PROTOTYPE THERMOELECTRIC CLIMATE SYSTEM FOR ITS USE IN RESIDENTIAL BUILDINGS

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Abstract

The School of Architecture of the University of Navarra has begun a project which consists in constructing a prefabricated module, consisting of a simplified inhabited housing unit, and monitoring over the course of one year the behavior of a thermoelectric installation that provides service to this module.

The principal objective of the project is to quantify the response capacity of a thermoelectric climate control system applied to a prototype, and evaluate its energy and economic costs in the case that the system were applied in an apartment building.

The development of this project represents the application in the field of construction of a technology that already is in use in other areas, fundamentally the military and aerospace. Therefore, we do not seek to demonstrate the performance of Peltier cells per se, but rather to evaluate how they function when applied to the residential area, and to analyze both the positive and negative aspects of their use.

1 Introduction

In this regard, it must not be forgotten that Spanish regulations also require the evaluation of the maintenance needs of climate control equipment, and, in this regard, Peltier cells offer an important advantage: Despite the fact that the initial investment is greater than with a conventional method of climate control, the maintenance costs are nearly zero.

For these reasons, an objective of the project is to estimate the construction and amortization costs of the application of this technology in the residential area.

Finally, depending upon the results obtained, it will be proposed that the project be concretized in a patent for a "prefabricated and decentralized facade module for the climate control of inhabited spaces".

The Thermoelectric Conditioning System (TCS) is designed to reach a high confort level for people living in the local. Without mechanical parts like pumps or compressors, there is no necessity for maintenance, reducing the possibilities of failures. The only mechanical elements are the dissipation heat fans placed in the external face of the prototype. There are also some minifans to evacuate the heat from the power elements.

Currently, the prototype is being constructed in the School of Architecture of the Universidad de Navarra, according with the following plan:

[Fig. 1]

Nevertheless, the optimistic architectural results have made possible the start of the necessary patent steps. So the authors can not show in these moments the technological interior of the interior but a sketch with its dimensions and main characteristics.

[Fig. 2]

Characteristics:

- Power consumption: 30 A
- Heat transfer capacity: 3 kW
- Number of Peltier cells: 42 (Marlow Industries, Inc)

- Manufacturer: Berotza (Spain)

The TCS is compact, and it is only necessary a reserve space in the building façade for its collocation as an prefabricated element. The external view is for the metallic frame with the dissipation fans and the air grills. The TCS internal view (from the user's point of view) is an aluminium surface, with the filtration air system and the adjustable air exit grill.

The TCS dissipation elements (before the external fans) are made using heat-pipe technology, which result is an important rise in the heat dissipation capacity reducing the surface necessities. In this way the air-flow is lower and so the noise level. This technology determines the vertical TCS position design. Power units that serve the TCS are placed on the external dissipation heat side.

In the local interior there is an electric board with the protection elements necessaries for its running. These elements are connected to the monitoring and control system. The electric supply is 230 V single-phase with an 30 A estimated consume in the maximum operational mode.

2 Engineering Development

2.1 DESCRIPTION OF the system

The inhabited space modelled has a cubic shape with edges of 2 m length. The four walls, the floor and the ceiling are of concrete (thermal conductivity 1.8 W/m□K) with 20 mm of thickness. In one of the walls there are 4 Peltier cells model ET-241-14-15-RS with internal and external heat sinks of 0.25 m^2 of equivalent heat transfer surface area. The parameters of the Peltier cells are: electric resistance, $R_e = 3.81\ \Omega$; thermal resistance, $R_t = 1.31$ K/W; Seebeck coefficient, $\alpha = 0.09$ V/K.

[Fig. 3]

2.2 MATHEMATICAL MODEL

The natural convection of the air inside the described enclosure can be studied solving the governing differential equations restricted to the boundary conditions inside the modelled flow domain.

