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Feasibility study of seasonal solar thermal energy storage in domestic dwellings in the UK

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ABSTRACT

Seasonal solar thermal energy storage (SSTES) has been investigated widely to solve the mismatch between majority solar thermal energy in summer and majority heating demand in winter. To study the feasibility of SSTES in domestic dwellings in the UK, eight representative cities including Edinburgh, Newcastle, Belfast, Manchester, Birmingham, Cardiff, London and Plymouth have been selected in the present paper to study and compare the useful solar heat available on dwelling roofs and the heating demand of the dwellings. The heating demands of space and hot water in domestic dwellings with a range of overall heat loss coefficients (50 W/K, 150 W/K and 250 W/K) in different cities were calculated; then the useful heat obtained by the heat transfer fluid (HTF) flowing through tilted flat-plate solar collectors installed on the dwelling roof was calculated with varied HTF inlet temperature (30 °C, 40 °C and 50 °C). By comparing the available useful heat and heating demands, the critical solar collector area and storage capacity to meet 100% solar fraction have been obtained and discussed; the corresponding critical storage volume sizes using different storage technologies, including sensible heat water storage, latent heat storage and various thermochemical sorption cycles using different storage materials were estimated.

1. Introduction

Around 29% of energy in the United Kingdom in 2015 is consumed by the domestic sector, which represents the second largest proportion of final consumption, surpassing the industrial sector (Department for Business, Energy & Industrial Strategy, UK, 2016). The domestic sector is the most responsive to fluctuations in temperatures as about 80% of household final energy consumption is for space and water heating (Palmer and Cooper, 2013). The steadily growing number of household in the UK and the rising level of comfort requirement are the other two additional factors resulting in continuously increasing energy demand. In the meantime, gas and electricity prices have approximately doubled comparing to those in the year of 2002 (Palmer and Cooper, 2013). Upward pressures of household energy bill and imperative transition to a low carbon fuel supply for space and water heating stimulates the research and development of energy efficient technologies with higher penetration of renewable energy source, contributing to UK's ambitious target of decarbonised society with better living standard.

The total amount of solar radiation incident on the roof of a typical home exceeds its energy consumption over a year; however, the solar heating will require long-term heat storage to help balance differences between solar heat generation and demand requirements with respect to both disparities in time and magnitude (Pinel et al., 2011; Xu et al., 2014). Large scale seasonal solar thermal energy storage (SSTES) system using water as storage medium has been demonstrated in Germany (Mangold and Schmidt, 2009; Fisch et al., 1998) and Denmark (Fisch et al., 1998). These systems store solar heated hot water in tank, pit, borehole or aquifer layer for district heating system, and the storage volume is from hundreds cubic meter to more than ten thousands cubic meter. Small scale SSTES system for several or even individual residential dwelling is much less explored in practice, since the system volume required by seasonal storage based on conventional sensible heat storage method cannot be acceptably small. Chemical reaction, sorption and phase change material storage technologies have been proposed and developed to improve energy storage density, and have been applied to SSTES system (Pinel et al., 2011; Xu et al., 2014).

Solar thermal energy has not been extensively explored in the UK (Eames et al., 2014), and there is very limited information and studies on the feasibility and rationality of applying SSTES techniques for individual dwellings in the UK. Effort is required to seize the opportunity and promote solar thermal energy utilisation and SSTES application in the UK with particular consideration of different locations and climatic weather conditions. This paper conducted case studies to evaluate the potential and viability of SSTES application in individual dwellings in

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Nomenclature

A	solar collector area (m^2)
c_p	specific heat (J/(kg K))
E	energy density (kWh/m^3)
I_h	global horizontal irradiance (kWh/m^2)
Q	heating load (kWh)
T	temperature (°C)
$\overline{UA}$	overall heat loss coefficient of dwelling (W/K)
$\dot{V}$	volumetric hot water consumption (m^3/h)
V	volume (m^3)

Greeks

β	slope of collector surface (°)
γ	surface azimuth angle (°)
ρ	density (kg/m^3)

