# BRAZILIAN CERAMIC TILE INDUSTRY: THERMAL ENERGY CONSUMPTION AND $CO_2$ EMISSIONS

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## ABSTRACT

Thermal Energy costs represent one of the largest portions of the cost of production of ceramic tiles, and $CO_2$ emissions resulting from this industrial activity are very significant. Any improvement of the efficiency of the thermal processes will result in a substantial reduction of the fabrication costs and $CO_2$ emissions. Given the increasing importance of these subjects, competitiveness and environment, in the last years a significant amount of information about the consumption of thermal energy in the ceramic tiles industry has been produced. Brazil is at present the second world largest producer and consumer of ceramic tile and the industries have a considerable diversity of equipment, fabrication routes (wet and dry), operation conditions and raw materials. In this scenario a survey was conducted in Brazilian tile industry with the objective of collecting information that would allow establishing correlations between the industry characteristics (fabrication route, equipment characteristics, operation conditions, main raw materials, etc.) and the thermal consumption in each part of the process and the total $CO_2$ emission. The present paper presents the results of this survey which shall provide guidance in measures to increase thermal efficiency of operating industries and in choosing new equipment.

## 1. INTRODUCTION

Brazil is the second largest producer and the second largest consumer of ceramic tiles in the world. The Brazilian internal market is responsible for consuming about 93% of its total production[1] and the Brazilian production expected for 2011 is 802.5 million $m^2$. As a result of the growth of this sector, it has increased significantly the demand for fuel to generate thermal energy, used in different stages of the production process (drying, spray drying and firing). These data could be used like a direct indicator of the production growth[2]. It is estimated that the sector's consumption of thermal energy is 7.9 x $10^{11}$ Kcal/month, and the main fuel it uses is natural gas. Despite these highly significant numbers, little information is available about the sector's energy consumption, unlike countries such as Spain and Italy, which have been recording such data for over a decade[3-5]. It should also be noted that two radically different routes are still utilized in Brazil in the manufacture of ceramic tiles (the Dry Route and the Wet Route) and that the technology park comprises machinery and equipment of different generations.

In general, the products obtained by dry route processes are semi-porous ceramic tiles that present water absorption from 6 to 10% and red fired colours. The dry route process is characterized by dry grinding (~5% of moisture content – which eliminates the spray dryers) and fast single firing (20-30 min).

The body composition obtained through dry route is differentiated by its typical composition and the milling/granulation process. The composition is formed, in general, only by a clay or by a combination of similar clays, in which there is a natural combination of minerals suitable to generate the desired products. The clays are extracted from natural deposits and transported by trucks to natural drying in grounds. The moisture content is reduced until 5% and the clays are homogenized and crushed. After that, the material goes to the grind. In dry milling, the raw materials go to a primary mill (hammer mill) and the coarser fraction is conducted to the secondary mill (pendulum mill). The resulting powder is humidified (~9% of water) and granulated. The following steps are similar to the wet route process.

A preliminary study conducted during 2007[6] and 2008[7] at several companies of the sector in Brazil revealed the existence of major differences in thermal energy consumption among them and also among machines operating in the same plant, possibly due to their constructive characteristics and operating conditions.

As the energy cost represents a great portion in the production costs of ceramic tiles and $CO_2$ emissions during the fabrication are quite significant, it is essential to know the thermal consumption in these companies. This knowledge is important to induce corrective actions related to the operating conditions of the equipment, to avoid energy waste and to define assertive investments in new equipment. However, there are few data about thermal consumption in the ceramic tiles fabrications, considering the particularities of the processes, the diversity of equipment, operating conditions and raw materials characteristics that need to be used to estimate $CO_2$ emissions in an accurate way.

This article presents the results of a systematic work developed in Brazil to determine the consumption of natural gas on kilns, dryers and spray dryers in ceramic tiles industries. The obtained data were processed and organized according to the type of product, stages of production and fabrication technologies. The results originate a database on thermal consumption and $CO_2$ emissions related to the fabrication of ceramic tiles in Brazil, revealing the peculiarities found in this field.

