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# Thermal and energy performance assessment of a thermoelectric heat pump integrated in an adiabatic box

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## HIGHLIGHTS

- Relation between the heat transferred by the Peltier cell to a space.
- Proving the ability of heating and cooling in a device without refrigerants.
- Preliminar study to improve the application of thermoelectricity in buildings.
- Verification of the COP values before a real scale prototype.

## ARTICLE INFO

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## ABSTRACT

The present study is focused on the analysis of the performance of a Peltier cell integrated in an adiabatic box in order to work as a heating and cooling unit. The box is a reproduction in small scale of the room of a building where a specific comfort temperature must be accomplished. This experimental setup is part of a continuous work which has developed several real scale prototypes.

Thermoelectric modules are becoming a usual solution in different fields. Its use in architecture and building services is still an innovative application, far from the market but increasingly researched in the last decade. The ability of heating and cooling in a unique device, the low maintenance requirements, noiseless properties and the possibility to be supplied directly by photovoltaic panels are some of the most remarkable advantages to implement this technology in architecture.

The application of thermoelectricity in buildings is not focused on the thermoelectric performance itself, but in the achievement of a comfort indoor temperature. Thus, one of the main key issues in this adiabatic box is the achievement of the perfect temperature control and the relation between the heat released or absorbed by the Peltier, and the room temperature.

The main goal of this article is to analyze and quantify this relationship to be able to optimize the performance of the Peltier cell in relation to the conditioned space and apply this knowledge in future architectonical prototypes, since no equivalent developments have been found in the integration in buildings and not only from the development of thermoelectric equipment.

## 1. Introduction

The main goal of this study is to control and analyze the performance of a thermoelectric heat pump under building conditions. All the key parameters are going to be measured and calculated in order to prove the feasibility of the thermoelectricity as heating and cooling unit.

The use of thermoelectric devices in a wide range of fields such as electronics [1], military [2], automotive [3] or building services [4], is an innovative solution that requires further research to become competitive in more functions [5]. The researches about its application in buildings are focused on the improvement of its low efficiency comparing with conventional solutions in the current market [6]. Several studies have analyzed the energy behavior of Peltier cells under different conditions: temperature, current intensity, voltage, etc. Most of these studies are focused on the Coefficient of Performance (COP) and its optimization [7].

The use of Thermoelectric Modules (TEMs) in buildings has been studied in different scales and environments, but still is far from achieving a commercial solution. Some of the first building applications

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**Nomenclature**

| | |
|---|---|
| A | current in amperes (A) |
| COP | Coefficient of Performance |
| DC | Direct Current |
| $I$ | current intensity in Amperes (A) |
| $I_{max}$ | maximum current intensity in supplier's datasheet (A) |
| K | temperature in Kelvin (K) |
| $K_m$ | thermal conductance of thermoelectric generation module ($W K^{-1}$) |
| MDF | Medium Density Fibreboard |
| N | number of thermocouples |
| $Q_c$ | power absorbed in cooling in watts (W) |
| $Q_e$ | electrical power consumed by the thermoelectric module in watts (W) |
| $Q_h$ | power generated in heating in watts (W) |
| $R_{heatsink}$ | thermal resistance of the heatsink (K/W) |
| $R_m$ | electrical resistance of thermoelectric module (Ω) |
| $S_m$ | Seebeck coefficient of thermoelectric module ($V K^{-1}$) |
| TCHU | Thermoelectric Cooling and Heating Unit |
| TEC | Thermoelectric Controller |
| TEM | Thermoelectric Module |
| $T_{amb}$ | ambient temperature of the conditioned room (°C) |
| $T_{box}$ | ambient temperature inside the box (°C) |
| $T_{in}$ | inner face temperature (°C) |
| $T_{out}$ | outer face temperature (°C) |
| $V$ | voltage in volts (V) |
| $V_{max}$ | maximum voltage in supplier's datasheet (V) |
| W | power in watts (W) |
| XPS | extruded Polystyrene |
| $Z$ | figure of merit ($K^{-1}$) |
| $\Delta T_{max}$ | maximum temperature difference between faces in supplier's datasheet (K) |

involved the development of active windows prototypes with TEM integration [8,9], which also were considered as active insulators to reduce the heat losses through the windows [10]. Those involving the air heating and cooling systems with TEMs were initially proposed by Cosnier et al. [11] and by Gillot et al. [12]. Last decade, the number of studies about thermoelectricity application in buildings has increased considerably, and in general, in can be considered that TEM integration in buildings can be implemented in three different solutions: integrated in windows, in walls and in roofs or ceilings. The case of the walls is the closest solution to the study presented in this paper.

