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THERMAL PAINT PRODUCTION: TECHNO-ECONOMIC EVALUATION OF MUSCOVITE AS AN INSULATING ADDITIVE

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ABSTRACT

Muscovite is known by its thermal and electrical insulating properties. Based on this, it was hypothesized that its addition on paints should increase the thermal resistance. The use of muscovite as mineral insulating is pointed out as advantageous due to its low cost compared to other materials used for this purpose, such as the ceramic microsphere. The use of a low cost material could open the access to the medium and low income families, implying two aspects: the life quality increase by thermal comfort and the increase of energy saving. Thus, this part of the population could open a new market to thermal paints.

Aiming to contribute to this issue, this work evaluated the thermal insulation performance of commercial paints containing muscovite additions and determined the economic evaluation for its industrial production. The thermal paint was formulated by adding 10%, 20% and 40% of muscovite to the commercial paint. This was applied on steel reinforced mortar boards. Thermal insulation tests were carried out in bench scale using an adapted box. The economic evaluation of the industrial production of muscovite-based thermal paint was conducted, considering the Brazilian economic market in this activity. The results showed its ability as an insulating agent due to a reduction of 0.667 °C/mm board by the addition of 40% muscovite. The economic analysis also demonstrated the feasibility of the thermal paint industrial production. The payback is favorable to 5 years when compared to the Selic short-term lending rate, with 21.53% of internal rate return and a net present value of US$ 15,085.76.

Keywords: thermal paint; muscovite; energy saving; thermal comfort

1. INTRODUCTION

Climate changes are responsible for the average temperature increase on Earth. Humans need to stay in a certain area of thermal comfort to perform their routine activities better (COSTELLO et al. 2009) (RUPP et al. 2015). For this purpose, fan and air conditioning (AC) systems are used. As a consequence, the demand for the AC equipment is increasing. The higher the use of AC systems, the greater the energy consumption (DJONGYANG et al. 2010) (STEEMERS; YUN, 2009). Nowadays, countries in development, such as Brazil, are facing water and energy crisis, requiring the use of thermal power plants to meet the demand. In this context, the development of new technologies that make buildings more energy efficient and offer an adequate thermal comfort is essential (WIJEWARDANE; GOSWAMI, 2012) (AZEMATI et al. 2013).

The global energy consumption has been growing, particularly in order to obtain thermal comfort in buildings (YANG et al. 2014). In Europe, the residential sector accounted for 26.6% of the final energy consumption in 2005. In Portugal, the energy content used for the buildings' thermal comfort already has a significant impact on global energy demand, and about 22% of the energy is used in residential buildings (DIAS et al. 2014). In Brazil, the energy consumption in homes regarding the use of

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AC system represents 20% of the national average (FREIRE et al. 2008). This consumption tends to be higher in regions where both winter and summer are extreme.

One barrier to improve the thermal performance is the financial issue. Currently, the initial costs for a sustainable housing are high. Therefore, the low-income population is unable to afford the costs and many consumers prefer more affordable options, even with the possibility of recovering the investment in a few years, due to a reduced energy bill (TAJIRI; CAVALCANTII; POTENZA, 2011). Thus, the development of a lower-cost alternative thermal insulation has a major importance (IKEMATSU 2007).

Thermal insulation coatings have acquired market because of its efficiency, especially when weather conditions are not extreme (DORNELLES 2008). Among the specific additives which may be incorporated into paints, the microspheres, whose particles are smaller than 200 micrometers in diameter, are preferred best. They show several differences compared to non-spherical additives, such as a smaller volume-area ratio that leads to a minor paint viscosity increase (BARBOZA; DE PAOLI, 2002).

The microspheres may be solid or hollow; these last ones have more applications. Examples of microspheres are glass, ceramic, carbon, graphite, or polymer (acrylic, poly vinyl chloride, polystyrene). Due to the “bubbles" air incorporation into the hollow glass microsphere, the material shows dielectric constant and good thermal insulating properties. It also results in low density (0.15 to 0.40 $g.cm^{-3}$) compared to conventional additives, for example, the glass spheres density (2.5 $g\ cm^{-3}$) (BARBOZA; DE PAOLI, 2002; ANON 2016).

