REDUCTION OF CO_2 EMISSIONS IN CERAMIC TILE MANUFACTURE BY COMBINING ENERGY-SAVING MEASURES

A. Mezquita[1], E. Monfort[1], E. Vaquer[1], S. Ferrer[1], J.M. Pitarch[2], M.A. Arnal[2], F. Cobo[2]

[1] Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE)

Universitat Jaume I. Castellón. Spain.

[2] Azulev, S.A.U. Onda. Spain.

Abstract:

Ceramic tile manufacture requires a great quantity of energy, mainly in the form of heat. The heat is principally used in the kilns and dryers, and it is obtained by natural gas combustion.

The increasing cost of natural gas, as well as the application of a new gas tax, the new legislation in regard to emissions trading, and the difficult current economic situation have driven the ceramic tile sector to implement energy-saving actions in the production process with the twofold aim of reducing energy costs and abating carbon dioxide emissions.

One such course of action is the European project REDUCER, funded by the European Commission and led by Azulev S.A.U., in which the Instituto de Tecnología Cerámica (ITC) also participates. This project seeks to implement energy-saving actions in company kilns and dryers in order to lower natural gas consumption and reduce carbon dioxide emissions in the tile manufacturing process.

One of the saving actions envisaged is the installation of a system of waste heat recovery from one of the company kilns to the tile body dryers. This new waste heat recovery system is to be added to and will complement the already existing system at the company, thus achieving maximum heat recovery from the kiln stacks. The recovered heat will go entirely to the green tile body dryers, thus reducing natural gas consumption in the dryers.

The designed installation seeks to recover 600 kW heat from the stacks of one of the kilns, entailing a natural gas saving of more than 120 k€/year and suppressing the emission into the atmosphere of 720 tons of CO_2/year, savings that are to be added to those attained with other energy-saving measures.

This paper describes the energy-saving actions implemented at the company, as well as the resulting energy savings.

Keywords: CO_2 emissions, energy saving, natural gas

1 INTRODUCTION

The ceramic tile manufacturing process uses a great quantity of thermal energy, obtained mainly from natural gas combustion [1]. This combustion process produces air emissions of carbon dioxide, one of the greenhouse gases responsible for global warming, whose emissions are internationally subject to monitoring and restriction.

The ceramic tile manufacturing sector is affected by Directive 2009/29/EC, which establishes a regime for greenhouse gas emission allowance trading [2], and it must therefore comply with all the legal obligations deriving from these regulations.

It is in this context that the project *"Reducing Greenhouse Gas emissions in the ceramic tile manufacturing process",* REDUCER, is set. The project is co-funded by the European Commission under the programme "Sustainable Industry Low Carbon Scheme (SILC)", aimed at supporting projects carried out in process industries affected by emissions trading in order to help address the challenges of a low-carbon economy and maintain industry competitiveness. In 2011, the European Commission published a Roadmap for moving to a competitive low-carbon economy in 2050 [3]. For the industrial sectors, which include the ceramic sector, the objective is to reduce CO_2 emissions by between 83% and 87% in 2050, values that are certainly very ambitious and that, according to certain simulations [4], will require radical changes in the technologies and actual product concept, as well as in the available energy sources.

However, the roadmap for the ceramic sector [5] establishes that in a first phase (to the year 2020) the greatest possible advantage is to be taken of the existing technologies for optimising installations and recovering heat.

The activities of the REDUCER project focus on these objectives, i.e. on reducing CO_2 emissions by implementing available technologies, in particular by optimising energy consumption in process facilities through the implementation of energy-saving actions in the facilities with the greatest natural gas consumption, and the installation of a waste heat recovery system from the kilns [6].

2 OBJECTIVE

The present paper describes some of the energy-saving measures implemented in the frame of the REDUCER project at the Azulev facilities. The most important measures have been the reduction in the gas volume flow rate in the dryer stacks, the reduction of the air volume flow rate at the kiln burners, and waste heat recovery from a kiln to several vertical dryers.

