Applied Energy 200 (2017) 303–314

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Thermoelectric cooling heating unit performance under real conditions

María Ibañez-Puy *, Javier Bermejo-Busto, César Martín-Gómez, Marina Vidaurre-Arbizu, José Antonio Sacristán-Fernández

Department of Building Construction, Services and Structures, Universidad de Navarra, Campus Universitario, 31009 Pamplona, Spain

HIGHLIGHTS

- Technical description of a second version of a thermoelectric cooling-heating unit.
- Performance testing of a thermoelectric cooling-heating unit under real conditions.
- Future improvements from a theoretical analysis.

ARTICLE INFO

Article history:
Received 19 January 2017
Received in revised form 24 April 2017
Accepted 3 May 2017

Keywords:
Thermoelectric cooling
Thermoelectric heating
Building application
Performance analysis
Air-conditioning

ABSTRACT

A Thermoelectric Cooling-Heating Unit (TCHU) is an innovative technology that uses the thermoelectric phenomena as a heating–cooling system for buildings. In TCHU, a direct current (DC) electrical current supplies the power to a Thermoelectric Equipment (TE) heat-pump system, which can transfer heat in one direction or another depending on the current flow. The unit is integrated in the building envelope.

At this stage of the study, a second prototype of TCHU has been developed using commercially available TE technologies. In this case, a vertical configuration of 16 TE modules is studied for their potential application as a heating and cooling system for residential buildings.

Different nocturnal tests have been developed to evaluate the performance of the new system under real conditions and to determine the coefficient of performance for these TE modules when operating under different voltage regimes. It has been studied not only the cooling mode but also the heating mode.

Based on the measured data, it has been demonstrated that the system can be successfully installed as a heating or cooling system in buildings.

Tests have confirmed the huge relevance of the temperature difference between the two sides of the cells, taking especial relevance in the cooling mode. It has also been demonstrated that for the cooling mode it is better to work with low voltage values.

Besides, some theoretical analyses have been developed in order to find out the most suitable configuration to obtain the best Coefficient of Performance (COP) of the unit in both cooling and heating.

1. Introduction

A Thermoelectric Cooling-Heating Unit (TCHU) is an innovative heating–cooling technology that uses the thermoelectric phenomena as a heating–cooling system for its application in buildings. The Peltier effect is produced when electric current flows through two different types of semiconductor metals. The current starts the heat transfer from one union to the other: while one union is getting cooler the other starts to heat up. If the direction of the current is changed, the heat transfer direction changes, too, hence Peltier cells can be used as heat pumps.

There are many studies that evaluate the behaviour and show the different applications of the Peltier cells and the materials that make them up [1–5]. Several classes of thermoelectric materials are being investigated for renewable power generation applications including IV-VI tellurides [6], half-Heuslers [7,8], and silicides [9], while for cooling applications Bi2Te3 based compositions are mostly considered.

Although the scientific principles of thermoelectricity are well-known, several studies have been performed to understand the heat transfer process in small and medium prototypes [10–13]. Particularly, the studies related to thermoelectricity have covered the areas of thermoelectric materials [14–16], manufacturing

* Corresponding author.
E-mail addresses: mibanez.3@alumni.unav.es (M. Ibañez-Puy), jbermejo.3@alumni.unav.es (J. Bermejo-Busto), cmargom@unav.es (C. Martín-Gómez), mvidaurre@unav.es (M. Vidaurre-Arbizu), jasacris@unav.es (J.A. Sacristán-Fernández).

http://dx.doi.org/10.1016/j.apenergy.2017.05.020

Nomenclature

COP	Coefficient of Performance
DC	direct current
I	current intensity in amperes (A)
I_{max}	maximum current intensity applied to the thermoelectric module
K_m	thermal conductance of thermoelectric generation module (WK^{-1})
PID	proportional integrative derivative
PV	photovoltaic panel
Q_c	power absorbed in cooling in watts (W)
Q_h	power generated in heating in watts (W)
R_m	electrical resistance of thermoelectric module (Ω)
S_m	seebeck coefficient of thermoelectric module (VK^{-1})
T_c	temperature of the cold face
T_h	temperature of the hot face
TCHU	Thermoelectric Cooling-Heating Unit
TE	Thermoelectric Equipment
V	voltage in volts (V)
V_{max}	maximum voltage applied to the thermoelectric module
W_e	electrical power consumed by the thermoelectric module
ΔT_{max}	maximum temperature difference between faces

techniques [17,18], costs analysis [19], the effects of geometry in the thermoelectric module [20,21], electricity consumption [22], and practical applications. In this last aspect, thermoelectricity has been mainly used to cool electronic devices [23–26] and as a refrigerator [27,28].