Besides its morphology and density, muscovite is quite flexible, elastic, with high tensile strength, and it can significantly withstand mechanical pressure perpendicular to a cleavage plane, but along the plane, it can be easily separated into very tiny leaves that are fireproof and not combustible. Muscovite is low-cost and there are mineral reserves available in Brazil for its exploitation, too (BRASIL (DNPM) 2014). In the industry, muscovite plates are designed to be used in extreme conditions and have good properties such as heat retardant, flame resistant, low

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thermal conductivity, good electrical insulation, high mechanical strength and nontoxic.

Based on these characteristics, the interest for a muscovite evaluation as a refractory thermal paint additive was developed. The purpose of this study was to perform a techno-economic evaluation for the industrial preparation of muscovite-based thermal paint. The aim behind this work was to obtain a low-cost thermal paint based on muscovite addition for its use in internal and external building walls.

2. RESEARCH METHODOLOGY

2.1. Preparation and thermal evaluation of paints with muscovite

Thermal paints were prepared by adding 0%, 10%, 20% and 40% by weight of muscovite to commercial high quality paint (Suvinil® Latex Premium, velvet matte, snow white). The mixing process was manual without further modification. The paint containing muscovite was diluted to 50% using tap water, and applied in steel reinforced mortar boards, using a paint brush. The boards did not receive plasterwork base, and three coats were applied in a 4-hour interval.

Thermal insulation promoted by formulated paints was evaluated using the system described in the Figure 1. The box was constructed using oriented strand board (OSB), whose dimensions were 1000 mm long, 600 mm wide and 550 mm high. The inner box was lined with expanded polystyrene boards (2 cm). A support shaped as a "U" was assembled at the middle of the box, where the plate to be studied was settled. Thus, the box consisted of two compartments separated by the mortar board coated with the paint being studied.

A domestic heating power (1500W) was placed at a distance of 20 cm from the painted mortar board face, which was left at full power during tests. Temperature sensors were placed on the center of each face of the mortar board (with and without paint) to determine the temperature difference, and consequently, the prepared thermal paint's insulator capacity. The box was kept closed throughout the test period.

The tests consisted on heating the compartment with the face of the mortar board containing the thermal paint, and determine the difference between the temperatures on the two faces of the board, hence of both compartments. The tests

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were carried out during 6 hours and the temperature on each face of the board was measured in 30- minute- intervals. Thus, the thermal insulation capacity of the paints with different formulations was determined.