2.2.1 Governing Equations

The *Reynolds Average* approach of the *Navier-Stokes* (*RANS*) equations, (1) and (2), and the Energy equation (3) is used to include turbulence effects in the mean flow variables. The buoyancy term has been included in the right side of equation (2) to take into account the movement provoked by density variations of the air. The air is modelled as ideal gas and its properties are temperature dependent.

$$\frac{\partial}{\partial x_i}(\rho \cdot U_i) = 0 \tag{1}$$

$$\frac{\partial}{\partial x_j}\left(\rho \cdot U_i \cdot U_j\right) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\mu + \mu_T)\cdot\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) - \frac{2}{3}\cdot\rho\cdot k\cdot\delta_{ij}\right] - g_i\cdot(\rho - \rho_0) \tag{2}$$

$$\frac{\partial}{\partial x_i}\left(\rho \cdot U_i \cdot c_p \cdot T\right) = \frac{\partial}{\partial x_i}\left[(\lambda + \lambda_T)\cdot\frac{\partial T}{\partial x_i}\right] \tag{3}$$

Turbulence is modelled using the *Standard k-ε* turbulence model which introduces two additional equations, one for the turbulent kinetic energy and other one for its dissipation rate. The *standard wall functions* approach has been adopted to deal with turbulence near the walls. The turbulent eddy and thermal diffusivity are calculated solving eqs. (4), with a constant value of *C*_ = 100, and (5), with a constant value of $Pr_T = 0.85$, respectively:

$$\mu_T = \mu \cdot \left[1 + \sqrt{\frac{\rho \cdot C_v}{\mu}} \cdot \frac{k}{\sqrt{\varepsilon}}\right]^2 \tag{4}$$

$$\lambda_T = \frac{c_p \cdot \mu_T}{Pr_T} \tag{5}$$

The radiation heat exchange is considered by means of the *Discrete Ordinates* (DO) model which is solved once every ten ordinary iterations. It has been assumed that the air does not participate in the radiation and that the different surfaces in the domain are gray and diffuse.

2.2.2 Flow Domain

The flow domain of the model corresponds to the air inside the room. A high quality hexahedral mesh has been used in the discretization of the flow domain. The number of cells is of the order of 500,000. The resolution of the mesh is higher in the near wall region so as to capture the larger magnitude gradients that take place there.

2.2.3 Boundary Conditions

The surfaces of the walls of the room, including floor and ceiling, are modelled as solid walls with one-dimensional heat conduction. In the outer side of these external walls convective boundary conditions are considered with an ambient temperature of 15 ºC and a heat transfer coefficient of 5 $W/m^2 \cdot K$. In the inner side of the walls the emissivity has been fixed to a value of 0.9.

In conjunction with these thermal boundary conditions, a non-slip condition is ascribed to fluid velocity at all the solid walls, and the shear stress is calculated considering smooth surfaces.

In the surfaces representing the internal heat sinks of the Peltier cells the equations that represent their mathematical model have been implemented in order to calculate the heat transferred by them to the air inside the room. These equations, (6)-(8), relate the power consumption of the cell, P, with the heat dissipated to the hot environment, q_{hot}, and the heat extracted from the cold reservoir, q_{cold}.

$$P = \alpha \cdot I \cdot (T_{hot} - T_{cold}) + I^2 \cdot R_e \tag{6}$$

$$q_{hot} = \alpha \cdot I \cdot T_{hot} + \frac{1}{2} \cdot I^2 \cdot R_e - \frac{(T_{hot} - T_{cold})}{R_t} \tag{7}$$

$$q_{cold} = \alpha \cdot I \cdot T_{cold} - \frac{1}{2} \cdot I^2 \cdot R_e - \frac{(T_{hot} - T_{cold})}{R_t} \tag{8}$$

The resolution of the former equations is coupled to the equations describing the air movement and the heat transfer inside the enclosure.