3 METHODOLOGY USED

3.1 Description of the studied installation

The studied installation consisted of a tile firing kiln and four dryers. The kiln was a single-deck roller kiln, 110 metres long. The heat input was produced by natural gas combustion at high-speed burners, the oxidising air coming from the cooling gas exhaust stack. The kiln had one flue gas exhaust stack and two cooling gas exhaust stacks.

The dryers in the installation were vertical dryers, each equipped with two natural gas burners set in the gas recirculation zones. The freshly pressed tiles were fed onto a dryer plane, replacing the already dried tiles on the same plane that exited the dryer for the glazing line. The moist tile feed then travelled upwards. The drying gases from the two burners entered the drying chamber and, after contact with the moist tiles, they were evacuated from the dryer; one part of the gases was exhausted into the air through the dryer stacks, while the rest was recirculated, their temperature being raised with the natural gas burners.

3.2 Experimental procedure for the determination of the variables

To implement and evaluate the energy-saving measures at the process facilities, certain variables needed to be determined experimentally. The variables measured in the kiln and the dryers, and the methodology used in their determination are detailed in Table 1.

Table 1 Variables determined in the implementation and evaluation of the energy-saving actions.

FACILITY	Variables measured	Sensor used
DRYER	Relative humidity of the stack gases (%)	Capacitive hygrometer
	Tile exit temperature (ºC)	Infrared pyrometer
	Tile exit residual moisture content (%)	Balance and oven
	Electric power consumption (kWh)	Grid analyser
KILN AND DRYER	Volume flow rate of consumed natural gas (Nm^3/h)	Flow meter
	Gas temperature in the stack (ºC)	K type thermocouple
	Gas volume flow rate in the stack (Nm^3/h)	Pitot tube and micropressure gauge
KILN	Oxygen content (%)	Gas analyser

3.3 Energy-saving actions

3.3.1 Reduction of the gas volume flow rate in the dryer stacks

The reduction of the gas volume flow rate in the dryer stacks saved energy because it reduced stack heat losses [4]. However, this action needed to be performed carefully because it modified drying air conditions and might therefore affect the tile properties when the tiles exited the dryer.

In this study, a hygrometer was installed in one dryer stack, in addition to a frequency inverter in the motor of the drying gas extraction fan. The fan rotation frequency was automated, based on the readout of stack gas humidity, so that the evacuated gas volume flow rate increased or decreased as a function of gas humidity. The variation of the gas volume flow rate has been plotted as a function of fan motor frequency.

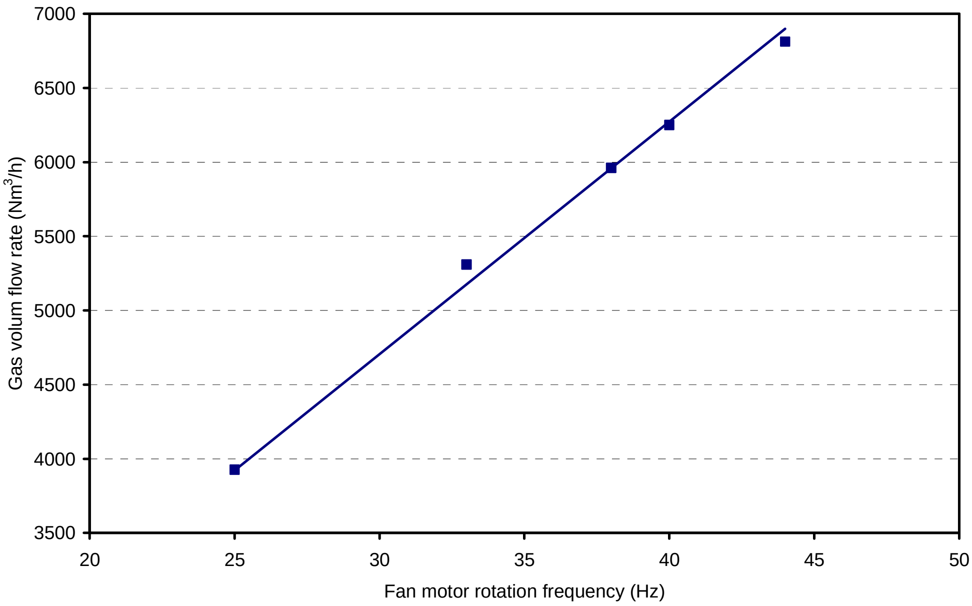

Figure 1. Relationship between the gas volume flow rate and the fan rotation frequency in the dryer stack.

