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Thermal Analysis Of Tetra Pak Packaging As Thermal Insulation

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ABSTRACT:- The aim of this study is to evaluate the thermal performance of long-life packaging when used as thermal insulation in the coverage of reduced scale residential models. As a way of reuse, it is possible to use the packaging in the confection of a sustainable alternative to thermal insulation that can be installed in roofs of buildings. The constructed models recreated the ambient conditions of a real building environment and allowed the realization of several experiments through the exchange of the coverage material. By means of recording equipment, the internal temperature data of the models were obtained and compared. The results show that when long-life packages were used as roof undercoverage and installed with their aluminized side facing down, the mean temperature reduction observed between two prototypes covered by the same roof material was 2.62°C. By reversing the side orientation, the reduction provided was 2.32°C and when used as lining, 2°C. In this way, the analyzed material proved to be an efficient option to improve the comfort conditions in buildings, aiding in the reduction of the internal temperature of the enclosures by acting as a reflective element to incident solar radiation.
KEYWORDS: Thermal comfort, thermal insulation, sustainability.

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I. INTRODUCTION

The thermal comfort in residences and industries is essential for the good performance of the activities in these environments. In general, this situation aims at reducing costs for construction. Due to the strong adhesion between the layers of the packaging, it becomes impossible to separation them economically. As a way to improve environmental thermal comfort, the use of long life packaging can be an excellent alternative as a thermal insulation. In general, reuse of packaging contributes to sustainable development.

As a way to improve thermal comfort and reduce construction costs, the use of long-life packaging in buildings roofs can be an option. This material is composed of several layers of three different materials, being, 75% paper, 20% polyethylene and 5% aluminum. The paper function in the packaging is to provide stability and traction resistance; the polyethylene is to protect against the humidity from the external environment; and the aluminum funcion is to block the passage of light and oxygen to the inside. The use of packaging can be justified by the fact that aluminum contributes significantly to the reduction of the ambient temperature, reflecting about 95% of the solar radiation (DA TRINDADE; MARTINI) [1].

Labaki et al. [2] experimentally investigated the thermal performance of the asbestos-based tiles without slab, tiles with blankets made of long life packaging in three situations. The first was blanket made of open boxes, the second was made with aluminum surface in contact with the tiles in contact with the indoor air, and the third was in closed boxes.

Selegatto and De Paula [3] investigated the re-use of long life packaging for coating of surfaces in domestic animals' houses with metallic coverings. There was obtained a mean reduction of 6.8°C in comparison with conventional domestic animals.

Michels et al. [4] analyzed the efficiency of different types of blankets found in the construction market and compared the performance by long life packaging. The results shows that radiant barriers formed through long life packages have the lowest thermal performance compared to those found in the construction market.

This work presents an experimental analysis whose objective is to study the thermal behavior of long-life packaging, verifying the magnitude of the reduction of temperature inside an enclosure from the use of this product and, concomitantly, adjusting its most appropriate destination, avoiding sending it to landfills.

II. EXPERIMENTAL INSTALLATION

In order to carry out the study, it was necessary to recreate the environmental conditions to which a building is exposed. Due to the inviability of performing experiments in real scale installations, because these have large dimensions, test cells were used, that is, reduced scale models that would contribute to the reduction of the cost and would also allow the realization of different tests. Two test cells were constructed, with structures made of SAE 1020 steel tubes, drawn, of square cross-section with external dimensions of 15 mm and thickness of 1 mm, welded in the form of a parallelepiped of 45 cm height, 60 cm length and 53 cm wide. After built, the structures had their sides and bottom faces closed by plywood sheets of 3 mm thickness.

The design of the roof structure of the test cells took into consideration the recommended minimum slopes for each type of tile that would be used. In this way, two types of structures were constructed. For the fiber-cement, aluzinco and "sandwich" aluzinco tiles, the structures had a slope of 28% or 12°, while the structures for concrete and clay tiles had a slope of 49% or 23°.