2.2.4 Discretization and Resolution

The *Finite Volume Method* (*FVM*) is applied to discretize the differential equations of the mathematical model described above, using a segregated implicit solver to solve the generated algebraic equation system. Therefore, equations are linearised and then sequentially solved using the Gauss-Seidel algorithm accelerated by an Algebraic Multigrid method [17]. The pressure-velocity coupling is achieved through the use of the *SIMPLE* algorithm [18]. Diffusive terms of the equations are discretized using a second-order centred scheme, and the convective terms are discretized using a second-order upwind scheme [16]. A body force weighted scheme [19] is chosen in the discretization of pressure to deal with this buoyancy-driven flow. All this numerical procedure has been implemented in the unstructured *CFD* code Fluent V.6.3 [20].

2.2.5 Convergence Criteria

Three main convergence criteria have been applied to determine when the numerical procedure described in the previous paragraph has converged to a solution. The first criterion consists of reaching perdurable values for the temperatures in the surfaces representing the Peltier cells, meaning that a converged steady state has been reached. The second criterion is the balance between the energy dissipated by the Peltier cells and the energy losses through the walls of the space. The final criterion is to check that the values for the scaled residuals of the equations are below certain magnitudes: 10^{-3} for the mass, momentum and turbulent equations and 10^{-6} for the energy equation.

2.3 RESULTS

Heat dissipated by each Peltier cell to the room: 68 W.

Power consumption by each Peltier cell: 46 W.

[Fig. 4]

[Fig. 5]

[Fig. 6]

[Fig. 7]

[Fig. 8]

3 Simulation model of prefabricated module

The description of this simulation will be detailed in the *XXXVII - IAHS WORLD CONGRESS ON HOUSING SCIENCE: DESIGN, TECHNOLOGY, REFURBISHMENT AND MANAGEMENT OF BUILDINGS 2010.*

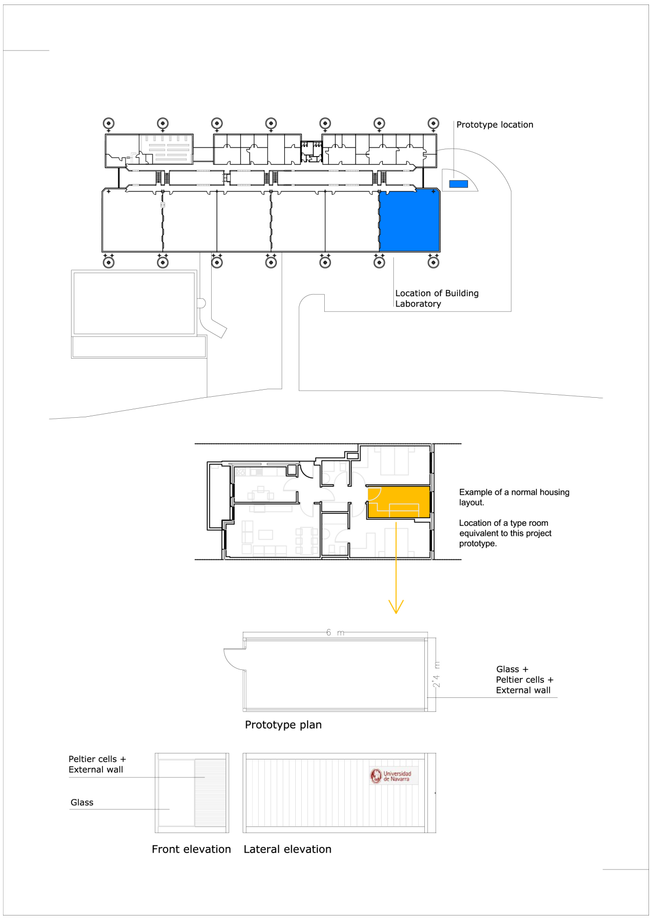

Figure 1: Prototype building considerations.

