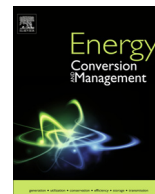




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The development of a thermoelectric power generator dedicated to stove-fireplaces with heat accumulation systems

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ABSTRACT

A significant part of the world's population (about 40%) cooks their meals and provides heating for their homes using wood-burning heating devices. Due to the relatively low cost of fuel and their aesthetic design, solid fuel stoves capable of heat accumulation are convenient and common. The use of dedicated small-scale power generators provides also additional benefits.

This paper presents the results of a study conducted to verify the possibility of generating power using stove-fireplaces with heat accumulation systems. In such units, the temperature of the flue gas should be kept at a certain level for the purposes of storing heat, which results from certain limitations of the thermoelectric generators. To verify the possibility of applying thermoelectric modules in such heating devices, a dedicated system with thermoelectric generators was selected from among various microcogeneration systems and implemented. Three types of heat exchangers were studied and the most efficient unit was selected for further testing. Two types of generators, with maximum operating temperatures of 320 and 175 °C, were compared. Subsequently, the characteristics of the latter were determined. The conducted tests allowed to determine the performance and the total efficiency of the generators that were used. It has been demonstrated that the maximum power of the generator would not exceed ca. 30 W_e and that there is no economic justification for such a device. However, providing a self-powered and self-sufficient operation of stove-fireplaces with heat accumulation systems remains an important goal.

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1. Introduction

The efficiency of energy generation and consumption is an essential aspect in the development of modern buildings. Also the low operating costs, energy security and comfort are not without significance. For these reasons, stove-fireplaces with heat accumulation systems (SFA) that are a combination of fireplaces and traditional accumulative stoves are becoming increasingly popular. The idea behind such devices is shown in Fig. 1.

Within the system, the heat produced while burning wood is stored in the accumulative heat exchanger and dissipated up to 12 h after the fire has died out. The resulting thermal efficiency of these devices reaches approximately 90% [2]. Such a high efficiency results also from the automation of the combustion process. The use of optimizers allows to control the amount of air supplied to the furnace and the temperature of the flue gas in the exchanger (in order to avoid tar condensation resulting from the insufficient temperature of the flue gas). The control of the air flow is achieved

using one or more proportionally opening choke valves operating in the range from 0 to 100%. The air flows through different inlets providing good mixing of gaseous products of wood gasification and oxygen, thus allowing for a clean combustion of the biomass.

Having the above in mind, the self-sufficient operation of stove-fireplaces with heat accumulation systems requires the development and application of a dedicated power generating system. Such systems should consist of a step-up/step-down voltage regulator (converting input voltage to a 12 V output), a battery charge controller and a battery (see Fig. 2). The power generated by the system will be used to actuate the choke valves and the controller (by means of a dedicated algorithm controlling the combustion process). In more advanced cases, the power may be used to power the circulation pump in the central heating/hot water system or other home appliances. Alternatively, the power may also be sold to the grid.

The power generating system in concern is dedicated to fireplaces with heat accumulating systems in which the heat from the flue gas is accumulated in special patented bricks and subsequently used for heating purposes. In such systems, the temperature of the flue gas after passing the TEG module should not

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Nomenclature

Symbols

t	temperature ($^{\circ}\text{C}$)
T	temperature (K)

Subscripts

e	electrical
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Abbreviations

CTC	comparative temperature coefficient
DC	direct current
DHW	domestic hot water
DPBT	dynamic payback time
DTA	differential thermal analysis
ETEG	exhaust-based thermoelectric generator

IRR	internal rate of return
MPP	maximum power point
MPPT	maximum power point tracking
NDIR	nondispersive infrared
NPV	net present value
PLC	programmable logic controller
PV	photovoltaic
RES	renewable energy sources
RTD	resistance temperature detectors
SFA	stove-fireplace with accumulation
SPBT	simple payback time
TE	thermoelectric
TEG	thermoelectric generator
TGA	thermogravimetric analysis

exceed certain limits. The system is designed so as to provide heat power for a period of 8–12 h after the end of the combustion process. As it was shown in [3], according to the numerical model of the heat accumulation module, the highest flue gas temperature at the TEG outlet should not exceed 300°C , while the lower temperature limit depends on the length of the heat exchanger and – as in the case of the considered units – was estimated to be at the level of 230°C (in such a case the heat accumulated in the module allows for a few hours of heating, which was confirmed by thermographic camera tests). Due to the rate of the heat exchange (flue gas – bricks) the optimal velocity of the flue gas is ca. 0.2 m/s , which is not sufficient for the regular operation of the modules of the TEG. This results in a limited range of operational conditions of the analyzed TEG.