In addition to the slope, the roof structures took into consideration the installation of the packaging blankets. For this, it was opted for the construction of removable structures, fixed through bolts and nuts, in order to facilitate the installation procedure of the blankets when used as lining or undercoverage. Each roof structure had 4 purlins (wooden beams that give support to the roof) with 2 cm of height. This dimension was recommended by Schmutzler [5] to ensure that, when the blanket was installed in the undercoverage position, it would not touch the roof, thus ensuring a perfect reflection of the heat. Fig. 1 shows the roof structures.

Figure 1. Roof structures (A) Roof structure for clay and concrete tiles; (B) Roof structure for fiber-cement, aluzinco and "sandwich" aluzinco tiles.

For the confection of the thermal blankets, 15 long-life packages were collected, intended for the preservation of dairy products. The packages were opened, cleaned, disinfected and then attached through a pneumatic stapler. The thermal blanket used as lining in the test cells was formed by 6 packages, while the blanket for roof undercoverage was formed by a total of 9 packages. The blankets installed in the test cells are shown in Fig. 2.

Figure 2. Blankets installed in test cells (A) Blanket as lining; (B) Blanket as roof undercoverage.

Fig. 3 shows the test cells with the different types of roof coverages used for the research.

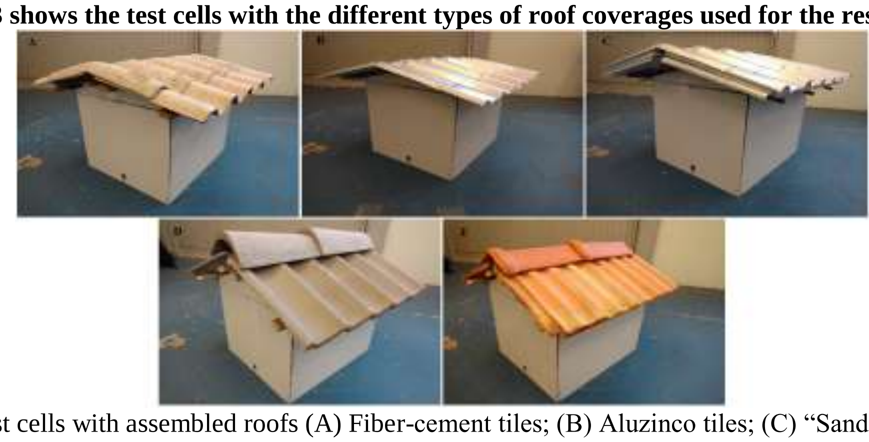

Figure 3. Test cells with assembled roofs (A) Fiber-cement tiles; (B) Aluzinco tiles; (C) "Sandwich" aluzinco tiles; (D) Concrete tiles; (E) Clay tiles.

To perform the data collection relating to the internal temperatures of the test cells, it was decided to use an electronic prototyping platform from the manufacturer Arduino. This platform is an electronic board composed of a microcontroller and input/output circuits that can be easily programmed, using a C/C++ based language, through the connection to a computer, via USB. Temperature and humidity sensors of the type DHT11 were also acquired, which allow temperature readings between 0 and 50 ºC with an accuracy of ± 2 ºC and relative humidity between 20 and 90%, with an accuracy of ± 5%. On the electronic boards were connected dataloggers, equipments used to record and store data in the moment in which they occurred. For the programming of the equipments sample codes were used, available in the manufacturer's website. The created code allows the meter to record and store temperature and humidity data at a user-defined interval. The mounted measuring instrument is shown in Fig. 4.