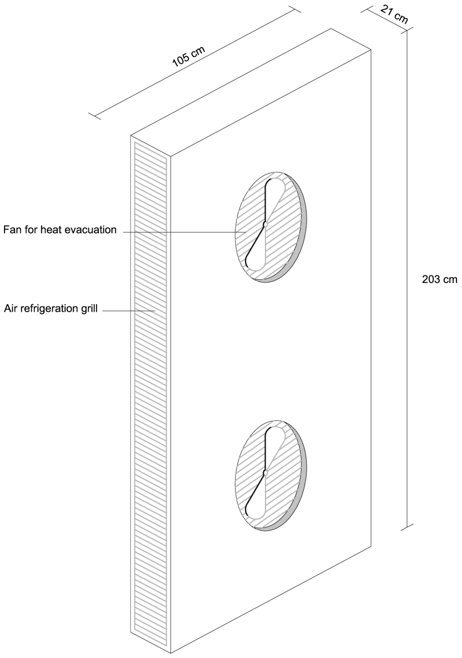

Figure 2: Prototype external view and dimensions.

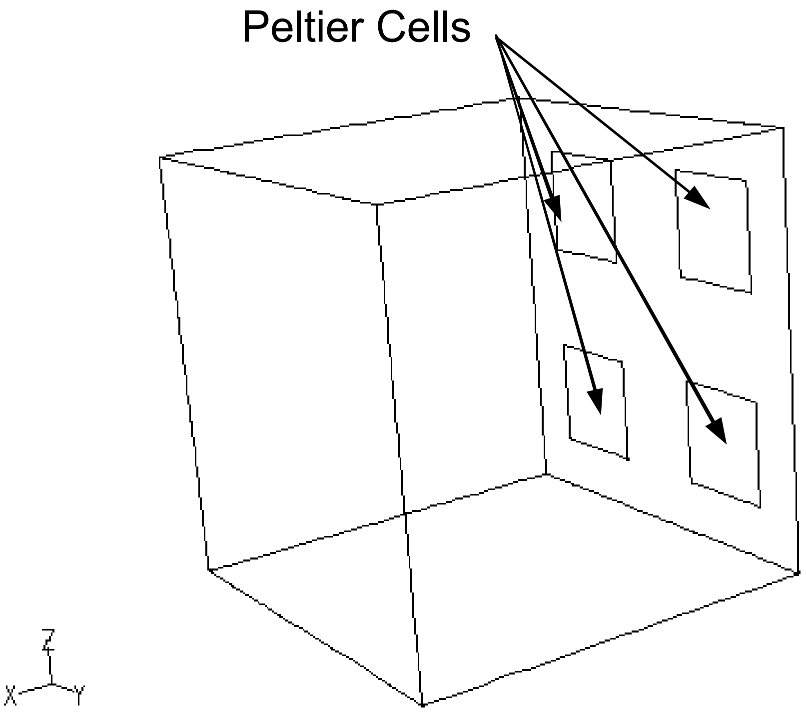

Figure 3. Cubic inhabited space with 4 Peltier cells in one side wall.

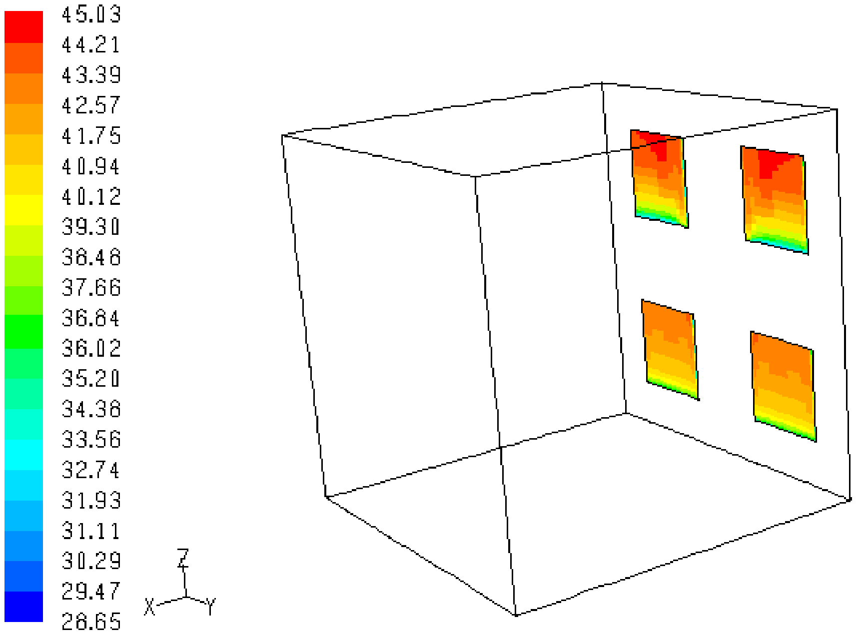

Figure 4. Temperature contours on the surface of the Peltier cells.

