Development of natural and innovative material for application as thermal insulation in buildings

Desenvolvimento de material natural e inovador para aplicação como isolamento térmico em edificações

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ABSTRACT

The advent of new technologies related to thermal insulation systems in civil construction helps buildings become more efficient, reducing their consumption of electric energy through air conditioning, and providing thermal comfort to users. The research aims to develop a facade cladding board for buildings, with thermal insulation starting from the vacuum, and corn cob. Facade coatings with mortar finish were developed, filling them with developed materials. Three prototypes were executed in the masonry of ceramic blocks, with dimensions of 60x60x64,0 cm. The Field Logger 512K (Lite) and PT100 sensors were used for data collection of external and internal temperature of the prototypes. Solar radiation data were collected by the university weather station, model Davis-6450. It is worth noting the average internal temperature reduction in Prototype 2 and 3, compared to 1 (without isolation), which was 2.74 ° C and 8.05 ° C.

Keywords: Civil construction. Thermal insulation. Corncob. Vacuum. Thermal comfort.

RESUMO

O advento de novas tecnologias relacionadas a sistemas de isolamento térmico na construção civil auxilia para que edificações se tornem mais eficientes, diminuindo seu consumo de energia elétrica por meio de climatização artificial, e proporcionando conforto térmico aos usuários. A pesquisa, tem como objetivo o desenvolvimento de uma placa de revestimento de fachada para edificações, com isolamento térmico partindo do vácuo, e do sabugo de milho. Foram desenvolvidos revestimentos de fachada com acabamento em argamassa, preenchendo-as com materiais desenvolvidos. Foram executados três protótipos em alvenaria de blocos cerâmicos, com dimensões de 60x60x64,0 cm. Na coleta de dados de temperatura externa e temperatura interna dos protótipos foi utilizado o equipamento Field Logger 512K (Lite), e sensores PT100. Dados de radiação solar foram coletados pela estação meteorológica da universidade, modelo Davis-6450. Destaca-se a redução média da temperatura interna nos Protótipos 2 e 3, em comparação ao 1 (sem isolamento), que foi de 2,74°C e 8,05°C.

Palavras-Chave: Construção civil. Isolamento térmico. Sabugo de milho. Vácuo. Conforto térmico.

1 INTRODUCTION

Civil construction grew by 18% from 2000 to 2015, about one-third of the total end-use of global energy, equivalent to one-sixth of the direct end-use CO2 emissions, with buildings accounting for the largest share of energy consumption and greenhouse gas emissions. The main factors that influence this growth in energy consumption are mainly the exponential growth of the population, which increases the demand for residential buildings and associated services. It becomes important to invest in renewable energy, social policies to mobilize society to reduce carbon emissions, and as the main objective, implement research and development programs in energy efficiency in buildings, focus on building systems, making strategic decision and dissemination, show opportunities to improve energy efficiency is the goal in the future construction market. It is extremely important to analyze the impacts of the construction envelope in energy consumption and study the materials of the facades, and this aspect should not be underestimated (GALLO and ROMANO, 17)

It is important to invest in innovation using advanced options, as the focus in the future construction market, being a necessary approach to improve the energy efficiency of building components (GALLO, 2014)

Technological advances in materials and systems of building automation have been drawing parallels between adaptive facades and the intelligent response of human behavior and our skin to environmental stimuli, increasingly viable to regulate the flow of energy through the thermal insulation of buildings, providing reduced energy consumption and occupant comfort (WIGGINTON and HARRIS, 2002), (ASCHEHOUG and ANDRESEN, 2008).

Given the changes in climatic patterns and the need for comfort and energy of occupants of buildings, static façades cannot provide consistent climate control without the use of some type of artificial climatic system, enabling the implementation of dynamic controls for facades, such as light control diurnal in the materiality, adaptable windows, etc. proposing energy savings and improved comfort of the built environment, being applied alone or in combination under a variety of climatic conditions (LEE et al., 2002; PERINO, 2008).

Currently, related to technological innovations, designers have software that provides information on each material used and helps improve the issues related to costs and losses. Thus, it can be said that well-designed projects are more relevant for optimization and rationalization in construction, with more precision and reduction of uncertainties compared to conventional construction (ARO and AMORIM, 2004).

Given the above, it can be said that the introduction of materials, techniques and technological equipment is related to the improvement of civil construction, leading to the better construction quality and reduction of the amount of waste produced. This is one of the great impasses faced by the companies on this branch. It is important to emphasize, according to Bianchi (2014), that the construction industry nowadays requests that issues related to sustainability and energy efficiency in buildings be considered and that the concern with the thermal insulation of buildings is a constructive technique directly related to this aspect.

There are several points related to the technological advancements, and that has been developing and modernizing products in recent years, in which an important system is three-dimensional printing. Porto (2016) describes that this technology has been used in several areas, such as medicine, aerospace, and the production of automotive parts. The author also points out that, as in these areas, the 3D printer can bring significant advances and benefits to civil construction, such as the reduction of labor and waste, providing greater quality and agility in construction time, as well as lower severity and decrease the worker's contact with risk situations.

In addition to the 3D printing system, the laser cutting technique is widely used in the industrial sector (INDAC, 17), having as main characteristics the high precision in the cut, manufacturing flexibility, high production capacity with consequent reduction of costs, and possibilities of cuts in several formats (straight, curved and complex), thus minimizing waste of material.

For Martins and Barros (2005), innovation in the construction sector should be considered as a competitive strategy, becoming an important tool for companies to have competitive advantages, adding efficiency and agility in production activities, as well as providing greater profitability to the company and significant improvement in the final quality. In the context of the evolution of civil construction, one can also highlight the use of natural elements as thermal insulation material (ASDRUBALI et al., 2012; ASDRUBALI et al., 2015).

1.1 THERMAL PERFORMANCE STANDARDS

The strategy developed by the European Union to mitigate the negative effects of climate change, mentions that by the year 2020 new buildings must be energy efficient, close to zero, consuming the same amount of energy as it can generate. It is up to each member state to develop the best method to achieve the objectives, and the climatic adaptation of buildings is a fundamental factor, following

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the guidelines of the European Parliament's Directive 2010/31 / EU on Energy Performance of Buildings (2010), determining that building materials should be used rationally and buildings should be energy efficient to minimize the emission of greenhouse gases (CAMBEIRO et al., 2016).

In Brazil according to data from the Energy Research Company, the Residential (29%), Commercial (19%), and Industrial (36%) sectors are responsible for 84% of current energy consumption, considered high (EPE, 2016). In a report prepared by EPE (2016), which presents "Brazil's Commitment to Combating Climate Change: Energy Production and Use", it identifies that for energy consumption there are three important challenges to be achieved: 1) energy efficiency for the reduction of the energy consumption of buildings and emissions of greenhouse gases (GHG); 2) expansion of energy self-production, to meet growing consumption and distributed generation; and 3) to meet annual energy consumption growth of 3% between 2014 and 2030 (disregarding self-production and including gains related to energy efficiency) (EPE, 2016).

NBR 15220 (2003), standardizes the techniques and parameters for the best thermal performance of buildings, is divided into five parts. The first part consists of tables that establish definitions, symbols, and units referring to the thermal performance of buildings. The second part presents the equations and typical values necessary for the development of the calculations of the thermal properties of building materials, such as solar factor, thermal delay, capacity, and thermal transmittance (U).

