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An inhouse code for simulating heat recovery from boilers to heat water

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ABSTRACT

The current tendency in energy domain is to reduce fuel consumption in favor of sustainable energy approaches. In this frame, the present work suggests an efficient way of heat recovery from boilers using concentric tube. The motivation behind the suggested concept is that it could be considered the cheapest, easiest to construct and simplest to use among all the existing heat recovery systems. In other words, the goal is to suggest a technique that could be utilized by a wider range of users regardless their technical level. Another advantage of the proposed concept is that is can be applied even on small scale boilers. With this in mind, a numerical tool is also developed allowing to make pre-studies to optimize the geometric parameters such as diameters and length, as well as to perform post-studies that allows to optimize operational parameters such as flow rates and fluids configurations. Furthermore, an experimental study is carried-out to validate the numerical results of the adopted heat exchanger. It was shown that water can be heated up to 100 °C depending on the flow rate and that the recovered heat increases through a rational function.

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1. Introduction

With the intensification of the negative repercussions of the energy crisis it is unescapable to adopt approaches that help in decreasing energy consumptions along with renewable energy solutions such as solar energy [1–7], wind energy [8,9], bioenergy [10,11], wave energy [12,13], biomass [14–16] and geothermal energy. Such approaches should rely on the Energy Consumption Map (ECM) to identify the elements with higher energy consumption. Indeed, the nature of the considered space will draw its ECM. For instance, in residential spaces one of the most energy consuming elements is Heating, Ventilating and Air Conditioning (HVAC) systems. On the other hand, HVAC systems have changed from being luxury to an essential need especially in regions with extreme weather or during hot or cold climate periods that why it is very beneficial to find techniques to reduce their energy consumption by reducing their energy loss. Energy management [17–19] is another approach that serves in solving energy crisis. One of its most effective techniques is heat recovery [20–22] which is defined as the capture of waste heat dissipated by an energy system to be used in other energy system [23,24]. Depending on the system dissipating waste energy, heat recovery may take different forms [25–27]: internal combustion engines [28,29], heat pumps [30], thermoelectric power generators [31], chimneys [32,33] and other applications [34–37]. Fig. 1 presents a schematic diagram of different applications of heat recovery from exhaust gases. On the other hand, recovered energy can be used for different purposes, that is to say recovering heat can serve not only for direct heating but also for indirect use such as thermoelectric power generation. Khaled et al. [33] conducted an experimental study on heating water from waste heat of a chimney. The authors designed a multi-concentric tank in which exhaust gas flows through pipes passing through the water tank. The results show a considerable increase in water temperature within short period of time. In Ref. [34] the authors performed a parametric study on waste heat recovery system from exhaust gases of a 500kVA generator. Different

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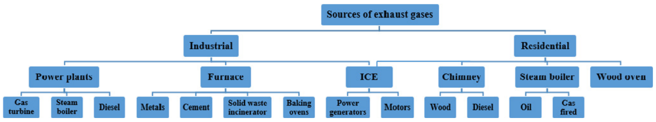

Fig. 1. Sources of waste heat.

configurations are examined. It was obtained that 26 kW of thermal energy can be captured by water, if a 0.75 diameter ratio is considered and the inner fluid is water. Ramadan et al. [36] pursue a parametric study on heat recovery from the hot air of condenser to preheat/heat domestic water. The authors studied the effect of the mass flow rate of air and water and constructed a thermal modeling of the system. It was shown that water temperature can increase to 70 °C depending on cooling load and mass flow rate of air. Kim et al. [37] performed a computational study to estimate the optimum position of a super heater utilized in an automotive waste heat recovery system combined with gasoline direct injection engine of 3.3 L V6. Besides, the authors conducted an experimental study to validate the results. Duan et al. [38] suggested a multi-stage slag waste heat recovery system in order to use the waste heat of blast furnace slag more effectively. The authors evaluated the environmental performance of the suggested system by using the life cycle assessment. Also, the authors analyzed the economic feasibility of the system as a function of capital cost and return analysis. In Ref. [39] the authors suggest to use the recovered heat to enhance the performance of heat pump.

