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ENERGY CONSERVATION THROUGH LATENT HEAT THERMAL STORAGE IN BUILDING MATERIALS

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1. INTRODUCTION

The necessity for preserving our fossil fuel resources has long been recognized but economic and environmental incentives to that end have increased dramatically in the past twenty years. However, the role of thermal storage in energy conservation, particularly in the building industry, has not kept pace with other advances in the field.

To address this need, work in this area of research has been ongoing for fifteen years at the Centre For Building Studies, Concordia University. The objectives of this work cover the development of thermal storage building materials which have the following general characteristics:

(a) be capable of absorbing and releasing appropriate amounts of thermal energy within a designated range of temperatures;

(b) be appropriate for any application where conventional building products are now used;

(c) be suitable for installation by tradesmen with ordinary skills in conventional structures;

(d) be suitable for manufacture in conventional production facilities; and

(e) have an installed cost such that the differential between them and conventional building products would be economically justified by the energy savings obtained by their use.

2. IMPORTANCE OF THERMAL STORAGE

In addition to the traditional use of stored heat for space heating there are a number of other applications which are gaining in importance and which, therefore, command our consideration. They include:

(i) time shifting of energy demand on supply systems to permit more effective use of off-peak power, gas and other energy forms so that both the utilities and their customers will benefit thereby;

(ii) improving the efficiencies of burners, chillers and heat pumps through diminution of operational cycling and more effective equipment sizing;

(iii) use of low cost energy which would otherwise be wasted. This would comprise heat from solar radiation, exothermic equipment and processes or any appropriate energy source where the supply may not be synchronous with the demand; and

(iv) absorption of periodic building load surges such as the heat generated for relatively short periods in auditoria. The absorbed energy could thus be released later to the building or exhausted to the atmosphere.

3. USE OF BUILDING MATERIALS FOR THERMAL STORAGE

We have studied the use of many new building materials for thermal storage with the intention of incoporating phase change materials (PCM's) in some of them to provide latent heat storage. PCM's will be described later.

In addition to their structural functions, certain building materials can perform very well as thermal storage elements for the following reasons:

(a) Some materials, particularly masonry and concrete, have both the necessary mass and specific heat characteristics to provide a significant degree of sensible heat storage.

(b) Heat storing building elements comprise significant areas of contact with the space to be conditioned, so that thermal exchange can occur in situ without the necessity for heat transport to and from storage.

(c) Some masonry materials can be adapted to function both as thermal storage elements as well as hot air conduits (e.g. concrete blocks) when, as an alternative to (b), it is more practical to use them in this manner to store condition air for subsequent delivery elsewhere.

(d) In materials such as wallboard and concrete blocks, heat is required to travel only a very short distance into the storage element. As a result, a heat exchanger is not required as would be the case with a large volume, central thermal storage vessel.

(e) Some building materials such as concrete, gypsum and wood demonstrate excellent absorptive and retentive properties for PCM's so that latent heat storage may also be achieved in addition to sensible heat storage.

4. FORMS OF THERMAL STORAGE IN BUILDING MATERIALS

(a) Sensible Heat Storage

While this form of heat storage has been practised for a very long time, its development was rather slow, since the cost of energy was relatively low until fairly recently. Then, the oil crisis in the seventies caused interest to be renewed in all aspects of energy conservation, including thermal storage. As a result, a number of studies were carried out to demonstrate the effectiveness of using building mass for thermal storage to save energy.

The amount of sensible thermal storage is a function of the building mass, so a relatively large amount will be necessary to meet the thermal requirements in areas which have pronounced climate savings. However, the resulting thermal inertia can give rise to undesirable temperature excursions in the building itself. For example, sufficient storage to meet winter requirements can result in overheating during the summer.

(b) Latent Heat Storage

Resolution of the problems associated with sensible heat storage in buildings began about 46 years ago with the use of PCM's to store latent heat as well. PCM's are materials which absorb heat while melting and release it when freezing. Those selected for thermal storage applications normally perform these functions within a few degrees and at an appropriate range in the scale.

To begin with, PCM's were contained in various types of receptacles. Then certain types, principally organic materials, were actually incorporated directly in porous building materials where they were retained in the liquid state by surface tension in the voids and capillaries. The addition of PCM's constituted a great step forward in the use of building materials for thermal storage because the total amount of sensible and latent heat storage can be several times that of the unimpregnated material as shown in Figures 1, 2 and 3. It follows that this will allow a given amount of heat to be stored with less building mass or a greater amount of heat with the same mass.

