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Shallow geothermal systems for Aveiro University departments: a survey through the energy efficiency and thermal comfort

Systèmes géothermiques peu profonds pour les départements de l'Université d'Aveiro: une enquête sur l'efficacité énergétique et le confort thermique

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ABSTRACT: Systems for heating, cooling and ventilation, typically HVAC systems, are usually responsible for most of the electric energy consumed in the majority of university buildings, typically accounting for more than 40% of energy consumption. Recently, the two campuses of the University of Aveiro grew to 61 buildings and the energy for heating and cooling faced a serious problem since the constructed area increased with more 5 new buildings since 2011, with the expectation of increasing growth in the coming years. This paper presents the strategy followed by the university to find new sustainable solutions, using shallow geothermal systems in new buildings, to achieve nearly zero energy buildings. With that purpose a department building with ground source heat pump system was monitored, namely energy consumption of the building, indoor environmental conditions, including a survey through the users to evaluate the indoor thermal comfort and air quality. The monitoring data allow determining the energy efficiency of the HVAC geothermal system compared with traditional systems for heating and cooling used in similar department buildings without compromising the indoor comfort. The results show, that the use of shallow geothermal systems, should be highly incentivised for university departments buildings and another similar type of buildings for Aveiro region.

RÉSUMÉ: Le système de chauffage, refroidissement et ventilation, typiquement appelé de système de HVAC, est normalement responsable pour la plupart de la consumation d'énergie électrique de la majorité des bâtiments universitaires. Actuellement, nous sommes en mesure de dire que ça représente un taux supérieur à 40% de consommation d'énergie. Récemment, les deux campus de l'université à Aveiro ont élargis à 61 bâtiment et l'énergie de l'échauffement et refroidissement sont passés par des sérieux problèmes depuis que le périmètre de construction à augmenté avec 5 nouveau bâtiments dès 2011, et l'expectative n'es que ça continue a grandir dans les prochaines années qui suivent. Ce document détaille la stratégie suivi par l'université en trouver des nouvelles solutions, utilisant le système superficiel géothermal, dans des nouveaux bâtiments, pour atteindre une baisse de la consumation d'électricité et carburant fossile, demandé dans la construction. Pour la suite du déroulement de notre étude, un département en construction a été monitorées à travers la consommation de l'énergie avec le système géothermal, inclue une surveillance de l'utilisateur qui a permis d'évaluer le confort et la qualité à l'intérieur thermal. Les données nous ont capacités de déterminer l'efficacité de l'énergie du système géothermal et comparer avec l'ancien système de réchauffement, refroidissement et rénovation de l'air utilisé dans un contexte similaire sans limiter le confort à l'intérieur. Les résultats nous montre, que l'utilisation du système géothermal, peut être très intéressante dans la construction des départements universitaires ainsi que dans des autres constructions qui peuvent le ressembler.

Keywords: Geothermal systems; thermal comfort; energy efficiency; theramal dynamic simulation; borehole

1 INTRODUCTION

According to the International Energy Agency (IEA) collected data at the world level, the CO_2 emissions and the electrical consumption evolution is quite similar along all the years. The growth between the years from 2000 to 2016 show an alarming rise of 41% (Energy Agency. 2018).

In Europe, knowing that the buildings are responsible by 30% of total primary energy consumed and of 40% of total CO_2 emissions, building energy efficiency plays a mandatory role in reducing energy demand and mitigating greenhouse gas emissions. However and despite the slight reduction of the CO_2 emissions at the residential buildings, we are still far away from the European CO_2 emissions goals (Figure 1).

