Construction of an Active Façade Envelope with Peltier Cells

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Abstract.

The team researchers have been investigating on alternative ways for buildings to waste less energy. The result is the consecution of a new facade system with Peltier cells, that is to say, a new system of air conditioning that works both as a machine as a facade. That means the application in the field of construction of a technology that is already in use in other areas, fundamentally the military and aerospace. **The new system has to be a prefabricated element that perfectly fix between the slabs**. The result of all these ideas is the construction of a prefabricated module, consisting of a simplified inhabited housing unit with a thermoelectric installation that provides service to this module. The prototype has been monitored during one year. The University of Navarra has got the national patent for a "**prefabricated and decentralized facade module for the climate control of inhabited spaces**". Moreover, the Thermoelectric Conditioning System (TCS) is designed to reach a high comfort level for people living in the local. Without mechanical parts like pumps or compressors, there is no necessity for maintenance, reducing the possibilities of failure. The only mechanical elements are the dissipation heat fans placed in the external face of the prototype. There are also some heat sinks to evacuate the heat from the power elements.

The next step is improving the system as a facade, paying special attention to carry out the legal façade envelope's requirements, such us, noise level, thermal transmittance, hydrothermal condition or behavior against fire… At the same time, it is going to be design a facade solution that tries to take advantage of inside and outside conditions in order to achieve the desire inside comfort conditions. Furthermore, the module is going to integrate photovoltaic panels to achieve a total autonomy system, which does not need to be connected to the traditional electrical network.

1.: Introduction

Managing comfort conditions inside a building is one of the most important aims of the building sector. That is, generally, mean that it is necessary not only to contribute to heat during the winter but also to take away the extra hot along the summer; moreover, this must be done wasting as less energy as possible. The envelope and the air-conditioning installation are determinant factors to reach this objective.

1.1.: The Facade Envelope

Besides the importance that the façade has from the aesthetic point of view, the facade has the important role of separating the inside environmental conditions from the outside ones. The future facade will be more adaptable to the changing environmental conditions and it will encompass building service installation to make it possible. The facade is becoming a complex product, highly interacting as an integral part of the building, reacting on the environmental conditions and user needs [1]. The façade is seen as an active component of the building.

1.2.: The Air-conditioning System

Getting the comfort conditions inside the building without an air-conditioning system is impossible for most of the climate. Generally, the different systems use to thermally equip the residential buildings are installations with capacity either for heating or cooling. Moreover, these systems need a very complicated auxiliary installation which increases the cost of the system and makes the execution more complicated. Mechanical parts like pumps or compressors are also needed. The researchers believe that a thermoelectric system that can be installed in the facade envelope would solve most of the disadvantages of the traditional system.
The thermoelectric technology has already developed but its use has been limited to the military and aerospace fields, where high-tech technology is needed. Its principal uses are military submarines, satellites, coolers to transport specific medicines, organs… [2, 3]. In construction field, there are some recently application. The Universidad Pontificia de Comillas has designed an active wall that works as a heat pump. Using the Peltier effect through thermoelectric modules, included between translucent or transparent materials allow the transport of heat between the two environments at different temperatures [4, 5]. Also, Tsung-Chieh Cheng and al. [6] have developed a solar-driven thermoelectric cooling module with a waste heat regeneration unit designed for green building applications.

2.: Material Execution of the Prototype

2.1.: Peltier Effect

The Peltier effect, one of three reversible thermoelectric phenomena, is produced when an electric current passes through two different types of semiconductor metals (n-type and p-type) connected each one with two unions (Peltier unions) with the same temperature. The current starts a heat transfer from one union to the other: while one union is getting cooler the other starts to be hot. If the direction of the current is changed the heat transference direction changes, too. $\mathbf{Q = K_{ab} \cdot I \cdot t. (K_{ab})}$.
The thermoelectric air-conditioning offers the possibility of heating and cooling with the same installation with a high reliability and a low cost of maintenance. It is possible to get an extraordinary regulation of the temperatures with a correct control system. Above all, the system does not emit CO_2 and it can be a totally autonomy installation if it is connected with solar cells. Besides, pipes, boilers or refrigeration towers…are not needed. However, there are some disadvantages such as the high price if it is compared with other solutions and that in spite of its high reliability the system is also composed of other elements that can decrease the global behavior.