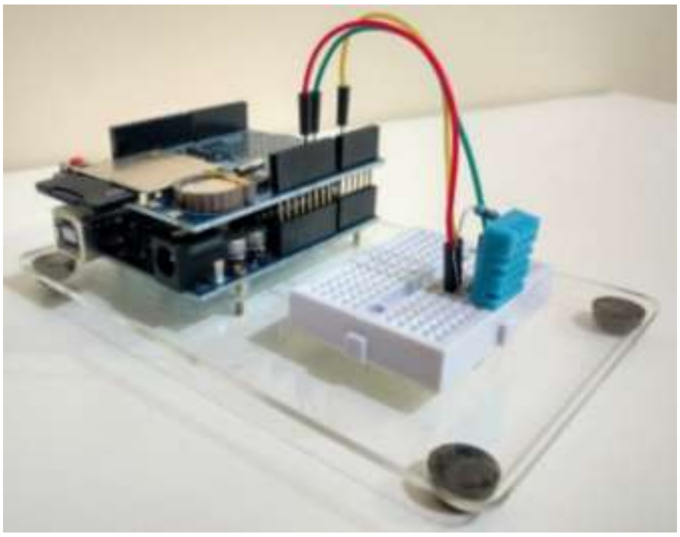

Figure 4. Measuring instrument

The data collection was divided into several stages which consisted in a series of temperature measurements in the interior of the developed prototypes, when exposed to solar radiation. They ocurred between 10 a.m. and 5 p.m., due to higher incidence of solar radiation at the local and occurred with a 5 minute interval between the temperature takes. The place of testes was flat and far from big constructions that could cause shading on the prototypes, which would interfere in data collection. Also, there should be a minimum distance of 2 meters between the prototypes, in order to avoid shading between them.

The first stage of measurement consist in analysis of the feasibility of the project, i.e., an investigation regarding the thermal behavior of the long-life packaging, verifying if its use as thermal insulation would be possible and efficient. The two following stages were a data analysis with the objective of seeking the maximum efficiency of the packaging thermal blanket, whether it was in lining or undercoverage function and with its aluminized side facing the tile or the inside of the prototype. The most efficient configuration was used for the sequence of the project.

From the fourth to the seventh stage, comparative tests were carried out where the prototype with fiber-cement coverage and insulation blanket made from packaging had its thermal performance compared to other types of roof coverages. The purpose of these stages was to verify how the chosen configuration would behave in relation to materials considered superiors.

In the eighth stage, an extra layer of insulation blanket was added to the initial configuration, in order to quantify the possible increase in the thermal performance of the material. In the ninth stage, the prototype no longer used the blanket as an insulating element of its roof, but rather as an inner lining of its walls, in order to compare its performance with the initial configuration.

III. RESULTS AND DISCUSSION

3.1 1st Stage

The first stage of the pre-determined series of measurements consisted, as previously commented, in an feasibility analysis of the study, thus being the most important. For this, both test cells were assembled with fiber-cement roofs and in one of them was added the insulation blanket composed of long-life packaging. Initially, the blanket adopted the undercoverage function, with the aluminized side facing down. In Table 1 it is possible to observe the recorded minimum, maximum and mean temperatures for the interior of both test cells.

Table 1. Results obtained in 1st stage (FCUD: Fiber-cement tile with undercoverage – aluminum side facing down and FC: Fiber-cement tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCUD	17	22	20.24
FC	19	25	22.86
Reduction	1	5	2.62

Through the previous table, it can be seen that the test cell that had the insulating blanket of long-life packaging, with the undercoverage function and its aluminized side facing down, had its internal temperature reduced by 2.62 °C when compared to the test cell without the insulating material. Thus, it was found that the use of packaging as thermal insulation was feasible, as it managed to significantly reduce the internal temperature of the test cell, reflecting the incident solar radiation on it. With this, the measurements were continued, aiming to seek the maximum efficiency for the insulation material, in the context of the physical arrangement.

3.2 2nd Stage

Continuing the study, the second stage had as objective to verify if, by changing the function of the insulation blanket, the efficiency would also be altered. For this, both test cells remained covered by fiber-cement tiles, but in one of them the insulation blanket was installed as lining, with its aluminized side facing down. In Table 2 it is possible to observe the recorded temperatures.

Table 2. Results obtained in 2nd stage (FCLD: Fiber-cement tile with lining – aluminum side facing down; FC: Fiber-cement tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCLD	17	23	21.09
FC	18	25	23.13
Reduction	1	3	2.04

Analyzing the previous table, can be observed that the insulating blanket installed as lining and with its aluminized side facing down was able to reduce by 2.04°C the internal temperature of the test cell, when compared to the configuration without insulation material. It was found, again, that the use of packaging as an insulator was feasible, but this time, using it as lining, the presented efficiency was lower, resulting in a reduction approximately 0.6°C lower than that obtained with the blanket installed as undercoverage. In this way, for the next measurements, had been set that the insulation blanket would be used as undercoverage.