TPES – total primary energy supply

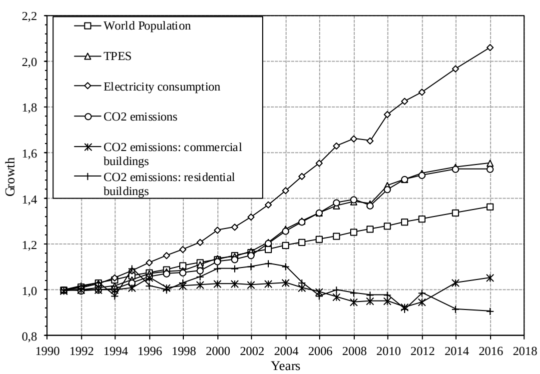

Figure 1. Indicatiors evolution from 1990 to 2016 (Energy Agency 2018).

In order to reduce these alarming numbers and to ensure a sustainable energy supply, ground source heat pump (GSHP) systems could be considered as a promising technology to provide heating and cooling for buildings with a low carbon footprint (Meng et al. 2018).

Nowadays, there are many technologies, including construction materials as well as equipment, being applied in buildings to improve energy efficiency. Regarding equipment the GSHPs are a system highly efficient, when compared with the traditional Heating, Ventilating and Air Conditioning (HVAC) technology. These systems use the ground as a heat source with more favourable temperatures when compared to outdoor air temperatures (Wu and Skye 2018).

A geothermal energy extraction system has the potential to consume a small amount of energy to transfer geothermal energy into the building, thereby reducing the energy demand to meet its heating or cooling needs. GSHP and heat pipes usually are used in conjunction with geothermal energy extraction systems. Some of the advantages that makes this type of application ideal for heating systems are their stable and reliable operating conditions and small space requirements.

From the bibliography developed by other authors were stated that the design results for the total length of the ground heat exchangers (GHEs) are affected by many factors. The groundwater flow in aquifers or regions with superficial levels of water, had a significant impact on the performance of GHEs, the total length of GHEs could be reduced by 9–25%, and the installation and operating costs could be decreased by 16% and 6% ,respectively, in cases with groundwater conditions (Han et al. 2018, Capozza, De Carli and Zarrella 2013, Mensah, Jang and Choi 2017).

This paper provides a comprehensive survey on the progress of the use of geothermal systems in Aveiro University campi.

2 METHODOLOGY

The strategy and the objectives of this study consists in assessing the potential of geothermal systems to provide thermal comfort and energy efficiency in Aveiro University departments buildings. In this case study, the buildings are equipped with ground heat exchangers and with a GSHP to exchange energy between the buildings and the ground. In this article two buildings are under study, however the geothermal systems are totally independent by building. Regarding geology, the buildings are located in a flat morphology of the Aveiro estuary, between 10 and 11 meters depth with the level of water located at 2.0 m depth.

The methodology of this work is depicted in the following points:

- Regional weather characterization;
- Building characterization summary;
- Thermal monitoring campaign;
- Energy consumption monitoring;
- Thermal dynamic simulation.

Regarding results, a thermal analysis using EN 15251 (EN15251:2007) and an energy consumptions characterization were performed, comparing the building in free float, and with the geothermal system running (CCCI building). The used methodology can be schematically depicted in Figure 2.