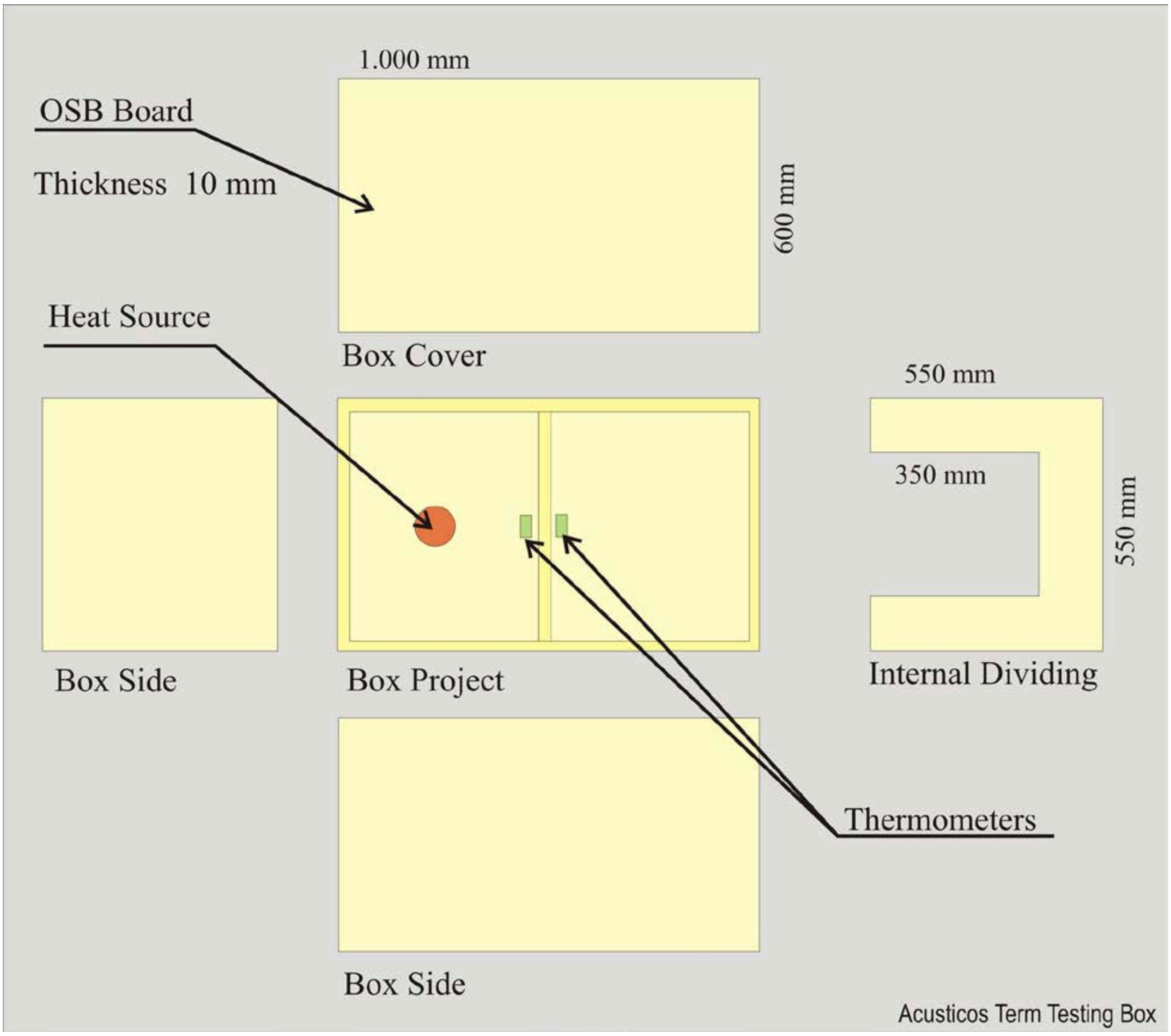

Figure 1: Schematic description of the system used to determine the insulating capacity of the mortar boards containing paint with muscovite in different additions.

2.2. Economic evaluation

The economic evaluation was performed considering fixed and variable costs; fixed and variable expenses and the demand or revenue forecast to generate expected revenue. To analyze the project's feasibility, we determined: the expected net income; the cost of goods sold (COGS); the mark-up; the internal rate of return (IRR) and the net present value (NPV).

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3. RESULTS AND DISCUSSION

3.1. Preparation and thermal evaluation of the paints containing muscovite

Prepared mortar boards showed a homogeneous surface, even without plasterwork as required base, and an adequate strength to handle and receive painting. The preparation and application of the paints formulated with muscovite were simple; no significant differences from those used in ordinary commercial paints were observed. Paint dilution provided an appropriate viscosity to the painting process (Figure 2).