In its third part, the standard (ABNT, 2003) presents guidelines of the Brazilian Bioclimatic Zoning, in addition to a set of constructive strategies, which aim to adapt the buildings according to parameters related to the eight bioclimatic zones, aiming at the thermal performance of the building. The fourth and fifth parts of the standard present procedures for determining the resistance and thermal conductivity (λ) of materials from the protected hot-plate and flow-meter methods.

NBR 15575 (2013), developed to standardize the performance of housing developments, in focusses on the establishment of minimum requirements to be reached for the execution of buildings. One of the requirements is the thermal comfort of the users, independent of the materials and the construction system used, based on the requirements of NBR 15220 (2003).

As previously mentioned, (ARO and AMORIM, 2004), the computational tools bring the possibility of developing more precise simulations, and for the development of this technique, NBR 15575 (2003) recommends the use of Energy Plus software.

1.2 THERMAL COMFORT X ENERGY EFFICIENCY

The definition of thermal comfort according to ASHRAE (LAMBERTS et al., 2004) is associated with man's sense of well-being and the thermal environment that surrounds it. It is important to emphasize that to have thermal comfort, it is necessary to balance the temperature between the heat generated by the body and the heat lost in the environment. NBR 15220 (2003) describes thermal comfort as the "psychophysiological satisfaction of an individual with the thermal conditions of the environment".

Corbella and Yannas (2003) and Lamberts et al. (2004) share the sensation of thermal comfort in human variables (physical activity and dress) and environmental variables (infrared radiation, solar radiation, temperature, movement, humidity, and air velocity). It is important to emphasize that variables such as sex, age, weight, activity performed in the place, among other variables also influence the sensation of the wellbeing of each person.

Related to projects of air conditioning systems, NBR 16401 (2008) establishes comfort parameters for the summer and winter periods, which characterize a sense of well-being for people (Table 1).

Table 1 | Thermal Comfort Parameters.

	Summer	*Winter*
TEMPERATURE (°C) / PERCENT RELATIVE HUMIDITY (%)	22,5°C to 25,5°C / 65%	21,0°C to 23,5°C / 60%
	23,0°C to 26,0°C / 35%	21,5°C to 24,0°C / 30%

Source: Authors.

1.3 THERMAL INSULATION MATERIALS

According to data from the Energy Research Company (17), the Residential (29%), Commercial (19%), and Industrial (36%) sectors accounted for 84% of current energy consumption, considered to be high consumption. In a second report (17), he emphasized that "Brazil's Commitment to Combating Climate Change: Energy Production and Use" identifies that for energy consumption there are three important challenges to be met: 1) energy efficiency to reduce the consumption of buildings and emissions of greenhouse gases (GHG); 2) expansion of energy self-production to meet growing consumption and distributed generation and 3) to meet annual energy consumption growth of 3% between 2014 and 2030 (disregarding self-production and including gains related to energy efficiency). Focusing on the first challenge, thermal insulation strategies are fundamental to serve it efficiently.

Dutra (2010) points out that the commercially used materials used for thermal insulation are: 1) Rock wool (or mineral wool), produced from liquefied rock, and with low thermal conductivity (λ = 0,035 / 0,040 W/m.K); 2) Glass wool, produced by hot glass expansion, and low thermal conductivity (λ = 0,04 / 0,055 W/m.K); 3) Polyurethane (PU), which has characteristics suitable for use in civil construction, and very low thermal conductivity (λ = 0,025 / 0,040 W/m.K); 4) Designed Polyurethane (λ = 0,016 /0,02 W/m.K); 5) Expanded Polyurethane (EPS), one of the most widely used materials for thermal insulation (λ = 0,035 /0,040 W/m.K); and 6) Extruded Polyurethane (XPS) (λ = 0,035 /0,040 W/m.K). The application of EPS in tests performed with External Thermal Insulation Composite System (ETICS) (SPINELLI et al., 2018), on the external face of the facade. Comparing prototypes with no application, and with ETICS application, a reduction of 81% in the thermal transmittance (U) and 68% of the energy consumption was achieved for the prototype with ETICS, considerably interfering in the design of air conditioners.

With the modernization of the construction systems, new technologies for thermal insulation appear. For example, the Basalt fiber blanket (MORETTI et al., 2016), in which the basalt fiber manufacturing process is like that of glass fibers, but with lower energy consumption and without additives. Basalt fibers have no toxic reaction with air or water or other chemicals, are non-flammable and explosion-proof. The tests developed with the material presented low indices of thermal conductivity. At a density of 165 kg / m³, the thermal conductivity value of 0.0312 W / m.K. Considering a density of 187 kg / m³, the thermal conductivity is equal to 0.0320 W / m.K.

In this paper, we present the results of a study on the thermal insulation components of materials such as glass fiber and vacuum laminated aluminum (Vacuum Insulation Panel - VIP), with a thermal conductivity index of λ = 0,030 W/m.K. In a study carried out in South Korea (BOAFOA et al., 2015), it highlights the efficiency of the panel with vacuum and fiberglass thermal insulation but emphasizes that the elements used as support for the installation of the material cause thermal bridges, causing heat transfer.

With bias for the use of natural materials, according to ASDRUBALI et al. (2012) (2015) a material can be considered as a thermal insulator if its thermal conductivity index is less than 0.07 W / m.K, and highlights several compositions of natural materials (corn cob - λ = 0,057 W/m.K, straw - λ = 0,051 W/m.K, pine bark - λ = 0,069 W/m.K, pineapple leaf fiber - λ = 0,057 W/m.K, rice husk - λ = 0,0566 W/m.K, straw- λ = 0,067 W/m.K, etc.) with wide possibility of use as material of thermal insulation in buildings.

SPINELLI et al. (2019a) presents in its studies for determining the thermal conductivity of slabs based on natural materials and innovative indicators of 0,07 W/m.K, highlighting or corn cob (λ = 0,052 W/m.K), a soy straw (λ = 0,058 W/m.K), pine bark (λ = 0,061 W/m.K) and recycled slimstone (λ = 0,063 W/m.K). When applying pine bark in a prototype, SPINELLI et al. (2020) reduced a 62% reduction in the thermal transmission index (U), contributing to a 52% reduction in energy consumption when using an artificial air conditioning system.

In a simulation using the RTQ-C method to assess energy efficiency, the application of natural and innovative elements on the facade of an educational building (brick + plaster), SPINELLI et al. (2019b) presents the evolution of the classification from level D to level A, proving that the use of natural elements for thermal insulation helps in the energy efficiency of the building.

1.4 OBJECTIVE

The main objective of the research is to develop a study related to the temperature of thermal comfort and improvement of energy efficiency, developing a coating for thermal insulation of facades of buildings. The study was developed from the comparison between three prototypes: Prototype 1 - No coating application; Prototype 2 - Application of facade cladding insulated with Corncob; Prototype 3 - Application of facade cladding with vacuum insulation. The external temperature (Te), internal temperature (Ti), and solar radiation data were analyzed, comparing the heat gain inside the prototypes, and the efficiency of the materials applied for insulation. The corn husk was selected for the study, because Brazil, mainly the southern region, has a large corn crop, where the estimated 2016/17 harvest was 91.5 million tons (37.5% growth), with 29.9 million tons for the first harvest and 61.6 million tons for the second. The total area of maize should reach 17.1 million hectares (SPINELLI et al.,2018). The vacuum element was developed to expand studies from innovative materials (MARTINS and BARROS, 2005).

