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Application of the Thermal Solar Energy in the Primary Circuit of Hot Water of the Four Palms Hotel

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Abstract: A proposal is made in the sanitary hot water system in a hotel installation consisting in the change of the black steel pipe system by high density polypropylene pipes in the primary circuit of the system. A field of vacuum tube solar collectors is sized to work in replacement of the heat recovery system of the water chiller. An economic and environmental analysis of the proposal is made. With the installation of the solar collectors, the hotel will deduct 27,545 liters (15,425 kg) of liquid gas propane (LPG) from its annual consumption, equivalent to 51,728 USD, avoiding the emission of 104,583 kg of CO_2eq into the environment. The simple recovery time of the investment will be 5.88 years. The results obtained demonstrate the feasibility of using solar thermal energy in the heating of sanitary water due to the decrease in the consumption of liquefied petroleum gas and, therefore, the environmental damage is reduced when greenhouse gases are no longer emitted.

Keywords: Sanitary hot water; Solar thermal energy; Solar collectors; Heat recovery; Energy saving; Economic saving

1. Introduction

It is based on studying pipes by intending to design an air conditioning and ventilation system to provide comfort and an optimal work environment to the working staff and the public to optimize operation. In this work it shows the implementation of innovative tools, acquisition of machines equipped with better technology in production processes, using the DMAIC methodology (also known as the five-step methodology. As a robust tool for improvement, it continuously interacts and the application of different tools to increase current productivity [1].

Other works expose the current situation of environmental behavior, throughout its life cycle, which allows us to quantify the environmental impact of these products. The production of air conditioning through the use of a centralized system that directly uses cold water from the sea or lake to cool the fresh water coming from air-conditioned premises, is a technically and economically feasible and simple way of using alternative energy that allows savings of more than 80% of electrical energy, so its environmental and economic impact is significant [2].

Other research reflects that carrying out a study of the environmental behavior of a building is an arduous task, due to the fact that there is not enough information on the construction materials, for a system that uses the micro tunnels for conduction of air and offers comfort conditions to the plants considering air temperature and volumetric flow as fundamental aspects in order to optimize energy consumption in air conditioning [3, 4].

A generalized correlation for combined inflow convection in ducts of arbitrary cross section is presented [5]. The new correlation is not recommended for ducts that have small aspect ratios that pinch the flow when convection is prescribed by the constant heat flux wall condition H2, while another study a new correlation for the Graetz problem in partial convection was developed [6].

For ducts of arbitrary cross-section, a proposed a general correlation for the Graetz laminar problem associated with convection in ducts of arbitrary cross-section and in later studies. The generalized Léveque solution for ducts of arbitrary cross section poses the asymptotic limit for mean perimeter convection generalizes for short ducts of arbitrary cross section. The results of this analysis can be incorporated into a generalized correlation for the complete Graetz problem in ducts of arbitrary cross section [7].

A mixing model for nanofluid flow analyzes based on the finite volume method was developed [8]. The results show that as the volume fraction of nanoparticles increases, the heat transfer and pressure drop increase in all the cases considered. Also, increasing the length of the duct bevel has a positive effect on convective heat transfer, despite the negative effect on pressure drop.

In the experimental results obtained in ducts of various cross-section shapes, to analyze the deep link between geometry and flow stability, experiments clearly showed the influence of geometry on the critical values of Reynolds numbers and in another study carried out by laminar flow of Newtonian liquids in ducts of rectangular cross-section a model for both physics and mathematics, considers in another study carried out the fully developed laminar flow of a Newtonian fluid, induced from rectangular cross section. Poisson's partial differential equation, the Saint-Venant solution, was used to calculate the Poiseuille number values, regardless of the aspect ratio of the rectangles [9].

Fluids flow stability in ducts of arbitrary cross-section, from these results, limit cases of Poiseuille flow of square and flat duct (infinite parallel plates) were considered. We show that there is a rectangle equivalent to a circular cross section for energy dissipation through viscous friction. Finally, we gave some mathematical consequences of this approach for the computations of the odd-integer zeta function [8].

