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MODELING AND VALIDATION OF THE THERMAL WALL MODEL WITH AND WITHOUT WATER FLOW FOR THERMAL COMFORT AND HOT WATER USE

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ABSTRACT
The research project seeks to validate a thermal wall model with the innovative use of ecological bricks. These bricks have continuous vertical holes; when placed one on top of the other, they will form pipes, like ducts for water, sewage, and electricity. The objective is to use them to pass pipes where water will circulate, forming a coil, in such a way that the thermal energy incident on the wall is captured, not totally, but in a good part, thus reducing the heat exchange between the internal and external parts, providing thermal comfort. Seeking to understand the efficiency of this system with the transport of water through the pipelines, simulations will be carried out on the Solid Works platform that will reproduce in a similar way the heat exchanges of the wall to be built and calculate the pressure losses in the pipes, this variable can be understood as the loss of dynamic energy of the fluid due to the friction of the fluid particles among themselves and against the walls of the pipe. This information will be of fundamental importance for the project since these results will later be compared to the data collected in the actual construction and will provide the basis for the eventual validation of the Thermal Wall model.

Keywords: Ecological brick. Thermal comfort. Loss of load.

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INTRODUCTION

It is noted that for thousands of years, man has been trying to maintain himself in environments that are at a temperature within the bearable limit or looking for ways to keep the temperature of the environment within this limit in such a way that there is no interference in his internal temperature. Man's concern with his well-being and comfort is directly proportional to the evolution of humanity; that is, the more evolved people become, the more demanding they become about their comfort and well-being. Thermal comfort is part of environmental comfort, which also includes visual comfort (including the psychodynamics of colors), acoustic comfort, and air quality. His studies are closely linked to the areas of Engineering and Architecture, as they are responsible for the conception and creation of the environments in which man spends a large part of his life (Lisbon, 2015).

According to Lisboa (2015), the human body can be compared to a "heat engine", which generates heat when it performs some work. The heat generated by the body must be dissipated in equal proportion to the environment so that the internal temperature of the body is neither raised nor lowered. As man is a homeothermic animal, that is, he must keep his body temperature practically constant, this imbalance caused between the generation and dissipation of heat by the body can cause uncomfortable sensations or even pathologies in more extreme cases (thermal stress). Thus, the basis of thermal comfort studies is found in the thermal balance verified between man and the environment around him, which was greatly boosted by the studies carried out in climatized chambers, especially those of Fanger (1970), in Denmark, whose proposed models are still used today and are standardized through ISO 7730 (1997). (International Organization for Standardization).

Just as in igloos, ice is used to build the walls, because water in the solid state has its thermal conductivity lower than in the liquid state, to soften a heat exchange between the internal and external parts, houses and buildings are built, most of the time, with ceramic masonry blocks, which also has the function of avoiding a large heat exchange. This type of block is still not enough to avoid this exchange; that is, the thermal resistance is still low because

it depends on the ratio between the thickness and thermal conductivity, where the thickness is and the conductivity K between perforated red brick (Kuffel; Tomim, 2018).

Proof of this is the great use of air conditioning in regions where the temperature is high and heaters where the temperature is low. $e = 10\ cm\ 0{,}7\ e\ 1{,}5\ ^{W}/_{m.K}$

A great solution to avoid the use of air conditioning is the use of ecological bricks. These bricks are modular and composed of sand, cement, and even construction waste, consisting of two central thick holes. They are easy to build because they are assemblable and require little material since they do not require cement as a binder between the bricks, requiring only an easy-to-apply glue. The construction is much faster since the use of beams and pillars is dispensable, constituting a self-supporting system. The brick is called ecological because of its manufacturing process that does not involve burning, eliminating both wood and waste gases from combustion.

Such a brick also makes it possible to use the holes, which are vertical and continuous, and when placed one on top of the other, form tubes, creating the opportunity for the addition of ducts for water, sewage, and electricity. In this work it is intended, because there is a great concern with the reuse of energy, to raise a study showing that this ecological brick has one more function about the holes, which is to pass through these holes water, forming a serpentine, in such a way that a good part of the thermal energy incident on the wall is captured to be used in the heating of water for future applications. This technique will also contribute to increasing the thermal resistance of this wall, which, as a consequence, will pass little thermal energy to the internal environment. In this way, there will be a gain in thermal comfort and electricity savings, as there will be no need for air conditioning devices or at least mitigate the use of these devices, which also contributes to energy and environmental issues.

Solar energy is an affordable and interesting renewable energy alternative for air conditioning systems. By replacing a conventional source with a renewable source of energy, solar energy, these systems meet renewable requirements. In this way, the thermal wall found in the absorption of thermal load is a solution to optimize internal comfort, to reduce energy consumption, and to reduce the negative impact on the environment. In order to understand and correctly size this first part of the project, it is necessary to insightfully study the importance of the Ecological Brick and its differences from other construction materials and the advantages that led to its choice.

The objective of this project is to highlight the feasibility of taking advantage of part of the thermal load generated by solar energy that falls on an ecological brick wall equipped with internal pipes arranged in the form of a serpentine. With this, it seeks to

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capture the thermal energy that the wall absorbs to heat water, allowing its reuse in future applications and contributing to the reduction of costs related to air conditioning. To achieve this purpose, it is proposed that the solar thermal load be absorbed directly by the pipes integrated into the wall, heating the water in circulation for later use. In addition, it is intended to improve thermal comfort by minimizing heat transfer to the internal environment, thus reducing the effect of solar radiation that raises the internal temperature. As a result, there will be a reduction in electricity consumption since the need to use air conditioning systems, such as air conditioning and refrigerators, will be lower. This decrease in the use of refrigeration equipment will also have a positive environmental impact, as it will result in a reduction in the emission of greenhouse gases often related to the operation of these devices.