2 METHODOLOGY

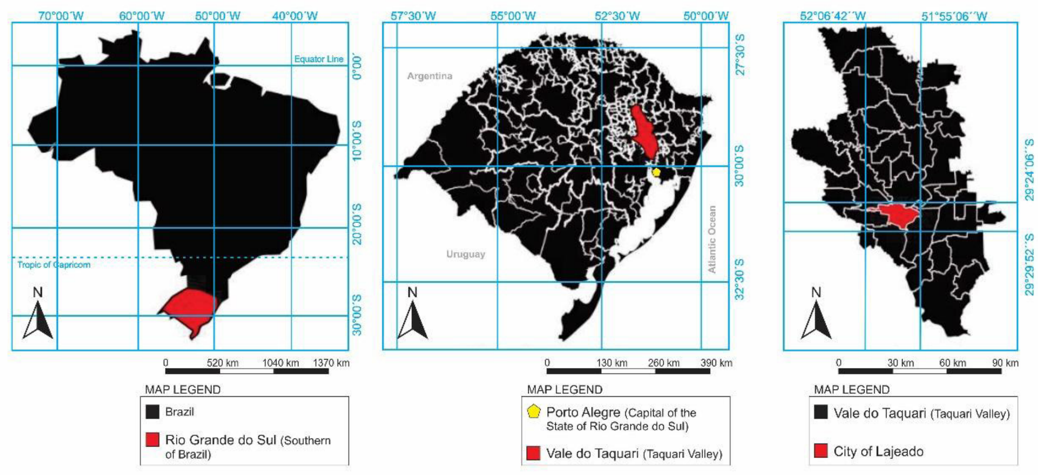


Figure 1 | Location of the State of Rio Grande do Sul in Brazil, Taquari valley in the state of Rio Grande do Sul, and the city of Lajeado in Taquari valley.

Source: Authors.

For the accomplishment of the study, the applied methodology (GIL,1999) is of exploratory research.

2.1 EXPERIMENT LOCATION

The city of Lajeado / RS-Brazil is in the Taquari Valley, 120 kilometers away from Porto Alegre, capital of the state of Rio Grande do Sul (Fig.1) (SPINELLI et al., 17). According to Spinelli et al. (17), in his study on bioclimatology, with the elaboration of the Bioclimatic Chart for the city of Lajeado / RS, data point out that there is a predominance of 45.26% days of the year when bioclimatic strategies are not necessary (Zone 1), due to the natural sensitivity of thermal comfort in buildings.

With 29.92% of the days, the zone of High Inertia / Passive solar heating (Zone 7) can be used, being able to use them separately or together, being thus this strategy used in the colder days. The Passive Solar Heating (Zone 8) strategy points to 10.24% for use of a natural heating resource, taking advantage of solar radiation heating through the openings to achieve thermal comfort temperature inside the rooms.

In the winter period (SPINELLI et al., 17) with 0.47% to the Artificial Heating strategy can be disregarded due to the low percentage of probability of use. Presenting approximately 15% of the days/year, the strategies of Zones 2 (Natural Ventilation), 10 (Natural Ventilation / High Thermal Inertia) and 11 (Natural Ventilation / High Thermal Inertia / Evaporative Cooling) correspond to the summer climate. Considering the possibility of using Zone 7 for winter, added with Zones 10 and 11 for summer, the strategy of High Inertia presents the total percentage of 36.5% of days of the year of use, being able to be considered in the projects of buildings the application of thermal insulation in buildings.

2.2 PROTOTYPES

For the development of the study, three prototypes were executed, with dimensions of 60 x 60 cm and a height of 64 cm. For its base and cover were used reinforced concrete slabs, with dimensions of 80 x 80 cm and 5.0 cm of thickness. The masonry was executed with solid ceramic blocks 11.5 cm thick and accented with mortar, a material widely used in the study region. In the roof was applied polyurethane insulation metal (5.0 cm), to minimize the transfer of heat by the horizontal surface. In Prototype 1 no facade cladding was applied, Prototype 2 was coated with corncob insulation boards, and for Prototype 3 the facade cladding plates were made with acrylic and vacuum interior.

The coatings of Prototypes 2 and 3 were made with dimensions of 32 x 30 x 4.2 cm, and mortar finish. The corn cob applied to the plates used in Prototype 2, was crushed and inserted in a plastic container. In the end, the coating of the plates began to be finished, being first performed with a 1.0 cm thick layer in the mortar, and thus placing thermal insulation material. Subsequently, the second layer of mortar was applied, also with a thickness of 1.0 cm (Fig. 2).

For the development of the facade cladding applied in Prototype 3, acrylic boxes with dimensions of 28 x 26 x 2.2 cm were executed using laser cutting technology, and then bonded with high strength adhesive material (Super Bonder Power Flex Gel). Inside the plates, reinforcements were executed, also in acrylic, so that in the air removal did not deform the larger faces. On the side of the acrylic box, a 1.10 cm opening was made, in which a plastic sealing device was applied, where the air was removed (Fig. 3). After the gluing of the sealing device, three days were left to dry the glue. To test the plaque seal, they were submerged in a vessel with water and checked if any of them had infiltration, adjusting some parts. After the adjustments were made, the tests were again applied to the parts.

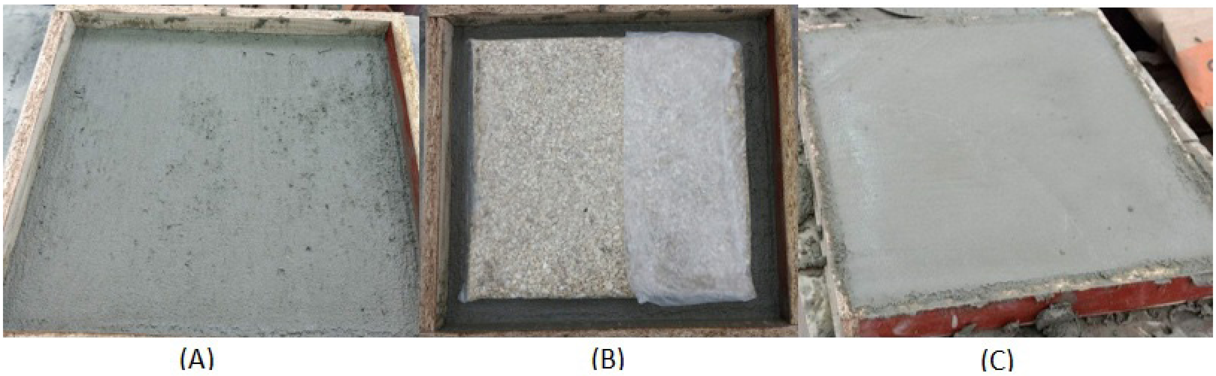


Figure 2 | Process of manufacturing the coating plates of Prototype 2. Execution of the first layer of mortar; Layer of corn cob; Application of the second layer of mortar.

Source: Authors.

