Renewable and Sustainable Energy Reviews 60 (2016) 852–866

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Latent heat storage in building elements: A systematic review on properties and contextual performance factors

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ARTICLE INFO

Article history:
Received 27 May 2015
Received in revised form
13 November 2015
Accepted 20 January 2016

Keywords:
Latent heat storage
PCM
Building element
PCM boards
PCM panels

ABSTRACT

A systematic review of latent heat storage in building elements was conducted to establish the current knowledge base and reveal key design and performance factors that could be used to define technologies available for immediate implementation and for specific applications. All relevant literature published by April 2014 was critically evaluated and a data extraction procedure was used to organise, analyse and report design and performance parameters of Phase Change Material (PCM) elements. The review of a total of 120 papers revealed that published information on these aspects is diverse and in many cases insufficient. The diversity of test conditions and variety of reported values indicate that physical properties and performance data concerning materials and complete PCM elements are not directly comparable. Therefore matching technologies and applications for specific climates and building typologies is not possible solely through published information. However evidence was collected which shows that, with appropriate design, PCM elements can contribute to reducing loads and achieving energy savings in buildings, while securing a comfortable indoor environment. Key design factors to this end were found to be the climate and target season, the design of appropriate controls for active and passive systems used in combination with the PCM elements and cost-related factors. The review also mapped the research foci to date, revealing the range of variations previously examined and potential research gaps worth pursuing in the future.

Contents

Abbreviations: FSPCM, Form stable PCM; GHG, Greenhouse Gas; HDPE, High Density Polyethylene; LCA, Life Cycle Analysis; LHS, Latent Heat Storage; PCFW, Phase Change Frame-wall; PCM, Phase Change Material; R&D, Research and Development; SSPCM, Shape Stable PCM; TGU, Triple Glass Unit; TIM, Transparent Insulation material; VIP, Vacuum Isolated Panel

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http://dx.doi.org/10.1016/j.rser.2016.01.115

1. Introduction

A strong potential in reducing current levels of energy consumption and Greenhouse Gas Emissions, especially those related to heating and cooling, has been recognised for the building sector [1]. A key challenge to this end is to reduce energy consumption and emissions from space conditioning without compromising thermal comfort needs. Current policy [1] supports the use of high insulation levels that are seen as effective in significantly reducing energy use in buildings [2]. However the dynamic behaviour of thermal mass and its positive contribution to delaying heat fluxes and regulating temperature fluctuations has been recognised [3–7] in contrast to the rigid thermal performance of lightweight and highly insulated building envelopes.

Latent Heat Storage (LHS) technologies that use Phase Change Materials (PCM) impregnated in lightweight building elements are considered as an interesting alternative to sensible storage in heavyweight constructions [8], with a theoretical volumetric storage density of up to 15 times higher than traditional storage materials [9]. The enhanced storage capacity of these materials is due to their latent heat storage ability i.e. they can undergo a phase change (e.g. melting/solidification) and therefore exchange more heat with the environment than through solely their sensible heat storage capacity. Attention is drawn to LHS-enhanced building fabric as current construction trends demand speed and ease of assembly and thus favour lightweight constructions [10].

Research on LHS technologies ranges from PCM material development to experimental storage applications and from system modelling to design guidelines. There is also R&D work undertaken for integration of PCM in building services [9,11–13]. However research in the subject is still fragmented and the actual potential held by these technologies in improving thermal conditions and reducing heating and cooling needs in existing and new buildings is not well understood. The aim of this study is to review published evidence, establish the current knowledge base and reveal key design factors for these technologies. The main objective is to examine whether current knowledge can be used to define technologies available for immediate implementation and technologies suitable for specific applications i.e. enable the matching of existing and emerging needs with technologies available.

A number of relevant past reviews has been identified; [8] had a focus on load shifting applications, [14] on PCM integrated into wall elements, [15] and [16] on materials, techniques for embedding PCM into building elements and resulting thermal behaviours. [17] reviewed selected studies on passive and active storage modes of building integrated PCMs. The more recent [18,19] and [20] have reviewed more broadly PCM integration processes, methods for measuring physical properties of finished elements, simulation tools and future research potentials. This study is different from these preceding reviews in that it encompasses and critically evaluates all relevant literature to date, whilst also addressing data quality and availability issues. To achieve that it employs a systematic (structured) review procedure as explained below.

2. Methodology

The systematic review presented here builds on a well-established methodology originating from the health and social sciences [21–22]. This methodology is applied here, not only to assure the comprehensiveness of the research, but also to guide the filtering of information identified. However the added value in systematic reviews is the transparency of the methodology used which allows reproducibility and thus creates a precedent for future reviews to build upon. Two electronic databases have been used in this study, *Web of Science* and *Scopus*, chosen for their prevalence in the subject area. Both databases provide abstract and citation information on peer-reviewed papers in the area of physical sciences [23–25].

2.1. Search and data selection

A systematic review uses clearly defined search criteria that are justified by the scope and orientation of the research [21,26]. The present review is concerned with LHS, having a focus on PCM integration in building elements. The keywords, operators and nesting combinations used for the searches in the two databases were as follows:

A. A generic set: TITLE (“thermal energy storage” OR “energy storage” OR “thermal energy” OR “heat storage” OR “thermal storage” OR “phase change material*” OR PCM) AND TOPIC (latent) AND TOPIC (application or system).
B. A focused set: TITLE ONLY (“phase change” or PCM) AND (wall*, roof, floor, panel, window, tile, curtain, shutter, building).

The search was deliberately broad, to allow all relevant publications indexed in the two databases to be identified. The first – generic – set search (A) was performed in September 2013 (Web of Science). The focused set search includes publications available online up to April 2014 (Web of Science + Scopus). The searches were followed by manual text screening that completed the selection process. The preliminary search revealed that a little more than 1/3 of the tracked literature was related to LHS applications in buildings. Around 1/6th of these was on PCMs integration in building elements and was selected for review, along with the results that came out of the second search set. Fig. 1 depicts a summary of the search process. A further filtering, using criteria for data quality and availability was performed (explained further below).

2.2. Data extraction

Following guidance for systematic reviews [21,26], a data extraction method was developed. In [27] evaluation criteria for thermal energy storage implementation have been proposed. Using these suggestions as a starting point, a list of parameters critical for successful design, implementation and performance of LHS building elements was formed. These parameters, organised in groups, are shown in Table 1 while in Table 2 a sample of the data extraction table is provided.

3. Results

3.1. Data availability and mapping

The search process tracked 140 studies to be reviewed. These covered a variety of building elements; more popular being walls (Fig. 2). Following the review, 20 papers were identified as inappropriate for data extraction and were excluded from the analysis. Reason for exclusion was lack of most or all data required for extraction [28–40]. For papers [41–47] that a more recent version was found the review included only the latest version [48–53].

Fig. 3 presents data availability in the 120 papers considered, revealing that very few papers offered data for extraction for all aspects reviewed. In some instances data availability was determined by the actual focus of the research. Very few papers were concerned with the role of internal (incidental) gains, and those were mostly dealing with simulation analyses [54–66]. A paper