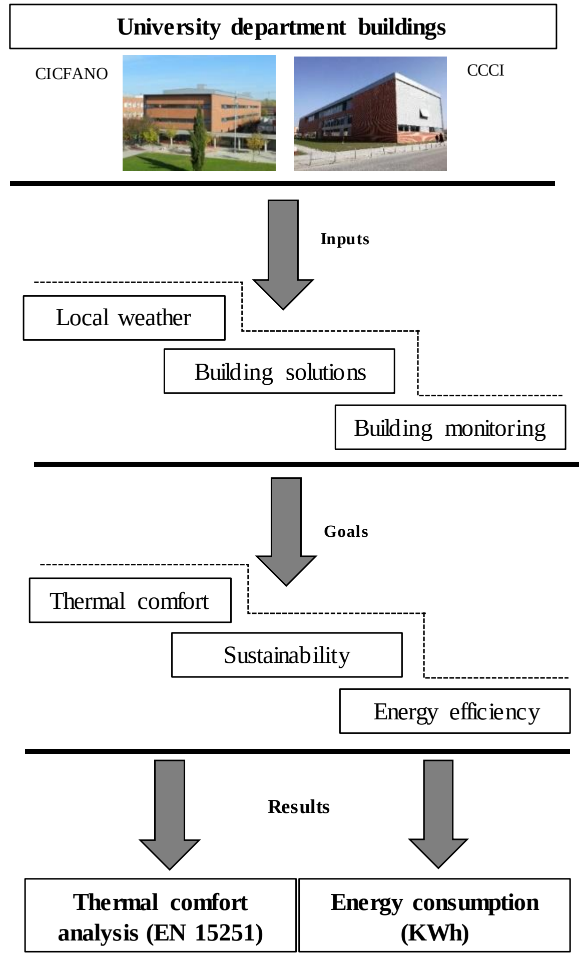

Figure 2. Methodology followed

3 CASE STUDY: DEPARTMENT BUILDINGS

3.1 Local weather characterisation

The Aveiro University campus is located nearby the city centre of Aveiro region, in the North coast of Portugal, 10km away from the Atlantic coast in direct line with the following coordinates: 40°37'49.62"N; 8°39'24.64"O. The terrain altitude is approximately 12 meters above sea level.

According to the World Map of Köppen-Geiger (Kottek 2006) climate classification (which is based on the monthly and annual values of daily mean air temperature and rainfall), Aveiro region has the Csb characterization (see Figure 3). This region is characterized by a warm temperature (C), a dry summer (s) and also with a warm summer (b).

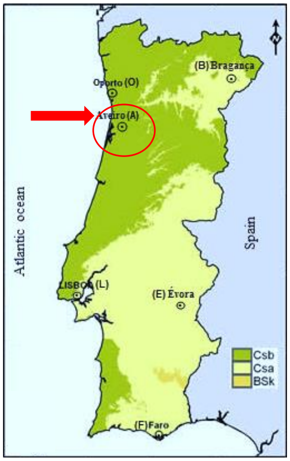

Figure 3. Portugal mainland climate classification (Source: Adapted by IPMA)

To cover the research performed, 3 different sources were analysed and used for different purposes:

i. Data from World Weather Map – for an overall classification of the Aveiro region weather in a full view of Portugal mainland;
ii. Data from Portuguese National Laboratory of Energy and Geology (LNEG) – for simulations and to have a representative weather over last 30 years;
iii. Real data – for a real characterization of the behaviour of the buildings and for calibration accuracy.

The data compiled by the LNEG were built from weather data collected by IPMA (Portuguese Sea and Atmosphere Institute) in measurements carried out between 1971 and 2000 for temperature, relative humidity and wind physical characterisation and from 1981 to 2010 for direct and diffuse irradiance (see Figure 4).

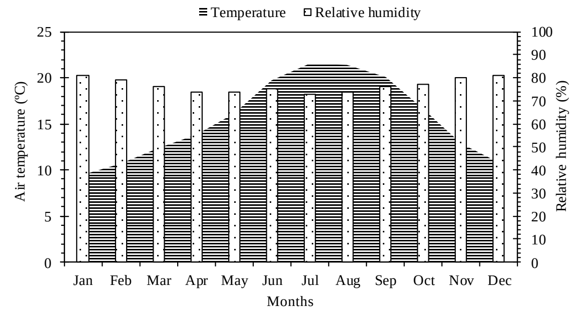

Figure 4. Average monthly air temperature and relative humidity (Source: Adapted by IPMA)

3.2 Geology characterization

Regarding geology, the buildings are located in a flat morphology of the Aveiro estuary, between the 10 and 11 meters depth. The geological surface could be characterized by the occurrence of cretaceous materials, with deposits of old beaches and fluvial terraces. Since the performance of the buildings piles and boreholes depends on the characteristics of the soils a physical characterization was performed during the construction period.

Results, reveals a lean clay with sand until 90 m of depth and a clayed sand between the 90 until 132 m depth and the level of water was found at 2.0 m depth.