Other authors investigate the effect of the round edge in the laminar Newtonian fluid flowing through a channel. As an innovation, the sine and cosine transform functions are used to solve the equation that governs the moment in Cartesian and cylindrical coordinates [10].

The problem of determining the shape factors for generic geometries that represent various configurations of porous media. They apply a Galerkin-based integral (GBI) method that determines the shape factors for the generic cross-sections of the pore channels. The Graetz problem, solves analytically for the constant laminar flow of nonlinear viscoelastic fluids in straight tubes of arbitrary cross section. The presented analytical algorithm is very versatile and can be easily applied to a wide spectrum of non-circular tube contours [11].

Anew model to predict the Nusselt number in the entrance region of non-circular smooth ducts and channels, both for uniform heat flux and for uniform wall temperature boundary conditions. The model, valid for laminar, transition, turbulent and fully turbulent regimes [12].

At present there is no thermo-hydraulic evaluation of the Four Palms Hotel, which characterizes the operational parameters, therefore the objective of this work is to carry out an evaluation and propose improvements that contribute to improving an evaluation and propose improvements that contribute to improving efficiency operational of it. For this purpose, the existing situation in the hot and cold-water lines at the Four Palms Hotel, its indicators and optimal operating parameters will be identified, and an improvement proposal will be made.

2. Methodology

2.1 Brief Description of the Facility Under Study

This work is carried out in the Four Palms Hotel, with 312 rooms of the Gran Caribe Hotel Chain due to the systematic complaints of the clients due to the lack of hot water for room service. The system apparently has no observable problems with the naked eye. It has two direct fired water heaters and 170 vacuum tube type solar heaters, 120 liters each with a thermo tank and electrical support resistors, located on the roofs of the buildings, with complementary systems incorporated such as recirculation and heat exchangers for hot water service to the rooms.

In addition to the technical networks, however, the hot water was not reaching the rooms, so it was decided to transfer this problem to a problem bank to be solved with a prioritized character due to its importance for the hotel, a diagnosis of the situation and detect several problems that were accumulating over time and continued operation since the service hot water system was installed and assembled in the hotel. This Sanitary Hot Water (DHW) system has the maintenance contracted with the Company of ALASTOR Boilers through an equalization every four months and its objective is cleaning, decaling, checking valves and technical parameters. It is unknown by the technical staff of the hotel facility if maintenance is effective or not in this period, since there is a lack of measuring instruments to measure temperatures and know the degree of encrustation, allowing this to measure efficiency in terms of gas consumption.

From two direct fired water heaters installed, one of them has pipes with loss of thickness and they present incrustations due to the hardness of the water used, with an operating time of eight years. The installation uses vacuum tube type solar heaters, but these have broken tubes, with loss of insulation in the hot water pipes, installed in isolation. Several technical networks of the system are not properly insulated or lacking, buried, with leaks and scale, clogged up to 60% of the area of the diameter of the pipes. There is no system of water softeners at room temperature at the entrance of the system to have better quality water in the process.

2.2 Thermo-Hydraulic Evaluation of Hot Water Pipes

The thermo-hydraulic evaluation of hot water pipes begins by defining the friction factor inside the pipes

through the Filonenko equation (the pipes are considered hydraulically smooth), which is given by [12]:

$$f = (1.82 \log Re - 1.64)^{-2} \quad (1)$$

The pressure drops in the pipes are determined from the Darcy Weibash expression [12].

$$\Delta P = f \frac{l}{d} \frac{V^2}{2g} + \sum_{i=1}^{i=n} K \frac{V^2}{2g} \quad (2)$$

where, ΔP is the pressure drop, in m. l is the length of the duct, in m. V is the flow velocity, in m/s. g is the acceleration due to gravity. K is the accessory loss coefficient. d is the internal diameter of the tube, in m.