A gas humidity setting was established for each work situation in the dryer, and this value regulated the volume flow rate of the evacuated gases, always holding the temperature and residual moisture content of the tiles within the values set by the company for the product being made.

In order to evaluate the impact on dryer operation of the volume flow rate control installed in the stack, the properties of the dryer stack gases (volume flow rate, humidity, and temperature), dryer energy consumption, and properties of the tiles exiting the dryer (temperature and residual moisture content) were monitored.

In addition to these variables, for proper comparison of the results between two different operating situations, other operating parameters were also noted, such as the dryer burner temperature setting, the temperature established in the dryer stabilisation zone, the product made, and dryer production.

3.3.2 Reduction of the oxidising air volume flow rate in the kiln burners

Natural gas combustion at the kiln burners uses air as oxidiser. The operation is usually performed with an important quantity of excess air in order to obtain an appropriate percentage of oxygen in the combustion gases to allow the oxidation reactions of the organic matter in the tile to develop satisfactorily.

At the burners, the oxidising air is heated by natural gas combustion at the temperature setting established in the kiln firing curve. When the air volume flow rate is reduced, natural gas consumption decreases because a smaller quantity of air needs to be heated, while the energy losses through the kiln flue gas stack decrease when the flue gas volume flow rate decreases [8][9].

However, the reduction of the oxidising air volume flow rate has other consequences, such as the modification of the static pressure in the kiln, so that this needs to be done carefully to assure that the static pressure profile is held within the appropriate parameters. This means that there is a cooling air input towards the firing zone, which allows a sufficient minimum oxygen content to be obtained in the kiln to maintain end product quality and kiln stability.

The reduction of the oxidising air volume flow rate was performed by modifying the kiln burners, replacing the existing ones with burners that could run with a smaller oxidising air volume flow rate.

The evaluation of the effectiveness of this energy-saving action, as well as its influence on certain kiln operating parameters, was analysed by comparing two similar production situations through the performance of a complete energy balance on the kiln and the experimental determination of a number of key process variables, such as static pressure, oxygen content, and the excess air coefficient in the kiln.

3.3.3 Kiln waste heat recovery to the dryers

At present, Azulev already has a heat recovery installation, which uses thermal oil as heat exchange fluid, from one of its kilns to a vertical dryer [10]. That installation was extended, incorporating another kiln as heat source and four vertical dryers as recovered-heat users.

The designed installation consists of waste heat recovery from the kiln flue gas stack and the cooling gas stack, in which two gas/thermal oil heat exchangers were installed for gas waste heat recovery.

The recovered heat was used in four of the company's vertical dryers in which, in turn, oil/drying gas heat exchangers were installed for the oil to transfer heat to the drying gases, thus reducing the energy input required from the natural gas burners in the dryers. The designed heat recovery system is schematically illustrated in Figure 2.