Subscripts

a	ambient
cri	critical
CW	cold water
HD	heating demand
HW	hot water
i	inlet
R	room
sc	solar collector
SH	space heating
sto	storage
u	useful

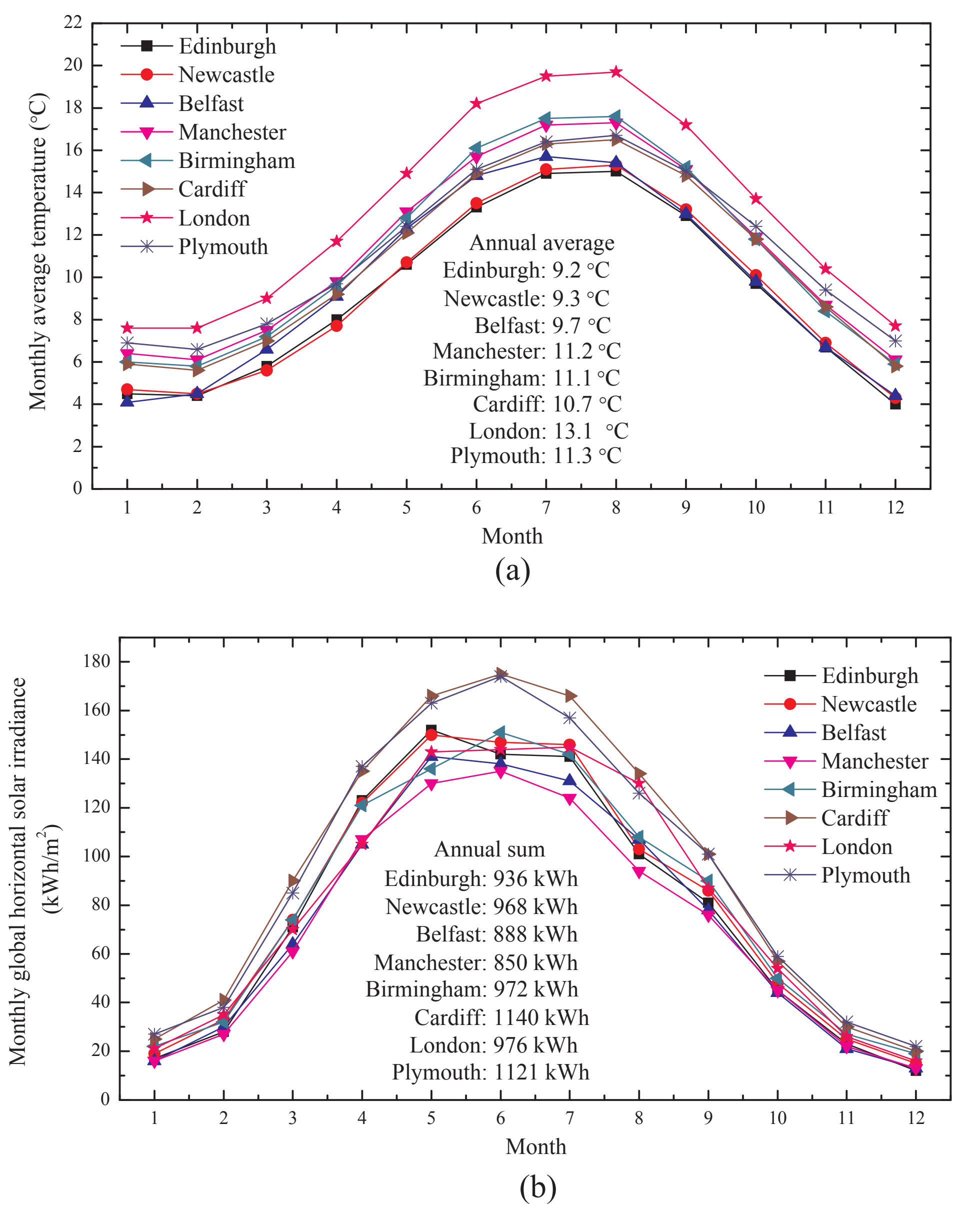

Fig. 1. Weather data of different cities, (a) monthly average temperature; (b) monthly global horizontal solar irradiance.