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energy savings of up to 25% in U.S. residential buildings. Considering that new PCM-enhanced building envelope components are installed in about 10% of U.S. homes, the potential for energy savings is between 0.2 and 0.5 quad/year (including an additional 10% of U.S. residential buildings that can be retrofitted using PCM-enhanced materials).

Presenting an overview of the use of Phase Change Materials (PCMs) within buildings, this book discusses the performance of PCM-enhanced building envelopes. It reviews the most common PCMs suitable for building applications, and discusses PCM encapsulation and packaging methods. In addition to this, it examines a range of PCM-enhanced building products in the process of development as well as examples of whole-building-scale field demonstrations. Further chapters discuss experimental and theoretical analyses (including available software) to determine dynamic thermal and energy performance characteristics of building enclosure components containing PCMs, and present different laboratory and field testing methods. Finally, a wide range of PCM building products are presented which are commercially available worldwide. This book is intended for students and researchers of mechanical, architectural and civil engineering and postgraduate students of energy analysis, dynamic design of building structures, and dynamic testing procedures. It also provides a useful resource for professionals involved in architectural and mechanical-civil engineering design, thermal testing and PCM manufacturing.

The U.S. Department of Energy s (DOE) Building Technologies Program s goal of developing high-performance, energy efficient buildings will require more cost-effective, durable, energy efficient building envelopes. Forty-eight percent of the residential end-use energy consumption is spent on space heating and air conditioning. Reducing envelope-generated heating and cooling loads through application of phase change material (PCM)-enhanced envelope components can facilitate maximizing the energy efficiency of buildings. Field-testing of prototype envelope components is an important step in estimating their energy benefits. An innovative phase change material (nano-PCM) was developed with PCM encapsulated with expanded graphite (interconnected) nanosheets, which is highly conducive for enhanced thermal storage and energy distribution, and is shape-stable for convenient incorporation into lightweight building components. During 2012, two test walls with cellulose cavity insulation and prototype PCM-enhanced interior wallboards were installed in a natural exposure test (NET) facility at Charleston, SC. The first test wall was divided into four sections, which were separated by wood studs and thin layers of foam insulation. Two sections contained nano-PCM-enhanced wallboards: one was a three-layer structure, in which nano-PCM was sandwiched between two gypsum boards, and the other one had PCM dispersed homogeneously throughout graphite nanosheets-enhanced gypsum board. The second test wall also contained two sections with interior PCM wallboards; one contained nano-PCM dispersed homogeneously in gypsum and the other was gypsum board containing a commercial microencapsulated PCM (MEPCM) for comparison. Each test wall contained a section covered with gypsum board on the interior side, which served as control or a baseline for evaluation of the PCM wallboards. The walls were instrumented with arrays of thermocouples and heat flux transducers. Further, numerical modeling of the walls containing the nano-PCM wallboards were performed to determine their actual impact on wall-generated heating and cooling loads. The models were first validated using field data, and then used to perform annual simulations using Typical Meteorological Year (TMY) weather data. This article presents the measured performance and numerical analysis to evaluate the energy-saving potential of the nano-PCM-enhanced building components.

Previous research studies have shown that incorporation of the phase-change material (PCM) in a building envelope material/component may bring significant reduction in the building energy consumption. A detailed knowledge of the key phase-transition (dynamic) properties, such as latent heat, sub-cooling, hysteresis during melting and freezing, etc., of the PCM-enhanced building materials is required to perform the whole building energy simulations and code work. In addition, the dynamic test data is critical in optimizing the distribution and location of the PCM within a building to maximize the energy savings. Until recently, the differential scanning calorimeter (DSC) has been the only available method to determine the dynamic properties of a PCM. Unfortunately, the DSC method is valid for small and homogeneous specimens, and is incapable of capturing the complexities observed in large-scale building components. Materials with non-uniform temperature distribution and non-homogeneity caused by the presence of additives, such as fire retardants, conduction inhibitors, and adhesives, cannot be analyzed by the DSC testing method. Dynamic heat-flow meter apparatus (DHFMA) is a recently developed method for dynamic property measurement of system-scale PCM and other building construction products. Although the DHFMA method is gaining acceptance among the scientific and research community, it is still under development. In this study, we focus on advancing the development, and conducting the validation of the DHFMA method. A detailed description of the DHFMA method is presented to highlight the difference with the conventional HFMA method. Next, a large-scale bio-based shape-stabilized PCM (ss-PCM) sample was tested using both DHFMA and DSC test methods. Specific heat as a function of temperature data measured by DHFMA method was found to be in very good agreement with slowest ramp and step data. This is the first direct verification of the HFMA method with the DSC method for PCMs.