## 2. METHODOLOGY

A selection was made of the manufacturers that would participate in the survey, based on their production capacity in $m^2$/month, production route (dry or wet), product typology, etc. According to this selection, the sum of the production of these manufacturers corresponded to approximately 20% of the national production of ceramic tiles (in $m^2$) and 35% of the production of spray-dried powder (in tons). These companies are located in the states of São Paulo and Santa Catarina.

Initial visits were then made to the companies that demonstrated an interest in participating in the survey. The purpose of these visits was to check out the plants' facilities and installations; verify the operating conditions of gas-driven equipment; check the location of pipeline installations and see how the consumption indicators worked (manometers and natural gas flow meters); suggest corrective actions to ensure the precision of measurements, if necessary; establish jointly with the machine operators the points where measurements should be taken and with what frequency; and collect general data about the equipment and products manufactured.

Most of the plants registered the values of pressure, volume and temperature of natural gas consumed three times per day during one month. The data thus generated were treated and adjusted (normalized)[3], providing information about the real thermal energy consumption of each monitored machine. Based on information about the product, production volume and operating conditions of kilns, dryers and spray dryers, a database was set up containing data on the consumption of thermal energy involved in the fabrication of ceramic tiles, allowing for comparisons among several product typologies, distinct processing routes, etc.

Furthermore, $CO_2$ emissions from the combustion of natural gas were calculated according to the total volume of natural gas consumption, calorific value and emission factor of fuel. $CO_2$ emissions from carbonate minerals during firing were calculated according to the contents of carbonates present in the bodies and their production volumes. Emissions produced from organic matter were not considered in this work.

## 3. RESULTS AND DISCUSSION

A total of 28 kilns, 21 dryers and 11 spray dryers distributed in nine plants were monitored. Based on the monitoring data, the mean consumption of each plant was estimated (Table I) from the sum of the average consumption of natural gas of dryers, kilns and spray dryers. These values are expressed in kcal/kg, enabling the amount of energy involved in processing a certain quantity of mass of material to be determined and direct comparisons to be made among products with different thicknesses. At most of the plants that use the dry route, monitoring of the thermal energy consumption focused on equipment producing BIIb type tiles with a nominal shape of 43 x 43 cm and a thickness of 7.0 mm. At the plants that employ the wet route, due to the greater variety of tile typologies produced, it was not possible to monitor machines that produced exactly the same type of product.

### 3.1. Thermal Energy Consumption

The data in Table I reveal significant differences in specific thermal consumption among the companies that participated in this survey. These differences were found not only among the manufacturers that use distinct processing routes (dry and wet routes) but also among manufacturers using the same route. An analysis of the consumption of manufacturers using dry processing indicates that the difference between the companies that presented the highest and lowest values, D and C, respectively, was more than 100 kcal/kg; in other words, company D's consumption was 17.4% higher than that of C. The same analysis applied to the results of wet processing companies indicated even greater differences in consumption, which exceeded 30.0% (company I's consumption was 32.0% higher than that of company F). It should also be noted that the main reason for the discrepancy in the average thermal energy consumption of the wet and dry processing plants was the presence of the spray dryer in the wet processing of tiles.

| Processing Route | Company | Specific consumption (kcal/kg) |
|---|---|---|
| Dry | A | 644.9 |
| | B | 613.8 |
| | C | 578.4 |
| | D | 677.6 |
| | E | 608.6 |
| Wet | F | 901.5 |
| | G | 1047.0 |
| | H | 1140.0 |
| | I | 1190.0 |

*Table I – Mean thermal consumption of the plants that participated in the survey.*

To facilitate the interpretation of the large number of data, they were grouped as follows:

- Total consumption per product typology (Fig. 1);
- Machine consumption per product typology (Figs. 2, 3 and 4);
- Machine consumption per processing route (Figs. 5 and 6).

The following acronyms were ascribed to the product typologies evaluated here:

- SP = Semi-Porcelain
- TP = Technical Porcelain
- EP = Enamelled Porcelain
- RSF = Red Single Fired
- WSF = White Single Fired
- MP = Monoporous

Most of the figures that indicate consumption of product typologies and of machines reveal the existence of a line instead of a full bar. In this case, the line indicated that the representativeness of the result is lower, in view of the small number of machines monitored.

