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Façade-integrated massive solar-thermal collectors combined with long-term underground heat storage for space heating

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Abstract

This work shows how façades of industrial buildings can be used as a heat source for a heat pump heating system. Opaque sections of the building skin are formed by façade-integrated massive solar-thermal collectors (FMSC) in order to collect solar radiation and heat from the ambient air. By means of a building-integrated long-term storage (BLTS), the heat collected during the summer period is conserved for utilization during the heating season. Depending on the current ambient conditions and the actual heat demand, different operating modes are to be applied: In part load with favorable external conditions the space heating demand is covered by direct use of the FMSC heat output. With rising heat demand and lower heat gain from ambient, heating is accomplished by a heat pump with FMSC or BLTS as heat source. With regard to architectural restrictions, FMSC surfaces have to be operated at temperatures above the dew point, avoiding formation of condensate or frost at the building surface. The performance of the system is modeled by means of TRNSYS, relying to available model types for the system components. The model of the core component, i.e. the FMSC, has been validated by a laboratory measurement. A design study has been carried out for an industrial building with a foot print of 1,300 m² and an annual heating demand of 82,000 kWh. Key aspect of the investigation is the identification of the most efficient system composition, characterized by the required size of collector area and heat storage volume.

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1. Introduction

Within this publication a novel solar-thermal space heating system is presented, comprising façade integrated massive solar thermal collectors (FMSC) and a building integrated long-term thermal energy storage (BLTS). Heating energy for the building is provided by an electrically driven heat pump resorting to FMSC and BLTS as sources of renewable low-temperature ambient heat. In former installations either a heat pump has been coupled to a FMSC serving as the ambient heat source [1-3], or a seasonal heat storage has been loaded by solar thermal heat from conventional solar collectors [4-6]. Whereas, the joint application of FMSC and BLTS has not yet been realized and investigated. Long-term energy storages may serve for heat supply to a plurality of users via a district heating network or to individual dwellings [7-8].

The novel heating system shall feature the following characteristics:

- synergistic integration of heat storage and building
- synergistic integration of solar collector and building façade
- increased energetic use of the building envelop by thermal activation of the façade.
- alternative to conventional geothermal installations: thermal use of the underground, independent from geothermal boundary conditions
- no permission for the geothermal use of the underground required
- independent from given local situation
- increased efficiency of the heat pump, resulting from elevated heat source temperature provided by a long-term heat storage.
- sufficient availability of low-grade ambient heat guaranteed by the use of a long-term heat storage.

1.1. Façade-integrated massive solar-thermal collector

An effective way for implementation of FMSC is the construction of pre-fabricated façade elements, as described by [1]. A solid concrete plate constitutes the structural basis, which is covered by a thermal insulation in order to minimize thermal losses of the façade element. The outer skin of the sandwich element is formed by the FMSC. It consists of a second concrete layer equipped with a tube meander allowing for thermal activation. This outer shell is mechanically linked to the inner load carrying construction by steel anchoring rods. This punctual connection of the outer and inner shell fulfills the structural requirements with only limited influence on the thermal behavior of the massive solar collector.

The heat carrier tube is completely embedded in the outer concrete layer, respecting all technological requirements with regard to the stability of the building element and the function and durability of the steel reinforcement. Thus, FMSC allow for perfect architectural integration of solar thermal collectors, as discussed by [9]. Even as a part of a complex façade design, a FMSC element is not distinguished from a thermally inactive façade section, as long as there are no visible changes of the outer surface induced by the thermal activation. This might happen when condensate or frost is formed on the outer skin due to an extensive extraction of heat, as shown by [1]. Of course such operational states have to be avoided by appropriate control of the solar collector system in order not to disturb the optical appearance of the building.

Regarding the vertical orientation of the façade-integrated collectors, a reduction of the solar thermal yield by about 30% has to be expected as compared to a roof-top installation with optimal inclination [10]. Yet, this reduced efficiency is acceptable, since façade area is used which conventionally does not contribute to the energy supply of the building.

A water/glycol mixture is circulated through a tube register incorporated in the FMSC. When the temperature of the outer shell of the building is higher than the temperature of the fluid, heat is extracted from the FMSC. The temperature of the solar collector is governed by the thermal balance comprising radiative exchange and heat transfer. An exhaustive discussion is found in [11]. The absorber surface of the FMSC receives solar radiation $\dot{Q}^{+}_{\mathrm{rad,s}}$ and long-wave radiation $\dot{Q}^{+}_{\mathrm{rad,l}}$ emitted by the sky and surrounding surfaces Simultaneously the FMSC acts as infrared emitter releasing the long-wave radiation $\dot{Q}^{-}_{\mathrm{rad,l}}$ according to its surface temperature. Governed by this surface temperature, also exchange of sensible heat $\dot{Q}^{+/-}_{\mathrm{air,sens}}$ by means of convective heat transfer takes place. In