Models for heating and for cooling an old building using water from boreholes

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1.Introduction – With the increasing price of the electricity and the problem of atmospheric pollution, un effort was made un effort was made to inform people about the needs of changing the way of cooling and heating the buildings. In our days, we have comfortable buildings using direct solar energy. The study of the energy needs of new buildings is now obligatory. Models about the needs for heat or cool a new building can be found on the literature, and people can choose the method of doing that, including the type of energy used. The situation is completely different for old buildings. The main objectives of our work is to make heating and cooling models for an old building, the College of the Holy Spirit, from the Évora University, using water connected in boreholes located in the vicinity of the building. The College was built in the sixteenth century, and has cloisters and walls partially covered with tiles of the seventeenth century. The floor and the ceiling of the rooms are covered with wood, This building is used for classrooms and for administration offices.

2.The climate of Évora – The climate of Évora is typically Mediterranean, with some Atlantic influence. Temperatures registered during Spring and Autumn are close to the desired temperatures for learn and work with comfort. The average maximum temperature values range between 14ºC in January and 33ºC in July and august. The average minimum temperature values range between 5ºC in January and 16ºC in July and August. Sometimes, temperature values of 0ºC or less are registered during the night, in Winter, and 40ºC during several consecutive days, in Summer [1]. For these reasons, we made models trying to estimate the heat necessary to heat the rooms in Winter and the heat we must extract from the rooms on Summer. Global solar radiation has an annual average value of 200 W/m^2 [2]. Global values measured by the Geophysical Center of Évora in 2013, show average values of 100 W/m^2 ,in January, and 300 W/m^2 in July and August.

3.The rooms – The building was built for a university and has many classrooms and rooms for administration offices. All the rooms studied, in the cloisters, have one door (made of wood) and two windows, located in the same wall. We made the study for one room, and considered all the rooms with the same dimensions. The room measured has dimensions of 6,72m x 10.19m x4.25 m. The thickness of the walls is 0.705 m. The door is made from dark wood, has dimensions of 2.42m x 1.46m and its minimum thickness is 0.05 m. The windows have dimensions of 1.33 m x 1.12 m. They can be protected by dark wood doors, with a thickness of 0.05m . The tiles of the walls, outside and inside the rooms, are blue and white, and the parts without tiles are white walls. The walls opposite to the windows are leaning on rock gneiss. The interior walls (2) communicate with other identical rooms. They do not enter in our calculations.

4. The water – The water used to climatize the building, is retired from four boreholes, each one with 100m depth, located near the building. Temperature measurements were made in one hole (RA4) since January 2013 to September 2013. Temperature was measured at several depths using temperature probes. The temperature of the water, from 30 to 90 m depth, was 18ºC in January and 19ºC during almost the period of measurement. The water comes, from the holes to the building, inside polyethylene pipes with a thermal conductivity of 0,35 W/(K m) and a wall thickness of 4.6 mm. The pipes are buried under the ground at 0,70 m depth. An electrical dipole-dipole profile was undertaken, to verify the extent of the occurrence of water deposits in the soil and the existence of hydraulic connections between two holes in the region (RA4 and RA3) [3]Flow tests performed in the holes indicate flow rates between 600l/hour (hole RA4) and 10000 l/hour (hole RA1) [4]. Transmissivity values obtained in the holes are 0,30 m^2/day in hole RA4, 0.41 m^2/day in RA3, 0.80 m^2/day in RA2, and 2.64 m^2/day in RA1 [4].

5. Models and data used – We made calculations considering a day and a night with mean temperature values obtained in July and August, and a day and a night with mean temperature values obtained in January. Heat transfer by conduction, convection and radiation was considered. The air outside the rooms was considered moving with a velocity of 1m/s and the coefficient of heat convection used was q= 9,045 v [5]. The thermal conductivity of the walls was estimated as K= 1.4 W /(K m). For the wood of the doors and floor, a value of 0.140 W/(K m) was used, and for the glass of the windows, the value used is 1.0 W/(K m). The emissivity used for white walls is 0.9, for the tiles is used 0.85, for glass 0.84 and for dark wood 0.82. The mean global solar radiation used for a summer day is 300 W / m^2 and for the winter day 100 W/m^2. An average absorption coefficient of 0.6 was used.

The desired temperature of the room in winter, during the day, is 22ºC. The mean temperature value for the air outside the room is 11.8 ºC. The temperature used for the air in the space beneath the cloister arches, near de wall, during the day is 12.8 ºC. For the temperatures of the air in a winter night, the values used are 7.2 ºC and 8.2 º C respectively. The desired temperature in the rooms, in a Summer day, is 24 ºC. The mean temperature value for the air outside the room is 30 ºC. The temperature for the air in the space beneath de cloister arches, near the wall, during the day is 29 ºC. The temperatures used for the air in a summer night are 16.3 º C and 18 ºC, respectively. For the temperature of rock (gneiss) and soil we used values of 17 º C in winter and 23 ºC in summer. Due to the cloister configuration only a small part of the front of the room receives direct solar radiation in a relatively small period of time, during the day. We used a period of time of 1 hour for winter and 3 hours for summer.

6.Results obtained for a winter day and a winter night-The results obtained for the heat lost by conduction in a winter day, using the data presented, are 1871.3 J/s. This value includes the heat transferred to the rock through the back wall (430 J/s), and the heat lost from the floor (479.4 J/s). The heat lost through the ,front wall 961.9 J/s. The heat lost by convection external to the room is 483.4J/s. This result was obtained considering that the protecting doors of the windows are open and the windows are closed. This means that natural heat convection must be considered inside the room and out side it. Using the results obtained from literature, a value of 2ºC was considered for the difference between the internal and the external temperatures. For the heat lost by radiation, we found a value of 244.4 J/s.