Based on the results presented in Figs. 1 to 4, it can be stated that there are substantial differences in specific thermal consumption according to the typology of ceramic tile manufactured. Note, also, that there are machines that produce the same product typology, but with very distinct specific consumptions, indicating the possibility of improvements in terms of reducing the consumption of thermal energy in the process.

In Fig. 1, note that the consumption of natural gas (NG) involved in the production of RSF tiles is lower, although the drying process of this type of product consumes the largest amount of energy. In this case, the lower consumption of kilns (Fig. 2) and the absence of spray dryers ensure low consumption. The typology involving the highest thermal energy consumption is WSF, mainly due to the high consumption of kilns (Fig. 3) and spray dryers (Fig. 4).

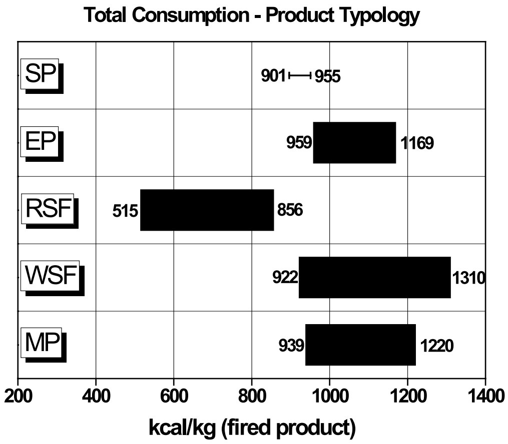


*Fig. 1 – Specific thermal consumption per product typology.*

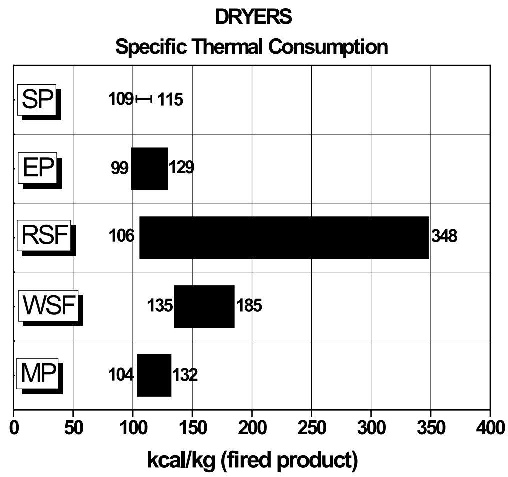


*Fig. 2 – Specific thermal consumption of dryers per product typology.*

It should be pointed out that the kilns used for firing the MP type product presented the highest specific thermal consumption (Fig. 3), even exceeding the consumption of kilns producing WSF products. A possible explanation for the fact that the kilns used for the production of EP consume less thermal energy than kilns that produce WSF and MP products may be the different generations of machines utilized, since the production lines used for the manufacture of porcelains in Brazil are generally more modern than the lines used for the other product typologies.

As for the spray dryers evaluated in this survey, a significant variation in consumption was found according to the product typology, with some of the equipment presenting about 50% higher thermal consumption than the most economic machines (Fig. 4).

Figs. 5 and 6 show the consumption of dryers and kilns, respectively, according to the ceramic tile fabrication technology. The higher consumption of dryers in dry processing (Fig. 5) may be attributed to the higher moisture content used in pressing these product typologies in Brazil and the high temperatures employed for the rapid removal of water in short cycles, ensuring high productivity. The largest discrepancies were found in the specific consumption of dryers used in dry processing, with some machines consuming three times more than the most energy-efficient machines.

