The benefit of using energy storage in New Zealand’s homes and offices

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An introduction to energy storage

Moving towards more energy efficient building has become a priority nowadays, due to the climate issue that we are all familiar with. The buildings sector is the largest energy-consuming sector, accounting for over one-third of final energy consumption globally and an equally important source of carbon dioxide (CO_2) emissions. In 2013, space heating and cooling, together with water heating were estimated to account for nearly 60% of global energy consumption in buildings (1).

Within this context, performing Thermal Energy Storage (TES) in buildings has become a priority. Energy can be mainly stored in three forms: sensible heat, latent heat or thermochemical heat (2). Conventional building materials use sensible heat to store energy, utilising thermal mass of the construction materials. However, in some parts of the world, such as New Zealand, lightweight constructions are more popular, due to their ease of construction and their architectural flexibility (3). Such a building has a much lower thermal mass and hence its interior temperature is more influenced by the outdoor temperature fluctuation. In such a building, large amount of energy is needed to keep its interior building temperature with comfort condition.

Storing energy in an effective way, which can be done through the use of phase change materials (PCMs) or thermochemical energy storage (TCES). We are in the early stages of developing a TCES unit. In this case, a reversible chemical or physical reaction is used to store heat for an indefinite period of time. Furthermore, TCES has a superior energy density compared to sensible or latent heat storage. On the other hand, PCM technology is widely available and well investigated, including the 20 years research conducted at University of Auckland, led by Prof. Farid. The use of PCM, with high storage density, is more effective when used in lightweight construction (4). Indeed, they can store between 5-14 times more heat per unit volume than sensible heat storage materials such as water, masonry and rock (5). Their use have been assessed by many researchers over the past decades (1,6-12). Unlike other materials, PCM absorb and release heat when changing state. This happens at a nearly constant temperature (13,14), which has two main benefits: it brings more constant temperature level inside a building and allows PCM application to be independent of the heating and cooling system employed (15). Barzin et al. (16) have summarized the following effects of PCM: (a) narrow the gap between peak and off-peak loads of electricity demand; (b) save operative fees by shifting the electrical consumption from peak periods to off-peak periods; (c) use solar energy continuously, storing solar energy during the day, and releasing it at night, saving energy and improving thermal comfort; (d) store natural cooling by ventilation at night in summer and use it to prevent room temperature from rising during the day, thus reducing the cooling load of air conditioning.

There are two types of PCM-based TES systems that can be used in buildings: active and passive storage systems. Active systems require an additional fluid loop to charge and discharge a storage unit. On the contrary, passive systems don't require such heat exchanger to extract heat or cold from the storage. The storage is part of the building envelope, storing energy in the form of latent heat. PCM can be incorporated into various building components, such as walls (17), floors (18), and window glazing (19), using micro or macro encapsulation.

Studies on PCM have been conducted in different regions of the world such as New Zealand (Behzadi & Farid 2011) (20), Spain, (Castell et al. 2010) (14,17) Sweden (Persson & Westermark 2012) (21), and Hong Kong (Chan 2011) (22). These studies have shown that PCM can be used effectively in a building located in the respective countries. However these studies have different methodologies, building design, and PCM usage.

How would energy storage aid New Zealand future energy?

New Zealand has tremendous knowledge in the development of energy storage materials (PCM); their encapsulation and use. The work which has been conducted at University of Auckland over the last 20 years has generated significant knowledge that could be used for true implementation within a very limited time period. Through both experimentation and simulation we have shown that energy storage is effective in a moderate climate, such as the atmospheric conditions over much of New Zealand. We have shown the strong need for a clever design when integrating PCM into buildings in order to make it cost effective. The goal is to find a trade-off between energy savings and comfort enhancement.

Importantly, in New Zealand, space heating was found to average 34% of total household energy use (23). The most common forms of space heating are wood burners, convection plug-in electric heating systems and heat pumps. The Energy Efficiency and Conservation Authority (EECA) offers a government programme which gives grants covering two-thirds of the cost of heaters in eligible homes (wood burner, pellet burner or heat pump) (24).

Energy storage could contribute significantly in reducing energy used for heating and cooling of buildings and hence reduce CO_2 emissions, specifically in New Zealand due to its moderate weather condition. The effect of integrating PCM technology into our nation falls under the broad headings of environmental, social and economic impact.

Environmental Impacts

In New Zealand home construction follows largely timber construction, having low thermal mass, which leads to significant indoor temperature fluctuations even when dwellings are properly insulated. Thermal storage will provide significant energy benefits in low thermal mass buildings. According to BRANZ, on average, New Zealand households use 3,820 kWh annually (standard error 350 kWh) purely for space heating (23). Our work has shown that it is possible to save 10% in heating in winter and up to 40% in autumn. If we take the worst case scenario of 10% saving, the total annual saving per household will be 382 kWh. This is close to our computer simulation outcome indicating that a saving of 1.5 GJ, which is equivalent to 417 kWh is possible. Along with several other environmental impacts, this will reduce CO_2 emissions nationally.