Lately, architects and engineers are looking for new strategies to use the principles of thermoelectricity in buildings. Some of the benefits of this technology are low maintenance, high precision and reliability, low levels of noise, the lack of auxiliary pipes and conducts, and also, easy installation and reduction of the installation volume. Furthermore, it can work off-the-grid if it is connected to photovoltaic panels and do not need working fluid, as opposed to conventional air-conditions or heating systems. However, these kind of application are still under investigation and some improvements are needed to increase their effectiveness to become competitive in the current market [29–31].

Regarding building applications, Cosnier et al. [32] developed a thermoelectric air-exchanger getting a cooling Coefficient of Performance (COP) between 4.5 and 0.3 with temperature differences between faces of 5 °C to 30 °C. They also achieved heating COP values between 4.5 and 0.7 with temperature differences between faces of 10–70 °C, concluding that the heating mode is always better than the cooling one because of the Joule effect. Furthermore, they analysed different current intensities (1–5 A) and gathered that the higher the intensity, the lower COP.

Gillot et al. [33] analysed under laboratory conditions an 8 pieces system with a current intensity of 4.8 A obtaining a 0.46 COP, realising that the higher the intensity, the lower the COP. Van Dessel and Foubert [34] proposed an active thermal insulation and tested a huge number of configurations (different cells, number of them, air gap thickness, etc.) obtaining very different results. Shen et al. [35] designed a Thermoelectric Equipment (TE) ceiling applying a 1.2 A intensity maintaining a cold face temperature of 20 °C achieving a cooling COP of 1.77.

He et al. [36] designed a system integrating a photovoltaic panel (PV) and a thermoelectric element (TE) to cold down a water tank. With 12 V and 2–3 A they reached a COP between 0.45 and 1.00 in cooling mode, concluding that the higher PV production, the lower COP. Cheng et al. [37] designed a PV + TE system with a water circuit for a small size prototype. With a current intensity of 0.7 A, they achieved a COP between 1.20 and −0.20. Xu et al. [38–40] design a windows that integrates a TE, PV and heat storage. By analysing different voltages (3, 5 and 7) and connection configurations between the devices. They obtained a heating COP between 1.06 and 2.37, and a cooling COP between 0.38 and 1.42. In both modes a lower voltage means a higher COP.

Liu et al. [41] analysed the COP in cooling mode with a fixed cold face temperature and various temperature differences, obtaining COP values between −0.5 and 2.0. Khire et al. [42] proposed several configurations of Peltier cells in an active building envelop for cooling, obtaining a maximum COP value of 1.58. Table 1 summaries the previous references.

Authors have been especially focused on developing a new thermoelectric heat and cooling unit integrated into the building envelope. The result has been the construction of a TCHU. It could be easily applied in both new and refurbishment projects as it has been conceived as a floor to floor system.

After - having been tested it [43], researchers have developed this second real scale TCHU prototype. This article presents the result of the second prototype after having been tested for one year in both heating and cooling modes under real conditions. Furthermore, a comparison with theoretical results has been developed to propose further developments in subsequent prototypes.

2. Thermoelectric behaviour

Thermoelectric behaviour has been widely discussed [44]. The thermoelectric effect is created when an electrical current goes through a semiconductor group of unions. Depending on the current direction, one side of the cell will absorb heat and release it into the other, and if the current direction changes, the effect is reversed. This effect is graphically explained in Fig. 1.

Formulae to calculate the heat absorbed and released by Peltier cells can be found in [23] as shown in Eqs. (1)–(5):

$$Q_h = S_m \cdot I \cdot T_h + \frac{1}{2} \cdot R_m \cdot I^2 - K_m(T_h - T_c) \tag{1}$$

$$Q_c = S_m \cdot I \cdot T_c - \frac{1}{2} \cdot R_m \cdot I^2 - K_m(T_h - T_c) \tag{2}$$

$$S_m = \frac{V_{max}}{T_{h0}} \tag{3}$$

$$R_m = \frac{(T_h - \Delta T_{max}) \cdot V_{max}}{T_{h0} \cdot I_{max}} \tag{4}$$

$$K_m = \frac{(T_h - \Delta T_{max}) \cdot V_{max} \cdot I_{max}}{2 \cdot T_{h0} \cdot I_{max}} \tag{5}$$

From an electrical point of view, the power generated by one thermoelectric cell can be calculated as shown in Eqs. (6)–(8):

$$W_e = I \cdot V \tag{6}$$

$$V = S_m(T_h - T_c) + R_m I \tag{7}$$

$$W_e = I \cdot V = I \cdot (S_m \cdot (T_h - T_c) + R_m I) = IS_m \cdot (T_h - T_c) + R_m I^2 \tag{8}$$

The Coefficient of Performance (COP) for both cooling and heating can be calculated with Eq. (9):