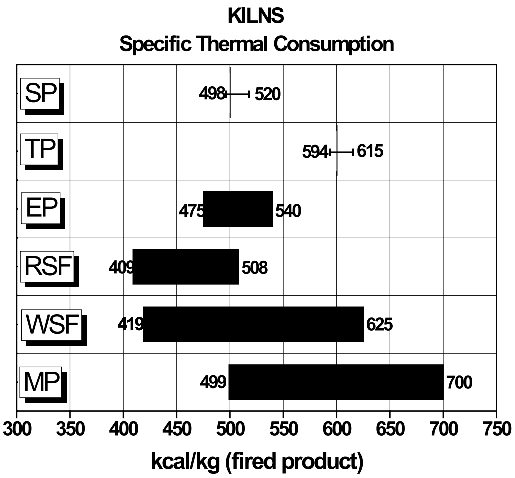


*Fig. 3 – Specific thermal consumption of kilns per product typology.*

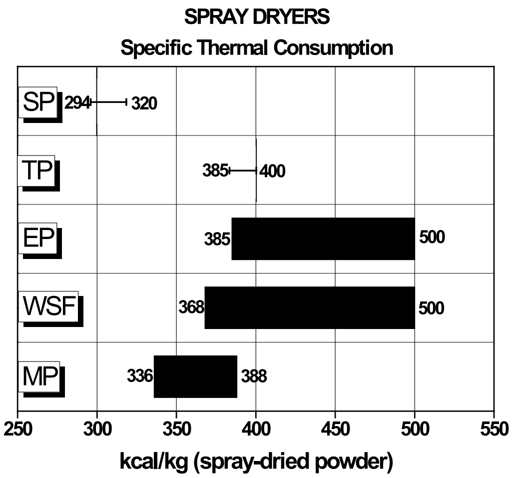


*Fig. 4 – Specific thermal consumption of spray dryers per product typology.*

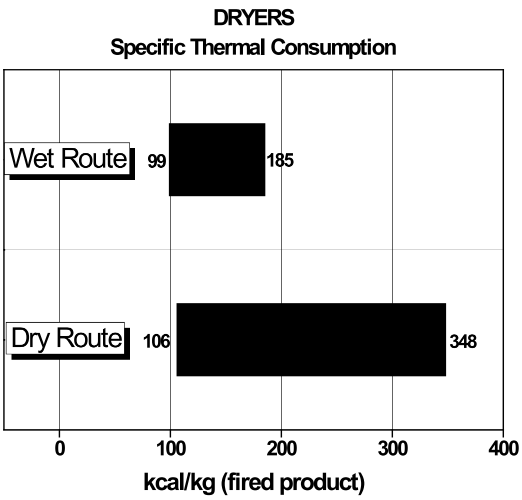


*Fig. 5 – Specific thermal consumption of dryers per processing route.*

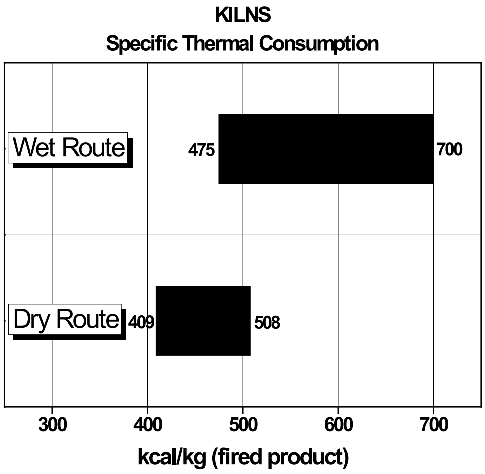


*Fig. 6 – Specific thermal consumption of kilns per production route.*

In Fig. 6, note that the kilns in wet processing generally presented a higher specific consumption than those of the dry route. Like most of the equipment used in wet processing in Brazil, these machines are from older generations than those used in dry processing, which may explain their higher consumption. Moreover, the products fabricated by wet processing have longer thermal cycles than those of the dry route, as well as higher maximum temperatures. In general, the body slip used in Brazilian dry processing consists exclusively of high-melting red clays, which allow for the use of low firing temperatures and very fast cycles.