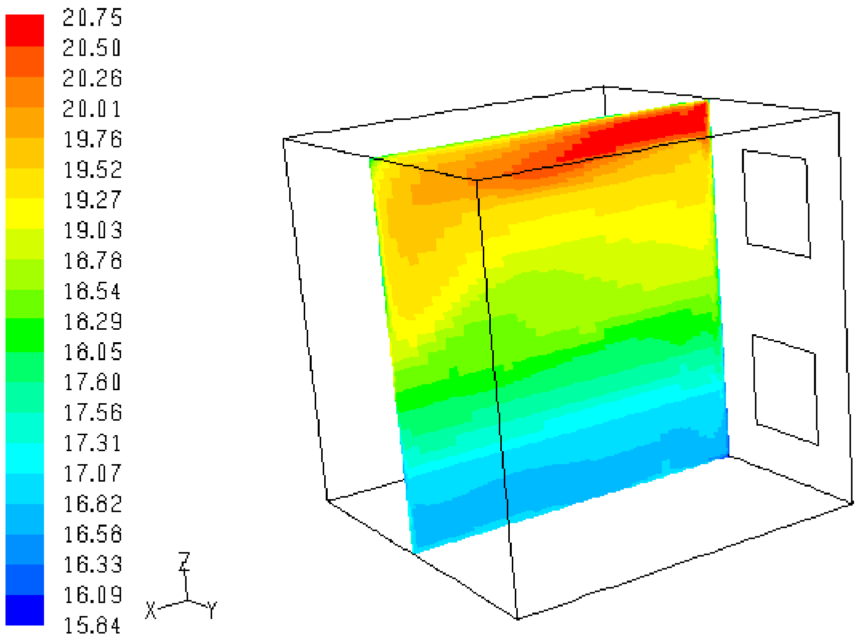

Figure 5. Air temperature contours in a central plane normal to the wall with the Peltier cells.

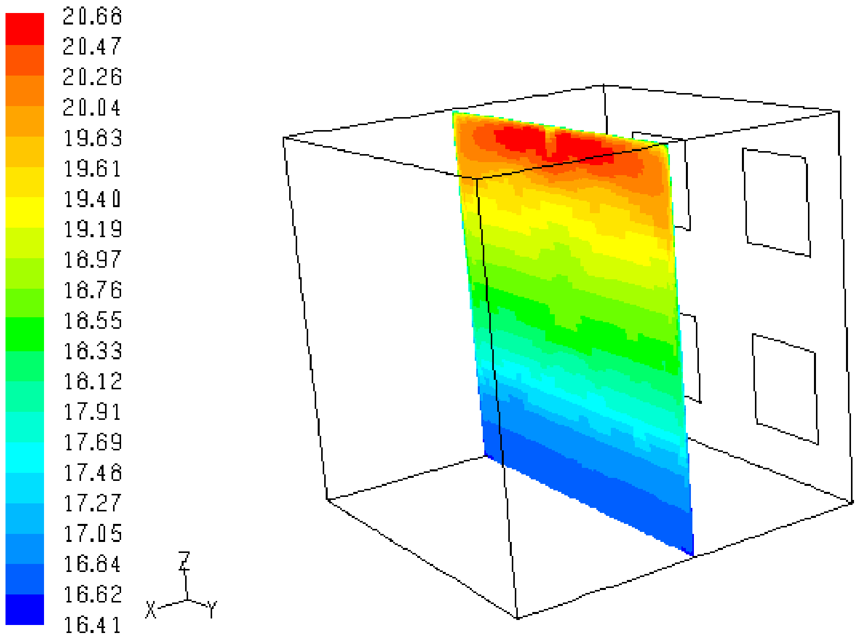

Figure 6. Air temperature contours in a central plane parallel to the wall with the Peltier cells.