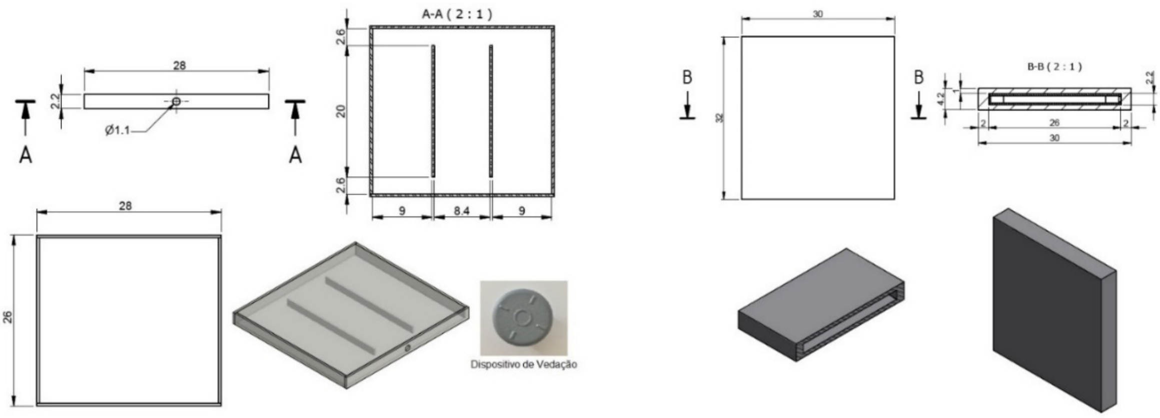


Figure 3 | Design of Vacuum Coating Plates.

Source: Authors.

When the sealing tests were completed, a 5 x 5 mm woven glass fiber cloth (Placlux) was applied to the acrylic boxes to allow better adhesion between the acrylic and the finishing mortar of the plates.

Removal of air from the interior of the plates was performed by the sealing device in which a needle was coupled to a manometer fitted to a pressure gauge connected to a compressor. With the removal of air, the internal pressure recorded in the box was -5.89 Psi, indicating the absence of air (vacuum). Finally, the coating of the plates began to be finished, being first performed with a 1.0 cm thick layer in the mortar, and thus positioning the acrylic box with the vacuum layer, wrapped with the glass fiber screen. Subsequently, the second layer of mortar was applied, also with a thickness of 1.0 cm (Figure 4).

After the construction of the Prototypes, the fixation of the plates in the facades of Prototypes 2 and 3 was carried out with the aid of metallic supports, and in the roof placed metal tile with thermal insulation of polyurethane (Figure 5).

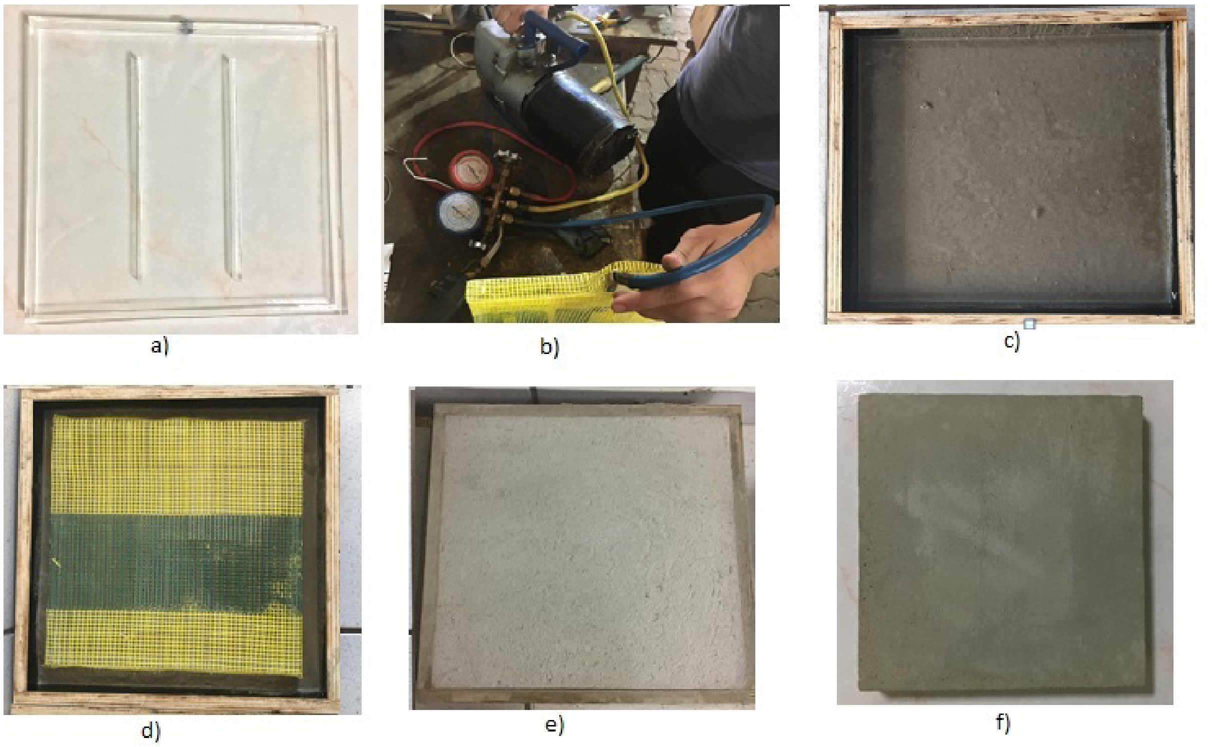


Figure 4 | Execution of the vacuum coating plate: a) Acrylic plate with laser cutting technology; b) Compressor and manometer for withdrawal of air - vacuum; c) First layer of mortar; d) Insertion of the acrylic box with vacuum layer wrapped with glass fiber cloth; e) Second layer of mortar; f) Final proposed element.

Source: Authors.

Figure 5 | Installation Facade Plates, and Finished Prototypes.

Source: Authors.

2.3. DATA COLLECT

To collect data related to the study, PT 100 (thermoresistor sensor) sensors connected to a datalogger (FieldLogger 512K) were used to store the data in the 15-minute interval, external (Te) and internal (Ti) of the Prototypes 1, 2 and 3. The stored data were transferred to a computer through a spreadsheet, and the days with significant external temperatures were analyzed, with intense heat recording. The study period corresponds to the months of October 17 to May 2018. Solar radiation, wind, and precipitation data were also collected from the University of Vale do Taquari - Univates, registered by the meteorological station Vantage Pro 2, of Davis brand, with sensor coupled model 6450.

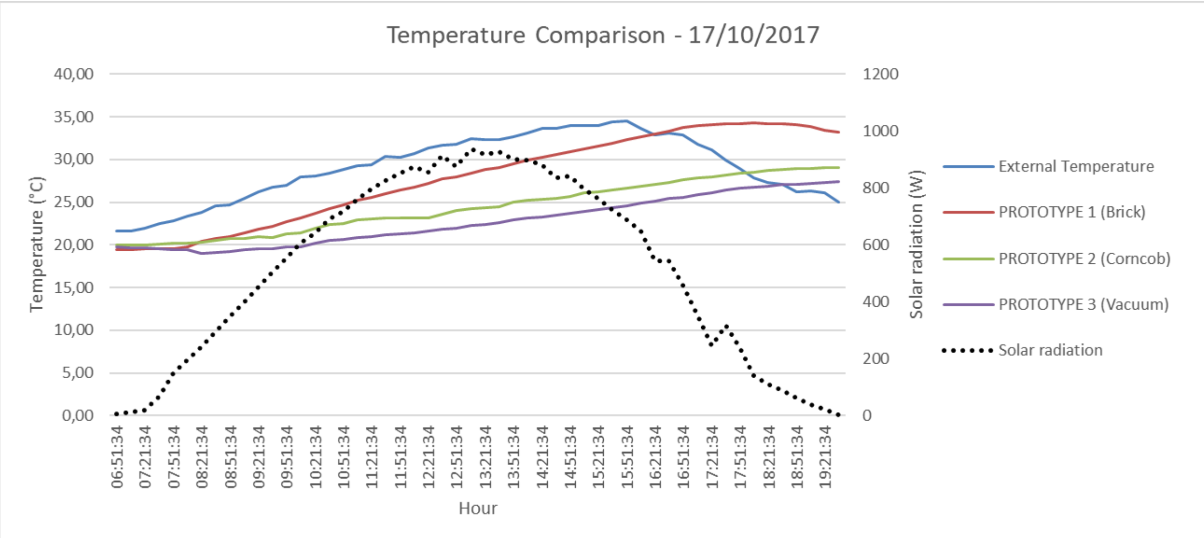
3 RESULTS

After the data were collected and sorted, we selected the days in which Te maximums and solar radiation levels for the periods were presented. These data were transposed in comparative graphs, together with the Ti of the Prototypes 1, 2 and 3, and verified the period necessary to reach the maximum Ti (thermal delay).