Table II shows the data related to the operating conditions of the studied kilns, $CO_2$ emissions during firing and the final characteristics of the products according to typology.

| | | MATERIAL | | OPERATION | | FINAL PRODUCT | | |
|---|---|---|---|---|---|---|---|---|
| | | **Contents of carbonates (%)** | **Calcination losses (%)** | **Cycle duration (min)** | **Maximum temperature (ºC)** | **Water absorption (%) **** | **Thickness (mm)** | **Specific weight (kg/m²)** |
| **Typology** | **Monoporous** | **14.0** ± 1.0 | **12.0** ± 0.6 | **36** ± 2 | **1152** ± 7 | **> 10.0** | **8.5** ± 0.2 | **15.5** ± 0.5 |
| | **Semi-Porcelain** | **1.8** ± 0.8 | **4.6** ± 0.2 | **33** ± 3 | **1170** ± 10 | **0.5 – 6.0** | **9.0** ± 0.3 | **17.5** ± 0.6 |
| | **Porcelain** | **1.0** ± 0.7 | **4.0** ± 0.4 | **45** ± 7 | **1205** ± 15 | **≤ 0.5 *** | **9.5** ± 0.4 | **19.5** ± 0.7 |
| | **White Single Fired** | **1.5** ± 0.5 | **4.4** ± 0.4 | **30** ± 2 | **1175** ± 12 | **6.0 – 10.0** | **8.0** ± 0.2 | **15.0** ± 0.5 |
| | **Red Single Fired** | **1.0** ± 0.5 | **4.0** ± 0.5 | **23** ± 3 | **1140** ± 10 | **6.0 – 10.0** | **7.0** ± 0.5 | **14.0** ± 0.6 |

(*) According to the NBR 15463/2007, the technical porcelain tile should have water absorption ≤ 0.1.
(**) Ranges of water absorption to classify products according to ISO 13006.

*Table II – Operating parameters average of the step firing in the steady state – pressed ceramic tiles.*

Table III lists the values of average consumption of thermal energy in the drying, firing and spray drying stages found in this study. The results in Table III indicate that the consumption of thermal energy in wet processing is, on average, much higher than in dry processing (about 70%). This is mainly due to the higher consumption involved in the spray drying stage of the wet route. However, the high consumption of kilns in wet processing also contributes to this significant difference between the processing routes.

Since specific consumption is directly correlated to the consumption of NG, it can be stated that, given the particularities of the Brazilian manufacturers involved in this study, expenditures on thermal energy in the dry route are much lower than in the wet route.

| | Study of the Brazilian Sector | | | |
|---|---|---|---|---|
| | Dry Route (kcal/kg of fired product*) | | Wet Route (kcal/kg of fired product *) | |
| | Interval | Mean value | Interval | Mean value |
| **Spray drying** | - | - | 294 – 500 | **424** ± 78 |
| **Drying** | 106 – 348 | **182** ± 70 | 98 – 185 | **126** ± 24 |
| **Firing** | 409 – 508 | **451** ± 38 | 475 – 700 | **536** ± 57 |
| **Total** | 515 – 856 | **634** ± 109 | 868 – 1385 | **1085** ± 160 |

* The values were determined based on the lower heating value (LHV) of natural gas.

*Table III – Consumption of thermal energy in the dry and wet processing routes.*

According to the results, the consumption of thermal energy in dry processing is divided into 71% in the firing stage and 29% in the drying stage, indicating that the thermal consumption in kilns is approximately 2.4-fold higher than in dryers. In wet processing, the spray drying stage is responsible for 39% of total thermal energy consumption, and the consumption of kilns is 4.1-fold higher than that of dryers.

## 3.2. $CO_2$ Emissions

Table IV shows the average $CO_2$ emissions from ceramic tiles production in Brazil. Presented data are related to emissions from natural gas combustion in different stages during the fabrication process in steady state. $CO_2$ emissions during firing (combustion and process emissions) are organized by product type, as shown in Fig. 9.

Emissions from ceramic tiles produced by dry route are much smaller than the emissions from wet route process. Lower firing cycles and lower carbonates contents in the raw materials can explain the results. In consequence, dry route process has lower levels of $CO_2$ emissions: combustion and process (Table IV and Fig. 10).