3.3 3rd Stage

The third measurement stage occurred in a similar manner to the first, in which both test cells were covered by fiber-cement tiles and in one of them the insulation blanket was installed in the undercoverage function. This is due to the fact that the blanket installed this way showed the highest temperature reduction recorded until then. However, at this time the blanket was reversed, that is, its aluminized side was turned upwards (facing the roof), in order to evaluate if the efficiency would be altered. In Table 3 it is possible to observe the recorded temperatures.

Table 3. Results obtained in 3rd stage (FCUU: Fiber-cement tile with undercoverage – aluminum side facing up; FC: Fiber-cement tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCUU	17	23	21.34
FC	19	26	23.66
Reduction	1	3	2.32

Through the previous table, it is observed that the insulating blanket with the aluminized side facing upwards decreased the internal temperature of the test cell by 2.32 °C, which represents a considerable reduction, but lower than that obtained when it had his aluminized side facing downwards. In Table 4 it is possible to observe the obtained temperature reductions in the first three measurement stages.

Table 4. Comparison between the first three measurement stages (FCUD: Fiber-cement tile with undercoverage – aluminum side facing down; FCLD: Fiber-cement tile with lining – aluminum side facing down; FCUU: Fiber-cement tile with undercoverage – aluminum side facing up)

Temperature reduction (°C)			
	Min.	Max.	Mean
FCUD	1	5	2.62
FCLD	1	3	2.04
FCUU	1	3	2.32

By analyzing the values in Table 4, it was defined that the blanket installed as undercoverage and with its aluminized side facing down was the most efficient configuration and would, therefore, be used for the following stages. Analyzing the aesthetic issue, using the blanket this way is interesting, as it can make the final visual more pleasint to the eyes of the residents, providing a better aesthetic finish to the environment, since otherwise, the existing on the packaging would be exposed. In addition, if the aluminized side facing up is used, the insulation blanket may have its reflective properties seriously compromised due to deposition of dirt, as happens in residential roofs over the years. Accumulated dust and pollution tend to reduce the reflectance of the material (quotient of the radiation rate reflected by a surface by the radiation rate incident on the same).

3.4 4th Stage

The fourth measurement stage marked the beginning of the compative study between the test cell equipped with the packaging insulation blanket, in its configuration taken as more efficient, and the test cells covered by other types of roof coverages. As previously mentioned, the objective of this and the next stages was to evaluate the thermal behavior of the low cost alternative solution proposed in this work, compared to the materials most commonly used in roofs of buildings. For this, one of the test cells was assembled with the insulation blanket in the undercoverage function, with the aluminized side facing down, and covered by fiber-cement tiles, while the other test cell was covered by aluzinco tiles. In Table 5 it is possible to observe the recorded temperatures.

Table 5. Results obtained in 4th stage (FCUD: Fiber-cement tile with undercoverage – aluminum side facing down; AT: Aluzinco tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCUD	16	23	20.42
AT	17	25	22.86
Reduction	1	3	2.44

In Table 5, it is possible to observe that the use of the packaging thermal blanket together with the fiber-cement coverage was able to reduce the internal temperature of the test cell by 2.44 °C, when compared to the other cell covered by aluzinco tiles. This result demonstrates how, despite the high reflectivity, the aluzinco tile was not able to prevent the internal temperature of the test cell to reach high values. This is due to the high thermal conductivity of the material, which offers almost no resistance to the passage of heat by conduction.

3.5 5th Stage

The fifth measurement stage followed the comparative tests. This time, the base prototype (fiber-cement coverage and packaging insulation blanket as undercoverage with the aluminum side facing down) had its performance evaluated before a prototype covered with "sandwich" aluzinco tiles (two sheets of aluzinco with a layer of polystyrene in its interior). In Table 6 it is possible to observe the recorded temperatures.

