. This is not very important because these rooms are not frequently used. The bedrooms with higher loads were located on the third floor because of the heat transmission through the roof and on the same floor, the north-east bedrooms have more losses than the south-west ones.

Room	Average thermal losses in winter	
	Maximum (W)	Minimum (W)
Bedrooms in the entresole	400 W	350 W
Bedrooms in the ground floor	365 W	280 W
Bedrooms in the 1st and 2nd floor	250 W	225 W
Bedrooms in the 3rd floor	600 W	500 W
Living room 1	4390 W	
Living room 2	3590 W	
Living room 3	2220 W	

Table 7. Winter loads

The glazed surface in each bedroom was 1.2 m^2, and in the living rooms 18.4, 22.6, and 20 m^2 respectively. Working with the summer results and fixing the restriction of working with cooling efficiencies close to 1, the cooling power obtained from each model is shown in table 9.

Room	Average thermal loads in summer	
	Maximum (W)	Minimum (W)
Bedrooms in the entresole	500 W	340 W
Bedrooms in the ground floor	470 W	270 W
Bedrooms in the 1st and 2nd floor	450 W	250 W
Bedrooms in the 3rd floor	550 W	400 W
Living room 1	4115 W	
Living room 2	7125 W	
Living room 3	4850 W	

Table 8. Summer loads

	Cooling power (W/m^2)	η_c
Model 1	285	1
Model 2	350	1
	370	0.95
	390	0.9

Table 9. Points of work of the active thermal wall

Taking into account the thermal loads and the glazed surfaces, it would be necessary to use both models. Model 1 would be utilised in rooms where natural light is the most important factor, such as the bedrooms. Model 2 would be used in other areas, for instance in the living rooms, to take advantage of the excess of cooling power produced and to balance the thermal loads in some rooms where it is impossible to do it using only its own glazed surface.

The same models working under winter conditions can balance the thermal loads, but with a low COP as shown in table 2. If the ambient temperature is higher (7ºC), it is possible to work with a COP of 2 (340 W, model 1) or 1.75 (330 W, model 2), see tables 3 and 7.

In both cases, it would be necessary to design a system of pipes to transfer the cooling (heating) power among different rooms, specifically in the bedrooms on the third floor. This system would be very simple because the energy interchange is always between close areas.

Conclusions

This paper presents a new concept for an active thermal wall based on thermoelectricity. It is designed to separate an enclosed space, such as a room, from its sourrounding environment. The active thermal wall works like an active insulant keeping the temperature of the enclosed space to the value required taking into account the temperature of the outer environment. This new wall allows for a reduction of the power of the classical air conditioning systems, making better use of the energy needed. The paper presents an analysis of the active thermal wall performance using finite element techniques and some experimental results based on a laboratory prototype. Furthermore, theoretical calculations have been performed for the application of the active thermal wall using two cases: a greenhouse and a student residence building.

Future steps to be taken will include the construction of a second prototype improving the constructive procedure of the first one, and solving of the transparency lose in transparent walls by using thin film technology.

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