3.3 Construction building solutions

3.3.1 CICFANO

The building has 4450 m^2 of gross area divided into the ground floor and two elevated floors both with similar geometry and areas. The heating and cooling demands are fulfilled resourcing to a geothermal system with a ground source and two heat pumps with C.O.P. (coefficient of performance) of 4.16. This geothermal system is composed by 85 concrete pile foundation structures that includes the heat exchanger pipes. The piles have diameters between 400 and 600 mm and 10 m depth. In this type of GHE, the pile diameter is larger than the traditional borehole, and spiral coils were used, rather than U-tubes.

Regarding the envelope solutions the building walls are composed of a double brick wall with an air gap partially filled with thermal insulation in the middle. The finished on the internal surface is plasterboard along all surfaces. The internal partitions are composed of structural plasterboard (in some cases double plasterboards) in both faces and acoustic insulation in the middle. Regarding the slabs, external floor slab and the flat roof are both composed by a massive layer in concrete. Table 1 resumes the main properties of the constructive solutions.

Table 1. Constructive solutions – CICFANO

Constructive Element	Insulation thickness (mm)	U value (W/m^2°C)
GF slab	-	1.22
Flat roof	60	0.49
External walls	40	0.44
Windows and doors*	-	2.40

* $U_{w,installation}$

The solar heat gain coefficients (g) of the windows and doors are 0.70. The thermal transmittance coefficient was determined taking into account the frame and glass edge thermal bridge in accordance with the standard ISO 10077 (EN10077-1 2006) and the installation thermal bridge in accordance with the European standard EN ISO 10211 (EN10211 2007).

3.3.2 CCCI

The building has 5490 m^2 of gross area divided into 4 levels (1 underground partial level, a ground floor and 2 elevated floors). The heating and cooling demand, are fulfilled resourcing to a geothermal system with a GSHP with C.O.P. of 4.5. This system has 53 boreholes with 150 mm diameter and 130 m depth and also 2 piles foundation, that include heat exchange pipes, to act as a new type of ground heat exchangers (GHE) known as ‘‘pile foundation GHE” or ‘‘energy pile”. The piles have 600 mm diameter and 10 m depth. The building slabs are activated to exchange heating and cooling, from the ground to inside the building and also an air handling unit with pre-heated/cooled air. Double brick wall with air gap partially filled with 6cm of thermal insulation thickness was the constructive solution of the vertical opaque envelope of the building, covered in the internal surface with usual plasterboards. Very high efficient windows are used, with thermal transmission coefficient (U_w = 1.70 W/(m^2°C)); solar heat gain coefficient (SHGC = 0.62) and external venetian blinds.
Table 2 resumes the main properties for the envelope solutions.

Table 2. Constructive solutions – CCCI

Constructive Element	Insulation thickness (mm)	U value (W/m^2°C)
GF slab	-	0.40
Flat roof	40	0.78
External walls	60	0.38
Windows and doors*	-	1.70

* $U_{w,installation}$

4 RESULTS AND DISCUSSION

In this section an analysis of thermal comfort and electrical consumption were performed. The indoor thermal comfort is evaluated according to the adaptive comfort algorithms with the accepted deviation of the indoor operative temperature defined by EN 15251 (EN15251:2007). From the three categories of comfort I, II and III defined by the standard the buildings under study fit on category II, which refers to a normal comfort level adjusted to new and refurbished buildings.

The second section of the results is related to the electric consumption analysis. An analysis of the electric consumption is performed considering the building running in free flow, and then, running with the geothermal system working.

4.1 Thermal comfort analysis

To accomplish with the thermal comfort evaluation the interior zones were equipped with monitoring sensors that ensure a continuous recording of the temperature and relative humidity covering all the internal partition of the CCCI building and covered the rooms with south orientation in the CICFANO building. The monitoring campaign of the CICFANO building could be detailed consulted in (Figueiredo et al. 2017) as well as the thermal analysis according to EN 15251.

