Experimental analysis of the thermal comfort provided by an electrical heater and a heat pump

J R García-Cascales, F Illán-Gómez, F J S Velasco, F Vera-García, A Dengra Vera and F García

1Thermal and Fluids Engineering Department, Technical University of Cartagena, Dr Fleming, s/n, 30202 Cartagena, Murcia, Spain
2Industrias Royal Termic SL (ROINTE), Polígono Industrial Vicente Antolinos, Calle E, P 43, 30140 Santomera, Murcia, Spain

E-mail: jr.garcia@upct.es

Abstract. After considering heating sector, one realises that there is no clear and consensual way to quantify or qualify the thermal comfort of the different technologies available to satisfy the heating demand of a home. This contribution tries to call attention to this by means of an experimental study of the thermal comfort provided by two very different technologies, an electrical heater and a heat pump. To do so, a test matrix is developed by considering [2]. Some experiments are carried out in a climate chamber constructed following [1]. The variables registered are used to determine the comfort variables defined in [3] for each technology. After both technologies are compared and some conclusions are drawn.

1. Introduction
The Technical University of Cartagena jointly with ROINTE, a Spanish leading electrical heaters manufacturer, has realised that there is no clear way to quantify or qualify the thermal comfort provided by the different technologies available in the market. According to the present authors, there is no consensus between manufacturers regarding the adoption and implementation of a ratio or parameter which, from the point of view of the thermal comfort, let the consumer identify and compare the way each heating technology behaves. Bearing this in mind, to call attention to this fact, an experimental analysis is carried out to compare the thermal comfort provided by an electrical heater and a heat pump. The paper is structured as follows, first the tests considered to characterise these systems are proposed. This is done by considering [2] standard. The installation and the equipment used to do this analysis is briefly described and later a comparison is carried out on the bases of the comfort parameters defined in [3]. Finally, some conclusions are drawn.

2. Test matrix definition
The experimental tests are performed in a climate chamber constructed following [1]. The chamber is divided into two compartments, one corresponds to the room where the heating system is tested and the other simulates an outdoor environment whose conditions are controlled following the specifications of each test. The tests performed are the eleven tests defined in Table 1. As the reader may see, three different weathers are considered, cold, mild and warm weather. Each test is defined by the outdoor temperature and the percentage of the heat load at which the test is going to be performed.

The systems studied are an electrical ROINTE thermal oil heater with a nominal power of 1000 W and a small high efficiency heat pump whose nominal heating capacity may varies, according to the
manufacturer information, between 700 and 3600 W, uses R32 as refrigerant, is A++, and has a SCOP of 4.6. Fan speed was automatically selected by the system. The nature of the construction of the climate chamber is such that the external load is formed by two contributions, that of an air stream coming into the test chamber at controlled outdoor conditions ($T_{\text{out}}$ in Table 1) and the heat load through the wall that separates the two rooms which has a glass window also defined according to the previously mentioned standard.

**Table 1.** Tests proposed according [2].

| Cold weather | Mild weather | Warm weather |
|--------------|--------------|--------------|
| $T_{\text{outdoor}}$ | Load (%) | $T_{\text{outdoor}}$ | Load (%) | $T_{\text{outdoor}}$ | Load (%) |
| -7 °C | 61 % | -7 °C | 88 % | - | - |
| 2 °C | 37 % | 2 °C | 54 % | 2 °C | 100 % |
| 7 °C | 24 % | 7 °C | 35 % | 7 °C | 64 % |
| 12 °C | 11 % | 12 °C | 15 % | 12 °C | 29 % |

To identify the flow rate of air corresponding to distinct percentage of load in each test, other eleven tests must be carried out. These are done by using the 1000 W electrical heater and following the procedure described in what follows: The chamber with the outdoor conditions is taken to the temperature required by the test, after the heater is switched on with the percentage of load desired and now the flow rate of outdoor air necessary to keep the ambient temperature of the test chamber is determined. After this, the test matrix with the necessary flows is constructed (Table 2).

**Table 2.** Tests performed for each technology.

| Test | $T_{\text{outdoor}}$ (°C) | Load (%) | Outdoor flow rate (m$^3$/h) |
|------|-----------------|----------|-----------------|
| 1    | 12              | 11       | 8               |
| 2    | 12              | 15       | 25              |
| 3    | 12              | 29       | 55              |
| 4    | 7               | 24       | 10              |
| 5    | 7               | 35       | 25              |
| 6    | 7               | 64       | 57              |
| 7    | 2               | 37       | 20.5            |
| 8    | 2               | 54       | 35.5            |
| 9    | 2               | 100      | 65              |
| 10   | -7              | 61       | 10              |
| 11   | -7              | 88       | 32              |

The tests are performed so steady state is reached when at least 3 hours of stable measurements are registered by the data acquisition system.

### 3. Results

The variables registered are those considered in [1] standard plus others which are necessary to determine the comfort parameters defined in [3]. So, several sensors were installed to measure additional wall temperatures, floor temperature, ceiling temperature and the temperature and air velocity at five different heights in the middle of the occupied zone. The comfort parameters calculated in this work are defined based on the concepts of Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) so that the local thermal discomfort depends on humidity, metabolic activity, wall temperature, air speed, and heat transfer through variables such as operative temperature ($T_{op}$), radiant temperature, and so on. The comfort parameters considered are...
- Draft rate (DR).
- Vertical temperature difference (PD1).
- Floor surface temperature (PD2).
- Radiant temperature asymmetry (PD3).