In this case, a more advanced operation of three basic systems is considered: a combustion channel, a thermoelectric device and a heat accumulation module. The previous works did not consider the impact of the flue gas temperature and the flow limitations on the operation of systems with heat accumulation. This is because the main task of these systems – to accumulate and slowly transfer the heat to the ambient air – is their imperative function.

2. The state of the art

The possibility of using thermoelectric generators heated by stoves and other small heat sources is a subject of many studies

worldwide. Research in the area of power generation, on the other hand, is generally not available in the context of stove-fireplaces.

Nuwayhid et al. have presented a power generating system with a TEG fitted to the side of a domestic woodstove and cooled by natural convection (using a heat sink). The maximum matched load power in a steady state, achieved using a single module, was 4.2 W [4]. These same researchers have also considered the possibility of continuous generation of $10\text{--}100\text{ W}$ of electric power using the heat from 20 to 50 kW wood stoves. In the first prototype, the maximum achieved power per module was at the level of 1 W (using low-cost Peltier modules). This was caused by the low temperature difference (limited by the maximum operation

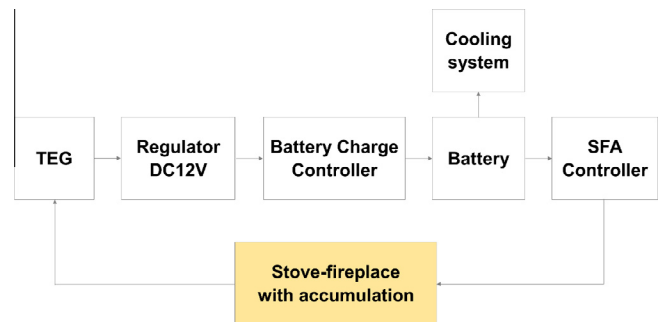


Fig. 2. The idea behind the power generation system for the SFA.

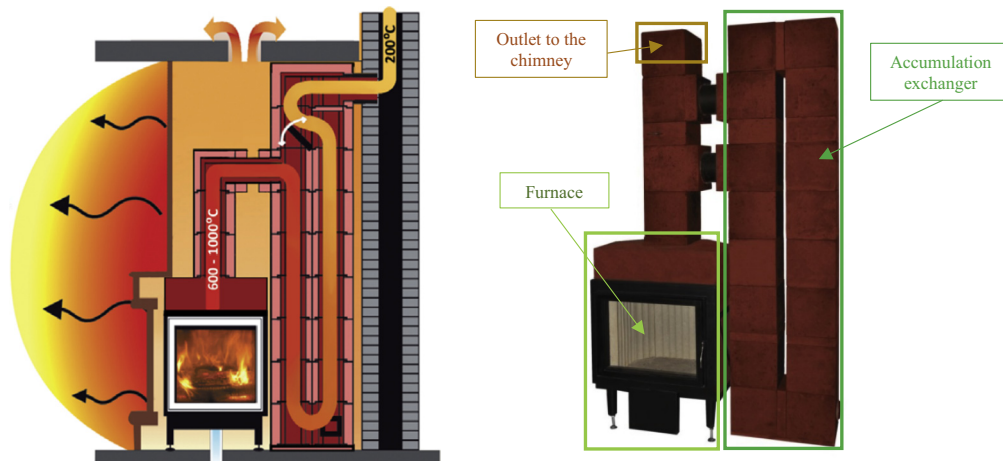


Fig. 1. The idea behind a stove-fireplace with heat accumulation system [1].

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