Regarding the CCCI building, it has been detailed monitored over one year: temperature and relative humidity. The data used is an average of all sensors inside the building (a total of 10 sensors were installed covering all thermal zones).

Figure 5 presents the comfort assessment for the monitoring period in accordance with the standard EN 15251. In the period between 20/9/2016 to 17/08/2017 the building is running in free flow (cloud of green dots - partial periods) and between the period 18/8/2017 to 20/09/2018 the geothermal system is working (cloud of black dots – partial periods).

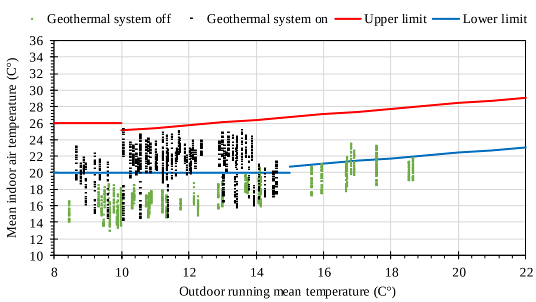

Figure 5. Annual Indoor air temperature (EN 15251)

Comparing the periods with and without the geothermal system on, a significant improvement of 44% in the indoor thermal comfort was attained associated to a low energy consumption, as observed in the following section 4.2.

4.2 Electrical consumption

4.2.1 CICFANO

The energy consumption of the building was assessed in the period between 21st mars 2015 to 21st mars 2018 (real data presented in Figure 7). A detailed model in EnergyPlus (EP) software was defined using twenty-four thermal zones, separated according to the main internal partitions, defined in the architectural blueprints.

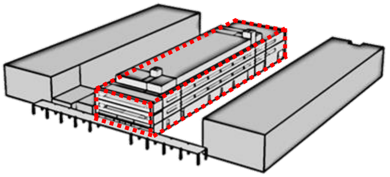

Figure 6. Numerical model full view

After calibration (detailed presented in Figueiredo et al. 2018), the model was run with a traditional HVAC system. From the outputs, the system for heating and cooling was responsible by consuming 45% of the total building energy during the summer and 65% during the winter season.

Confronting the results from monitoring with the results from dynamic simulation a difference from 13.02 kWh/m^2.a (real data with the real geothermal system) to 60.18 kWh/m^2.a (simulated data with a traditional HVAC system presented in (Figueiredo et al. 2017)) and a difference from 9.26 to 15.6 kWh/m^2.a were observed, respectively, for heating and cooling seasons. These values represent a reduction in the energy consumption of 40.6% in cooling and 78% in heating comparing both systems: a geothermal heat pump system vs. traditional HVAC system with a COP of 1. The floor treated area of the building is 4038m^2.

4.2.2 CCCI

In the CCCI building, the approach to assess the efficiency of the system for heating and cooling was based only with real results (without dynamic thermal simulation).

Firstly, the energy consumption of the building was assessed in the period between 20th September 2016 and 17th August 2017. In that period, the system for heating and cooling was not running and the daily energy consumption reaches a maximum of nearly 596 kWh (108 W/m^2), related with electric light and equipment and lifts.

Then in the period between 18th August 2017 and 20th September 2018, the energy consumption was assessed with the system for cooling and heating turned on.

Comparing the results without and with, heating and cooling, and considering the same building internal and external conditions, the acclimatization system is responsible for an increase of the electric energy of 70.71% in winter and 41.22% in the summer season. These values represent a consumption of the system of 13.42 kWh/m^2.a (consumption in winter period) and 3.13 kWh/m^2.a (consumption in summer period), with 4038m^2 of the floor treated area.