Since 2000, an ORNL research team has been testing different configurations of PCM-enhanced building envelop components to be used in residential and commercial buildings. During 2009, a novel type of thermal storage membrane was evaluated for building envelope applications. Bio-based PCM was encapsulated between two layers of heavy-duty plastic film forming a complex array of small PCM cells. Today, a large group of PCM products are packaged in such complex PCM containers or foils containing arrays of PCM pouches of different shapes and sizes. The transient characteristics of PCM-enhanced building envelope materials depend on the quality and amount of PCM, which is very often difficult to estimate because of the complex geometry of many PCM heat sinks. The only widely used small-scale analysis method used to evaluate the dynamic characteristics of PCM-enhanced building products is the differential scanning calorimeter (DSC). Unfortunately, this method requires relatively uniform, and very small, specimens of the material. However, in numerous building thermal storage applications, PCM products are not uniformly distributed across the surface area, making the results of traditional DSC measurements unrealistic for these products. In addition, most of the PCM-enhanced building products contain blends of PCM with fire retardants and chemical stabilizers. This combination of non-uniform distribution and non-homogenous composition make it nearly impossible to select a representative small specimen suitable for DSC tests. Recognizing these DSC limitations, ORNL developed a new methodology for performing dynamic heat flow analysis of complex PCM-enhanced building materials. An experimental analytical protocol to analyze the dynamic characteristics of PCM thermal storage makes use of larger specimens in a conventional heat-flow meter apparatus, and combines these experimental measurements with three-dimensional (3-D) finite-difference modeling and whole building energy simulations. Based on these dynamic tests and modeling, ORNL researchers then developed a simplified one-dimensional (1-D) model of the PCM-enhanced building component that can be easily used in whole-building simulations. This paper describes this experimental-analytical methodology as used in the analysis of an insulation assembly containing a complex array of PCM pouches. Based on the presented short example of whole building energy analysis, this paper describes step-by-step how energy simulation results can be used for optimization of PCM-enhanced building envelopes. Limited results of whole building energy simulations using the EnergyPlus program are presented as well.

PCM Enhanced Building Envelopes presents the latest research in the field of thermal energy storage technologies that can be applied to solar heating and cooling with the aim of shifting and reducing building energy demand. It discusses both practical and technical issues, as well as the advantages of using common phase change materials (PCMs) in buildings as a more efficient, novel solution for passive solar heating/cooling strategies. The book includes qualitative and quantitative descriptions of the science, technology and practices of PCM-based building envelopes, and reflects recent trends by placing emphasis on energy storage solutions within building walls, floors, ceilings, façades, windows, and shading devices. With the aim of assessing buildings energy performance, the book provides advanced modeling and simulation tools as a theoretical basis for the analysis of PCM-based building envelopes in terms of heat storage and transfer. This book will be of interest to all those dealing with building energy analysis such as researchers, academics, students and professionals in the fields of mechanical and civil engineering and architectural design

Residential and commercial roofs and walls are currently designed and tested using steady-state criteria. The resulting R-values, based on the apparent thermal conductivity, are used by building standards as an important measure of energy performance. Building envelope components, however, are subject to dynamic environmental conditions. This mismatch between the steady-state principles used in design and code requirements and their dynamic operation results in relatively low thermal efficiencies. Although several research centers have developed experimental methods for transient analysis of building envelopes, there are no standardized testing procedures available for screening materials and systems for which performance depends on dynamic response. For example, a full-scale dynamic evaluation of phase change materials (PCMs) is needed to assess their energy saving benefits. A nationally accepted small-scale (one to two foot size specimens) testing procedure is not available for the analysis of dynamic thermal characteristics of conventional thermal mass systems or PCM-enhanced materials. At the same time, data on these characteristics are necessary for whole-building simulations, energy analysis, and energy code work. The transient characteristics of PCM-enhanced products depend on the PCM content and quality. The only readily available method of thermal evaluation uses the differential scanning calorimeter. Unfortunately, this method requires small, relatively uniform test specimens. This requirement is unrealistic in the case of PCM-enhanced building envelope products such as PCM-cellulose, PCM-glass fiber, or PCM-gypsum blends. Small specimens are not representative of PCM-based blends, since these materials are not homogeneous. Jan Kosny and David Yarbrough, Oak Ridge National Laboratory, P.O. Box 2008, MS 6070, Oak Ridge, TN 37831-6070. Elizabeth Kossecka, Polish Academy of Sciences, Institute of Fundamental Technological Research, Pawinskiego 5 B, 02-106, Warsaw, Poland. A procedure for making dynamic heat-flow measurements using existing instrumentation has been developed to analyze the benefits of thermal storage. This small-scale testing method is useful for thermal analysis and as a potential quality control method for producers of PCM-enhanced building materials. The research may provide the basis for consensus standard development. This paper uses as an example a dynamic testing process for PCM-enhanced cellulose insulation.