5. P.C.M.'s

Most of the PCM's selected for incorporation in building materials involve a solid-liquid phase change. However, solid-solid transitions are also possible in some products over various temperature ranges. The PCM's used in building elements fall into two principal categories: inorganic and organic.

(a) Inorganics

These materials, which principally comprise salt hydrates, have some useful characteristics:

(i) high latent heat per unit volume

(ii) no flammability hazard

(iii) wide range of state change temperatures

(iv) low cost.

However, they also have some undesirable properties:

(i) they are corrosive and incompatible with many building materials

(ii) they need special containment and storage space

(iii) they have a marked tendency to supercool

(iv) their components melt incongruently and segregate.

It should be noted that studies are ongoing to find appropriate nucleating and thickening agents to overcome supercooling and incongruency. To be useful for incorporation in building materials, such measures must be effective over a normal building life and research towards this end shows encouraging results.

(b) Organics

About twenty years ago, interest was first demonstrated in organic PCM's. These materials have a number of important properties for this application:

(i) the constituents melt congruently

(ii) supercooling is not a serious problem

(iii) they are chemically stable

(iv) there is a wide range of suitable materials from which to choose

(v) they are compatible with and can be absorbed in many building materials

(vi) the installed and operating cost is competitive with inorganics.

Their undesirable characteristics are:

(i) flammability

(ii) a few have an undesirable odour

(iii) some experience significant volume change during phase change

(iv) certain PCM's may react with some concretes.

At the present stage of development, the only remaining points to be solved are:

(i) flammability of some potentially useful PCM's remain to be evaluated

(ii) the compatibility of certain higher alcohols with some concretes remain to be improved.

6. CURRENT RESEARCH IN THERMAL STORAGE BUILDING MATERIALS

At the Centre For Building Studies, Concordia University, research has been ongoing for 14 years in the development of a wide range of energy storing building materials. These include gypsum wallboard, concrete blocks, bricks, tiles and various types of concrete. However, this presentation will be confined to a brief discussion of only the first two which are the most advanced.

(a) Wallboard

Whereas several means of PCM incorporation can be used, direct incorporation and immersion are both practical. However, the former method appears to be the most economical procedure for large volume production so considerable effort was expanded in developing a technique for incorporating PCM in wallboard so that its standard characteristics were not significantly affected and this was eventually achieved and demonstrated by a series of tests. Impregnated 12.7 mm wallboard has the same heat storage capacity as 65 mm of 1750 kg/m^3 concrete when both are raised through 6°C around the melting point of the PCM.

The thermal storage capacity of PCM wallboard in the average house is about 100 MJ. This approaches the space heating requirements for those periods of the year in Canada when we have warm days and cool nights. Under these circumstances, a suitable thermal storage facility can use the diurnal temperature swing to offset all or part of the power and fuel requirements for space heating and cooling. This reason is much longer in the U.S. and other countries which enjoy a more temperate climate than Canada. However, during a Canadian winter, the thermal storage capacity of PCM wallboard constitutes only 20-50% of the daily space heating requirements so its principal function under these conditions is to provide the thermal storage required so that the very significant power demand for electrical space heating (up to 25% of total demand in Quebec) can be time shifted to reduce the peak demand on the power system and obriate new, very expensive installations. It also serves to reduce furnace cycling. Studies have shown that this could result in an average reduction of fuel consumption of about 30%. Similar improvements could also apply to heat pumps and chillers.

(b) Concrete Block

In the case of concrete block, both immersion and direct incorporation of PCM appear to be satisfactory procedures. It will be noted however that the alkalinity of concrete must be suitably reduced by means of pozzolans and/or other materials so that it is compatible with certain PCM's. It should be noted that we have pioneered this work as well as developing new direct-mix incorporation procedures.

When compared with conventional concrete block, the structural characteristics of PCM concrete are comparable and in some cases, such as moisture absorptance and resistance to freeze-thaw cycling, they are markedly improved. The energy storage capacity when passing through a 6°C temperature range around the PCM melting point are greatly increased as shown in Figures 1, 2 and 3.

It will be seen from these figures and using a provisional recovery factor of 66% that a house could easily be designed to provide about 400 MJ storage. This value is the approximate daily space heating requirement for the average home in the coldest cities in Canada during the coldest months of the year.

In addition to their role in energy conservation, PCM concrete blocks have great potential for load shifting and peak load applications.

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