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Thermal storage with phase change material integrated in small-scale systems for low-temperature waste heat recovery

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Introduction

The current interest in thermal energy storage is connected with increasing the efficiency of conventional fuel dependent systems, by storing the waste heat in low consumption periods or harvesting renewable energy sources with intermittent character. Much of the studies are directed towards creation of compact solutions, to replace the presently used hot water tanks requiring very large space. This is especially important for small capacity thermal systems in buildings, in family houses or small communities. The present work identifies the requirements for latent heat storage (LHS) on the basis of the state of the art in the field. It compares the most cost and energy efficient systems in residential applications for hot water, heating and cooling with thermal storage and the methods for their investigation and optimization. The resulting conclusions from the collected and compared information aim at a novel compact design of a cost-effective thermal energy storage.

Available equipment for low-temperature heat recovery- examples in Bulgaria

One example of direct waste heat recovery, realized in Bulgaria, is a contact economizer system with a packed column. The unit works by mixing in countercurrent the waste exhaust gas with cooled water to produce hot water for domestic and preheating uses. It allows for effective low-grade heat recovery from exhaust gases with significant humidity and recover up to 13-15% heat (fuel economy). Such systems are included in the best practices, however they are relatively scarcely used when compared to the indirect type.

Sources and temperature levels of waste heat in Europe and in Bulgaria

Industry	Temperature, °C	Waste potential TWh/year
Food and beverage	<100	1.25
Chemical, non-metallic minerals, food, and paper industries	100-200	About 100
Chemical, non-metallic minerals	200-500	About 78
Steel industry	>500	About 124
Total		304.13

Table 1. Waste heat potential of industrial processes in EU (2015)