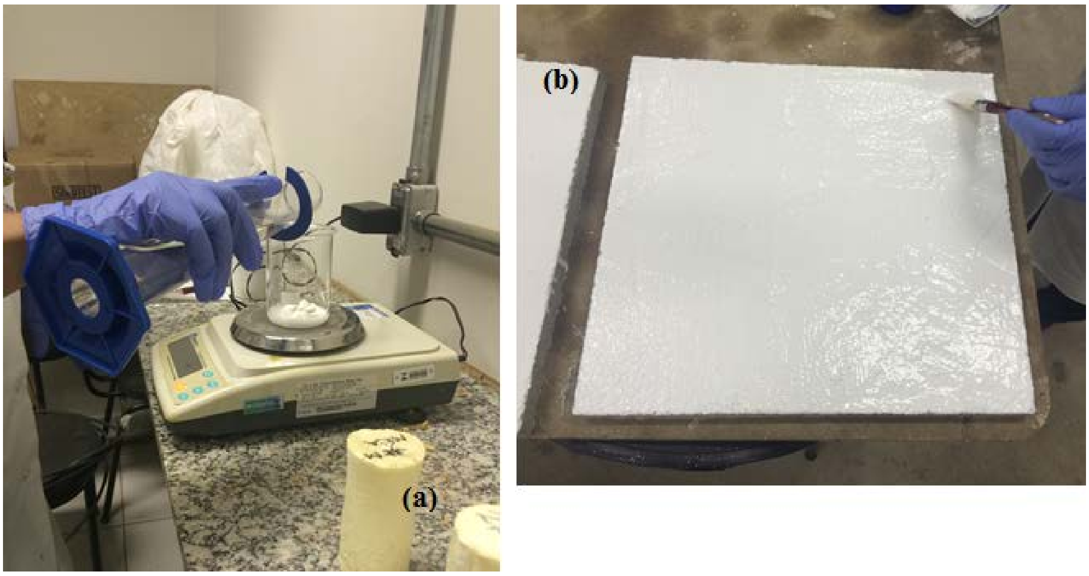

Figure 2: Weighing and dilution of paints for application (a); Paint application on the boards (b).

It was not possible to identify clear differences in the viscosity of the paints with different formulations after dilution, during it application process; however, the kinematic viscosity was determined. The higher the muscovite content, the higher the viscosity of diluted paint (Table 1). It was observed that the formed film was smoother as the amount of muscovite in the formulations increased. Also, it was more uniform and had higher qualities in comparison to the film without muscovite.

Table 1: Kinematic Viscosity of paints with muscovite addition after dilution to be applied to the mortar boards.

Muscovite addition (% wt)	***After dilution cSt (mm^2/s) – 27ºC***
0	37,00
10	50,47
20	55,63
40	67,22

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The thermal insulation capacity of the prepared muscovite-based paints was evaluated. The boards were subjected to heating for 6 hours, with the temperature being recorded every 30 minutes in both compartments of the box. The maximum temperature reached in the compartment containing the heater was of 61°C. A temperature difference about 23 °C after 360 minutes was observed between the two compartments. The temperature difference (ΔT) was reported as a specific temperature difference (°C/mm) due to the differences in the boards` thickness. Thus, it was possible to identify the heat transport between the two compartments of the box, through the insulating board in function of the heat exposure time, as shown in Figure 3.

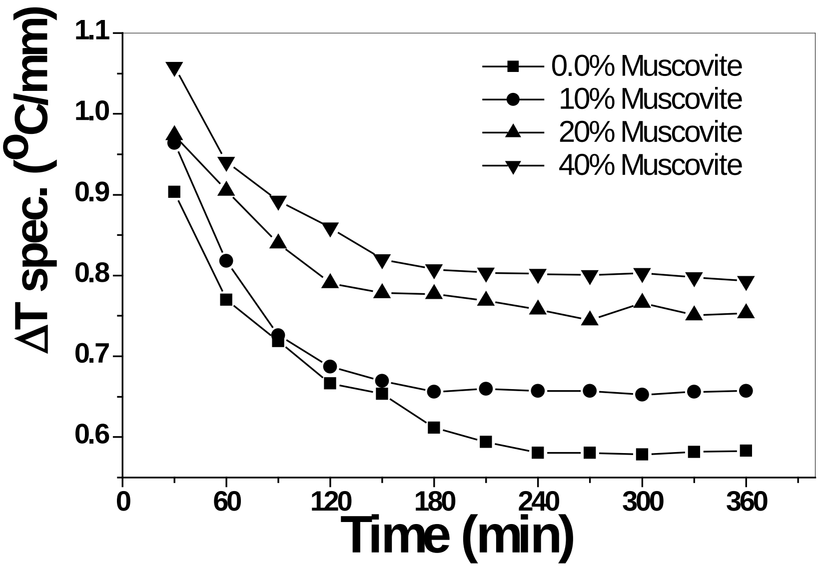

Figure 3: Specific temperature differences on both sides of the boards in function of the heating time.