3.1. DATA ANALYSIS

The data arranged on October 17, 17, have the maximum temperature of 34.50 ° C, the prototype Ti recorded at the same time of 32.30 ° C, the Ti of Prototype 2 of 26.60 ° C, and Ti of Prototype 3 of 24.60 ° C, differences of 2.50 ° C, 7.9 ° C and 9.90 ° C in relation to Te. Maximum solar radiation was recorded at 938 W / m², occurring steadily and uniformly, with some recorded cloudiness. The maximum of Ti Prototypes 1 (34,30 ° C), 2 (29,00 ° C) and 3 (27,50 ° C) occurred, respectively, with 1:45 min, 3h15min, and 4h of A Teima of the day (Graph 2), and its consistency of temperature of 5.5 ° C (Prototype 2) and 7 ° C (Prototype 3) between the outer and inner maxims. The largest external temperature difference concerning Prototype 3, at 2:15 p.m., with Te = 33.60 ° C, solar energy of 882 W / m², and Ti = 23.30 C (difference of 10.30 C), maintaining the comfort temperature (ABNT, 2008).

Graphic 1 | Temperature Comparison 17/10/17.



Source: Authors.

Table 2 summarizes the relevant data collected for the first analysis phase. We highlight the Ti difference between Prototypes 1 and 2, with an average variation of 2.7ºC, not being so efficient if we buy prototypes 1 and 3. The difference of Ti between Prototypes registered a mean variation of 8.0ºC , differing on October 16, 17 with 4.8 ° C (Graph 3), and April 8 and 4, 2018, with 4.7 ° C, which presented a high solar radiation index, and absence of constant winds.

For these dates, cloudiness periods were recorded for the afternoon period, and a high percentage of relative air humidity, which may have helped to increase Ti. It is important to analyze the thermal delay for Prototypes 2 and 3, being always exceeding 2h and 3h, even in periods of high and constant solar radiation. It is important to point out that, for 10/16/17, the maximum Ti of Prototype 3 remained constant for a period of time up to 2h, that of Prototype 2 remained constant in the interval of 1h45min, while in Prototype 1, this time interval was reduced, of only 30min, causing in the rapid loss of heat.

Table 2 | Data Analyzed First Step. Note: For solar radiation V (variable) and C (constant).

			PROTOTYPE 1 (WITHOUT ISOLATION)			*PROTÓTIPO 2 (CORN COB)*			*PROTÓTIPO 3 (VACUUM)*		
DATE	*Te (°C)*	*SOLAR RAD. MAX. (W/m²)*	*Ti (°C)*	*THERMAL DELAY (h)*	*Ti MAX. (°C)*	*Ti (°C)*	*THERMAL DELAY (h)*	*Ti MAX.(°C)*	*Ti (°C)*	*THERMAL DELAY (h)*	*Ti MAX. (°C)*
04/10/17	32,40	979 – V	27,40	2h45min	31,30	22,60	3h30min	25,60	20,90	4h00min	24,60
05/10/17	34,30	873 – V	31,20	2h00min	33,90	26,30	3h00min	28,80	24,10	3h45min	27,50
16/10/17	31,50	1028 – V	27,30	1h45min	29,00	22,30	2h45min	25,30	21,70	2h30min	24,20
17/10/17	34,50	938 – C	32,30	1h45min	34,30	26,60	3h15min	29,00	24,60	4h00min	27,50
24/10/17	29,00	954 – C	26,50	2h15min	28,60	22,60	3h00min	25,40	19,20	3h15min	22,00
02/11/17	31,70	1000 – C	29,80	2h00min	31,80	26,80	2h45min	28,50	22,20	3h15min	24,50
20/11/17	31,60	1018 – C	28,10	2h00min	31,10	24,70	3h30min	28,20	18,00	3h45min	21,40
23/11/17	33,20	1023 – C	28,90	1h30min	30,60	25,60	2h15min	27,60	17,90	3h45min	20,50
24/11/17	33,90	999 – C	32,00	1h30min	33,40	28,70	1h30min	30,30	22,50	2h00min	24,10
02/12/17	34,20	1154 – C	32,00	2h00min	33,80	28,50	2h15min	31,00	22,20	2h45min	24,70
06/12/17	35,00	999 – C	31,90	2h45min	33,90	29,00	3h15min	31,50	22,50	4h15min	25,30
09/12/17	33,40	1037 – C	29,50	2h45min	31,70	27,40	2h15min	29,10	20,30	3h30min	22,40
10/12/17	36,90	1079 – V	33,40	2h45min	35,00	31,20	3h00min	33,20	23,90	3h00min	25,80
13/12/17	38,10	1062 – C	34,40	1h00min	35,60	30,60	2h30min	33,20	22,90	2h45min	25,70
14/12/17	36,40	953 - V	33,30	1h00min	34,00	31,40	1h15min	32,30	24,00	5h45min	27,20
15/12/17	35,70	1014 – C	34,40	2h30min	35,30	30,50	3h00min	32,90	24,80	4h00min	27,90
16/12/17	38,60	1127– V	34,60	4h00min	38,60	31,70	5h30min	35,90	26,60	5h15min	29,90
17/12/17	37,90	934 – V	33,80	15min	34,50	32,40	15min	33,10	26,60	15min	27,30
21/12/17	34,00	1170 – C	31,60	2h45min	33,30	29,20	3h00min	31,00	24,20	3h45min	26,90
22/12/17	36,80	1161 – V	35,00	2h30min	36,10	32,30	2h45min	33,80	27,70	4h15min	29,40
26/12/17	34,50	1039 – V	31,40	1h45min	33,30	27,80	2h45min	30,70	21,90	2h45min	25,10
27/12/17	36,80	1167 – V	35,70	2h00min	36,50	33,00	2h00min	33,90	26,10	3h30min	29,10
28/12/17	34,40	1006 – C	33,50	1h00min	34,10	31,00	2h15min	32,00	26,50	2h45min	27,90
29/12/17	34,30	1260 – V	31,70	45min	32,80	29,60	1h00min	30,70	25,20	2h00min	26,40
31/12/17	34,50	1175 – V	33,70	1h15min	34,80	31,20	1h45min	32,10	25,70	1h45min	26,80
01/01/18	32,60	1045 – V	31,00	2h15min	32,70	29,80	4h15min	31,60	24,90	3h45min	26,40
03/01/18	33,30	1197 – V	30,60	3h00min	32,10	28,90	2h15min	30,10	22,60	3h30min	23,70
04/01/18	35,20	1042 – C	33,00	2h15min	35,90	29,60	4h00min	32,10	23,90	4h15min	26,90
05/01/18	38,10	1086 – V	35,70	1h45min	37,20	32,80	2h00min	34,40	26,30	1h45min	27,90
08/01/18	31,20	1191 – V	31,00	1h30min	32,00	28,80	1h45min	29,80	23,50	2h00min	24,70
09/01/18	33,00	1029 – C	32,80	1h00min	33,40	30,20	1h30min	31,20	24,40	2h15min	26,00
08/02/18	36,60	997 – C	34,00	2h45min	37,60	30,80	3h45min	34,00	22,10	4h30min	25,40
09/02/18	36,90	1108 – V	33,50	4h15min	35,20	31,20	4h15min	33,50	22,50	4h15min	24,70
10/02/18	33,30	1086 – V	30,10	3h30min	32,90	28,40	4h00min	31,20	19,10	4h30min	22,70
16/02/18	33,70	1000 – C	31,04	1h45min	32,80	28,80	1h45min	30,30	19,70	2h15min	21,50
17/02/18	35,10	1028 – C	32,60	1h45min	34,70	29,10	2h30min	31,90	19,60	3h15min	22,70
18/02/18	35,50	1024 – C	33,90	2h15min	36,80	30,80	3h45min	33,70	22,10	4h30min	25,00
21/02/18	31,50	1099 – V	28,20	15min	28,50	26,50	30min	26,80	16,90	30min	17,10
25/02/18	32,80	979 – C	31,10	1h45min	32,40	28,80	2h15min	30,30	19,00	3h00min	20,40
26/02/18	31,90	1049 – C	29,90	2h00min	31,90	27,90	2h30min	29,80	18,10	4h30min	20,90