METHODOLOGY

TEMPERATURE MEASUREMENT INSTRUMENTS FOR DATA COLLECTION

For the validation of the studies that will be presented, a physical wall will be built with specifications determined according to what the project needs. Temperature data will be collected using a Novus FieldLogger and 8 type K thermocouples.

The FieldLogger (figure 1) is a module for reading and recording analog and digital variables with high resolution and speed. There are four types of input channels in FieldLogger: analog, digital, remote, and virtual. In this study, the eight available analog input channels will be used. These are configurable for reading voltage, current, and thermocouple signals.

Figure 1 - FieldLogger, Novus.

Source: FieldLogger Catalog – Novus, 2019.

Thermocouples will be used for temperature measurements. These are simple temperature sensors with accurate measurements and are affordable due to their low cost. Thermocouples are widely used in the most varied temperature measurement processes. It is composed of two different metals joined at one end. When there is a temperature difference between the joined end and the free ends, there is a potential difference that can be measured by a voltmeter. Different types of thermocouples have different types of curves, such as potential *versus* temperature difference.

The thermocouples that will be used are of type K (Figure 2). This type of thermocouple is composed of Cromel (90% Nickel and 10% Chrome alloy) and Alumel (95% Nickel and 5% Aluminum alloy). According to the FieldLogger (Novus) Instruction Manual, the K thermocouple has a measurement range of -130°C to 1372°C (-202°F to 2501.6°F). With an accuracy of ± 0.2% (F.E.) and ± 0.1°C.

Figure 2 - K thermocouples.

Source: Authors, 2019.

THERMAL WALL

Modeling

For the construction of any physical model, it is necessary that there is a project, a delineation of the enterprise to be carried out, in this case, a drawing on some CAD platform. For the thermal wall project, the modeling specifications followed the criteria of the manual press used to manufacture the bricks.

The press will manufacture bricks with the following dimensions: 200 mm long, 100 mm wide, 50 mm high, diameter of the vertical holes of 50 mm, and a space between the

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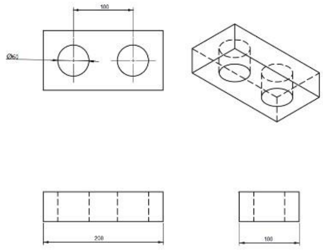
centers of the holes of 100 mm. These data can be observed in the following plot (figure 3), built on the Auto CAD platform.

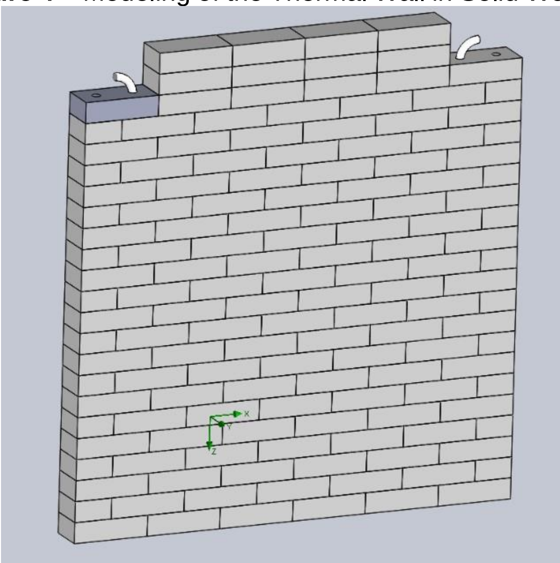
Figure 3 - Views and perspective of the entire ecological brick



Source: Authors, 2019.

Based on this data, it is possible to design the wall (figure 4) formed by these bricks and the serpentine (figure 5) that will pass through it. The following models were made on the Solid Works platform. These models will be used later in the simulations.

Figure 4 – Modeling of the Thermal Wall in Solid Works.



Source: Authors, 2019.

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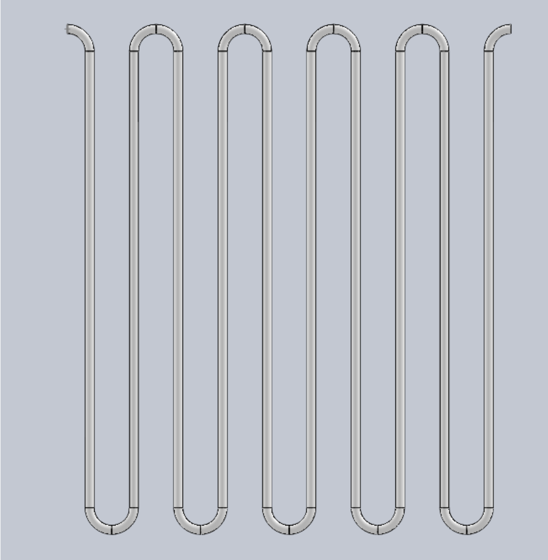
Figure 5 – Coil modeling in Solid Works.



Source: Authors, 2019.

The projected wall will have 6 bricks aligned horizontally at its base and 23 vertically, forming a wall 1.20 m wide and 1.15 m high.