According to the data presented in Table V, the dry route process emits almost 50% less $CO_2$ per ton of ceramic tile produced when compared to the wet route process. The aspects responsible for the results are: absence of spray drying, lower firing temperatures, short firing cycles and low carbonate contents in the raw materials.

| Processing stage | | Combustion emissions * | | Process emissions * | | TOTAL | |
|---|---|---|---|---|---|---|---|
| | | Wet Route | Dry Route | Wet Route | Dry Route | Wet Route | Dry Route |
| Spray drying | | 99 ± 5 | - | - | - | 99 ± 5 | - |
| Drying | | 29 ± 2 | 42 ± 4 | - | - | 29 ± 2 | 42 ± 4 |
| Firing | Monoporous | 126 ± 11 | - | 70 ± 3 | - | 196 ± 12 | - |
| | Semi-Porcelain | 116 ± 2 | - | 8 ± 2 | - | 124 ± 2 | - |
| | Porcelain | 129 ± 5 | - | 5 ± 1 | - | 134 ± 5 | - |
| | Red Single Fired (glazed) | - | 105 ± 6 | - | 5 ± 1 | - | 110 ± 6 |
| | White Single Fired (glazed) | 132 ± 8 | - | 7 ± 1 | - | 139 ± 8 | - |
| TOTAL | Monoporous | 254 ± 18 | - | 70 ± 3 | - | 324 ± 20 | - |
| | Semi-Porcelain | 244 ± 9 | - | 8 ± 2 | - | 252 ± 9 | - |
| | Porcelain | 257 ± 12 | - | 5 ± 1 | - | 262 ± 12 | - |
| | Red Single Fired (glazed) | - | 147 ± 10 | - | 5 ± 1 | - | 152 ± 10 |
| | White Single Fired (glazed) | 260 ± 15 | - | 7 ± 1 | - | 267 ± 15 | - |

* in Brazil, the emission factor for natural gas is 183 g $CO_2$/kWh.

*Table IV – Specific $CO_2$ emissions in the manufacturing process of ceramic tiles for Wet and Dry routes (kg $CO_2$/t fired), in steady state.*