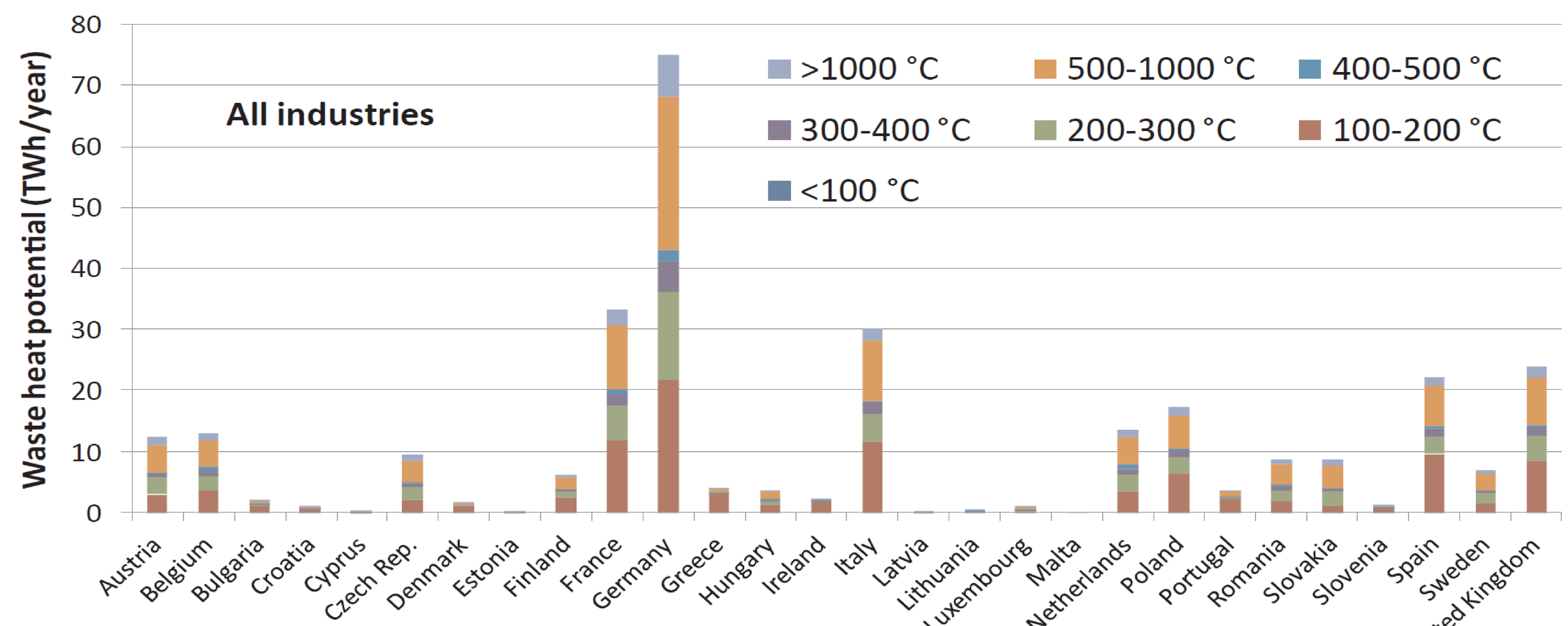

Figure.1 Waste heat potential in each EU country per temperature level in all industries (2015)

Source: M. Papapetrou et al., Appl. Thermal Engineering 138 (2018) 207–216

Phase change materials (PCMs) and thermal energy storage (TES) types

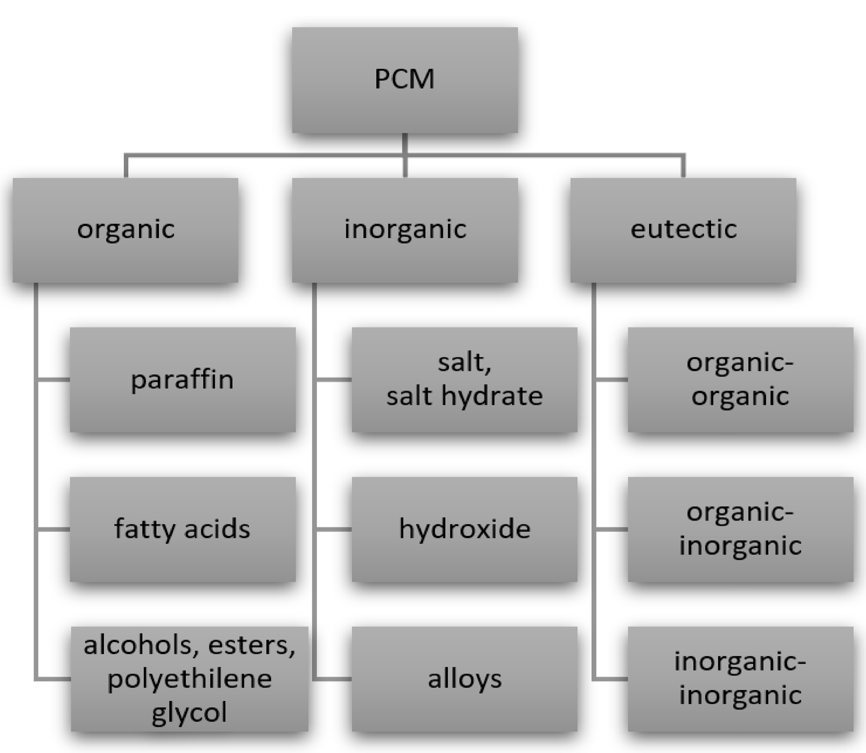

Figure. 2. Types of PCM

TES System	Capacity (kWh/t)	Power (MW)	Efficiency (%)	Storage period (h, d, m)	(€/kWh)Cost
Sensible (hot water)	10-50	0.001-10	50-90	d/m	0.1-10
PCM	50-150	0.001-1	75-90	h/m	10-50
Chemical Reaction	120-250	0.01-1	75-100	h/d	8-100