Table 6. Results obtained in 5th stage (FCUD: Fiber-cement tile with undercoverage – aluminum side facing down; SAT: "Sandwich" aluzinco tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCUD	17	25	22.39
SAT	15	24	20.66
Increase	1	3	1.73

Table 6 shows that in this measurement, the prototype with the insulating blanket and coverage of fiber-cement tiles presented higher internal temperatures than the other prototype, which was covered by aluzinco tiles with a layer of polystyrene. The mean difference of displayed temperature was 1.73°C. The superior thermal performance presented by the "sandwich" aluzinco tile is due to the use of the polystyrene in its interior. With a thickness of 30 mm and thermal conductivity of 0.035 W/m.K, this material offers great thermal resistance to heat transfer by conduction which, when associated with the high reflectivity of the aluzinco, results in the reduction of the internal temperature of the analyzed enclosure. Despite the lower performance, the material presented here as an alternative termal insulator has fulfilled its role. The objective of this work is to present a sustainable option aimed at the low-income population. Therefore, the results of this measurement should not minimize the relevance of the research.

3.6 6th Stage

The sixth stage of measurement was again a comparative test, where, at this time, the prototype covered by fiber-cement tiles and with the insulation blanket was confronted by another prototype, this one covered by clay tiles. In Table 7 it is possible to observe the recorded temperatures.

Table 7. Results obtained in 6th stage (FCUD: Fiber-cement tile with undercoverage – aluminum side facing down; CT: Clay tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCUD	15	24	21.62
CT	14	23	20.18
Increase	1	3	1.44

Thoruh the previous table, it is possible to observe that the prototype that contained the insulating blanket presented higher internal temperatures than the other prototype, covered by clay tiles. The mean temperature difference was 1.44°C. According to Bueno [6], the exchange of humidity between the clay tile and external and internal air explains the better thermal performance of this material. This happens due to the porosity of the material, which allows humidity to be absorbed from the air. This humidity is evaporated using part of the incident solar energy, which is converted into evaporation energy, not heating the tile. Although it presented lower thermal efficiency, the configuration of the prototype containing the recycled material blanket did not result in much higher internal temperatures than those of the prototype with clay tiles. Furthermore, the cost of a roof composed by clay tiles is high, both by the unit value of the tile as the required structure for its support. Again, since the objective of this paper is to present a sustainable alternative to reduce the internal temperature of low-income families residences, the results of this measurement should not reduce the relevance of the research.

3.7 7th Stage

The seventh stage of the planned measurements consisted, again, in a comparative test, this time between the prototype covered by fiber-cement tiles and with the packaging blanket and a prototype covered by concrete tiles. Table 8 shows the results obtained in this tests.

Table 8. Results obtained in 7th stage (FCUD: Fiber-cement tile with undercoverage – aluminum side facing down; CT: Concrete tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCUD	19	24	22.18
CT	16	23	20.66
Increase	1	3	1.52

Through the previous table, it is observed that the prototype that contained the insulation blanket presented higher internal temperatures than the other prototype, covered by concrete tiles. The mean temperature difference was 1.52°C. Again, the superior thermal performance of the concrete tile is explained by the porosity. The more porous the material, the greater its permeability, which allows it to incorporate more humidity, or even liquid water, resulting in lower tile temperature throughout the day. The concrete tile is a superior material to the fiber-cement tile. Despite this, the addition of the insulating blanket made of long-life packaging allowed to reduce the termal performance difference between these materials, without adding cost. In this way, this measurement allowed, once again, to prove the efficiency of the sustainable insulation blanket. At the end of this stage, were finished the comparative tests between the prototype covered by fiber-cement tiles containing the insulation blanket and the prototypes covered by materials commonly used in civil construction.

3.8 8th Stage

The eigth measurement stage had as objective to verify wether, by doubling the thickness of the insulation blanket made of packaging, the thermal efficiency of the material would increase. The thickness of long-life packages may vary acoording to the unit analyzed and the manufacturer. The packages used in this study had a mean thickness of 0.45 mm, thus, when using an insulation blanket composed of two layers of the material, the final thickness resulted in approximately 1 mm. To perform this stage, both prototypes were covered by fiber-cement tiles, as was done in the first three measurements. In one of them, the insulation blanket was installed, again, in the undercoverage function. In Fig. 5 it is possible to observe the insulating blanket used for the measurement.

Figure 5. Roof structure with double-layer blanket.

Table 9 shows the recorded temperatures.