Once these variables are calculated, the thermal environment category is evaluated by considering the value of PPD, PMV, DR and the different percent of dissatisfied associated to vertical temperature difference, floor surface temperature, and radiant temperature asymmetry [3]. The standard assigns a letter A, B, and C (best to worst categories respectively). In the results shown below, the numbers 1, 2, and 3 are used respectively for these categories. Number 4 means out of category. Table 3 shows the average value obtained for all comfort variables. A decimal value of the category means that during the period of time considered category has varied between to different thermal categories. Between C and out of category in most cases for the heat pump.

| Test | $T_{op}$ (°C) | PMV (%) | PPD (%) | DR (%) | PD1 (%) | PD2 (%) | PD3 (%) | Category |
|------|---------------|---------|---------|--------|---------|---------|---------|----------|
| 1    | EH 21.4       | HP 22.1 | 0.0     | -0.2   | 5.0     | 6.2     | 0.0     | 40.4     | 0.5 0.8 6.2 6.1 0.7 0.3 1 3.7 |
| 2    | EH 21.1       | HP 21.4 | -0.1    | -0.3   | 5.2     | 7.6     | 0.0     | 34.1     | 0.3 0.7 6.5 6.6 0.8 0.3 1 3.6 |
| 3    | EH 21.4       | HP 21.7 | -0.1    | -0.3   | 5.1     | 6.9     | 1.7     | 31.4     | 0.4 0.7 6.2 6.5 1.1 0.5 1 3.5 |
| 4    | EH 21.4       | HP 21.9 | -0.1    | -0.2   | 5.2     | 6.2     | 0.0     | 27.4     | 0.9 1.3 6.6 6.5 1.1 0.4 1 3.1 |
| 5    | EH 21.7       | HP 21.6 | 0.0     | -0.3   | 5.1     | 6.8     | 0.0     | 26.8     | 0.6 1.7 6.2 6.7 1.0 0.6 1 3.0 |
| 6    | EH 21.4       | HP 21.7 | -0.1    | -0.4   | 5.4     | 7.9     | 0.2     | 36.8     | 0.4 1.0 6.3 7.1 1.4 0.7 1 3.6 |
| 7    | EH 21.5       | HP 21.6 | -0.2    | -0.3   | 5.5     | 7.2     | 0.0     | 22.1     | 0.9 3.5 6.5 7.2 0.7 0.7 1 2.9 |
| 8    | EH 21.3       | HP 21.4 | -0.2    | -0.5   | 5.9     | 10.6    | 0.0     | 37.0     | 0.5 1.4 6.5 8.1 2.0 0.8 1.7 3.8 |
| 9    | EH 21.3       | HP 21.4 | -0.2    | -0.4   | 5.9     | 8.9     | 0.1     | 25.9     | 0.5 1.7 6.7 7.6 2.1 0.6 1.7 3.1 |
| 10   | EH 21.5       | HP 21.7 | -0.2    | -0.4   | 5.7     | 10.2    | 0.0     | 32.0     | 4.0 13.3 7.0 9.2 1.8 1.8 2 3.8 |
| 11   | EH 21.3       | HP 21.7 | -0.3    | -0.3   | 6.3     | 7.5     | 0.0     | 23.2     | 2.2 5.0 7.0 8.2 4.2 0.9 2 3.1 |

The thermal category obtained for each test has been represented in figures 1 and 2 as a function of the outdoor temperature and the air flow rate entering the testing room.
4. Conclusions
This work has characterised the comfort provided by two very different heating technologies, an electric heater and a heat pump. This has been done by considering the comfort variables defined in [3]. To do so, a test matrix has been defined by taking into account [2]. Attention has been drawn to the fact that the heater sector might need an index or a ratio which let the consumers know the expected comfort according to the heating technology acquired. The experiments have been carried out in a climate chamber constructed following [1]. The variables registered have been used to determine the comfort variables for each technology. After comparing both technologies the following conclusions may be drawn:

- The efficiency of the heat pump is always greater than that of the electric heater for the tests studied. While the efficiency of the electric heater is insensitive to the outdoor conditions or the thermal load, the heat pump is highly dependent on these variables.
- At outdoor severe conditions the heat pump efficiency decrease dramatically, with COP values of about 1.8 for outdoor temperatures of -7 °C. In far more severe climates, the efficiency of the heat pump might be comparable to that of the electric heater, while in mild weathers it may be 3 or 4 times higher.
- The thermal comfort reached by the heat pump is, independently from the weather conditions and the load, much lower than that provided by the electric heater, specially due to the discomfort caused by air movement which in most case makes that the thermal category of the space studied have an out of range value considering the scale of categories stablished in [3].

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References
[1] EN 60675:1995 Household electric direct-acting room heaters. Methods for measuring performance.
[2] EN 14825:2019 Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance.
[3] ISO 7730-2005 Ergonomic of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local comfort criteria.