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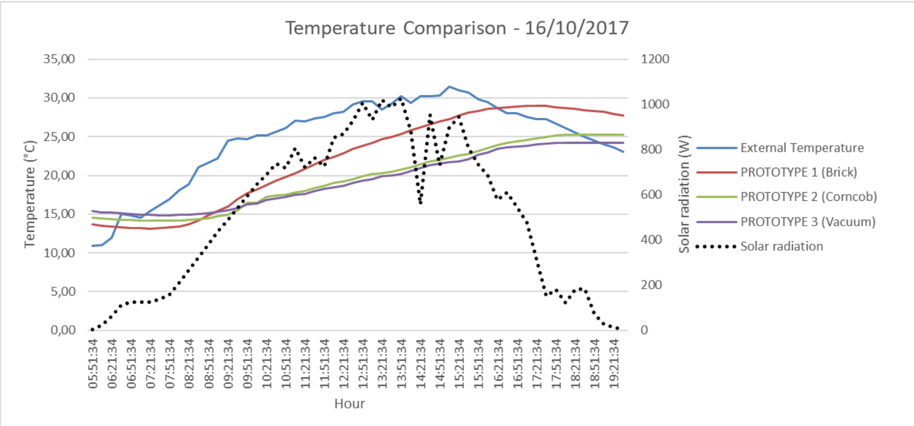
			PROTOTYPE 1 (WITHOUT ISOLATION)			PROTÓTIPO 2 (CORN COB)			PROTÓTIPO 3 (VACUUM)		
DATE	Te (°C)	SOLAR RAD. MAX. (W/m²)	Ti (°C)	THERMAL DELAY (h)	Ti MAX. (°C)	Ti (°C)	THERMAL DELAY (h)	Ti MAX.(°C)	Ti (°C)	THERMAL DELAY (h)	Ti MAX. (°C)
28/02/18	31,70	1045 – V	29,40	1h15min	30,90	27,50	3h30min	29,50	17,70	3h00min	19,70
01/03/18	33,80	1034 – V	32,00	1h00min	32,70	30,40	45min	31,00	20,00	1h15min	20,90
02/03/18	33,10	1052 – V	31,00	2h45min	32,90	29,10	2h45min	30,70	19,70	2h45min	21,00
03/03/18	30,90	789 – V	28,50	3h15min	31,10	27,30	3h30min	29,20	17,60	3h30min	19,30
04/03/18	31,40	930 – V	27,40	7h00min	32,20	26,20	7h30min	29,80	16,90	7h30min	19,80
05/03/18	35,40	996 – C	33,90	2h30min	36,10	31,20	2h45min	32,80	21,60	3h30min	23,40
06/03/18	32,40	1016 – V	30,90	1h30min	32,30	29,40	1h45min	30,50	19,70	1h45min	20,80
23/03/18	32,30	1044 – V	27,20	4h30min	30,00	24,00	6h00min	28,00	19,70	5h45min	23,20
24/03/18	32,70	516 – V	27,00	2h00min	29,20	26,20	2h45min	28,10	21,90	2h45min	23,60
29/03/18	31,10	1054 – V	27,70	3h00min	30,00	26,20	3h15min	28,20	21,30	3h30min	23,30
30/03/18	30,20	918 – V	27,70	2h15min	29,60	26,20	3h30min	28,00	22,20	3h15min	24,00
07/04/18	33,40	786 – V	31,70	3h45min	33,30	27,20	4h30min	29,70	25,60	4h45min	28,10
08/04/18	32,30	767 – C	31,00	1h15min	32,40	27,40	2h00min	29,50	25,80	3h15min	27,70
09/04/18	32,20	762 – C	31,30	2h15min	32,90	27,70	2h30min	29,70	26,00	3h45min	28,00
10/04/18	33,40	773 – V	32,10	2h00min	34,90	28,30	3h15min	30,80	26,40	3h30min	29,00
11/04/18	35,50	757 – C	33,90	2h30min	37,50	29,70	3h45min	32,90	27,90	3h30min	31,00
12/04/18	36,20	801 – C	34,70	2h15min	37,70	30,40	3h15min	33,10	28,50	3h45min	31,20
18/04/18	32,30	760 – C	29,90	3h15min	33,30	25,80	4h15min	29,40	23,60	4h15min	27,20
19/04/18	32,70	727 – C	31,40	2h45min	35,20	26,90	3h45min	30,20	25,20	4h15min	28,40
22/04/18	31,80	711 – C	28,70	4h00min	32,90	24,80	5h00min	28,60	22,60	5h00min	26,80
23/04/18	31,50	705 – V	29,30	45min	30,20	27,00	3h00min	28,50	24,90	2h45min	26,30
24/04/18	30,80	821 – V	28,30	2h00min	29,90	26,20	3h00min	28,20	24,20	2h45min	26,10
25/04/18	31,60	705 – V	28,70	2h00min	31,00	26,40	4h15min	29,10	24,60	4h30min	27,20
28/04/18	32,90	661 – C	31,20	2h30min	34,80	27,20	3h45min	30,40	25,00	3h30min	28,20
29/04/18	33,50	678 – C	31,50	2h15min	34,70	27,40	4h00min	30,90	25,50	3h45min	28,70
08/05/18	30,00	664 – C	28,20	2h45min	30,30	24,40	4h00min	27,10	22,30	3h30min	24,80
10/05/18	30,00	625 – V	28,10	2h00min	29,40	25,30	3h00min	27,20	21,70	3h15min	23,40

Source: Authors.