The pipe chosen that proved to be the most appropriate for the project was from the Tigre brand. The diameter chosen was 20 mm. For this pipe, it was what proved to be ideal. Taking into account the pressure that the fluid should exert to travel all the way through the coil as well as the curves. 90° curves were adopted instead of knees, as the former provides lower load losses. That said, the coil will be made up of 10 rectilinear tubes of 1.10 m and 20 90° bends of 50 mm in length.

Simulation in Solid Works

According to Saldanha (2019), engineers and mathematicians have been trying to better understand and predict fluid dynamics and heat transfer phenomena through CFD (Computational Fluid Dynamics) simulation. According to him, the objective is clear: to optimize the design of products and processes that involve fluid flow and, at the same time, minimize the costs, time, and experimental efforts incurred.

And with the same objective, to optimize the design of the thermal wall, the total pressure loss that the fluid will suffer when passing through the coil and the passage of solar radiation through the wall will be calculated using simulation in Solid Works, indicating theoretical values that can be later compared to the actual results.

It is important to take into account that the wall will have the space between the pipe and the internal walls of the brick filled with soil-cement. In this way, the thermal resistivity

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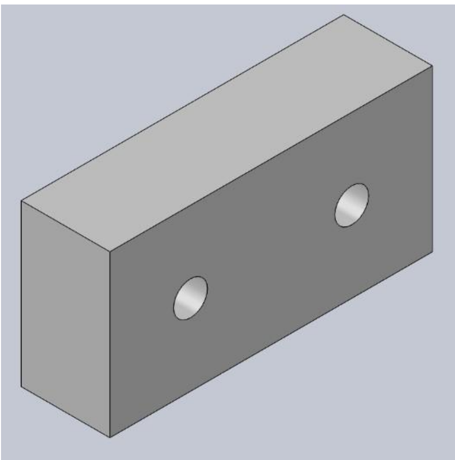
of the air will not interfere with the results achieved. Therefore, bricks should be modeled with only 20 mm of hole (Figure 6), the equivalent of piping.

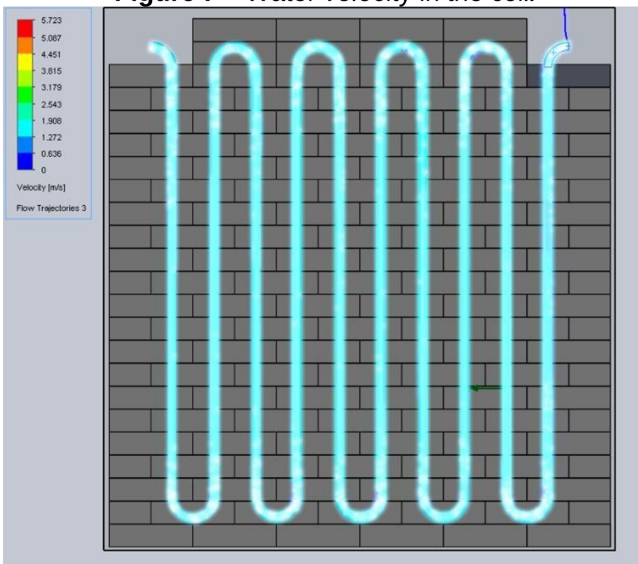
Figure 6 – Brick modeled in Solid Works with diameter dimensions changed for simulation.



Source: Authors, 2019.

The following are the simulations (Figures 7 and 8).

Figure 7 – Water velocity in the coil.



Source: Authors, 2019.

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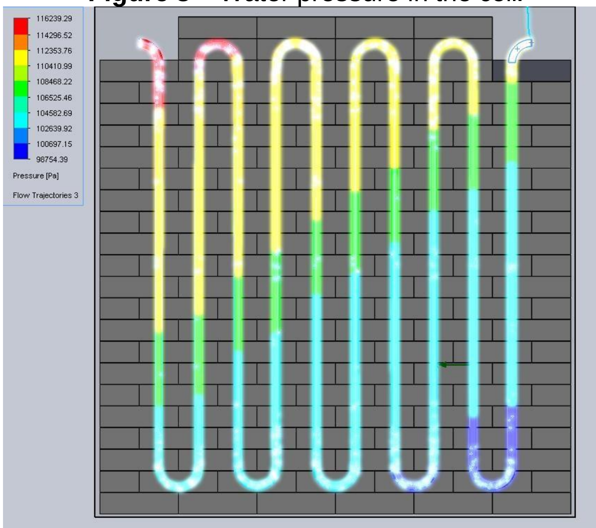
Figure 8 – Water pressure in the coil.



Source: Authors, 2019.

The simulations will result in the values of velocity reached by the fluid in the coil, the temperatures that the wall can reach along the interactions, the temperature that the water can reach, and also the value of the pressure loss that the fluid will have at the end of the passage through the pipe.

For this, some values must be entered before the simulation; one of them is the velocity of the fluid when entering the pipe. It can be found from the value of the volumetric flow rate that the liquid is when it enters the coil.

With the help of a 13-liter bucket, one can time the time it will take the liquid to fill it. When the faucet of the building that hosts the experiment comes out, the bucket can be occupied in 59 seconds. To find the flow rate, the ratio between volume and time is made, finding 0.2204 L/s, transforming it to m^3/s 2.203x.$10^{-4} m^3/s$

Velocity can be found by means of the following equation:

$$v \cong \frac{4 \,.\varphi_{tub}}{\pi . d^2} \qquad (1)$$

The value for "d" must be the diameter of the pipe under study. In this case, 20 mm, we then use 0.02 m. The value found for the velocity will be 0.7016, approximately 0.7 m/s. This velocity must be inserted in the simulation as the velocity of the fluid.

