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# Dampening of wood batch combustion heat release using a phase change material heat storage: Material selection and heat storage property optimization

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ABSTRACT

The use of wood stoves for space heating in energy effective residential buildings can be problematic due to the batch combustion giving a highly transient heat production and the limited regulation of the combustion process. Increasing the heat storage capacity and lowering the maximum heat release from the stove has been proposed to improve the utility of wood stoves. Latent Heat Storage (LHS) solutions will lower and even out the heat release from stoves. However, finding a suitable Phase Change Material (PCM) for a LHS solution can be problematic. In this work an analytical method for ranking PCM candidates for LHS solutions is proposed. The method takes into account PCM properties, in addition to LHS properties that have to be tailored to the selected PCM. The method is validated with numerical models using realistic heat production profiles from wood stoves. The numerical results show significant benefits of using PCMs in LHS solutions over traditional solutions. There exists significant work on PCMs and their properties, but little work on how to select a PCM for a given application. This work contributes to a more efficient selection process, decreasing the work required to select the optimum PCM for a LHS.



## 1. Introduction

In Norway, a large share of the electricity produced is used for residential heating in resistance heaters. The national power consumption is increasing, while the power production is stagnating [1]. To increase the energy sustainability and security Norway has decided to encourage the use of more biomass for heating purposes. The goal is to increase the bioenergy production by 100% from 2008 to 2020 [2]. To achieve this goal, the consumption of biomass must increase. For this to happen there must be viable ways for biomass (wood) combustion to replace non-sustainable electrical resistance heating. This means that the versatility of wood stoves must increase. Modern wood stoves have thermal efficiencies of 70%–80% at nominal loads [3], and stoves are therefore a good and economic source of heat during extended periods of cold weather. Wood stoves do not operate as well at outputs lower than their nominal load, as this causes less efficient combustion conditions and higher emissions of unburnt particles and gases. Wood combustion in a wood stove is a batch combustion process and will give a heat production that is highly transient, due to the heterogeneous composition and successive thermal decomposition nature of logs of wood [4]. In addition, the combustion process is difficult to regulate without proper control equipment. Wood stoves in Norway are generally natural draft stoves, and without electric connection for control purposes. Heating during periods of moderate ambient temperatures and low heat requirements is therefore less beneficial, as overheating or inefficient combustion limit the viability of the stove.

The latest building standard in Norway includes new heat insulation requirements that will decrease the heating demand of new houses. Research has showed that this will be difficult to handle for current wood stoves on the market [5]. Using wood stoves as the main heating source, stoves having nominal loads below 4 kW should be developed, as the heat requirements are in the order of 3–5 kW for houses in cold climates [6] and about 2.5 kW for Central European houses [5].

If the heat release pattern is dampened, the heating season for

*Abbreviations:* MAD, Mean absolute deviation; LHS, Latent heat storage; SHS, Sensible heat storage; HTE, Heat transfer enhancement.

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**Nomenclature**

*Abbreviations*

| | |
|---|---|
| MAD | Mean absolute deviation |
| LHS | Latent heat storage |
| PCM | Phase change material |
| SHS | Sensible heat storage |
| HTE | Heat transfer enhancement |

*Symbols*

| | |
|---|---|
| b/L | Geometry parameter used by Equation (13) [21] [−] |
| Bi | Biot number [−] |
| $c_p$ | Specific energy density at constant pressure [kJ/kgK] |
| $C_r$ | Latent heat ratio [−] |
| $C_{crit}$ | Critical overcharging ratio [−] |
| c | Heat transfer constant [$WK^{4/5}/m^2$] |
| ε | Porosity, volume fraction of PCM [−] |
| $e_v$ | Volumetric energy density [$J/m^3$] |
| $h_{cold}$ | Cold side heat transfer coefficient [$W/m^2K$] |
| $H_{sl}$ | Heat of fusion [kJ/kg] |
| k | Thermal conductivity [W/mK] |
| L | Heat storage thickness [m] |
| $T_{amb}$ | Ambient temperature [K] |
| $T_m$ | Melting temperature [K] |
| $\dot{q}''$ | Heat flux [$W/m^2$] |
| $\overline{q''}$ | Average heat flux [$W/m^2$] |
| ρ | Density [$kg/m^3$] |
| r | Geometry parameter used by Equation (13) [21] [−] |
| $T_m$ | Melting temperature [K] |
| ΔT | Temperature difference [K] |
| $\Delta t_{cycle}$ | Duration of one firing cycle (1.5 h) [s] |