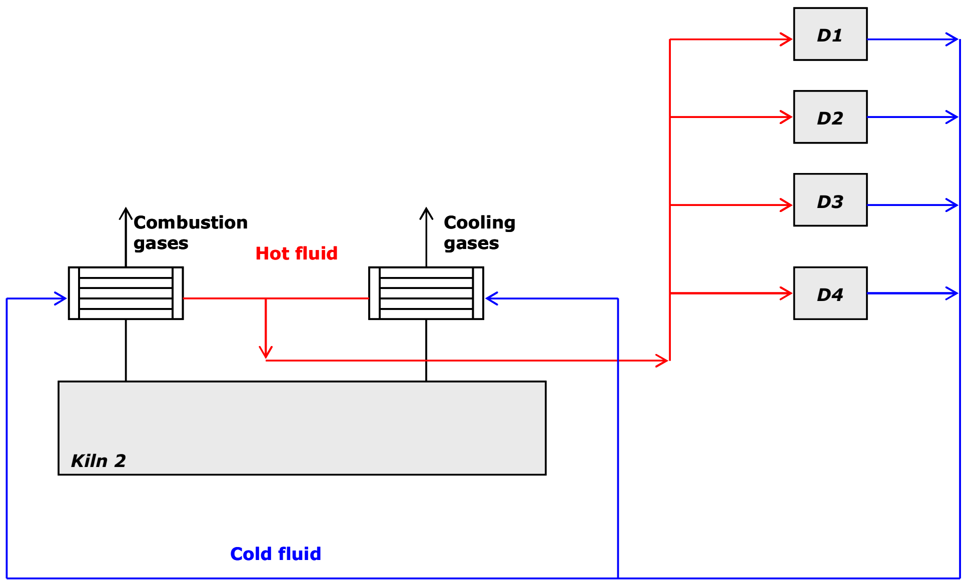

Figure 2 General scheme of the new heat recovery installation.

The quantity of heat recovered in the dryers was quantified by evaluating the natural gas consumption, with and without heat recovery, in each dryer.

The energy saving was measured and verified according to the methodology described in the international performance measurement and verification protocol (IPMVP) promoted by the Efficiency Valuation Organization (EVO). In this case, Option C, verification of the entire facility, was followed because each dryer had an individual natural gas counter.

4 RESULTS OBTAINED

The energy saving obtained in the implementation of the energy-saving actions described in section 3 are set out below, together with the quantification of the reduction in carbon dioxide emissions.

4.1 Reduction of the gas volume flow rate in the dryer stacks

The evolution of gas humidity and temperature in one dryer stack and the rotation frequency of the drying gas extraction fan, during 6 running hours of the dryer, have been plotted in Figure 3. The figure shows the operation of the set automatic control. The frequency inverter remained at a constant value, about 30 Hz, while the humidity in the stack stayed at about 5%. Under these conditions, the drying process was performed satisfactorily, tiles being obtained with the appropriate temperature and residual moisture content for subsequent decoration.

When the humidity in the stack dropped below 4.5%, owing to a shutdown in dryer operation, the volume flow rate in the stack decreased, fan frequency gradually dropping to 25 Hz. The stack volume flow rate was kept at this minimum volume flow rate until, after restarting dryer operation and the entry of moist tiles into the dryer, gas humidity in the stack increased again. When the gas humidity setting was exceeded, the volume flow rate of the evacuated gases increased once more in order to extract a greater quantity of water from the dryer and keep drying gas humidity at about 5%.