After 200 minutes, the specific temperature difference stabilizes. From this, it was possible to compare the insulating capacity of the boards containing muscovite. Considering the standard board (without muscovite addition), the temperature difference between the board sides is 0.584 °C/mm. The boards containing 10%, 20% and 40% of muscovite have a temperature difference of 0.658 °C/mm, 0.754 °C/mm and 0.795 °C/mm, respectively. Thus, it was found that the addition of 10%, 20% and 40% muscovite increases the paint insulating capacity on 12.7%, 29.1% and 36.1%, respectively. Figure 4 shows the specific temperature difference

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according to the percentage of muscovite added to the paint, after 360 minutes of thermal exposure.

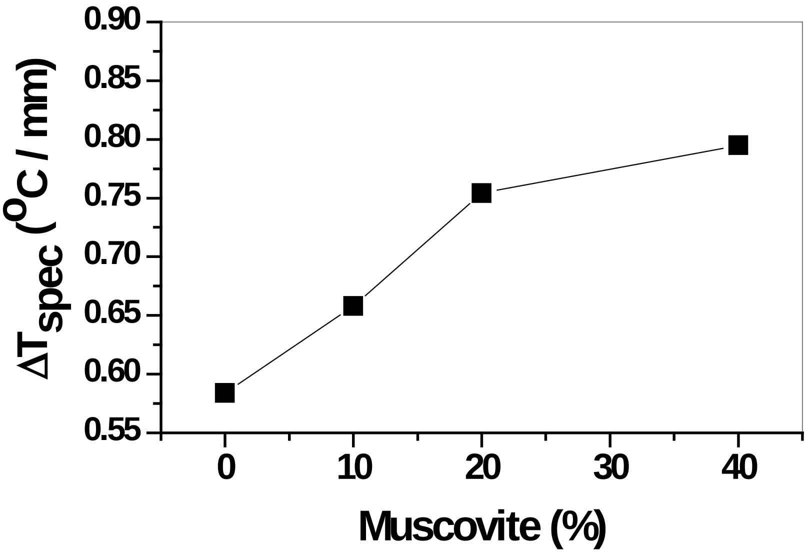

Figure 4: Specific temperature difference in function of muscovite addition, after 360 minutes of heat exposure.

It has been observed (Figure 4) that the muscovite addition above 20% increases the thermal insulation capacity; however, it is no longer linear. This behavior occurs because the thermal conductivity and optimum thickness relation of thermal insulating materials is not linear.

Although the results present a difference up to 0.211 °C/mm of the board by adding 40% of muscovite, it is important to note that this thermal insulation was obtained from a 0.3 mm paint film thickness. This result suggests that the application of 1.0 mm thickness of paint film is able to reduce the temperature up to 0.667 °C/mm of board. In this case, considering a 10 mm thick board, the 40% muscovite paint is able to reduce up to 6.67 °C, being comparable to ceramic microspheres (Anon 2016). Thus, muscovite is considered very attractive to be used as a thermal insulating additive.

3.2. Production economic evaluation

Results of the economic viability analysis for the industrial production of thermal paint containing mica muscovite are presented. The thermal paint is obtained

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by simply mixing the additive with good quality paint as base. Thus, the scenery for the economic evaluation considered the simplest configuration of a production unit.

- ***Initial Investment***

The initial investment is estimated at US$ 74,899.95 (Table 2), which comprises the expenditures required for the company's constitution, such as the acquisition of a property, a mixer tank, furniture, and office appliances. The initial cost in the first month of production is estimated at US$ 7.474,98.

Table 2: Initial investment for the thermal paint production.

ITEM	***VALUE (US$)***
Site Bulding	55,000.00
Mixer tank	8,750.00
Furniture	2,000.00
Office appliances	1,675.00
Initial raw material cost	6,601.39
Labor cost (1st production month)	873.56
TOTAL	74,899.95

- ***Operational Costs and Expenses***

For an economic analysis, the expenses necessary for the company development were dismembered and qualified as costs and expenses, which are fixed or variable (Table 3). Equipment depreciation costs were not considered because the sale price was also not inflated during the period.