*Subscripts*

| | |
|---|---|
| crit | Critical |
| cold | Denoting the cold side (facing the ambient) |
| eff | Effective, taking PCM and HTE properties into account |
| foam | HTE − metal foam |
| hot | Denoting the hot side (facing the stove) |
| ideal | Ideal |
| l | Liquid |
| m | Melting |
| s | Solid |

wood stoves can be lengthened, and the utility of wood combustion as a heat source will increase. The combustion chamber in a stove does not necessarily need to be altered to lower the heat release from a stove system. A heat storage system can be used to absorb the heat produced and dampen the heat release to the room, as shown in Fig. 1. In the figure a relatively flat LHS is placed in such a way that the heat released from the stove has to be intermittently stored in the LHS before it can be released to the ambient.

Traditionally, and currently, soapstone is used as sensible heat storage (SHS), due to its relatively high density, thermal conductivity and heat capacity. The soapstone is usually lining the stove so that the heat transferred to the room from the stove is first intermediately partially stored in the stone and then released primarily by convection and radiation. Hence, the heat is stored as sensible heat in the stone and the heat released to the surrounding is dampened.

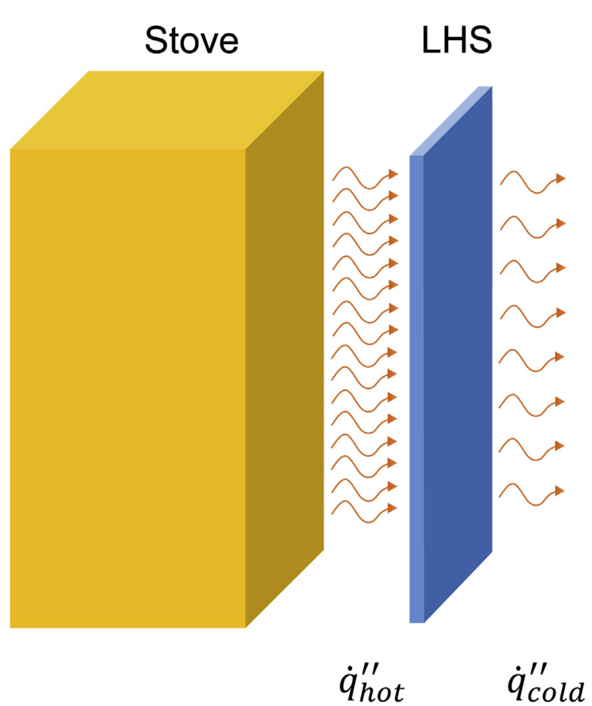


**Fig. 1.** Position of heat storage in relation to the stove and ambient environment.

It is possible to flatten the heat release more by storing heat latently, by the use of a Phase Change Material (PCM). This will anchor the heat storage temperature to the phase change temperature as long as a phase change is occurring. This will flatten the heat release, as a stable temperature will cause a stable heat release. PCMs with high volumetric and gravimetric energy densities will result in a Latent Heat Storage (LHS) being relatively small and lightweight compared to sensible heat storage solutions [7]. There are many possible PCM candidates suitable for wood stove applications, with differing melting points and thermal properties. The choice of material will affect the geometry and composition of the heat storage, and the functionality of the final solution.

There are consumer and practical design considerations to take into account when designing a stove which inevitably results in a certain amount of heat that will bypass the heat storage and be released to the ambient directly. The heat production that a heat storage has to dampen is therefore lower than the nominal effect of the wood stove. Typical heat input and typical heat output from a LHS and SHS were generated and is shown in Fig. 2. The heat input plotted is an average heat flow of 1 kW over a period of 1.5 h. The shapes of the heat release from a sensible and a latent heat storage system are as described above. It can be observed that the PCM provides a more stable heat release than soapstone.

The objective of the present work was to develop a method for early stage screening of PCMs that takes into account the wood stove heat production profile and the possible methods of heat transfer enhancement in a latent heat storage.

## 2. PCM and heat storage properties

The application of PCMs in wood stoves is new, and relevant