2.2.: Description Thermoelectric Prototype

2.2.1.: Engineering development

The result of all these ideas was the construction of a prefabricated module, consisting in a simplified inhabited housing unit with a Thermoelectric Conditioning System (TCS) installation that provides service to this module. This project has allowed quantifying the answer capacity of the new system and evaluating the

energetic and economic costs.
The TCS is designed to reach a high comfort level for people living in the local. The TCS is compact, and it is only necessary a reserve space in the building façade to be set as an prefabricated element. The prototype is located in School of Architecture of the Universidad de Navarra in Pamplona, a city with a climate between that of the Mediterranean and the Atlantic [1].
The Peltier cell works as a heat transfer. It is used in an air-air system, which combined cavities and fans to make the system works. That is the reason why the ventilation and the air moving are essential. The Peltier cell absorbes the heat of the external ventilated cavity in winter and gives it to the internal cavity. During the summer the process is the opposite.
The construction of the prototype also has benefited from the data obtained from the modeling of the HVAC system using TRNSYS, comparing with other 'conventional' HVAC systems, located in a living space studied in different climatic zones. As a result of these previous studies the number of thermoelectric elements and the power of the system were over measured in order to increase the reach of the research. It is possible to choose the maxim power and to limit it, if necessary.
The air-conditioning equipment is made up of 84 Peltier cells RC12-8, which are placed in groups of two thermoelectric cells, 70 W each, connected in series. This makes, a total of 42 thermoelectric systems that are added to the base sheet[2].
The connection of the thermoelectric equipment is made in groups of two which are connected in series. That is to say, four Peltier cells are connected in series to form a group. All these groups are connected in parallel. Altogether there are 21 groups that need a voltage of 50 V DC.
The series connection is made with a thermal protector with automatic rearmation which allows disconnection of the equipment from the electrical power supply, which in case of a serious failure of the system would protect the Peltier cells and the heat-pipe.
The construction of a prototype with these characteristics has implied considerable difficulties in the design and execution of solutions which are easily resolved in other 'traditional' systems, but which in this case have to be expertly resolved, such as the converter transistor resolution, the power supply unit regulation or reducing the weight of the whole. We have found several related references in: [7].
The installation that works at the same time as a façade has different layers, following the sketch below.

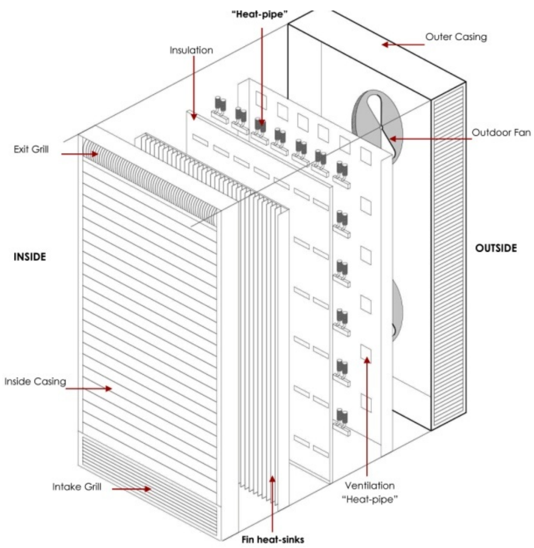


Figure 1. Axonometric view of the thermoelectric system Although this aspect is not complicated in technical terms, it is one of the major design challenges for the architectural team due to the special layouts the components must have in order to work correctly.

2.2.2.: Heat dissipation

Peltier systems generate a large amount of heat that, unless it was effectively evacuated, it would damage the installation. This means that heat dissipation elements must be used. The external dissipators use **heat pipe** technology, which means an increase in the heat dissipative capacity by reducing the area occupied for the whole [8]. The internal dissipators are **heat sinks**. These two dissipation systems have two objectives: to increase the transfer area of the Peltier cell so that it does not over-heat and to achieve greater transfer of heat to both the external and internal air. To improve this latter goal, each of the thermoelectric climatizer dissipation systems has a ventilator.