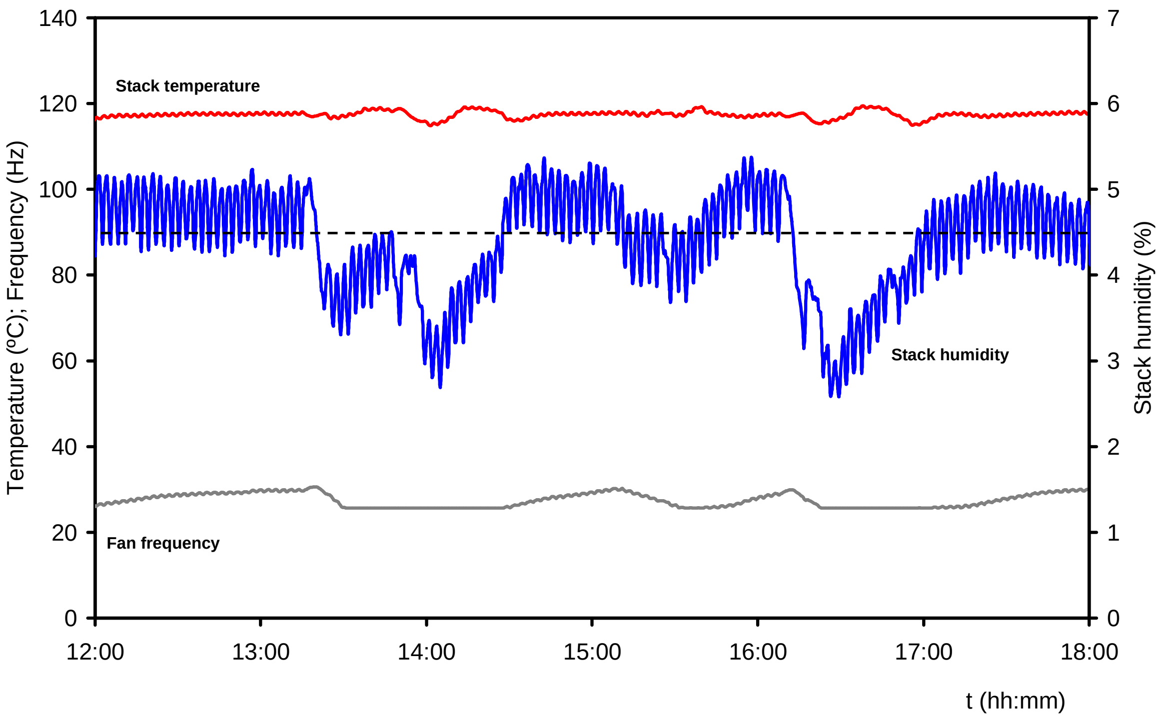

Figure 3 Automatic control of the drying gas extraction stack.

To evaluate the energy saving associated with the reduced gas volume flow rate in the stack, dryer energy consumption was evaluated under steady working conditions, with different stack gas flow volumes, keeping the other process variables (product, temperature settings, etc.) constant as far as possible.

Specific thermal energy consumption has been plotted against drying gas extraction fan frequency for porcelain tiles of two different sizes (30 cm x 60 cm, and 45 cm x 45 cm) in Figure 4.

It shows that, as was to be expected, energy consumption decreased when the volume flow rate of the stack gases diminished. The relationship between both parameters was linear, and it differed depending on the product made because dryer production, temperature settings, etc. were also different. Though the fit of the experimental data is not excellent, it may be deemed satisfactory (R^2>0.75) because on an industrial level it is very difficult to maintain exactly the same working conditions in a dryer, as small adjustments continuously take place in the work variables, which affect dryer energy consumption.

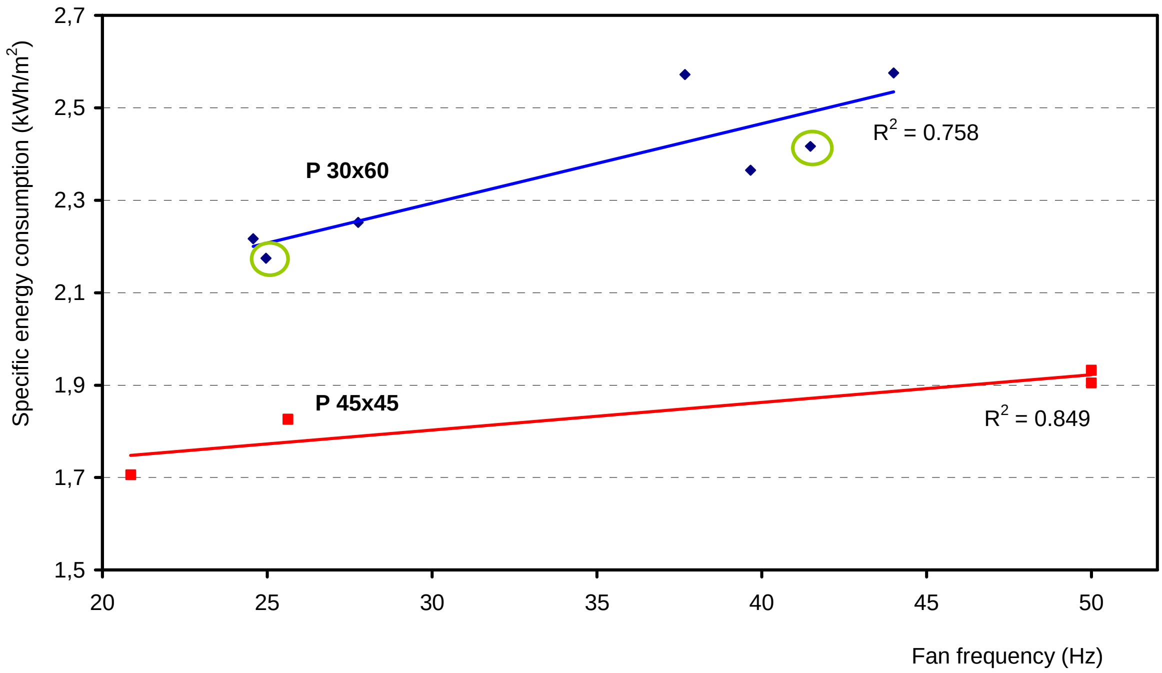

Figure 4 Relationship between specific consumption and fan frequency.