Solid Works also requires ambient and initial temperature values to be entered. The option that should add solar irradiation on the wall is also selected. The value for solar

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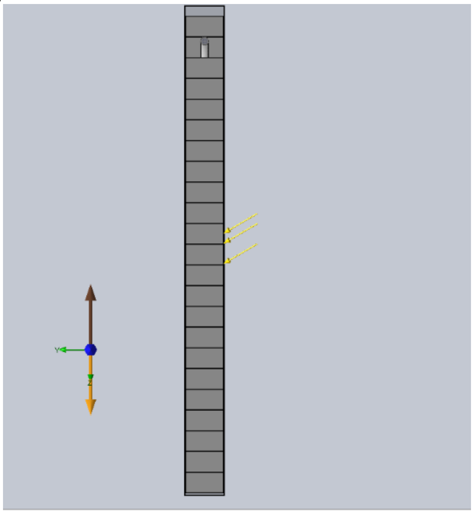
radiation will be 208 w/, the amount that falls on the Earth. Finally, the vectors should be positioned, as can be seen below (figure 09) the solar radiation on the wall.m^2

Figure 09 – Solar radiation incident on the wall.



Source: Authors, 2019.

Construction

Brick Manufacturing

After the simulations, the construction stage begins. The manufacture of the bricks followed the guidelines established by the ABNT NBR 10833 Standard - Manufacture of brick and soil-cement block using a manual or hydraulic press.

The first and possibly the most important part of brick manufacturing is the preparation of the raw material. As explained earlier, the soil must be clay sand; that is, it must contain 70% sand and 30% clay. This soil was extracted from an excavation that was taking place on the Paulo VI campus of the State University of Maranhão.

(1) Soil preparation: According to Sahara (2018), the ideal mixture should contain 7 buckets of soil and 1 of cement. A pre-mix with a hoe should be made before, with the help of a watering can, drizzle a little water.

(2) Compaction of the ecological bricks: The buckets with the soil are placed in the silo. It is important that the bucket is not removed at the time of dumping the soil, so moisture can be preserved. The manual press is activated to compact the bricks. The professional manual press used has a compaction of 1.5 tons with the effect of 6 tons.

(3) Curing: The bricks, at this stage of manufacture, can be stacked or lined up, always with the cores facing upwards, for the curing process (figure 10).

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Immediately after making them they must be covered by a tarpaulin so as not to lose the moisture that is essential to achieve perfect curing. And it is important that they remain so during the first day, without the need to get wet. The next day there should be a slight spray. From the third to the fifth day of curing the bricks should be thoroughly wetted. From the sixth day onwards they must be stocked.

Figure 10 – Bricks in the process of curing.

Source: Authors, 2019.

From the fifteenth day on, the brick is ready for construction (figure 11). The half brick can be manufactured by cutting the modular brick in half in the absence of a mold (figure 12). Just as the channel can be manufactured from cuts in the initial brick (figure 13).

Figure 11 – Brick in good condition Figure 12 – Half brick. Figure 13 – Duct for construction.

Source: Authors, 2019. Source: Authors, 2019. Source: Authors, 2019.

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Construction of the Thermal Wall for studies

After the brick curing process, it is possible to start the construction of the thermal wall model.

First, the construction site was established. The chosen space receives a lot of solar radiation in the afternoon, ideal for studying. And also, the connection with a room that will serve as a base to accommodate the FieldLogger. This room will also have its red ceramic brick wall being studied together with the thermal wall, so the results can be compared later.

(1) Construction should start with a base of solid ecological bricks. Followed by a row of channels. These will serve to accommodate the coil curves (figure 14). The curves must already be connected to the pipes.

Figure 14 – Channels with curves.

Source: Authors, 2019.

(2) In order for data collection to provide accurate information, it is necessary that the space between the pipe and the internal walls of the bricks be filled with soil-cement (figure 15).

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Figure 15 – Filled spaces.

Source: Authors, 2019.

(3) Finally, when the wall is close to being completed, the curves at the top of the coil must be fitted. There will be two ends, where one will be the water inlet and the other the outlet (figure 16). After the curves, another row of channels will be placed and finished with solid ecological bricks. A Styrofoam sheet is positioned between the two walls so that the data is not compromised by the reflection of the solar incidence on the reference wall, as well as maintaining the temperature of the ecological wall.

Figure 16 – Hose attached to the water outlet.

Source: Authors, 2019.

Data collection

At the end of the construction of the thermal wall, the thermocouples must be arranged in order to collect data from specific areas. Each area will receive a thermocouple, these will be connected to the FieldLogger. Each input will receive the temperature data and turn it into tables or graphs. They will be arranged as follows:

(1) Thermocouple 1: It will be called "Int. Ref Environment", that is, it will collect the ambient temperature data inside the reference room.

(2) Thermocouple 2: It will be "External Ref. Environment". Like the first, it will collect the ambient temperature, but outside the buildings.

(3) Thermocouple 3: It will be "Exterior Wall". This thermocouple will collect the temperature that the outside of the reference wall will receive. It must be protected so that it does not receive direct sunlight, so that it can collect the temperature of the wall more accurately.

(4) Thermocouple 4: It will be "Int. Ref. Wall". Just like the previous one, it will collect data from the reference wall, but from the inside.