2.2.3.: Control system

The **power supplies** and the **control system** of the installation are the most important achievements of the project.
The control system allows for regulating the working of the system by maintaining the temperature conditions within the desired range.
The control is a simple PLC, which manages the feed of the thermoelectric cells and the over-all protection of the equipment. The PLC can extend its modules with output and input data, and can also manage the conditions of functioning, delays, temporizers, alarms, etc. The advantage that the incorporation of this type of controls offers is that it allows for great leeway to change the parameters, with hardly any limits to maneuvers or study.

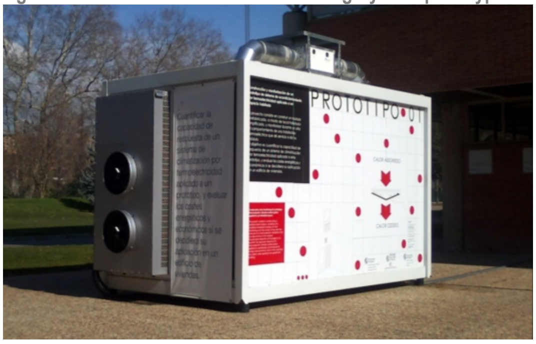
3.: Results

3.1.: National Patent

[1] See e.g. information from the Spanish State Agency of Meteorology <www.aemet.es
[2] Marlow Industries, Inc. For the cells used when hot side is 50˚C, the electrical supply is 78 W per cell

The thermoelectric system that it has been already described is an important innovation in the field of construction; in fact, researchers have achieved the **national (Spanish) patent for a “prefabricated and decentralized facade module for the climate control of inhabited spaces”** for the work already described.

Figure 2. The Thermoelectric Conditioning System prototype



3.2.: Thermal and Electrical Behavior

After the study of the data obtained from over 1000 hours of complete tests, the behavior of the prototype has been found to fulfill the objectives proposed, as it reaches the working range foreseen in the software simulations.

Regarding the thermal behavior of the prototype, the impulsion of air is produced in the upper part of the prototype, with an air current which reaches the full space to be acclimatized. At the very bottom, the air returns, which causes a flow that covers the full space, until the set temperature is reached.

Table 1: Thermal behavior of the system on different situations.

	Set Point	**Control**	**Mode**	**ΔT Int-Ext (˚C)**	**Electrical Consumption (kWh)**
Behavior on a hot day	19	PID	COLD	5	2.5
Behavior on a cold day	22	PID	AUTO	15.73	2.75

Regarding the electric behavior, we must indicate that the electricity supply is 230 V single-phase with a 30 A consumption in the maximum operational mode, but obviously the electrical consumption is as varied as the tests carried out.

For economic reasons, the walling materials have low thermal inertia and scarcely any insulation. This fact has a direct effect on the thermoelectric climatization system, making it less effective than if the conditions of the building were those of a conventional dwelling. We must also underline that the prefabricated space is a freestanding element, so the area of wall surface exposed to the elements is high, as, therefore, are the undesirable temperature losses and gains.

Thus the construction of this prototype with materials with low thermal inertia means that, in order to achieve the comfort temperature, the electricity consumption is high. Nevertheless, although this may be seen as a negative factor, it is not so, as the prototype behavior has been very similar to that obtained in the computer simulations, which also indicate that if the enclosures/envelope corresponded to a normal dwelling, the electricity consumption would be far lower.

4.: What is next?

The researches team would like to continue investigating in order to improve the solution. To improve the system is necessary to study the system as a facade and afterwards testing the improved system in a real situation.

4.1.: Study of the system as a facade envelope

Until now, the project has been focused on the system as an installation, leaving in a second place its development as a facade. Nevertheless, it is important to understand that when the TCS is turned off the module has to give answer to all the facade requirements.

Firstly, to study the system as a facade envelope is necessary to get better some points of the system:

- Weight of all the system is still high if a prefabricated solution between the slabs is being looked for.
- External fans have to be more and litter than the current ones to reduce the noise level.
- The system needs to get the electricity from a photovoltaic panels to make the system efficient.
- Improve the aesthetic component; because it is the image of the building.