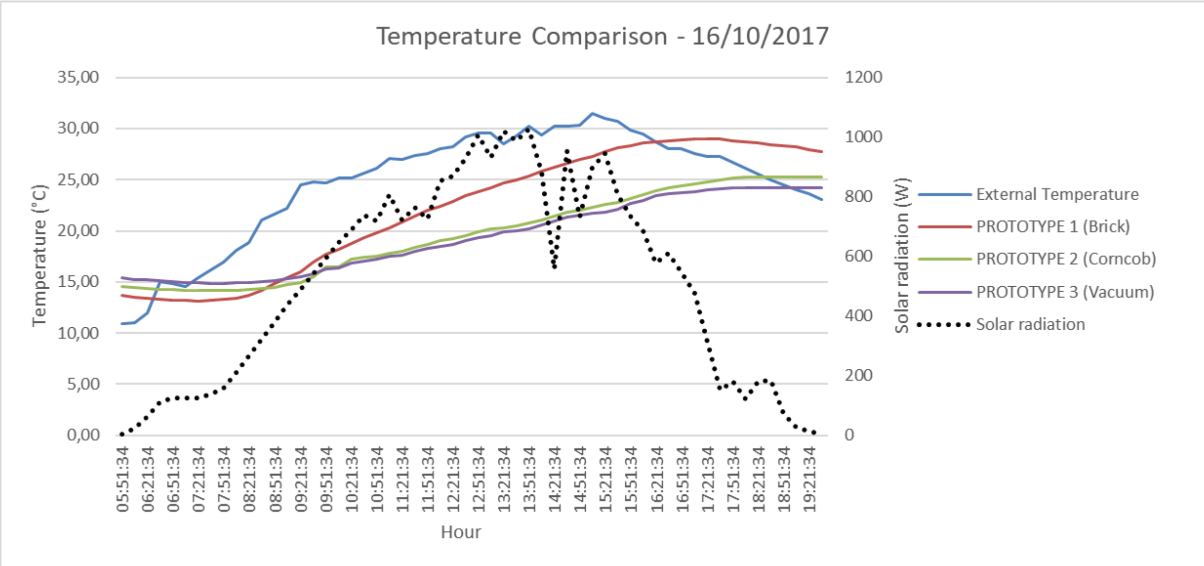
Graphic 2 | Temperature Comparison 16/10/17.



Source: Authors.

The date of 12/29/17 recorded the maximum solar radiation index during the experiment period with 1260 W / m², even with strong cloudiness, and reached the maximum of 34.30 ° C. The variation of Ti presents more intense for Prototypes 1 and 2, being for a long period of the day surpasses to 30 ° C, above the ideal temperature of comfort. In prototype 3 the Ti variation remains small, of 3.30 ° C, while Prototypes 1 and 2 had a Ti variation of 7.90 ° C and 3.90 ° C. It stands out the strong fall of the solar radiation and Te at the beginning of the afternoon, due to the occurrence of rain. It is evident the thermal insulation capacity applied in Prototypes 2 and 3, but Prototype 2 Ti is always superior to Prototype 3, due to the accumulated heat content of the previous day, and the higher density of the insulation material (Graph 4).

Graphic 3 | Temperature comparison 29/12/17.



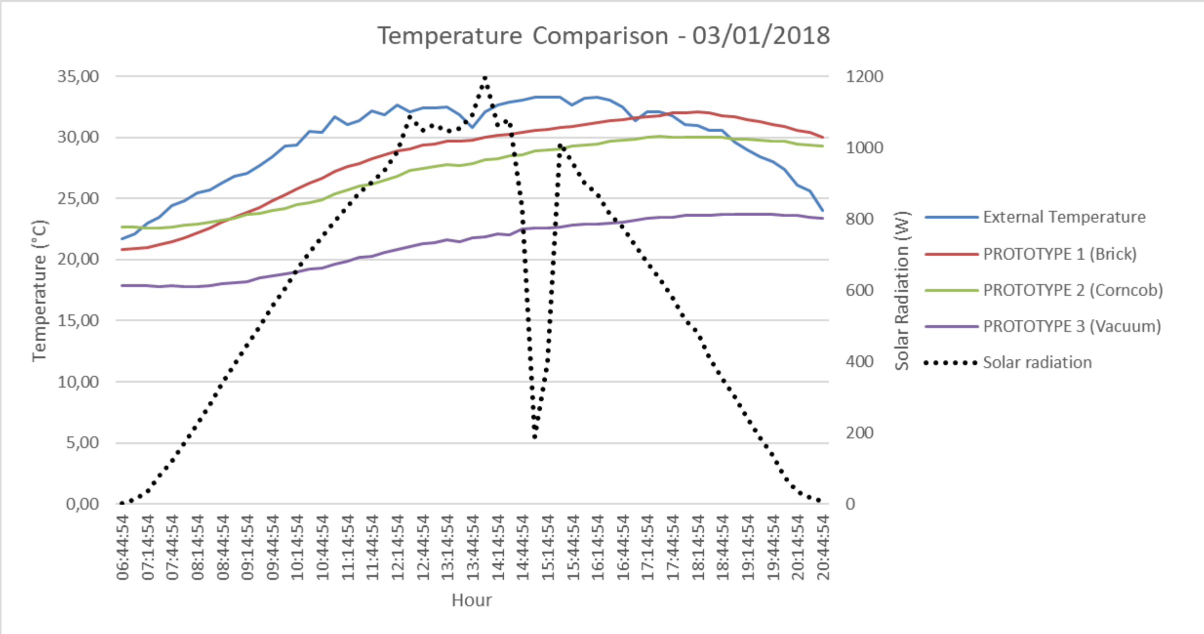
Source: Authors.

It is evidenced the high-density index of the insulation material at the moment of heat loss of the internal environment, with a value of 4 ° C in Prototype 1, 2,20 ° C in Prototype 2 and 0,80 ° C in Prototype 3, for a period of 4 hours. Thus, the thermal insulation material with the vacuum layer stands out if compared to the material applied with the use of corn cob.

On 03/01/2018, it had the second-highest recorded solar radiation index, value of 1197 W / m², and Te variation of 14.20 ° C. Prototype 3 recorded maximum Ti of 23.70 ° C, remaining within the comfort temperature range, as presented in NBR 16401 (ABNT, 2008). For Prototypes 1 and 2, the maximum Ti was higher than 30.00 ° C.

The absence of insulation in Prototype 1, caused a Ti variation of 11.30 ° C, and the heat accumulated from the previous day in Prototype 2, the recorded Ti variation of 7.50 ° C (Graph 5), this due to high thermal transmittance (U) of the composition of the brick wall, because the moment the masonry cools, the internal temperature drop process accelerates, which does not occur with prototypes with insulation application. Even the experiment taking place in the summer period, it is now proven that the heat loss is slowed down for the winter period when the wall has thermal insulation elements in its composition.

Graphic 4 | Temperature comparison 03/01/2018.



Source: Authors.

3.2. DATA ANALYSIS - 48H PERIOD

Thus, it becomes important to analyze the behavior of the materiality of the Prototypes for a 48h interval, and thus to analyze the behavior regarding the accumulation/loss of heat between the diurnal and nocturnal periods. For this analysis, the days that presented high solar radiation rates, Te and Ti were selected.