The average heat transfer coefficient for the confined fluid is determined by the simplified Dittus-Bolter relationship, which is given by [12]:

$$Nu = \frac{\alpha_1 d}{\lambda} = 0.023 Re^{0.8} Pr^{0.4} \quad (3)$$

2.3 Initial Description of the Facility Under Study

The hot water service system (WSS), corresponding to the Hotel, in the Varadero tourist area. It is made up of three centralized water chillers which recover part of the overheating heat. Under current conditions, the condensation heat recovery system is not installed due to the great deterioration of the pipes that interconnect the different components of the primary circuit, so that the entire volume of water consumed in the hotel is produced by an Alastor brand water heater, model CAC-750, with a hot water production of 750 gal/h (2.84 m^3/h) and a fuel consumption of 17 kg/h of LPG, which represents an expense considerable financial and environmental resources for the entity and the country.

The heat exchange between the primary and secondary circuits is carried out in two Alfa-Laval brand plate heat exchangers. The DHW accumulation system is made up of four tanks of 8 m^3 each for a total of 32 m^3, the stored water is driven to the different rooms of the hotel and the one that is not consumed returns supported by the recirculation pump, a system of primary pumping with two in-line pumps (one reserve) of G = 8.2m^3/h and H= 15 m, and the secondary with the same design and pumps of G=7.56m^3/h and H=8m.

2.4 Analysis of the Climatologically Study of the Area

Table 1. Effective solar radiation

Month	Mean solar radiation (kWh/m^2/día)	Effective solar radiation
January	4.11	4.52
February	5.09	5.26
March	6.1	5.85
April	7.03	6.15
May	7.16	5.86
June	6.85	5.41
July	7.08	5.79
August	6.74	5.96
September	5.96	5.83
October	5.14	5.56
November	4.25	4.87
December	3.71	4.25

The objective of this study was to know the solar availability in the locality. The climatological data used are latitude, ambient temperature, average daily global solar radiation on a horizontal surface, direct solar radiation and daily average diffuse solar radiation. For this, an analysis of the average solar radiation in the 12 months of the year is performed, which was affected by several factors such as: correction factor H for air quality, radiation intensity during the day and the corrective factor K depending on the latitude and inclination of the collector,

resulting in the effective solar radiation shown in Table 1.

The f-chart method is used, which shows the analysis of the solar installation that will provide the necessary energy for the operation of the collector field, allows knowing the monthly energy demand, as well as the energy that is used and lost during operation. of the solar field, which are within the values obtained by other authors who use this method to predict the operation of this type of installation.

3. Results

3.1 Analysis of the Dimensioning of the Collector Field

For the design of the field of collectors, a search was carried out for the main suppliers of vacuum tube solar collectors, and with the data obtained in previous sections, a selection was made.

The Viessmann vacuum tube type manifold of the Vitosol 200-TM model was selected since it presents the possibility of orienting its tubes at an angle of ±45º. This product has two variants of the selected model, with 9 or 18 tubes, so a search is made for the ideal place for its installation, which turns out to be the surface of the ceiling of the engine room (place where the boiler), being as close as possible to the system components such as accumulators, exchangers and pumps, and also to the chillers. Said area has two surfaces of 660 m^2 for a total of 1,320 m^2 of usable surface, without intermediate obstacles, or blunt objects that cast shadows on them, so that the proposed recommendation is complied.

To determine the catchment area, the number of collectors and the necessary surface for the installation, the calculation was carried out, which yielded the following results: Catchment area: 639 m^2 Number of collectors: 196 units, Necessary surface: 1,039 m^2.

As the collection area turned out to be large, it was decided to select the largest variant of this model, which has 18 tubes, representing 3.26 m^2 of collection surface and a gross surface area of 5.3 m^2, since it has two collection areas. 22 x 30 m, it was decided to opt for series-parallel connections of said collectors, taking into account the limitations established in their connection, and as the manufacturer of the collectors does not establish any limitation regarding this type of arrangement, it was decided by distributing the 196 collectors in two branches of 98 units in each section, and each one in turn is distributed by two groups of 49 units, as shown in Figure 1.