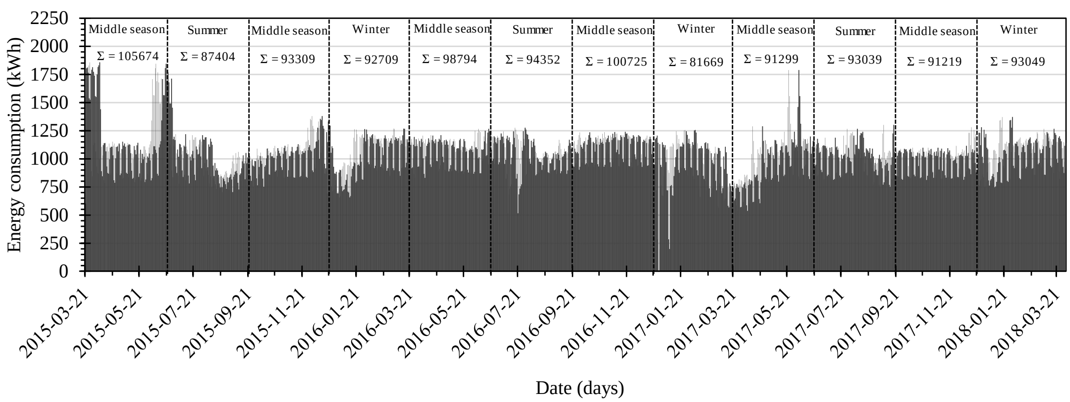

Figure 7. Total building energy consumption: CICFANO

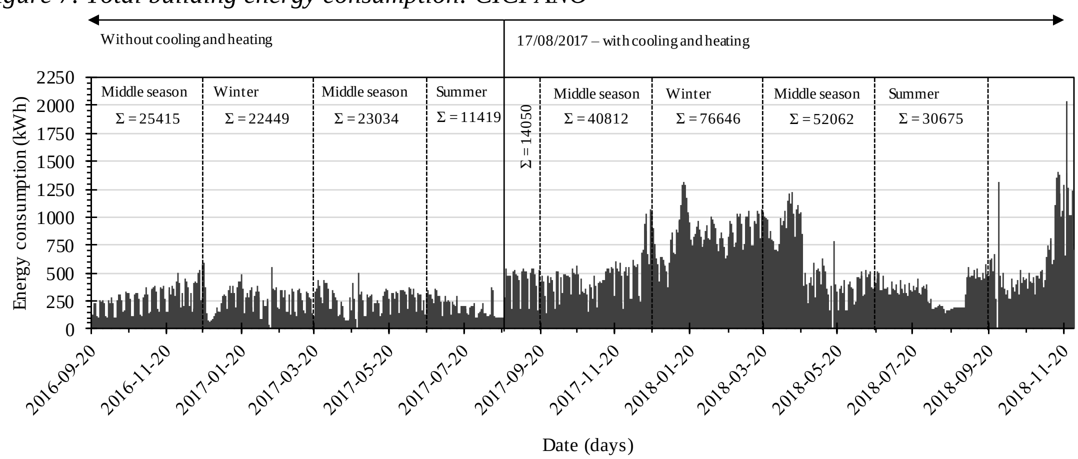

Figure 8. Total building energy consumption:CCCI

5 CONCLUSIONS

This study uses real and simulated data to assess the thermal comfort and energy analyses of two university department buildings equipped with geothermal systems in the Aveiro region, in mainland Portugal.

In general, the thermal results show that the use of the geothermal system for heating, has the potential to increase thermal comfort in approximated 50% associated to low level of energy consumption, in an average of 13 kWh/m^2 for the winter season.

Regarding the overall electric results, it is possible to conclude that the buildings have similar energy needs for heating. Analysing the cooling needs the CCCI building presents only 3.13 kWh/m^2 instead of 9.26 kWh/m^2 presented by CICFANO building. This huge difference was due to the exterior blinds (shading system) presented in CCCI building and due to the south glazing façade of CICFANO. The CICFANO building only presents interior shadings using blackouts and the south façades of CCCI has exterior shadings.

In sum, it is stressed that the geothermal systems should be highly incentivised to be applied to Mediterranean and Southern European climates such as Aveiro region. Moreover, it is fundamental to bear in mind that constructive solutions and decisions are extremely important to attain an overall result more interesting.

6 ACKNOWLEDGEMENTS

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