In the period of 21 and 22 December 17 (Graph 6), the solar radiation index approaches 1200 W / m², highlighting the accumulation of atmospheric heat, with high Te indexes, mainly on day 22, higher than 35 W. To this day, the solar radiation was in constant elevation in the morning, contributing to the accumulation of heat. Graph 6 shows the constancy in the Ti difference of the prototypes, with loss of heat for the night, but more accelerated in Prototype 1, due to the absence of insulation. Prototype 2 showed a Ti index higher than 33.00 ° C, while in Ti prototype 3 Ti was recorded at 29.40 °

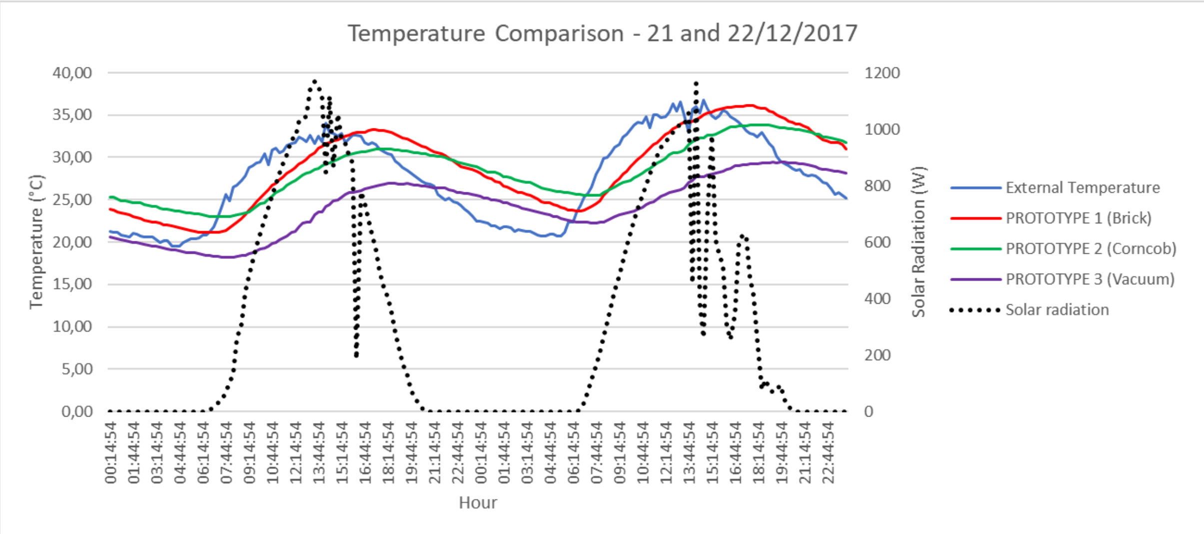
The variation of Te and Ti from day 21 to day 22, which remained constant, with a difference of maximum of 2.80 ° C for Te and Ti of Prototypes 1 and 2, and 2.50 ° C for Ti of Prototype 3. By maintaining a similar difference, and in a lower register, the accumulation of heat in the internal environment from one day to the other is not characterized.

The data recorded for the days 16 and 17 of February of 2018 (Graph 7), stands out a small variation of the solar radiation index of overnight (28 W / m²), and a difference of 1.40 ° C to Te on the second day. The variation of Ti of Prototype 1, recorded at 1.90 ° C, and Prototype 2 of 1.60 ° C, higher than the variation of Te, can be considered here, and therefore the heat accumulation can be considered. For Prototype 3, the Ti variation recorded was 1.20 ° C, lower than the Te variation, thus not characterizing the accumulation of heat.

3.3. FEATURED PATHOLOGIES

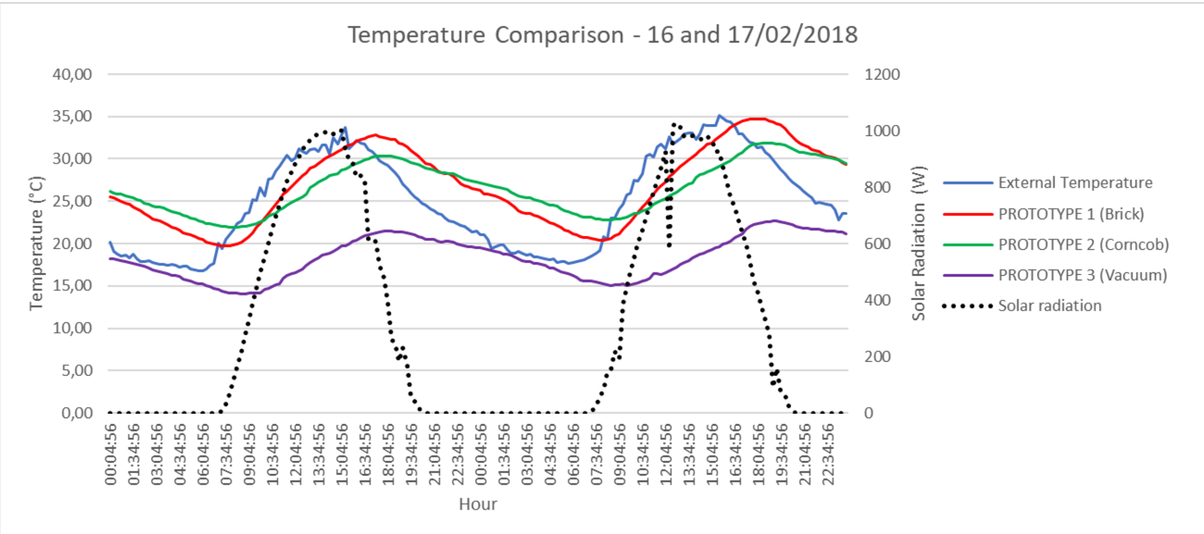
Due to the prototypes being exposed to direct solar radiation, rain, wind, and constant temperature changes, there were cracks in the coating plates in vacuum insulation. Such pathology probably occurred due to the difference in thermal expansion of the materials, as well as the lack of adhesion between acrylic and mortar. The behavior of the fissures was collected periodically, and during the study period, there was no worsening of the pathologies, and there were no falls of mortar parts. It can be said that this behavior is related to the use of fiberglass mesh, improving the adhesion between materials. For the insulation coating plates based on a corncob, they did not present visible pathologies and should undergo in-depth analysis in this case, because the materials with different behavior to heat, dilating differently.

Graphic 5 | Temperature comparison 08 e 09/01/2018.



Source: Authors.

Graphic 6 | Temperature comparison 16 e 17/02/2018.



Source: Authors.

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4 CONCLUSIONS

With the growing environmental concern, the importance of the use of constructive components that contribute to lower energy consumption and of fossil fuels in the manufacturing process, as highlighted by Dutra (2010), stands out.

Concluding the analysis of the presented data, it is verified that the data analyzed for Prototypes 2 and 3, in which the coating plates were fixed with the application of corncob and vacuum layer, registered a significant reduction of Ti when compared to Prototype 1 (uncoated) and Te. The reduction of Ti to Prototype 3 is more markedly emphasized. When the data of the 67 days recorded in Table 2 were analyzed, the mean value recorded for the maximum Ti difference between Prototypes 3 and 1 was 8, 05 ° C, while the mean difference for Prototypes 2 and 1 was 2.74 ° C.

It is important to emphasize that either Ti data presented according to the parameters established by NBR 16401-2 (2008) and by Givoni (apud LAMBERTS; DUTRA and PEREIRA, 2004), and it is necessary to deepen the study related to the percentage of relative humidity air.

For the data recorded concerning Prototype 2, it is worth mentioning that in previous studies, they already present information when the thermal conductivity of the billet bush applied for thermal insulation (λ = 0,057 W/m.K), (ASDRUBALI et al., 2015), being necessary the revision of the method of application of the material in constructions, considering that the index is considered ideal for its use, but did not present efficient in its application in the prototype.

It is also worth noting that the study is still under development, seeking to deepen the information related to the determination of the thermal conductivity of the plate with vacuum interior (following the Hot Plate and Cold Plate methods, according to NBR 15.220 (2003), so that consistent data can be used in the development of computational simulation for the energy efficiency of buildings.

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