Several studies were dedicated to investigate heat recovery from exhaust gases of boilers. Most of the works aims to optimize boilers performance and increase the thermal efficiency of the power plant [40–44]. moremore, the existing approaches of heat recovery from boilers could be classified within two main branches either heating the inlet air [45–48] which can be considered as a pre-heating step or optimizing [49,50] the heat recovery process. In Ref. [46] the authors performed a thermodynamic performance analysis for a water sprayed waste heat recovery boiler. The aim of the study is to calculate the improvement in the thermal efficiency of the boiler. The water that condenses from the main boiler and waste heat recovery system is utilized and sprayed onto the air. Ma et al. [47] developed a techno-economic analysis on heat recovery system from 600 MW brown coal fired boiler. A new hot air recirculation (HAR) system is examined. In addition, the performance of conventional bypass flue process is calculated. Zhao et al. [51] have developed a mathematical model to investigate the thermoelectric generation characteristics of recovering heat from exhaust gases of natural gas boiler. The authors suggest to enhance the performance of thermoelectric generators using gas humidification. The rest of the manuscript is organized as follows. Section 2 gives briefly a theoretical background on HVAC systems and presents the principle of the concept of applying heat recovery concepts in HVAC applications. In section 3, the thermal modeling of the complete system, as well as the operational mode of the code are exposed. Section 4 is then devoted to the results and parametric analysis. Finally, section 5 draws the main conclusions of the work.

2. Heat recovery concept

Several techniques could be adopted to perform space heating [16]. In all-water systems, heating is provided by supplying hot water using water distribution from a central equipment. A boiler is used to heat water thanks to fuel burning. Heated water is then distributed to the different rooms via a heat exchanger at each room terminal as shown in Fig. 2. The functional block diagram of the proposed waste heat recovery system can be represented as shown in Fig. 3.

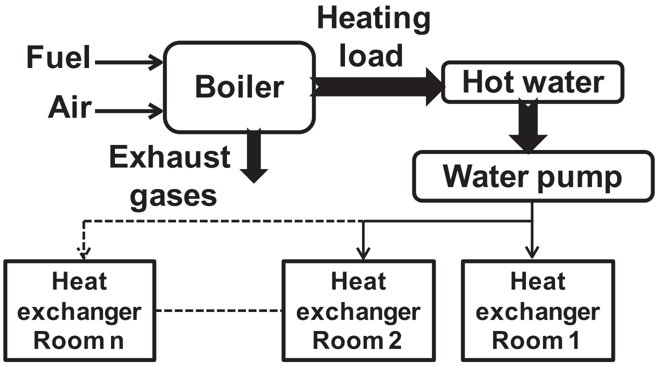

Fig. 2. Central All-Water heating HVAC system.

The energy input resulting from fuel burning is divided between useful heating load (around 80%) transferred to the space and around 20% of heat in the exhaust gases. The principle of the proposed heat recovery system is to circulate the exhaust gases into pipes inserted in water pipes connected to the cold water supply or inversely in such a manner to form a concentric tube heat exchanger.

3. Thermal modeling and computational code

The heat exchanger considered in the present study is counter flow concentric tube heat exchanger with the exhaust gases of the boiler flowing in the inner diameter $D_i$of the exchanger and water flowing in the annulus of the exchanger. The outer diameter of the exchanger is noted $D_o$and the exchanger has a length$L$. In this type of exchanger and neglecting the heat transfer between water in the annulus and the ambient air, the energy balance can be written as [17]:

$$\dot{m}_w C_{p,w}\left(T_{w,out} - T_{w,in}\right) = \dot{m}_g C_{p,g}\left(T_{g,in} - T_{g,out}\right) = U \cdot A \cdot \Delta T_{\ln} \quad (1)$$

Where:

$\dot{m}_w$and $\dot{m}_g$ are respectively the water and gas mass flow rates, $C_{p,w}$ and $C_{p,g}$are respectively the water and gas specific heats, $T_{w,in}$and $T_{g,in}$are respectively the water and gas inlet temperatures, $T_{w,out}$and $T_{g,out}$are respectively the water and gas outlet temperatures, $U$the overall heat transfer coefficient between the two fluids streams, $A$the area of heat transfer between the two fluids, and $\Delta T_{\ln}$the logarithmic mean temperature difference between the two

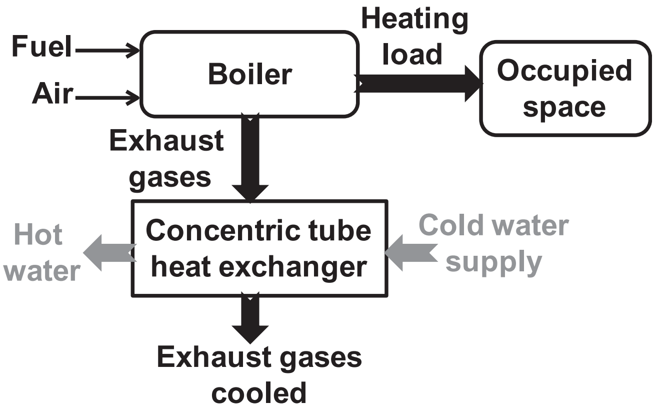

Fig. 3. Functional block diagram of the proposed waste heat recovery system.

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