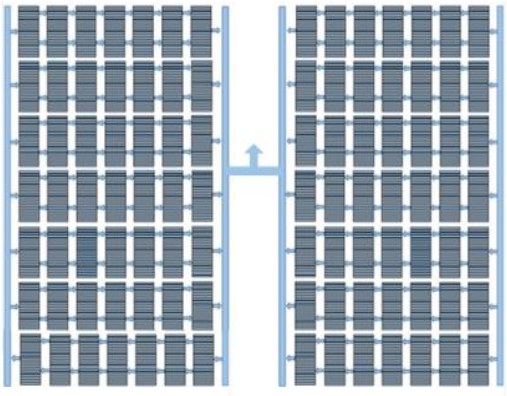

Figure 1. Design of the collector connections

3.2 Analysis of the Selection of Pipes and Thermal Insulation

In the case of pipes, it is recommended to carry out a capital replacement of the primary circuit, as it is in a critical state, for which reliable options are studied in terms of quality and it is determined by their characteristics to select Random polypropylene pipes (RPP) of the Niron brand. RPP is a polymer (plastic), which, due to its excellent properties, makes it the best alternative for the distribution and supply of pressurized drinking water, both in the domestic and industrial sectors, including food, as it guarantees total non-toxicity for humans.

Among its many qualities, it stands out that it does not transmit odor or taste to the water, they are resistant to working conditions (pressure and temperature), the union is made by thermo fusion, it does not require mechanical connections or filler material and one of the main advantages is that does not suffer corrosion, neither external nor internal, since it is located in an area prolific to corrosion by marine spray. In the economic aspect, it is important to highlight that any polypropylene pipe, regardless of the supplier, will always be much cheaper compared to galvanized and copper ones, this selected model shows it.

For the selection of the insulation, the Armaflex supplier is chosen, known in Cuba, being the most used in the

Varadero area, since it has a high level of reliability among its customers and a great product quality. To determine its thickness, the manufacturer's catalog is used, which is supported by the RITE 2013 regulation "Minimum insulation thicknesses for pipes and accessories that transport thermal fluids" [13]. The thickness selection procedure is shown through fluids that flow outside or inside buildings, and through which it is determined that 40 mm corresponds. In Figure 2 is given a graphical representation of the relation between insulation thicknesses for the pipes, temperature relative and thermal conductivity of the pipe material wall.

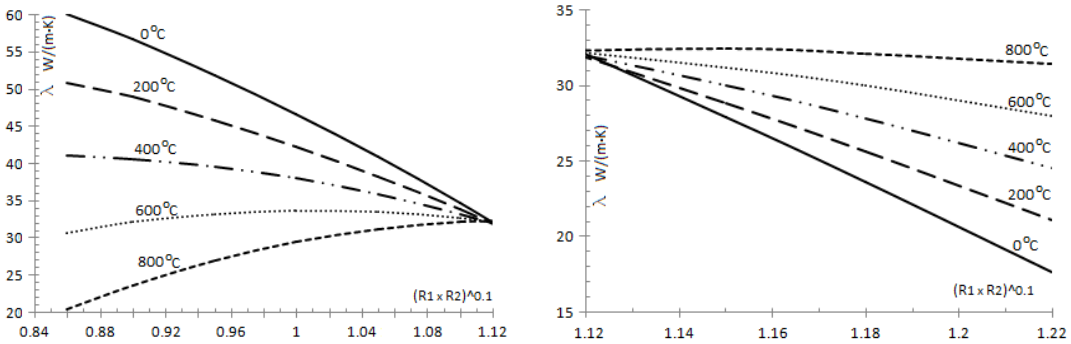

Figure 2. Graphical relation between pipes diameter and thermal conductivity with temperature

The amount of material needed for the pipes and the insulation is the same, to obtain it, measurements are made in the installation itself despite having the same plans, and it is known that the distance between the pipes is 20 m, being round trip and having three coolers, it is determined that 100 m is what is needed. Once the minimum thickness of the insulation and the diameter of the pipes are known, the prices of each one is determined, which are 3.71 USD and 8.60 USD, respectively, according to the BFI exchange rate [14].