Some of the variables analysed in the operation when the extraction volume flow rate of the drying gases was lowered, fan frequency being reduced from 42 Hz to 24 Hz, are compared in Table 2. The two situations compared in Table 2 are highlighted by a circle in Figure 4.

Table 2 Reduction of the gas volume flow rate in the dryer stack. Comparative analysis of two working situations.

Parameter	Starting situation	End situation
Composition	Porcelain tile	
Fired tile size (cm x cm)	30 x 60	
Fan frequency (Hz)	42	25
Gas volume flow rate in the stack (Nm^3/h)	6813	3763
Stack gas temperature (ºC)	122	119
Stack gas humidity (%)	3.2	4.0
Tile exit temperature (ºC)	98	97
Tile exit moisture content (%)	0.007	0.011
Gas volume flow rate in the stack (Nm^3/h)	6813	3763
Thermal consumption (kWh/m^2)	2.417	2.175
Electric power consumption (kWh/m^2)	0.210	0.192
Thermal energy saving (%)	**10.0 %**	
Electric energy saving (%)	**8.43 %**	

It may be observed that, when the volume flow rate of the drying gases extracted from the dryer decreased, drying gas temperature decreased while gas humidity increased because water extraction from the dryer diminished.

This variation observed in the properties of the drying gases did not affect the properties of the tile bodies exiting the dryer because, even though the residual moisture content increased slightly, it remained below 0.5%, a value customarily considered the limit at the dryer exit for the tile to be able to withstand the next process stages without breakage. With regard to temperature, this decreased slightly, though it remained within the appropriate values for the subsequent glazing process.

In short, a 45% reduction in the gas volume flow rate in the dryer stack, performed by reducing the frequency of the gas extraction fan motor, yielded a thermal energy saving of 10% and an electricity saving of 8.4%, expressed per unit surface area of the processed dry product.

4.2 Reduction of the oxidising air volume flow rate in the kiln

The reduction of the oxidising air volume flow rate was addressed by replacing the kiln burners. This replacement reduced the gas volume flow rate in the flue gas stack, and it slightly decreased the oxygen content in the combustion chamber.

In addition, an important saving in natural gas was obtained in the kiln. The main kiln operating parameters relating to the reduction of the oxidising air volume flow rate are detailed in Table 3 for the starting situation, showing the usual oxidising air volume flow rate, and for the end situation, showing the lower oxidising air volume flow rate.

Table 3 Comparative analysis of certain operating parameters in the kiln for the starting and end situations.

Parameter		Starting situation	End situation
Composition		Red-body stoneware tile	
Oxidising air volume flow rate	Nm^3/h	3750	3300
Combustion gas temperature (*)	ºC	173	173
Combustion gas volume flow	Nm^3/h	14151	11700
Oxygen content in the stack	%	16.3	15.8
O_2 content in the kiln	%	11.1	9.0
Combustion gas enthalpy	kW	873	720
Natural gas consumption	kWh/t fired tile	536	501
Energy saving	kWh/t fired tile	35	
	%	6.5	
	GWh/year	2.74	
CO_2 emissions abatement	kg CO_2/t fired tile	16.1	
	t CO_2/year	**555**	

(*) Temperature recorded after dilution with ambient air

As the above table shows, the reduction in the combustion air volume flow rate lowered specific natural gas consumption by 6.5%.

The oxygen content in the combustion chamber fell by about 2%, but it remained at about 9%, a sufficiently high value to assure proper decomposition of the organic matter in the tiles. This is because cooling gases were fed into the combustion chamber as a result of an optimised static pressure profile, and they introduced oxygen into the combustion chamber.