Looking to the values obtained, we can say that the heat lost by conduction is higher than the sum of the heat lost by convection and the heat lost by radiation. This means that the heat lost by conduction can be overestimated and that heat can suffer diffusion through the air, near the front wall. The temperatures of the rock and the soil, near the back wall and over the floor, increases with the time of heating the building, and the value of the thermal gradient is less than the value used.

When the door is open, the hot air goes directly from the room to the outside. The estimate for the heat lost by convection is 777.2 J/s. Now, the heat lost by convection plus radiation is higher than the value obtained by conduction. This means that the temperature of the room is decreasing.

During the night, the doors and the protecting doors of the windows are closed. There are no radiation from the sun. At the beginning of the night, the heat lost by conduction through the front wall is 1178 J/s, and the heat lost by radiation is 189.2 J/s. The heat lost by conduction can be overestimated again due to the decreasing temperature inside the room.

The calculus of the results presented can be considered valid only when the stationarity is achieved. In fact, this state can be achieved only some days after heating. Using a value of 1500 kg/$m^3$for the density of the walls, and 666 J/(kg K) for the specific heat, we conclude that it is needed a time interval more than 8 hours to change the temperature of the front wall by 1ºC, during the day. During the night, the time interval is 7.2 hours. Considering 9 hours for the day and 15 hours for the night, the temperature change of the wall will be 2ºC during the night and 1ºC during the day, without heating. Making a similar calculation for the back wall, the time interval needed to change its temperature by 1ºC is 28 hours. This means that an horizontal thermal gradient is developed inside the room, with the highest temperatures near the back wall. In order to obtain the time needed for a change of 1ºC in the temperature of the air inside the room, we used a pressure of 1 atm, a density value of 1.196 kg/m^3 at T=22ºC, and a specific heat at constant pressure of 1007 J /(kg K) [6]. The value obtained is 3.1 minute. This value compared with 7.2 hours (time need to change the temperature of the front wall by 1ºC) can be considered instantaneous. If we want to make a more refined calculus, we must consider, during the day, the sun radiation incident in the walls. Due to the configuration of the cloisters, direct solar radiation reaches the front wall of the rooms only in the evening or in the early morning. We consider that only 50% of the wall is achieved. The value used for the solar incident energy is 350 W/m^2 in January and 500 W/m^2in July and August. For the calculation of the energy received we must know the value of the coefficient of absorption (absorptivity). The values used for this parameter are α=0.26 for the tiles and white wall, and α=0.59 for the wood of the doors [6].A transmissivity value of 0.88 was used for the glass of the windows. The value obtained for the heat obtained by this process is 1769.8 W. This means that, when the solar radiation strikes the wall, the net energy is 807.9 W from the outside to the inside of the room. This result influences significantly our calculus but it happens only during 1-2 hours a day, when the cloudiness is null. In January, the existence of clouds has a great probability of occurrence, so we ignored this effect in our calculus for winter.

When the door is open, the cool air enters and tends to head toward the back wall replacing the hot air that tends to rise, forming a convection cell.

7. Our proposal- The conditions of thermal comfort are related with temperature (22 to 25ºC), and relative humidity (from 30 to 70 %, with the most desirable value of 50%). The air must be replaced by fresh air. The requirements per person are 8 L/s in the classrooms and 10 L/s in offices and conference rooms [6]. We propose to heat the room with water collected from four holes located near the building. After running through the building, the water must return to the holes. In winter, the temperature inside the holes is 18ºC. We want to heat the air inside the room to a temperature of 25ºC. The water coming from the holes must pass through a compressor in order to increase to a temperature of 28ºC. Using a minimum power of 7 kW and a mass flow rate of 0.16 kg/s it is possible to obtain the desired temperature. After that, the water goes to a heat exchanger where its temperature decreases to 18ºC and the air temperature increases from 20ºC to 25ºC.Using a water flow rate of 0.08 kg/s per room, it is possible to heat 560 L/s of air. We can think on classes with 30 students. This means that in order to obtain a change in the air needed for comfort, the system must work and stop at approximately equal time intervals.

Moisture content affects the effective conductivity of porous mediums such as soils and build materials, and thus the heat transfer through them. Several studies have indicated that heat transfer increases almost linearly with moisture content. Moisture content also affects the specific heat and thus the heat storage characteristics of building materials. Data from the Centre of Geophysics of Évora show that values of relative humidity measured in Évora during January 2013 range between 55 and 89%. January is the month with more cloudy days and raining is frequent. This means that air from the atmosphere has more moisture than desirable. We must take account of this fact.

8. Some conclusions – The models made to obtain an estimate of the heat needed to heat the rooms during winter gives values that allow the use of the water collected in boreholes located near the building. Although cloisters configuration enables solar radiation to strike the front wall of the building during some hours a day, we must use this values for the model made for a summer day. The principal difference between the models for this building and the new ones is the high values of thermal inertia. We found that the front wall needs 7 hours to change its temperature by 1ºC and the back wall needs 28 hours. This fact induces thermal gradients in the room and prevents cooling and heating of the room. The holes can provide the water needed for our proposal, without problems. The main problems are related with humidity in Summer because we have relative humidity values of 24 or 25% during July and August.

9. Future work – We want to introduce in the models the effect of the heat lost by the ceiling and the roof and the heat obtained by solar radiation striking the roof. A special attention must be given to the problem of relative humidity necessary to obtain thermal comfort.

10. References

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