In this study, the variable costs were raw materials and electricity. The fixed cost was also directly correlated to expenditure on the production process, but it did not change according to the amount produced. Thus, the fixed cost considered was labor directly related to the production. Variable expenses considered in the analysis were sales charge / representatives and maintenance of machinery and equipment. The costs and expenses are detailed in Table 3, for 360 L.

Table *3*: Operational costs and expenses.

COSTS	**VALUE (US$)**	**%**
Variable	766.99	99.73
Fixed	2.04	0.27
Operational Variable		7.00
Fixed Operational (12 months)	17,316.56	
Taxes		10.54
TOTAL	**769.04**	

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- ***Projected demand***

According to the Brazilian Association of Paint Manufacturers (ABRAFATI), the building paint volume produced in 2014 was 1,119 million liters. Therefore, a market share of 3.50%; with a growth target of 5% per annum was considered in the projected demand calculation (Table 4).

Table 4: Projected demand for the thermal paint with muscovite production.

YEAR	*QUANTITY (L)*	*5 GALLONS = 18 L*
2016	39.165	2.176
2017	41.123	2.285
2018	43.179	2.399
2019	45.338	2.519
2020	47.605	2645

- ***Projected gross revenue***

To determine the projected gross revenue, the definition of the selling price is required. The sale price was set taking into account the prices of competing products and substitutes, as well as the proposed market share. The sale price of an 18 liter-bottle was defined as US$ 70.00. Thus, the projected revenue was obtained by crossing the selling price with the projected demand, which is described in Table 5.

Table 5: Projected gross revenue.

Year	***Value (US$)***
2016	139,626.67
2017	159,314.16
2018	167,265.00
2019	175,630.00
2020	184,415.00

- ***Net Profit***

Set the sales price and calculated the operating costs and expenses, the first analysis of the project is to design the expected net profit. For this purpose, the Income Statement was drawn up, as described in Table 6. It has been observed that the cost and expenses structure resulted in a Cost of Goods Sold of 55.45%, and a markup of 44.55%. This resulted in a net profit of US$ 23.828,29, i.e., profitability (net income) of 15.64% compared to other revenues.

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For purposes of net income analysis and comparison, we considered the Basic Interest Rate of Economy, i.e., the Selic rate. In November 2015, the Copom, body responsible for maintaining the Selic rate, set a goal of the Selic rate at 14.25% p.a.; therefore we can see that our expected net profit obtained a more favorable and attractive result than the basic savings compensation.

Table 6: Income Statement.

	Value (US$)	***%***
Gross Revenue	152,320.00	100.00
Taxes	- 16,054.52	10.54
Net Operating Revenue	**136,265.47**	**89.56**
Variable Cost	- 79,216.65	52.01
Fixed Cost	- 5,241.56	3.44
Total Operational Costs	**- 84,458.21**	**55.45**
Operational Expenses - Variable	- 10,662.40	7.00
Operational Expenses - Fixed	- 17,316.56	11.37
Total Operating Expenses	**- 27,978.96**	**18.37**
NET INCOME	**23,828.29**	**15.64**

- ***Internal Rate of Return (IRR)***

The Internal Rate of Return (IRR) comes from English Internal Return Rate (IRR) and it's a mathematical and financial formula used to calculate if the discount rate would have a certain cash flow equal to zero in its net present value. In other words, it would be the rate of return on investment in question. The IRR is one of the key indicators in the project return analysis. The IRR calculation was performed according to Equation 1.

$$VPL = O = Investimento\ Inicial + \sum_{t=1}^{N} \frac{Ft}{(1+TIR)^t} \qquad (1)$$

Where "F" means the cash flow of each period and "t" is the period in question. Thus, it has been observed how each cash flow is divided by the high TIR in relation to its respective period, since the interest in this case are the compounds. Moreover, all this must be equal to zero. The detailed cash flow statement can be seen in Table7.

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Table 7: Cash flow statement, currency in US$.