With regard to the flue gas stack, the flue gas volume flow rate decreased, though the flue gas temperature was not affected. The heat losses through this stack were thus diminished, even though they were still high.

This energy-saving action entails an annual natural gas saving of 2.74 GWh/year, involving an economic saving of 96000 €/year and a CO_2 emissions abatement of 555 t/year.

4.3 Kiln waste heat recovery to the dryers

The installation of the thermal oil-based waste heat recovery system pursued the reduction of kiln heat losses and waste heat use in the dryers.

The performance of a complete energy balance on the kiln in the initial working situation, determining the output of the installed heat exchangers, enabled estimating the quantity of recovered energy and, consequently, the natural gas saving to be obtained in the vertical dryers.

At the moment of writing this paper, the heat recovery system is in the final assembly stage. The energy recovered from the stacks and the savings shown are therefore preliminary estimations, which will be verified after the start-up of the installation.

The result of the energy balance made on the kiln before the installation of the heat recovery system and the estimation performed for the kiln working situation once the heat recovery is running are presented in Table 4. It is estimated that it will be possible to recover a total of 600 kW, 200 kW from the flue gas stack and 400 kW from the cooling gas stack.

Table 4 Results of the energy balance on the kiln before and after the installation of the heat recovery system.

STREAM		Starting situation (%)	End situation (%)
INPUTS	Combustion	100	100
OUTPUTS	Chemical reactions	12	12
	Combustion gases	26	17
	Cooling gases	52	34
	Heat recoveries	---	27
	Losses	9	9
	Tiles	1	1
Kiln energy efficiency (*)		**12**	**39**

(*) Calculated as the quotient of the energy used and the total energy input.

As may be observed in Table 4, before the installation of the heat recovery system, about 77% of the kiln energy input was released into the atmosphere through the flue gas and cooling gas stacks, without being recovered.

After the installation of the heat recovery system, this percentage dropped to 55%, kiln energy efficiency increasing from 12% to 39%.

With regard to dryer operation, this is not expected to be affected by the heat input from the thermal oil, as the heat recovery with thermal oil previously installed in one of the company's vertical dryers has not led to any changes in dryer operation [10]. However, after the start-up of the installation, the proper operation of the dryers will be verified, and the real energy saving achieved will be experimentally determined.

4.4 Overall energy saving achieved

The implementation of the three energy-saving measures described provides an important natural gas saving in the manufacturing process, and consequently a reduction in carbon dioxide emissions.

Table 5 details the estimated annual savings. It should be noted that, for the calculation, the results shown in this work, obtained under given operating conditions, have been extrapolated to a year's operation. The kiln has a production time of 7680 h/year, while the four dryers have a production time of 5940 h/year.

Table 5 Results of the energy balance on the kiln before and after the installation of the heat recovery system.

Energy-saving action	Thermal energy saving (kW)	Annual energy saving (GWh/year)	Annual emissions abatement (t CO_2/year)
Operation 1: Reduction of the gas volume flow rate in the dryer stacks	110	0.66	133
Operation 2: Reduction of the oxidising air volume flow rate in the kiln	341	2.74	555
Operation 3: Waste heat recovery from the kiln to the dryers	600	3.56	722
TOTAL	1051	6.96	1411

In addition, during the performance of operation 1, an electric energy saving was obtained in the dryers of 0.04 GWh/year, amounting to 8.43%.

5 CONCLUSIONS

The present study allows the following conclusions to be drawn:

- An automatic control was implemented of the gas volume flow rate in the vertical dryer stacks as a function of drying gas humidity This measure did not modify the conditions of the exiting dried tiles, and it showed that, at gas volume flow rate reductions of about 45%, specific thermal energy consumptions in the dryer decreased by 9.9%.
- Reducing the air volume flow rate at the kiln burners yielded an estimated thermal energy saving of 2.74 GWh/year, which amounts to 555 tons of CO_2 a year.
- A thermal oil-based heat recovery system was installed, which was joined to the already existing system at the company, increasing the quantity of heat recovered from the kiln stacks and therefore further reducing energy consumption in the tile body vertical dryers. The new phase of the installation is estimated to recover 600 kW heat.

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