Secondly, it is necessary to study the behavior of the system as a facade envelope. In order to get this aim the research team is going to base its study on previous Universidad de Navarra researches about the technological innovation in facade envelope system. [9, 10, 11]. It is important to take into account different conditions:

- Noise level.
- Thermal transmittance.
- Hydrothermal condition.
- Air quality inside the cavities.
- The way of making the cavities ventilated.
- The use of thermal lag, heat accumulation in the inside components.
- Possibility of communication between the two cavities in order to take advantage of their conditions to reach the internal comfort conditions.

The different necessities and ideas for the facade are:

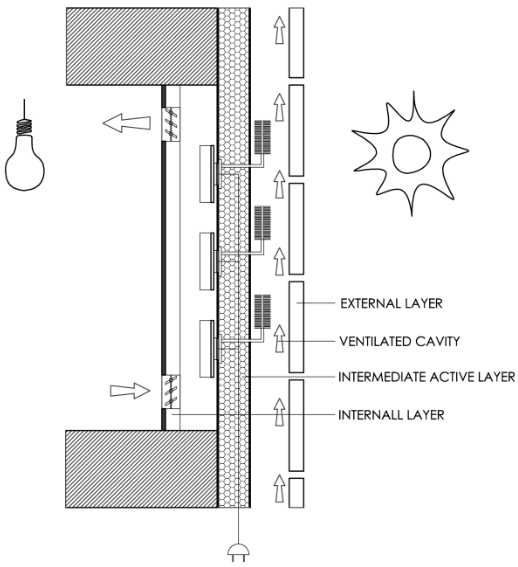


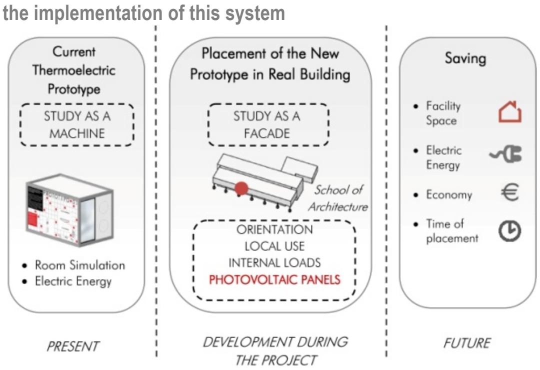
Figure 3. Active facade scheme

All of these conditions are important to improve not only the energetic efficiency of the system but also the thermal well-being of the building users.

4.2.: Fabrication and testing of the new facade module with Peltier cells

The investigation may continue being as much experimental as it could. That is the reason why, in spite of the fact the most real conditions have tried to be simulated to test the previous system, the improve facade module ought to be tested in real conditions. Instead to be tested in an inhabitable space, the research team would like to install it in a real building. Our purpose is to use a room of a building of the University of Navarra, in Pamplona.

Fig 4. The figure shows the current situation of the project, the future idea to test the improved prototype and the savings that it would be obtained with the implementation of this system



5.: Conclusion

The aim of the project is to achieve the characterization of an advanced active facade system with Peltier HVAC, which allows in the future its industrialized manufacture and its incorporation into new buildings or its use for energy rehabilitation in existing buildings.

The final goals of applied research of this project can be summarized as follows:

- Integrate an autonomous HVAC system, based on the principles of thermoelectricity and powered by photovoltaic energy (renewable and free) in a modular construction element of facade system, lowering the cost of existing solutions to complex spaces like submarines, and adapting them to less strict requirements like office or residential buildings.
- Evaluate the performance of this technology in its application to architecture and analyze the positive and negative aspects of its implementation. Quantify the responsiveness and performance of the system in its specific application to inhabited spaces.
- Ensure thermal comfort of the occupants and compliance with the requirements set by the Spanish law (CTE), considering its dual role as an active constructive element (facility) and a passive building element (facade system).
- Reach a standardized constructive solution which can be applied in the energy rehabilitation of existing buildings.
- Estimate the impact in terms of construction cost-benefit and amortization that could have the application of the Peltier cell technology in conventional architecture. Assess the minimum conditions of maintenance that this solution has in the proposed cases.

- Considering the Life Cycle Analysis of architectural elements, study to what extent the durability of this system also contributes to reduce the environmental impact of HVAC facilities, compared to the one that is currently produced by conventional systems.
- Long term, reduce CO2 emissions associated with buildings construction.

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