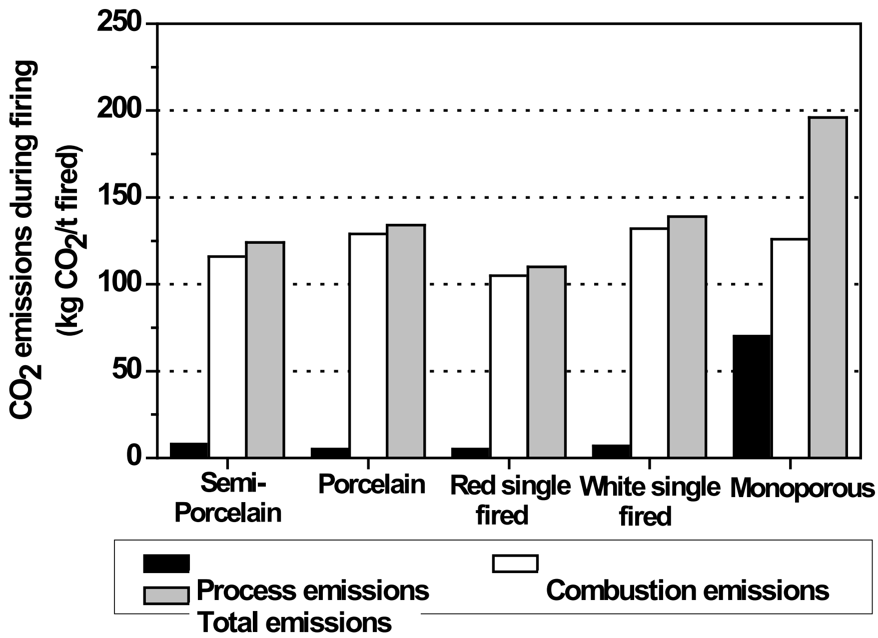


*Fig. 9 - $CO_2$ emissions in the stage of firing (steady state).*

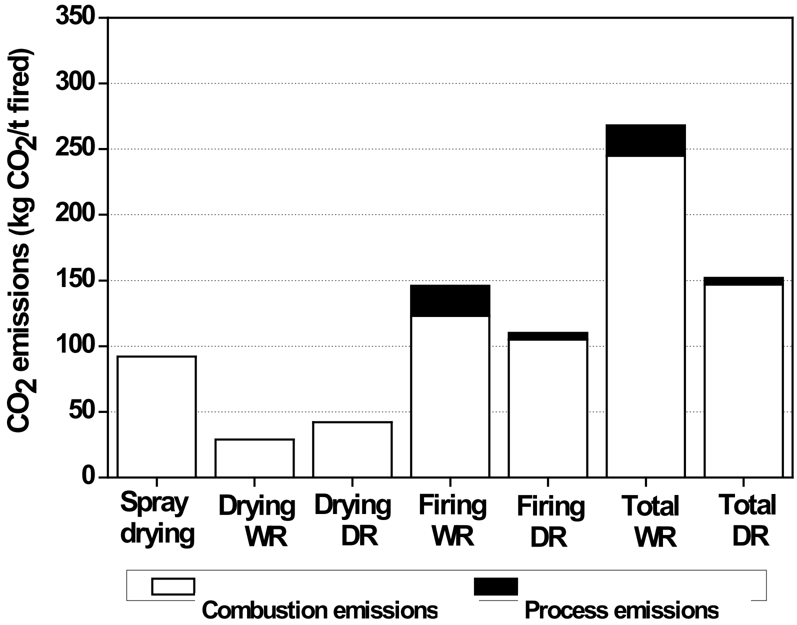


*Fig. 10 – Average $CO_2$ emissions (steady state).*

| | $CO_2$ emissions (%) | | | Specific emissions (kg $CO_2$ /t fired) | Specific emissions (kg $CO_2$ / m² fired) |
|---|---|---|---|---|---|
| | Combustion emissions | Process emissions | Total | | |
| **Wet Route** | 90 | 10 | 100 | 285 | 4.81 |
| **Dry Route** | 97 | 3 | 100 | 152 | 2.13 |

*Table V – Specific total $CO_2$ emissions in the manufacturing process of ceramic tiles for Wet and Dry routes (kg $CO_2$/t fired).*

## 4. CONCLUSIONS

Based on the findings of this survey, the following conclusions can be drawn:

- There are numerous discrepancies in the consumption of thermal energy at plants that use the same processing route and that produce the same product typology. These discrepancies may be attributed to the different types of equipment (technology, dimensions and manufacturer) and their distinct operating conditions. In this context, there is a significant margin for the reduction of thermal energy consumption in the fabrication process of ceramic tiles.

- The consumption of thermal energy in wet processing is approximately 70% higher than in dry processing due to the increment of the spray drying stage and the high energy consumption of kilns. Although the dryers in dry processing consume more energy, the kilns in this processing route show a lower average consumption than those used in wet processing. These results should be analyzed taking into account the peculiarities of the dry route used in Brazil, which currently uses latest generation equipment and very specific clays in terms of firing behaviour.

- In the wet route, the total consumption of thermal energy is distributed as follows: 49% in Firing, 39% in Spray drying, and 12% in Drying. On the other hand, in the dry route, this consumption is 71% in Firing and 29% in Drying. The relationship between kiln and dryer consumption is differentiated according to the processing route. The thermal consumption of kilns in wet processing is 4.1-fold higher than that of dryers, while in dry processing this consumption is 2.4-fold higher.
- Among the typologies of ceramic tiles evaluated, WSF (white single firing) tiles presented the highest thermal energy consumption and RSF (red single firing) tiles the lowest. Among the typologies manufactured by the wet route, SP (semi-porcelain) tiles presented the lowest consumption. It should be noted that machines of different generations were monitored in this survey and that although these results reflect the reality of the Brazilian industrial park, they may differ significantly according to the characteristics of body slips and the machines used in the fabrication of the same products.
- Dry route process has lower emissions related to the absence of spray drier and the low content of carbonates in the raw materials. In consequence of that, it was allowed to get progressive growth of production of ceramic tiles in Brazil with reduction of specific CO2 emissions, due the domination of the dry route process in the Brazilian production of ceramic tiles.

In general, the results of this survey indicate that the use of natural gas by Brazilian ceramic tile manufacturers could be more efficient. Information obtained by managing energy consumption can contribute significantly to the manufacturers' strategic decisions, which are evidenced by greater energy efficiency, and hence, reduction of energy costs.

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