Table 9. Results obtained in 8th stage (FCDU: Fiber-cement tile with double-layer undercoverage; FC: Fiber-cement tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCDU	16	24	21.04
FC	17	28	23.89
Reduction	1	4	2.85

The previous table shows that the prototype containing the double layer insulation blanket had a mean internal temperature 2.85 °C lower than the other prototype. In relation to the first of the measurement stages, where a single blanket was used as undercoverage, the addition of a new layer of insulating material reduced the mean internal temperature by 0.23 °C, which represents approximately 8.7% of improvement in thermal performance. As aluminum reflects 95% of the incident solar radiation on it, the application of a second layer of the material did not significantly alter the results. From the point of view of the use of the material, it is not interesting to use two layers of insulation, because it is necessary to double the amount of packages to obtain a small improvement. With the same amount of material, it would be possible to apply the insulation blanket in two residences, providing better comfort conditions to more people.

3.9 9th Stage

The ninth and final of the measurement stages did not evaluate the efficiency of the long-life packaging blanket as a component of the roof, but rather as a thermal insulation element of the walls of the prototype. For this, the packages were attached through a pneumatic stapler and fixed to the inner walls of the test cell by means of double-sided adhesive tape. The packaging were installed with the aluminized side facing inwards, as can be observed in Fig. 6. For this stage, both prototypes were again covered by fiber-cement tiles.

Figure 6. Inner lining of the prototype

In Table 10, it is possible to observe the recorded temperatures.

Table 10. Results obtained in 9th stage (FCIL: Fiber-cement tile with inner lining; FC: Fiber-cement tile)

Temperatures (°C)			
	Min.	Max.	Mean
FCIL	16	23	20.83
FC	18	26	23.28

Reduction	2	3	2.44

Observing the previous table, it is verified that the use of long-life packaging as thermal insulation of the walls of the test cell resulted in a reduction of 2.44 °C in the internal temperature, when compared to the other test cell. The results obtained in this measurement indicates that, both as roof undercoverage and as inner lining of the walls, the recyclable material is efficient as thermal insulation, presenting similar temperature reductions. However, due to the thermal performance similar to the blanket as undercoverage, the use of packaging as inner wall lining is not interesting, since the amount of material required for such is greater. As stated earlier in this paper, 9 long-life packages were used to make the roof undercoverage blanket, while 16 packages were required for the inner walls lining blanket. In this way, it is possible to obtain the same temperature reduction, or even higher, using less material.

IV. CONCLUSIONS

The present work had as its initial objective to evaluate the thermal performance of long-life packaging as thermal insulation. Compared to a prototype without the insulation material, the addition of the packaging thermal blanket as undercoverage of the roof, with its aluminized side facing downwards, reduced the mean internal temperature by 2.62 °C. By positioning the aluminized side up, the mean reduction was 2.32 °C, whereas when using the mantle as lining, the mean reduction achieved was 2 °C. These values, although smaller, still represent a considerable improvement in the analyzed thermal conditions.

It was also observed that by doubling the thickness of the thermal blanket, the obtained values were higher, resulting in a mean reduction of 2.85 °C. When using the material as inner lining on the walls of the prototype, the reduction was 2.44 °C. However, the greater amount of material needed to obtain these numbers makes the use of the blankets in these ways at a disadvantage.

Through the results, it was observed that, even when using the packaging thermal blanket as undercoverage of fiber-cement tiles, which are a cheap material with low thermal performance, lower internal temperatures can be obtained than those using aluzinco tiles, material with higher cost. Still, when compared with materials considered superior, such as clay, concrete and "sandwich" aluzinco tiles, the configuration used, although not providing lower temperatures, allowed to reduce the difference between its thermal performances.

The large-scale implementation of the theme addressed in this work would make it possible to achieve several ecological, economic and social benefits, by avoiding the destination of this material to dumps and sanitary landfills; reducing the need for air conditioners and fans where the solution is applied and encouraging environmental education, contributing to the formation of a sustainable mentality.

The experimental results allow to verify that the analyzed material is an efficient option to improve the comfort conditions in buildings, helping to reduce the internal temperature of the enclosures by acting as a reflective element to the incident solar radiation.

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