(5) Thermocouple 5: It will be "Wall Proj. Ext". This will collect the temperature of the ecological wall, where the face is facing the incidence of the sun.

(6) Thermocouple 6: It will be "Wall Proj. Int". It will collect the temperature that the internal face of the ecological wall demonstrates.

Before starting the temperature collections, the FieldLogger configuration is required. It will determine the directory where the information will be forwarded, the interface, which in this case will be "slave". This is where analog channels will be enabled and thermocouples will have their calibration customized. This calibration is ideal so that the data can be accurate. The configuration will also enable the records, when the collection begins, the mode and time for the end, which channels will be selected and the time interval between the records.

When the configuration is finished, it is sent to the equipment (figure 17). As determined at the time of setup, collection will begin.

Figure 17 – FieldLogger interface.

Source: Authors, 2019.

The collections will take place at different times. Of the 4 collections in total, only 2 will have their data used, since the collections carried out on July 18 had their references impaired by the rainy day.

However, two data collections obtained information that met expectations for a sunny day.

The Water Collection with constant flow took place on July 19 during the period from 13:30 pm to 15:00 pm on the same day. To collect the temperatures of the water flows, manual measurements were performed with the aid of a precision thermometer, 0.1°C.

The Retained Water Collection took place during the period from 3 pm on the 19th to 9 am on the 22nd.

RESULTS AND DISCUSSIONS

SIMULATIONS

The simulations generated the following results (figure 18)

Figure 18 – Print of the results exported to Excel.

Goal Name	Unit	Value
SG Min Velocity 1	[m/s]	0,426415477
SG Av Velocity 1	[m/s]	0,676523506
SG Max Velocity 1	[m/s]	0,855556525
SG Max Static Pressure 1	[Pa]	116222,8872
SG Max Static Pressure 2	[Pa]	109402,7831
SG Min Temperature (Solid) 1	[°C]	34,16256061
SG Av Temperature (Solid) 1	[°C]	36,32040617
SG Max Temperature (Solid) 1	[°C]	38,37532732
SG Min Temperature (Solid) 2	[°C]	30,36139933
SG Av Temperature (Solid) 2	[°C]	31,11023974
SG Max Temperature (Solid) 2	[°C]	34,25829158
SG Max Temperature (Fluid) 1	[°C]	28
SG Max Temperature (Fluid) 2	[°C]	28,04445551
Perda de carga	[Pa]	6820,104053

Source: Authors, 2019.

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The table exported to Excel directly from Solid Works shows the maximum speed at which the fluid arrived, which is approximately 0.86 m/s. The temperature of the outer face of the thermal wall is entitled "SG Av Temperature (Solid) 1", and after 170 interactions resulted in a value of 36.32°C. The one on the inner face of the wall, "SG Av Temperature (Solid) 2", indicates 31.11ºC. Showing a difference of more than 5°C between the faces of the wall.

The simulation also resulted in a pressure drop value of 6820 Pa, that is, the pressure difference between the outlet and the inlet of the fluid.

It is also possible to find the temperature at which the water will be at the end of the interactions. With the initial value of 28°C, it rises to only 28.044°C. The change is small, however, it indicates the absorption of solar energy.

COLLECTIONS

Water in constant flow

The first sample of temperatures corresponds to the study in which the water was passing in a constant flow inside the coil. The first observations are that the temperatures in the reference wall, both inside and outside, are always higher than the temperatures of the thermal wall (figure 19). This indicates that the Thermal Irradiation from the sun, when passing through the Ecological Wall, found, not only in the thermal resistivity of the brick but also in the absorption of heat by the water, an additional barrier in its trajectory to the inner side of the wall.

Figure 19 – Print of the results collected by the FieldLogger in Excel.

DATE	TIME	AMB EXT REF	AMB INTER REF	PARED EXT REF	PARED INT REF	PARED PROJ EXT	PARED PROJ INT	Difer. Paredes Extern.	Difer. Pared. Intern.
19/07/201	13:30:01	40,73	32,71	44,11	34,08	40,63	31,97	3,48	2,11
19/07/201	13:40:01	38,78	32,35	44,81	34,20	41,60	32,44	3,21	1,76
19/07/201	13:50:01	37,84	32,68	46,12	34,63	42,49	32,87	3,63	1,76
19/07/201	14:00:01	38,61	32,61	47,12	34,78	43,03	33,00	4,09	1,78
19/07/201	14:10:01	38,89	32,48	48,11	35,10	43,58	33,27	4,53	1,83
19/07/201	14:20:01	38,57	32,93	49,28	35,59	44,34	33,53	4,94	2,06
19/07/201	14:30:01	41,33	33,13	50,99	35,99	45,30	33,79	5,69	2,2
19/07/201	14:40:01	40,40	32,96	51,09	36,48	45,79	34,13	5,3	2,35
19/07/201	14:50:01	37,76	33,16	51,76	36,82	46,63	34,32	5,13	2,5
19/07/201	15:00:01	40,44	33,26	53,29	37,23	47,33	34,57	5,96	2,66
								Média	Média
								4,596	2,101

Source: Authors, 2019.

It is possible to notice in the table, marked in blue, the times and the biggest differences between the temperatures of the internal and external walls. At 3 p.m., the ambient temperature outside reaches 40ºC. The reference wall that receives the direct

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incidence of the sun marks 53.29°C, while the temperature of the thermal wall, which is also exposed to direct incidence, marks only 47.33ºC. Showing a difference of 5.96°C. The same happens when we analyze the internal faces of the walls. The reference side indicates 37.23°C while the project side marks 34.57°. A difference of 2.66°C.