The CRC Handbook of Thermal Engineering, Second Edition, is a fully updated version of this respected reference work, with chapters written by leading experts. Its first part covers basic concepts, equations and principles of thermodynamics, heat transfer, and fluid dynamics. Following that is detailed coverage of major application areas, such as bioengineering, energy-efficient building systems, traditional and renewable energy sources, food processing, and aerospace heat transfer topics. The latest numerical and computational tools, microscale and nanoscale engineering, and new complex-structured materials are also presented. Designed for easy reference, this new edition is a must-have volume for engineers and researchers around the globe.

Different types of Phase Change Materials (PCMs) have been tested as dynamic components in buildings during the last 4 decades. Most historical studies have found that PCMs enhance building energy performance. Some PCM-enhanced building materials, like PCM-gypsum boards or PCM-impregnated concretes have already found their limited applications in different countries. Today, continued improvements in building envelope technologies suggest that throughout Southern and Central US climates, residences may soon be routinely constructed with PCM in order to maximize insulation effectiveness and maintain low heating and cooling loads. The proposed paper presents experimental and numerical results from thermal performance studies. These studies focus on blown fiber glass insulation modified with a novel spray-applied microencapsulated PCM. Experimental results are reported for both laboratory-scale and full-size building elements tested in the field. In order to confirm theoretical predictions, PCM enhanced fiber glass insulation was evaluated in a guarded hot box facility to demonstrate heat flow reductions when one side of a test wall is subjected to a temperature increase. The laboratory work showed reductions in heat flow of 30% due to the presence of approximately 20 wt % PCM in the insulation. Field testing of residential attics insulated with blown fiber glass and PCM was completed in Oak Ridge, Tennessee. Experimental work was followed by detailed whole building EnergyPlus simulations in order to generate energy performance data for different US climates. In addition, a series of numerical simulations and field experiments demonstrated a potential for application of a novel PCM fiber glass insulation as enabling technology to be utilized during the attic thermal renovations.

This book presents recent research in the area of hygrothermal building performance, acoustic and natural lighting performance in buildings, phase change materials (PCM) and energy storage. Discussing the state of the art in the field, and covering topics relevant to variety of engineering disciplines, such as civil, materials and mechanical engineering, it will appeal to scientists, students, practitioners, lecturers and other stakeholders.

Smart Buildings: Advanced Materials and Nanotechnology to Improve Energy Efficiency and Environmental Performance presents a thorough analysis of the latest advancements in construction materials and building design that are applied to maximize building efficiency in both new and existing buildings. After a brief introduction on the issues concerning the design process in the third millennium, Part One examines the differences between Zero Energy, Green, and Smart Buildings, with particular emphasis placed on the issue of smart buildings and smart housing, mainly the envelope and how to make it more adaptive with the new possibilities offered by nanotechnology and smart materials. Part Two focuses on the last generation of solutions for smart thermal insulation. Based on the results of extensive research into more innovative insulation materials, chapters discuss achievements in nanotechnology, bio-ecological, and phase-change materials. The technical characteristics, performance level, and methods of use for each are described in detail, as are the achievements in the field of green walls and their use as a solution for upgrading the energy efficiency and environmental performance of existing buildings. Finally, Part Three reviews current research on smart windows, with the assumption that transparent surfaces represent the most critical element in the energy balance of the building. Chapters provide an extensive review on the technical features of transparent closures that are currently on the market or under development, from so-called dynamic glazing to bio-adaptive and photovoltaic glazing. The aesthetic potential and performance limits are also be discussed. Presents valuable definitions that are given to explain the characteristics, requirements, and differences between zero energy, green and smart buildings Contains particular focus on the next generation of construction materials and the most advanced products currently entering the market Lists both the advantages and disadvantages to help the reader choose the most suitable solution Takes into consideration both design and materials aspects Promotes the existence of new advanced materials providing technical information to encourage further use and reduce costs compared to more traditional materials