In this context, there are several studies that have analyzed this integration at different scales. Luo et al. [13] analyze the application of TEMs in a Building Integrated Photovoltaic Thermoelectric (BIPVTE) wall, where the potential for energy saving of the system is assessed. This system was previously studied and developed in [14,15] by Liu et al. demonstrating that the wall can not only eliminate conventional building envelop thermal loads but also provide a certain cooling capacity for space cooling at the same time. They addressed the importance of a power control system and the need of improving the heat dissipation system of the TEMs. In a similar way, Irshad et al. built a real scale prototype to heat and cool a testing room in Malaysia [16] and later, they analyzed the same system powered by a PV system, in this case not integrated in the same façade design [17]. They concluded that the heat sinks and the fans played an important role in maintaining, as lower as possible, the temperature difference between the hot and the cold side of TEMs. Zhang et al. [18], who analyzed the performance of thermoelectric modules in electronics, support the same conclusion by saying that the role of heat sinks was decisive since the performance of the Peltier module depends on the type of heat sink used.

In a different scale, there are numerous interests around the thermoelectric field. From those studying the thermoelectric materials development it must be highlighted the last advances on highly efficient thermoelectric compositions for power generation applications including half-Heuslers [19], lead telluride [20,21] and germanium telluride [22]. And although they are not the main object of this article, they are included here as it is necessary to be attentive to the developments that these materials can provide for their application in buildings.

Regarding parameters affecting the thermoelectric performance, the studies have been focused on the importance to ensure the heat dissipation [23] and the affection of, the heat sinks design [24], heat exchangers design [25] and the geometric parameters of a TEM [26].

The research group that presents this article also has developed previous studies regarding the integration of TEMs in a building façade. The first study consists on the development of a Thermoelectric Cooling and Heating Unit (TCHU) for it used in residential buildings [4,27]. The second one is an improvement of this TCHU completely integrated in a ventilated active façade [28]. Both, the external studies and the group's experience have demonstrated that achieving an accurate control becomes a great challenge due to the fact that the thermoelectricity efficiency depends on several parameters [7] such as the geometric design [29–32], the effectiveness of the dissipation elements [25,33–35] and the current supplied [36]. Then, the electronic control system is a complex part of the work.

From these previous experiences and before facing the construction of a third prototype [37], the research group decided to build a laboratory scale adiabatic box in order to more deeply analyze each parameter that affect the thermoelectricity control with an architectural purpose. A similar study was developed by Wang et al. [38], where a box of 1 $m^3$ volume was built and a simulation of its application in a residential house was carried out. They have hold test only for heating demand and have not made an analysis of the relation between $T_{amb}$ and the $T_{in}$, as is presented in this article.

This article presents the study of the performance of a Peltier cell as a thermoelectric heat pump integrated in an adiabatic box. This adiabatic box would represent a room and it is tested under different constant outdoor ambient temperatures ($T_{amb}$) and different target indoor temperatures ($T_{box}$). Even though the building sector is not immediately related with the performance of thermoelectric elements itself, indirectly it is related with its application as cooling and heating unit that fulfil the indoor comfort, hence the main factor that must be controlled is the temperature.

The analysis of the experiments is focused on two main objectives. On the one hand, the relation between the temperature of the inner face of the TEM ($T_{in}$) and the indoor box temperature ($T_{box}$). On the other, the limitations of the system and optimization options towards an application in a real scale thermoelectric heating and cooling module integrated in a façade.

## 2. Experimental set-up

An adiabatic box with an inner space of 40 × 35 × 40 cm has been designed. This space simulates a room in a real scale prototype. The goal of the article is to achieve to equal the target temperature ($T_{in}$) and the inside temperature of the box ($T_{box}$) with a constant outdoor ambient temperature ($T_{amb}$). The tests are hold in a conditioned room.

The adiabatic box has been designed with one removable face to easy the development of the tests. The immovable faces of the box have a common insulation thickness of 10 cm of extruded polystyrene (XPS) and one 2 mm Medium Density Fibreboard (MDF) panel. The removable face has a similar configuration with 10 cm of XPS and two