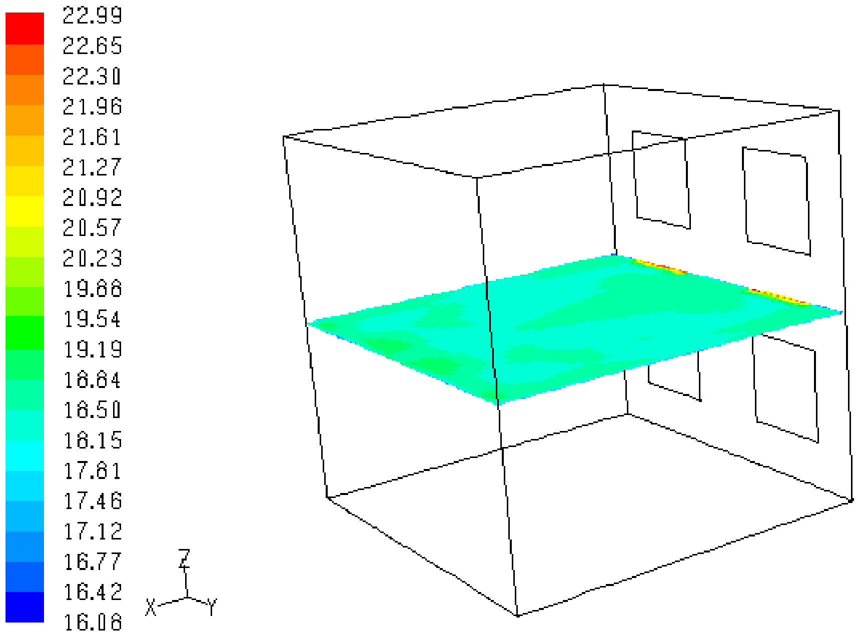

Figure 7. Air temperature contours in a horizontal central plane normal to the wall with the Peltier cells.

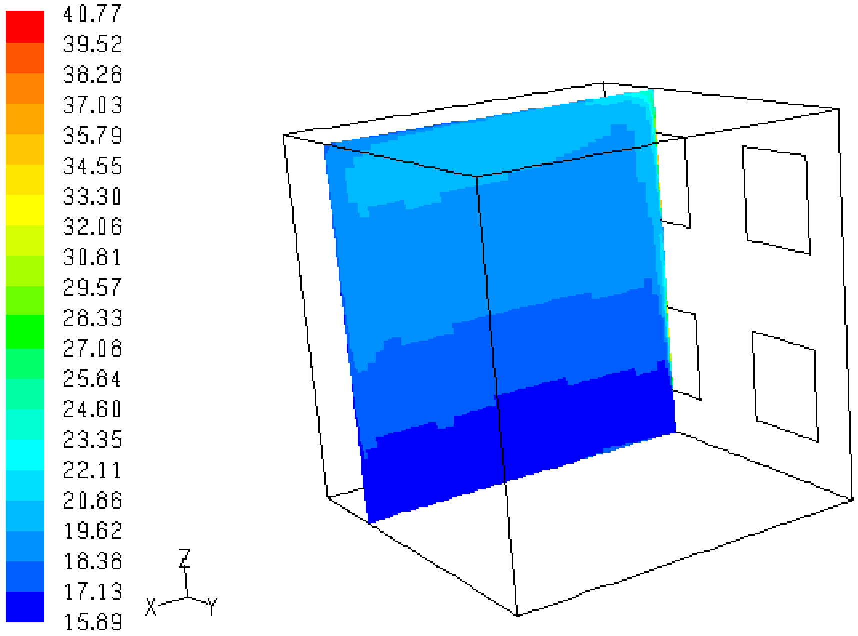

Figure 8. Air temperature contours in a plane cutting two of the Peltier cells.