3.3 LPG Consumption, Economic and Environmental Damage

Currently the hot water production system in the facility is through the LPG heater, which contributes significant consumption, last year there was an expense of 106,086 liters in the boiler, that is, only for the production of hot water. For the analysis of the saving of LPG consumption in relation to the installation of the solar collectors, an estimate is made based on the working hours of the heater, since said time is not recorded and it is an automatic ignition process, it is expected that it will work only 8 hours/day, at night, although leaving a three-way valve in case of breakage or high demand. In this period of time, since the collectors cannot work due to the absence of solar radiation [15, 16], the heater and the storage tanks with the liquid accumulated from the previous hours of the day will cover this service.

The expense reported by this equipment was obtained based on fuel consumption and its price per liter, which varies from 0.475 to 0.591 liters/USD, taking 0.533 liters/USD as an average value. Figure 1 shows this consumption. The data used is shows in Figure 3. This data is from year 2020, since due to Covid issues, the facility was closed to international tourism. The last exchange rate given by the Central Bank of Cuba establishes that 1 CUC≈1 USD.

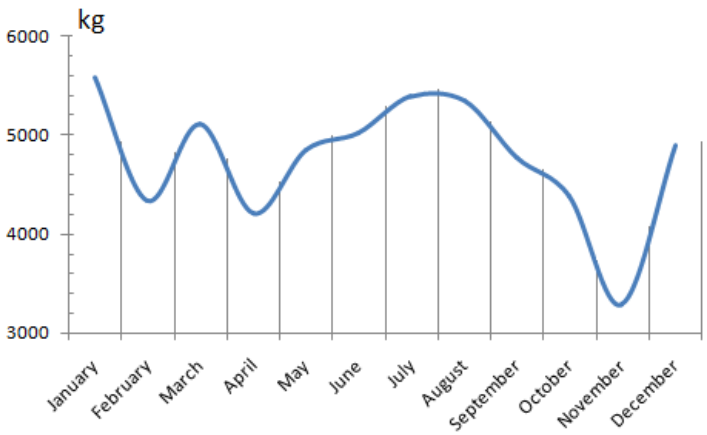

Figure 3. Monthly rate of LPG, year 2020

4. Conclusions

With the substitution of iron pipes for Niron in the area exposed to the external environment, external corrosion of the tube will be prevented, granting more reliability to the service. To meet the heating needs of the primary DHW circuit, a total of 196 Vitosol 200-TM solar collectors is needed, representing a surface area of 1,039 m^2. With the installation of the solar collectors, the hotel will deduct 27,545 liters of LPG (15,425 kg) from its annual consumption, equivalent to 51,728 USD, avoiding the emission of 104,583 kg of CO_2eq into the environment. The simple recovery time of the investment will be 5.88 years.

Author Contributions

Conceptualization, Y.C-M. and M.G-S.; methodology, Y.C-M. and M.G-S.; software, Y.C-M. and M.G-S.; validation, Y.C-M. and M.G-S.; formal analysis, Y.C-M. and M.G-S.; investigation, Y.C-M. and M.G-S.; resources, Y.C-M. and M.G-S.; data curation, Y.C-M.; writing—original draft preparation, Y.C-M.; writing—review and editing, Y.C-M. and M.G-S.; visualization, Y.C-M. and M.G-S.; supervision, Y.C-M. and M.G-S.; project administration, Y.C-M. and M.G-S.

Data availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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