It is also noted a similarity with the real model and the simulation done previously. In the simulation, it is possible to see a difference of 5°C between the faces of the project's wall. And in the model built there is a difference of approximately 10°C on average between the external and internal faces. Showing smaller values for the interior.

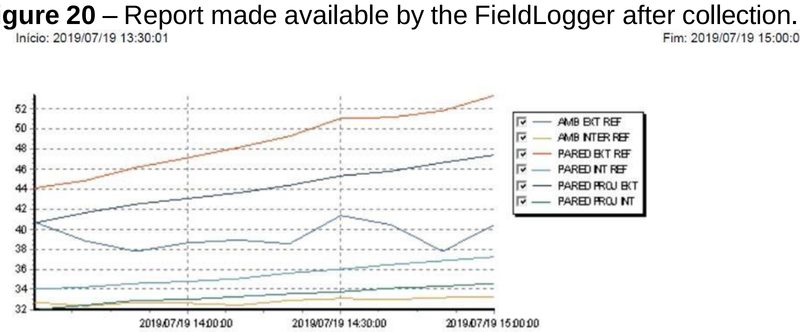
These differences indicate that the thermal energy that passes more easily through the reference wall is not only slower in the thermal wall, but can also be identified on the external faces. This is due to the action of water and its lower temperature compared to bricks, as well as the thermal resistivity of the brick.

The temperature of the water when entering the pipe was measured at 29.8°C by the precision thermometer. When leaving the pipe, the water was at a temperature of 30.7°C. The increase of almost 1°C is due to the absorption of thermal energy falling on the wall by the water that passes through the coil.

The average difference between the temperatures of the internal walls is plus 2°C. This temperature deviation is the difference between an uncomfortably hot environment and a place where there is thermal comfort.

The data collection also gives us a graph where it is possible to observe the differences in temperatures in a more explicit way (figure 20).

Figure 20 – Report made available by the FieldLogger after collection.



Nome do Canal	Valor mínimo	Valor máximo	Valor médio
AMB EXT REF	37,76	41,33	39,33
AMB INTER REF	32,35	33,26	32,83
PARED EXT REF	44,11	53,29	48,67
PARED INT REF	34,08	37,23	35,49
PARED PROJ EXT	40,63	47,33	44,07
PARED PROJ INT	31,97	34,57	33,39

Source: Authors, 2019.

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It is possible to notice that even the average temperature values of the thermal wall are lower than the reference wall. The data for the external walls are 48.67°C and 44.07°C, reference wall and thermal wall respectively. And for the internal faces of the walls, there are 35.49°C and 33.39°C, respectively for the reference wall and the project wall.

Water retained in the coil

The second sample of temperatures corresponds to the study in which the water was retained inside the coil. Even without running water, it is also possible to notice temperature differences between the faces of the walls (Figure 21).

Figure 21 - Print of part of the results collected by the FieldLogger in Excel.

DATE	TIME	AMB EXT REF	AMB INTER REF	PARED EXT REF	PARED INT REF	PARED PROJ EXT	PARED PROJ INT	Dif. Pards. Ext	Dif. Pared. Int.
19/07/20	13:30:01	40,73	32,71	44,11	34,08	40,63	31,97	3,48	2,11
19/07/20	13:40:01	38,78	32,35	44,81	34,20	41,60	32,44	3,21	1,76
19/07/20	13:50:01	37,84	32,68	46,12	34,63	42,49	32,87	3,63	1,76
19/07/20	14:00:01	38,61	32,61	47,12	34,78	43,03	33,00	4,09	1,78
19/07/20	14:10:01	38,89	32,48	48,11	35,10	43,58	33,27	4,53	1,83
19/07/20	14:20:01	38,57	32,93	49,28	35,59	44,34	33,53	4,94	2,06
19/07/20	14:30:01	41,33	33,13	50,99	35,99	45,30	33,79	5,69	2,2
19/07/20	14:40:01	40,40	32,96	51,09	36,48	45,79	34,13	5,3	2,35
19/07/20	14:50:01	37,76	33,16	51,76	36,82	46,63	34,32	5,13	2,5
19/07/20	15:00:01	40,44	33,26	53,29	37,23	47,33	34,57	5,96	2,66
19/07/20	15:10:01	39,87	33,27	54,26	37,47	47,49	34,66	6,77	2,81
19/07/20	15:20:01	41,08	33,47	55,77	38,10	48,54	35,15	7,23	2,95
19/07/20	15:30:01	40,39	33,72	55,68	38,54	49,43	35,76	6,25	2,78
19/07/20	15:40:01	41,84	33,95	56,83	38,78	50,39	36,30	6,44	2,48
19/07/20	15:50:01	41,81	34,01	57,55	39,15	50,86	36,89	6,69	2,26
19/07/20	16:00:01	39,72	34,35	57,74	39,78	51,64	37,65	6,1	2,13
19/07/20	16:10:01	38,14	34,32	57,49	40,03	52,11	38,21	5,38	1,82
19/07/20	16:20:01	37,67	34,63	56,76	40,57	51,60	38,92	5,16	1,65
19/07/20	16:30:01	39,75	34,57	57,02	40,74	52,16	39,41	4,86	1,33
19/07/20	16:40:01	37,87	34,74	56,44	40,93	51,73	39,83	4,71	1,1
19/07/20	16:50:01	36,35	34,97	54,87	41,34	51,02	40,29	3,85	1,05
19/07/20	17:00:01	35,39	35,06	52,49	41,53	49,38	40,53	3,11	1
19/07/20	17:10:01	36,62	35,01	52,63	41,54	49,48	40,80	3,15	0,74
19/07/20	17:20:01	34,31	35,06	44,91	41,72	44,43	41,02	0,48	0,7
19/07/20	17:30:01	33,15	35,03	41,97	41,72	42,82	41,16	-0,85	0,56
19/07/20	17:40:01	33,09	34,87	40,57	41,52	41,45	41,06	-0,88	0,46
19/07/20	17:50:01	32,35	34,81	40,99	41,26	40,64	40,79	0,35	0,47
19/07/20	18:00:01	31,56	34,78	38,17	40,77	39,41	40,45	-1,24	0,32
19/07/20	18:10:01	31,81	34,73	36,85	40,33	38,54	39,96	-1,69	0,37
19/07/20	18:20:01	31,08	34,59	36,11	39,86	37,86	39,55	-1,75	0,31

