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The use of ground heat storages and evacuated tube solar collectors for meeting the annual heating demand of family-sized houses

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Abstract

The use of storages for sensible heat is limited because parts of the input thermal energy end up as unavoidable heat losses. In order to minimize this loss, it is necessary to keep the surface area to volume ratio (S/V) as low as possible. This occurs when the volume of a body with a certain shape increases. In addition to a large volume it is important to use materials with a high volumetric thermal capacity, as long as sensible heat is being used for storage. This condition is best met by water or a combination of substances with water. In the field of interseasonal storages, for solar heat to cover the heating demands of small residential buildings, the general belief is that the relative small volume needed, results in too much heat loss and therefore individual seasonal storages seem to be of no useful solution.

However, the theoretical considerations and simulations in this paper show that this is a prejudice. It is possible to supply a great deal of the thermal energy needed for small residential homes with interseasonal ground storage for solar heat. The loss of heat is acceptable if the storage is designed in the correct way.

The ground heat storage should be of cuboidal shape, using the local soil as storage material, if possible. The storage containment must be heat-insulated and damp-proof. The placement of the storage could be within the heated building, adjacent to it or nearby. As such systems may be useful as retrofit for existing houses this study assumes that the storage system has no contact with the heated house. The heat is supplied by evacuated tube solar collectors and their feature to produce effective heat with high temperature (above 100 °C) is used.

Keywords: Ground heat storage; Residential building; Seasonal heat storage; System simulation; Evacuated tube solar collector

1. Introduction

The limited availability of fossil energy resources at affordable prices and the related problems in terms of climate change necessitate the use of regenerative energies such as solar energy. It is not the amount of solar heat that is a barrier for its use but the fact that availability and demand are often out of phase (Schölkopf et al., 1998). In order to match supply and demand it is necessary to use interseasonal heat storage. By its use a surplus of heat can be stored and made available at a time of shortage.

Thermochemical and thermal storage are two basic options for storing heat (Carlos, 1992). With thermochemical storage heat is stored by reversible chemical processes. With sole thermal storage the chemical structure of the storage material remains the same, and the influx of heat is stored by an increase in enthalpy. It can be differentiated into storage of sensible heat (change temperature) and

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Nomenclature

c	specific heat capacity (J/kg K)
ρ	density (kg/m^3)
λ	heat conductivity (W/m K)
q_i	inner source of heat (W/m^3)
$VE_{m,n,p}$	voxel (m,n,p axis-indices) (–)
$V_{m,n,p}$	volume of $VE_{m,n,p}$ (m^3)
T_{fluidin}	inlet temperature of the fluid (°C)
T_{fluidout}	outlet temperature of the fluid (°C)
NTU	number of transfer units (–)
h	heat transfer coefficient (W/m^2 K)
A	surface (m^2)
Q_d	heat demand (kW h/a)
Q_c	collector output (kW h/a)
Q_s	energy content of the heat storage (kW h)
ΔQ_s	increase of energy content between start and end of the operational year (kW h)
$\Delta Q_{s\ \max}$	maximum change in energy content within a year (kW h)
Q_l	loss of energy between start and end of the year (kW h/a)
Q_u	useful heat from the storage (kW h/a)
$f_u = Q_u/Q_d$	solar coverage rate (–)
$f_c = Q_c/Q_d$	relative collector output (–)
$q_{\max\ s,d} = \Delta Q_{s\ \max}/Q_d$	maximum change in stored energy related to annual heat demand (kW h/kW h/a)
$f_l = Q_l/Q_d$	relative heat loss (–)
$\Delta q_s = \Delta Q_s/Q_d$	relative increase of energy (–)
$q_{\max\ s,u} = \Delta Q_{s\ \max}/Q_u$	maximum change in stored energy related to the useful heat from storage (kW h/kW h/a)
V_S	storage volume (m^3)
A_C	collector surface (gross) (m^2)
A_{SI}	surface of the storage volume (m^2)
HT(n)	house type(n) with specific annual heat demand (–)
$S_V = A_{SI}/V_S$	specific surface (m^{-1})
T_{AM}	annual average of mean storage temperature (°C)
T_{ASI}	annual average of mean storage surface (inside the insulation) temperature (°C)
$q_{u,c}$	useful heat per m^2 collector surface (kW h/m^2 a)
$q_{u,v}$	useful heat per m^3 storage volume (kW h/m^3 a)

storage of latent heat, which occurs at phase transition. Storage time can vary from short (hours to several days), medium (several days to several weeks) or longer periods of time (up to several months). This long term storage is commonly known as interseasonal storage. However if the length of time is only a few hours, the term buffer is used instead of storage.

Most of the existing or planned large seasonal storages of solar energy do store it as sensible heat. The storage matter is mostly water, natural soil, special soils (i.e. gravel, grit or sand) or a combination of these materials. The advantage of these materials is that they are easily and inexpensively obtainable. Small storages nearly always use water as their storage medium (up to 40 m^3 Abschlussbericht zum BMU-Vorhaben Förderkennzeichen 0329268B, 2008), because of its high specific heat capacity. The disadvantage of larger water storages is that they usually need provisions against water loss, which is of course not difficult for buffers (Giebe, 1989). Another disadvantage is their limitation of the maximum storage temperature (usually between 90 °C and 95 °C); for higher temperatures the system must be pressurized which brings an additional load on the system components.

2. ‘State of the art’ interseasonal heat storage devices

In many countries the development of thermal interseasonal storage began with the first oil crisis in the 1970s. Nevertheless this has not led to an intensified use of this type of technology and the proportion of the energy demand that is covered is not worth mentioning. This was due to the falling and sometimes very low energy costs in the period afterwards, which made interseasonal storage uneconomic. However, scientific work continued and was coordinated for example by the IEA (International Energy Agency) founded in 1974, and whose Head of the Energy Collaboration Division described solar heating and cooling as the “sleeping giant” (http://www.iea.org, 2008; Pflüger, 2007).

With crude oil and natural gas prices once more soaring at the beginning of the 21st century, and a growing insight worldwide that reducing CO_2 emissions is vital for climate protection, different ways of storing energy are seen as an alternative solution again. This has led to an increased funding of research, development and use on different levels, e. g. by the activities of ESTTP (European Solar Thermal Technology Platform) which aims at accelerating the development of solar thermal technology or the PREHEAT project (Policy Reinforcement for Heat Storage Technologies in Europe) which tries to increase the awareness of funding possibilities for the development and implementation of improved heat storage technologies (http://www.esttp.org, 2008; http://www.preheat.org, 2008.).

In Germany the focus was and still is on funding research and development of large solar collector systems for residential areas with long term heat storage (with volumes of 3000–60,000 m^3) and a comparatively high number of dwelling units (7500–15,000 m^2 heated living space).