Table 2. Typical parameters of TES systems

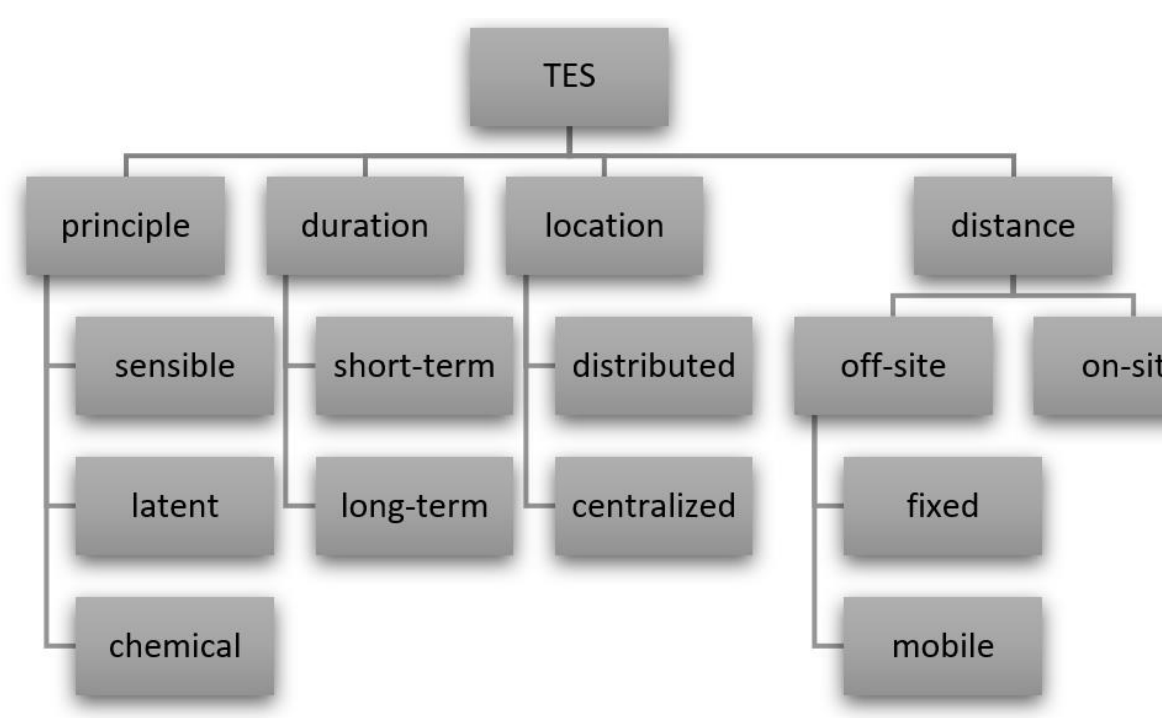

Figure. 2. TES for low-temperature heat sources (waste or renewable) in district heating

Heat transfer intensification- solutions, modelling and efficiency analysis

The heat transfer intensification of a compact thermal storage unit with PCM includes measures common for any heat exchanger like optimal hydrodynamic regime of operation and improving thermo-physical properties of working fluid, insulation and material of solid heat transfer surfaces. In addition to this, the presence of PCM brings specific measures:

- improving thermo-physical properties of PCM by high conductive additives in the form of nano-particles, fibres, lamellae and foams.
- encapsulation of PCM
- extending the PCM enclosure surface with external or internal high conductive fins, strips and matrix.

The mismatch between the waste heat source and the user demand in temperature level brings the necessity of heat to heat conversion. Options for heat to heat conversion include the vapor compression heat pump, absorption heat pump and absorption heat.

Conclusions: performance requirements for latent heat storage

Based on the presented overview, the following basic requirements for compact LHS for hot water and space heating can be drawn:

- Proper PCM – melting temperature 5-10°C over the necessary outlet temperature of the HTF, proper thermal, physical, chemical properties of PCM, availability, economical, stable for a long time. Improvement of the PCM thermal conductivity by additives and extended surface is required. There are commercial LHS with hydrate salts.
- Heat transfer intensification by reduction of HTF convective resistance. Optimal organization of the fluid flow. Very useful tool are |CFD simulations.
- Compact size and proper configuration of the unit- most preferred Shell-and-tube type. Encapsulation of PCM seems promising, but still under investigation in the considered space-heating and hot water systems.
- The TES should allow connection to different sources of waste or renewable heat and integration in existing space-heating and hot water systems.

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