Source: Authors, 2019.

This study took place shortly after the first study. It started at 3 pm on the 19th and ended at 9 am on the 22nd.

The largest temperature differences between the external walls can be found between the collections made at 3:10 p.m. and 4 p.m. Being on average a distance of 6.58°C. The lower temperatures of the design wall are clearly influenced by the water that is inside the coil. Proof of this are the temperatures collected in the following hours. While at 6:20 p.m. the ambient temperature drops to 31°C and the temperature of the reference wall goes to 36.11°C, that of the project wall is at 37.86°C. Higher than the reference at

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1.75°C. This happens because the water that is in the coil has absorbed thermal energy and accumulated it, not being properly changed after a period.

However, the same did not happen between the internal faces of the walls (Figure 22).

Figure 22 – Print of part of the results collected by the FieldLogger in Excel.

20/07/20	09:20:01	30,36	30,07	31,00	29,74	29,06	27,09	1,94	2,65
20/07/20	09:30:01	29,71	29,80	30,68	29,63	28,87	27,08	1,81	2,55
20/07/20	09:40:01	29,51	30,19	30,83	29,97	28,94	27,24	1,89	2,73
20/07/20	09:50:01	30,69	30,24	31,20	30,05	29,17	27,28	2,03	2,77
20/07/20	10:00:01	31,03	30,60	31,66	30,28	29,44	27,35	2,22	2,93
20/07/20	10:10:01	30,19	30,63	31,44	30,46	29,58	27,46	1,86	3
20/07/20	10:20:01	31,43	30,73	32,97	30,65	30,59	27,58	2,38	3,07
20/07/20	10:30:01	31,71	31,03	33,99	30,92	31,66	27,79	2,33	3,13
20/07/20	10:40:01	30,94	31,15	34,06	31,09	31,88	27,96	2,18	3,13
20/07/20	10:50:01	32,59	31,17	34,60	31,21	32,20	28,10	2,4	3,11
20/07/20	11:00:01	32,00	31,47	34,84	31,57	32,70	28,46	2,14	3,11
20/07/20	11:10:01	31,45	31,36	34,95	31,63	32,98	28,56	1,97	3,07
20/07/20	11:20:01	32,52	31,77	35,10	31,92	33,04	28,85	2,06	3,07
20/07/20	11:30:01	32,95	31,70	35,45	32,03	33,45	29,06	2	2,97
20/07/20	11:40:01	30,99	31,65	35,00	32,13	33,24	29,26	1,76	2,87
20/07/20	11:50:01	32,50	31,76	36,07	32,28	34,08	29,50	1,99	2,78
20/07/20	12:00:01	30,93	32,14	35,95	32,68	34,05	29,79	1,9	2,89
20/07/20	12:10:01	33,84	32,14	36,69	32,96	34,84	30,15	1,85	2,81
20/07/20	12:20:01	32,61	32,13	36,74	33,05	35,05	30,32	1,69	2,73
20/07/20	12:30:01	33,96	32,36	36,59	33,33	35,26	30,60	1,33	2,73
20/07/20	12:40:01	31,61	32,39	35,82	33,31	34,78	30,70	1,04	2,61
20/07/20	12:50:01	32,15	32,13	35,10	33,35	34,21	30,94	0,89	2,41
20/07/20	13:00:01	31,68	32,29	35,04	33,43	34,32	31,05	0,72	2,38
20/07/20	13:10:01	30,25	32,43	34,04	33,60	33,56	31,23	0,48	2,37
20/07/20	13:20:01	31,23	32,44	33,72	33,73	33,38	31,50	0,34	2,23
20/07/20	13:30:01	31,85	32,57	33,75	33,80	33,27	31,50	0,48	2,3
20/07/20	13:40:01	31,24	32,42	33,84	33,73	33,42	31,56	0,42	2,17
20/07/20	13:50:01	31,12	32,16	33,44	33,48	33,05	31,46	0,39	2,02
20/07/20	14:00:01	30,16	32,28	32,88	33,58	32,68	31,58	0,2	2
20/07/20	14:10:01	30,63	32,05	33,42	33,41	32,95	31,47	0,47	1,94
20/07/20	14:20:01	30,99	32,16	33,89	33,47	33,07	31,52	0,82	1,95
20/07/20	14:30:01	29,11	32,02	32,73	33,42	32,41	31,50	0,32	1,92

Source: Authors, 2019.

