Chapter

Introductory Chapter: Path to Net Zero Energy Buildings

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1. Overview

Energy demand and usage is expected to change significantly with changing weather patterns, affecting heating/cooling demands and electricity demands. Energy supplies will face changing conditions, such as reduced efficiency of thermal plants, cooling constraints on thermal plants, and increased pressure on transmission and distribution systems. International Energy Agency (IEA) estimates 1°C of temperature increase can reduce the available summer electricity generation capacity up to 16% by 2040 in the United States alone [1]. Sea level rise, permafrost melting, intense and more frequent extreme weather events, increased wind speeds, and ocean storms will all negatively impact energy infrastructure. For example, large numbers of overhead power lines over extended distances could easily be brought down. Consequently, it is likely that the building sector will be highly impacted by climate change and associated weather patterns. It is also true that the building sector is well positioned and has the potential to mitigate such effects to a great extent.

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Research Strategic Plan 2010–2015, even limited deployment of net zero energy (NZE) buildings within this timeframe will have a beneficial effect by reducing the pressure for additional energy and power supply and the reduction of greenhouse gas (GHG) emissions [2]. The implementation of NZE buildings requires use of multiple innovative technologies and control strategies for space heating and cooling and water heating. Hybrid photovoltaic-thermal (PV/T) systems, building-integrated photovoltaics (BIPV), and thermal energy storages have been identified by the US Department of Energy (DOE) as technologies that could make substantial contributions toward that goal [3].

2. Current state of the art

Attempts have been made in using distributed energy systems (DRE) to meet electricity and thermal energy demand of a building. For example, photovoltaic/thermal (PV/T) systems, which produce electricity and heat, have been applied effectively to building roofs and facades to offset or eliminate fossil fuel demand in buildings. But they are treated as separate and distinct systems from each other and from the building envelope. This lack of system integration represents a lost opportunity to simplify and derive additional gains in efficiency. To address this PV/T system integration into the building structure has been the next step in research and development. Arrays of photovoltaic modules with heat recovery capability, which are integrated into the building envelope so that the assembly replaces elements of the facade and/or the roof, thereby reducing overall cost, are known as building-integrated photovoltaic/thermal (BIPV/T) systems. It has been reported that BIPV/T systems have the advantages of (1) reducing the temperature of the PV panels and increasing electrical efficiency, (2) extending the life of the system by reducing the tendency of the modules to delaminate, and (3) recovering thermal energy for spacing heating and domestic hot water heating purposes. BIPV/T systems have the potential to meet all building envelope requirements, such as mechanical resistance and thermal insulation [4–7]. Heat recovery is accomplished by fluid circulation behind the array of photovoltaic modules, which heat up when exposed to sunlight. This thermal energy either can be directly used for space and/or domestic water heating or can be delivered to an air source heat pump (ASHP) to enhance its performance [6–10]. This is particularly important where the coefficient of performance (COP) of the ASHP decreases because of colder outdoor temperatures. It has been reported that ASHPs offer low initial cost compared to ground source heat pumps (GSHP), with 40% reduction in installation cost [4], but their COP decreases in colder outdoor temperatures [11]. Coupling ASHPs with BIPV/T systems has been reported to have the potential to further reduce building heating and cooling costs and dependence on nonrenewable heating fuels. For example, it has been reported that the energy consumption of the ÉcoTerra (Montreal) house was only 26.8% of a typical Canadian home when a BIPV/T system was coupled with a GSHP [12]. As mentioned earlier, with a 40% reduction in installation cost [4], and with a "pre-treatment" of the outdoor air by a BIPV/T system, ASHPs coupled to a BIPV/T system are an attractive alternative to GHSPs coupled to BIPV/T systems and have great potential to increase building energy efficiency.

Another technology that has been shown to improve the thermal performance of buildings significantly is thermal energy storage (TES) system [13–17]. This is especially attractive in regions with extended period of freezing, such as Alaska, where the performance of ASHPs is poor during cold weather. Concrete is the most common and effective building material used as thermal mass [18]. Concrete slabs can be utilized as effective TES systems [19–21]. It has been suggested that since the BIPV/T system is an air-based system, the collected thermal energy can be released to concrete slab TES during daytime. During the night, when the outdoor temperature is cold, the stored thermal energy can be released to the air source heat pump, leading to the enhancement of the overall coefficient of performance of the ASHP.

Renewable energy sources often are not available when needed or do not meet the fluctuating demand for heating. For example, in summer, a thermal solar heater's output is large compared to winter time. In such cases, seasonal thermal storage systems are employed. In fact, energy storage is a key to facilitating the widespread use of many renewable energy resources. Large heating and cooling loads can be addressed through seasonal solar thermal energy storage—SSTES [22]. Thermal energy storage is also a key element in building mechanical systems. It allows covering heating and cooling needs in an efficient and economical way, particularly domestic hot water—DHW [23]. Sensible heat storage, using readily available simple materials such as rocks, is one of the most widely used techniques for thermal energy storage. It is simple and least expensive [24, 25]. In addition, sensible heat storage systems have the advantage of reversible charging and discharging capabilities for unlimited number of cycles, i.e., over the life span of the storage, unlike, for example, phase change materials [26]. The use of simple materials, such as rocks and sand which are readily available in many areas, makes sensible heat storage long lasting, safe and relatively easy to install, and applicable for remote areas [25]. Sensible heat storage systems have applications in residential, industrial, and commercial settings. For example, the Drake Landing Solar Community uses a combination of seasonal ground-based thermal storage with short-term liquid storage tanks [27]. Large-scale seasonal storage systems have been constructed in Switzerland, Denmark, Finland, France, the Netherlands, the United States, Turkey, Korea, Germany, and Canada.

Another thermal storage technology, latent heat storage (LHS) systems, involves the storage of energy in phase change materials (PCMs). Thermal energy is stored and released with changes in the material's phase. LHS has the advantage of being compact, i.e., for a given amount of heat storage, the volume of PCMs is significantly less than the volume of sensible heat storage. This allows for less insulation material and applicability in places where space is limited. Another advantage of PCM is that they can be applied where there is a strict working temperature, as the storage can work under isothermal conditions. Phase-transition enthalpy of PCMs is usually much higher (100–200 times) than sensible heat. Consequently, latent heat storages have much higher storage density than sensible heat storages [28]. Current PCM research is mainly focused on technologies that deal with materials (i.e., storage media for different temperature ranges), containers, and thermal insulation development. There is still a need for basic and applied research and development of design methods, research and development to improve performance analysis; reduce operation cost of installed systems; assure their long-term, smooth operation; and improve their efficiency. More research is also required in understanding system integration and process parameters as well as improving reacting materials [29].

Another technology that stores thermal energy from the sun is in the form of chemical energy. The process is known as solar thermochemical energy storage (TCES). Through a reversible endothermic chemical reaction, energy is stored as a chemical potential using the solar thermal energy. TCES does not yet show clear advantages for building applications, despite the potentially high energy density. Currently, there is no available material for thermochemical energy storage that satisfies all the requirements for building operations. Besides, thermochemical solutions require different tanks and heat exchangers that should be carefully addressed for small-scale applications. Also, additional research efforts are needed to optimize operation conditions, efficiency, costs, and system designs.

In conclusion, the path to zero and net zero energy buildings requires multiple technologies working together. Currently, these systems are treated as separate and distinct systems from each other and from the building envelope. There is a need for system integration and development of effective control strategies to simplify and derive additional gains in building energy efficiency. Buildings with integrated distributed energy systems are resilient to catastrophic weather events.

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