New Zealand is a pioneer in using ripple control to switch off water heater during peak demand times. The concept could be implemented in a larger scale to control heating and cooling in buildings for the purpose of shifting electricity peak loads, which is difficult to achieve without energy storage. Furthermore, there is the potential that the large scale uptake of heat pumps currently being seen in New Zealand will place greater demands on the electrical supply network. New Zealanders are now using heat pumps more frequently than other conventional sources of space heating, further impacting the electrical network. From the 2001 Census, 72% of New Zealanders are now using electricity as the fuel type to heat a dwelling (25). In 2007, approximately 160 MW worth of heat pumps were installed into residential homes. Scenarios were considered by the Electricity Commission in 2008 and it was indicated that a new electrical generation plant will be required just for the growth in electrical heating (25)**.** This will obviously place pressure on transmission and distribution infrastructure too. Furthermore, it is suggested that replacing all solid-fuel burners with heat pumps will result in an increase in 60% of our winter peak load demands (25). A new cooling load on the electrical supply network is now being seen which did not previously exist. 58% of participants in the BRANZ study used a heat pump for cooling (25). This results in a new electricity demand at a time when New Zealand's hydro dams are traditionally low. This demand for both electricity supply and transmission and, in dry years, could contribute to electricity shortages. Lastly, with New Zealand moving towards the use of electric cars a load on our supply network will be seen at night.

By collecting solar heat during the day and using this at night, the heating load will be shifted, aiding in reducing this peak load. Studies show that the market growth rate of solar heaters is decreasing from 18% in 2011 to 2% in 2018 while the growth rate of photovoltaic (PV) in 2018 was 25%. This is because PV has the capability of electricity storage; however, its low efficiency (15% to 20%) makes it impractical to be used for space heating. Solar water heaters, on the other hand, require extra facilities such as indoor radiators, which are not available in many buildings. Also, water has low energy density and hence to store a certain amount of energy a large volume of water and high level of insulation is required. Furthermore, the energy in water is stored in the form of sensible heat, which gives a variant outlet temperature. Solar air heaters, however, have high efficiency (~70%) and are compatible with HVAC systems in buildings. Hence, PCM technology can be easily integrated into New Zealand households. Solar air heating systems in North America are typically designed to cover between 20% and 30% of the annual space heating demand of buildings.

Photovoltaic-Thermal (PVT) collectors integrate photovoltaic and thermal solar energy conversion in a single device and reach higher yields per area. Regular photovoltaic systems convert 15–20 % of the incoming radiation to electricity, while the rest remains unused. In hybrid PVT systems, a part of this energy is transferred to the air and harvested as (useful) heat. This way, PVT systems can play an important role in the supply of local renewable energy, both in the form of electricity and heat, and use up to 70 % of the incident solar radiation, reducing peak demand loads for New Zealand.

However, such collectors can provide thermal energy during the availability of solar radiation only, while the main heating requirement of buildings is during late afternoon and night when no solar energy is available. To tackle this limitation PCM as thermal energy storage allows solar energy or excess thermal energy to be stored for later use. The generated high-grade electricity can be used for lightening, to run the heat pump needed for space heating and cooling and the excess energy can be fed into the grid. Furthermore, a smart control system can maximize the potential of PCM storage and the generated electricity, hence, a highly productive system. Such a system is an ideal option for solar neighbourhoods which are increasingly important to achieve net zero energy districts and low carbon cities. This is compatible with Section 9 of the document which facilitates the local and community engagement in renewable energy and energy efficiency. As concluded by the University of Canterbury, New Zealand needs to begin preparing for the widespread introduction of electric vehicles with smart grid technology and increased renewable integration (26), something that PCM technology could play an integral role in.

Social Impacts

There is significant evidence showing that New Zealand dwellings are excessively cold in winter, subject to damp and vulnerable to mould. The 2018 Census showed that 318,891 or more than 1 in 5 homes were affected by dampness (27). From the HEEP study, the average temperature in New Zealand living rooms ranges from 14.7-16.5 °C (23). This is a jarring statistic, as the World Health Organization recommends a healthy living temperature to be above 18 °C (21 °C for infants or elderly). Damp and cold homes lead to respiratory illnesses. One of the promises of heat pumps is that householders will be able to maintain steady temperatures. However, the majority New Zealanders do not keep their heating on consistently- 32% only heat in the evening (28). Most users only use a heat pump at one set point, rather than using a different temperature for different times of day (25). Furthermore, we tend to spot heat our living rooms, and most importantly from a health viewpoint, seldom do we heat bedrooms (23). TES and specifically PCM with control systems, as aforementioned, would alleviate these issues as the householder will no longer have to modify their heating practices in order to live in a dry and warm home.

Furthermore, smart insulation in building walls and ceiling has been identified as a possible solution to improving indoor air comfort and health condition of occupants. It can also reduce the high bill associated with running heating/cooling appliances in buildings with significant carbon dioxide emission reduction. For building insulation to be efficient, they must meet the recommended standards set by the New Zealand Building Code (29). For example, according to a 2015/16 House Condition Survey by EECA up to 41% of residential houses in New Zealand fall short of this standard (30) . The direct consequence of this is the loss of heat of about 30–35% from the roof alone. The use of smart insulation that systematically combines PCM and insulation of minimum thickness can be used to reap the benefit of thermostatic regulation of indoor air, higher thermal energy storage and better heat transfer management within the building fabrics. This will not only reduce the cost required for insulation but also further decrease the run time of our heating/cooling appliances. To this end, in our laboratory at the University of Auckland, we have shown that PCM can be incorporated to various insulation materials such as polyurethane foams, pink batts and high- and low- density polyethylene with reasonable evidence of the PCM retained in the insulation. Like the Canadians are doing, the time is now for the New Zealand government to adopt a smart city approach to improve the living conditions of her dwellers through the use of smart insulation in homes.

Economic Impacts

When considering each household in New Zealand uses 3820 kWh annually on space heating, the savings by installing a PCM-based storage system are significant. It has been calculated that in place of current space heating technologies used in New Zealand, the average household would save $110.78 over the winter months and $443.12 over Autumn. With the government currently subsidising efficient and environmentally friendly space heating options for New Zealanders, PCM technology would also provide New Zealanders with a cheap source of space heating.

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