In the period of the 20th, from 10 am to 2 pm, the greatest differences between the temperatures of the internal faces of the walls were recorded, reaching up to 3.13°C of difference. And, as in the first collection, it proves that it is possible to achieve lower temperatures using this thermal wall model.

With the help of the precision thermometer, it was possible to measure the water temperatures before entering the coil and the water temperature at the end of the collection. Marked by the thermometer, the water when entering marked approximately 29°C. However, at the end of the collection, the temperature had already reached 50°C.

When the absorption of thermal energy by the water is noticed, it is necessary to change the fluid periodically. The temperature of the fluid may change the temperature of the environment. As you can see in the table that the temperature differences between the external faces of the walls decrease until the reference wall has a lower temperature and the difference is negative.

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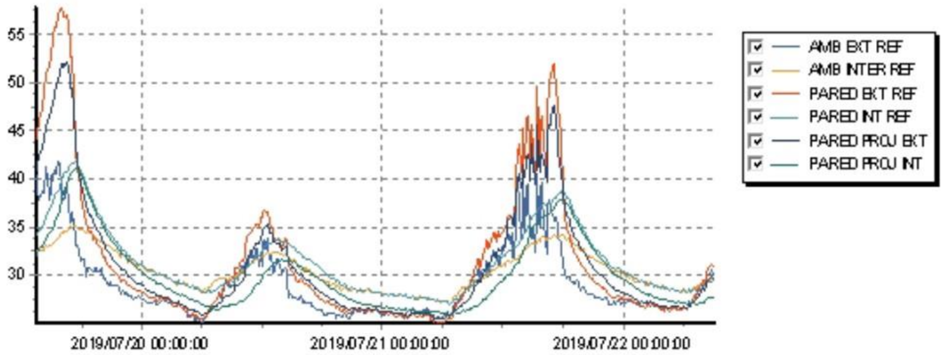
And to conclude the study of this collection, the FieldLogger also provided a report including a graph that better explains the changes in temperatures throughout the collection (figure 23).

Figure 23 – Report made available by FieldLogger after collection.

Início: 2019/07/19 13:30:01 Fim: 2019/07/22 09:00:01



Nome do Canal	Valor mínimo	Valor máximo	Valor médio
AMB EXT REF	25,19	41,84	29,24
AMB INTER REF	27,02	35,06	30,51
PARED EXT REF	25,02	57,74	31,59
PARED INT REF	27,02	41,72	31,49
PARED PROJ EXT	25,47	52,16	31,19
PARED PROJ INT	25,94	41,16	30,11

Source: Authors, 2019.

And even so, the average values between the temperatures of the inner and outer faces of the thermal wall are lower than those of the reference wall. At 1.38°C in relation to the internal faces of the walls.

CONCLUSION

The research project consisted of developing a thermal analysis of the thermal wall model with water flow for thermal comfort and use of hot water. Initially, it was sought to understand the knowledge involved through the existing literature to support the criteria of analysis, testing and manufacturing during the execution of the project. From the theoretical studies carried out, the simulations performed and the study around the collection of data from the temperatures of the constructed model of the thermal wall, it is possible to conclude that:

(1) Much of the thermal energy incident on the wall is captured and absorbed by water and bricks. The phenomenon is noticeable when verifying the increase in water temperature when passing through the coil in constant flow and when it is dammed inside. It is in a potable state and can be used later, for domestic and other purposes, such as replacing the heated water of the electric shower or being used for food purposes, in addition to numerous other applications. It is concluded, then, that the objective "Reuse of solar load" was achieved.

(2) It was observed, when it was observed that the temperature of the internal face of the thermal wall was at temperatures lower than the external one and lower than the internal face of the reference wall, that the thermal load that normally passes through the walls, practically without loss, was largely absorbed, optimizing the Thermal Comfort.

(3) It is possible to see that the temperature of the internal environment of the project wall manifests lower temperatures compared to a wall built with red ceramic brick. Therefore, it is possible to deduce that when building an environment using these guidelines, the built environment will have temperature levels considered comfortable, thus reducing the use of air conditioners and refrigerators, reducing electricity consumption.

(4) It is plausible to infer that the reduction of consumption levels of air conditioners and refrigerating appliances will not only reduce the consumption of electricity, but will also reduce a considerable amount of greenhouse gas emissions, where it is common knowledge that one of the main culprits are air conditioners. Just as the reduction in the use of air conditioning will result in a lower negative environmental impact, the use of Soil-cement Bricks will also add to this, as it is possible to judge from what is presented in "1.1.2. Ecological".

(5) It is also noted that the most advantageous way to use the Thermal Wall is with the periodic change of the water that is inside the coil, that is, with flow. This will occur normally throughout the reuse of water.

(6) It is also understood that the times when the thermal wall proved to be more efficient were precisely at the times when the days were warmer. Thus, in the experiment with constant flow and in the one with dammed water, the times from 2 pm to 3 pm showed the greatest temperature differences.

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It is concluded, from what was inferred, that the Thermal Wall showed positive results and achieved its objectives. The construction of an ecological brick prototype promoted a performance evaluation regarding the heat flow exceeded by it, compared to the common brick.

Finally, it is certain that this project can still be significantly explored to obtain a better understanding of the foundations and related phenomena. It is believed that through the results obtained here through the applied methodology, this research becomes a source to improve the understanding of the application of the ecological brick with the objective of optimizing thermal comfort and other projects of the same nature of the academic community of this university.

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