	**Start**	_**2016**_	_**2017**_	_**2018**_	_**2019**_	_**2020**_
Resources: in		139,626.66	159,314.16	167,265.00	175,630.00	184,415.00
Resources: out	- 74,899.98	122,328.53	133,138.32	138,677.47	144,507.19	150,629.63
Outgoing cash flow	- 74,899.98	17,298.13	26,175.84	28,587.52	31,122.80	37,785.29

From the graph shown in Figure 5, it was possible to apply the IRR calculation formula, which resulted in a value of 21.53%.

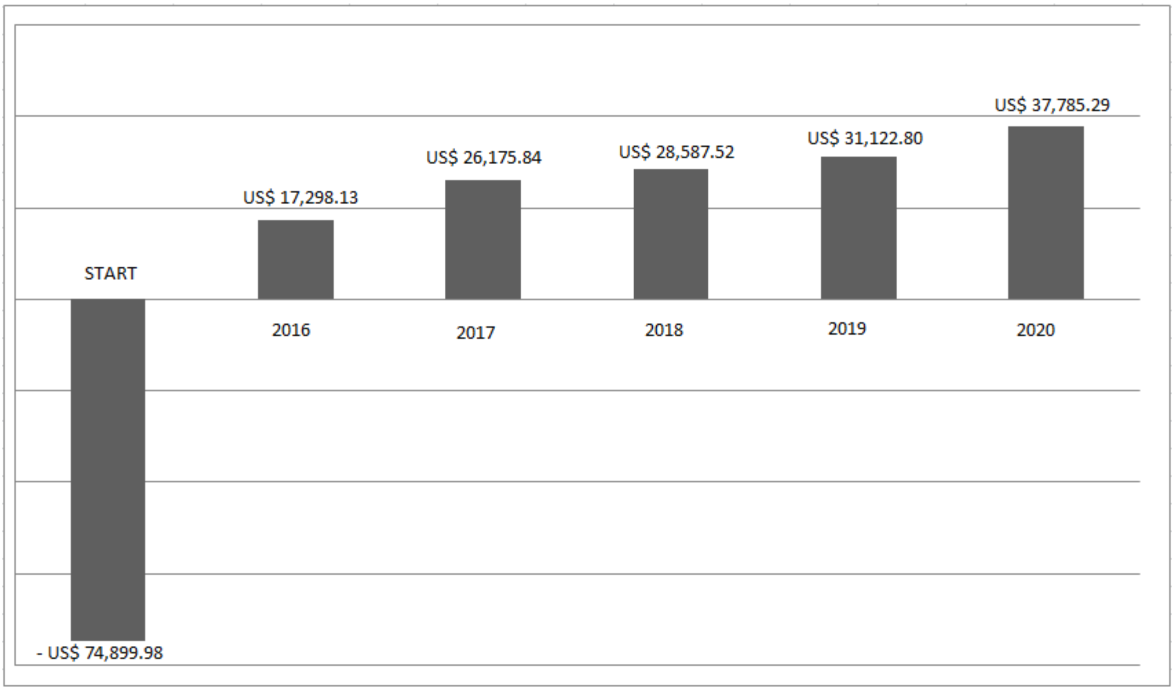

Figure 5: Balance cash flow

Using the Selic rate (14.25% p.a.) as a baseline, the project proves to be feasible by analyzing the internal rate of return. In addition, the calculated NPV given the Selic rate, results a Net Present Value of US$ 15,085.76, demonstrating once again the feasibility of the project.

4. CONCLUSION

This study showed the thermal paints are capable of promoting thermal comfort by reducing the building internal temperature. This contributes to minimize the air conditioning use, providing lower energy consumption. Consequently, it contributes to the natural resources preservation and reduction of environmental pollution.

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The use of muscovite as an additive is versatile, once it increases about 36% the thermal insulation capacity of an ordinary commercial paint. It also improves the finishing film formed aspects after application. In addition, it is possible to obtain the muscovite-based paint by simply mixing the muscovite in the paint; consequently, no remarkable changes in line are required to the industrial production.

The muscovite addition on commercial paints was considered a techno-economic feasible process. The methods used for the project analysis showed positive and attractive results. The net income, IRR and NPV showed returns on investments higher than the returns achieved in the current financial market. Thus, our evaluation about the process is that the investment is an opportunity that results in real economic gains.

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