Energy Efficiency through Thermal Energy Storage – Evaluation of the Possibilities for the Swedish Building Stock, Phase 1

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SUMMARY

As a first step in assessing the potential of thermal energy storage in Swedish buildings, the current situation of the Swedish building stock and different storage methods are discussed in this paper. Overall, many buildings are from the 1960’s or earlier having a relatively high energy demand, creating opportunities for large energy savings. The major means of heating are electricity for detached houses and district heating for multi dwelling houses and premises. Cooling needs are relatively low but steadily increasing, emphasizing the need to consider energy storage for both heat and cold. The thermal mass of a building is important for passive storage of thermal energy but this has not been considered much when constructing buildings in Sweden. Instead, common ways of storing thermal energy in Swedish buildings today is in water storage tanks or in the ground using boreholes, while latent thermal energy storage is still very uncommon.

INTRODUCTION

A directive in Sweden to reduce the energy demand in buildings by 50 % until 2050 has put increasing pressure on research in the fields of building technology and energy efficiency in buildings. Thermal energy storage (TES) is one way of working towards achieving this goal. Different applications using TES have been shown to increase energy efficiency, reduce power peaks and/or reduce harmful emissions of systems supplying the heating and cooling needs of buildings. This project aims to survey the various possible technologies and to identify those that are most suitable for the Swedish context. In a secondary phase, the most promising technologies and systems will be analyzed in more detail through case studies. Both active and passive storage technology is studied and the scope of the project includes all buildings that are heated or cooled.

METHODS

In the first phase of the project statistics for the building stock, its heating and cooling loads and the predominant system types used for meeting these loads are compiled and analyzed. Additionally a literature survey is made of the thermal storage technologies that can be applied to the Swedish building stock and especially those that are already utilized. Later, key figures will be derived concerning the effectiveness in terms of improved energy efficiency, peak shaving and emissions reduction. This will be done for individual systems and then the combined effects for the whole building stock are estimated. In a later phase of the project, the different technologies will be compared using the derived key figures (including costs) and the most suitable will be chosen for more detailed case studies.
RESULTS

As a first part in the literature study, the Swedish building stock and its energy demand was examined. The existing use of thermal energy storage in Swedish buildings is presented with some examples, as well as other techniques and examples from other countries that could also be of interest in Sweden.

Residential building stock

Up until 1990 information on the residential building stock was collected and processed every five years, but no counting of the buildings has been done since then [1]. Instead today’s statistics are based on the values from 1990 and recalculated with the knowledge of newly built, rebuilt and demolished buildings. According to the statistics from 2007 there are 2.4 million dwellings in multi-dwelling houses and 2 million dwellings in (semi-)detached houses (1.74 million buildings) [1]. Of the dwellings in multi-dwelling houses almost 72 % were concentrated to the three largest cities in Sweden (Stockholm, Göteborg and Malmö), while the same figure for detached houses was 27 %.

During 2008 a total of 31.5 TWh of purchased energy for heating and hot water in detached houses was supplied using 40 % electricity, 36 % biofuels, 16 % district heating and the rest oil and others [2]. The use of oil for heating residential buildings has decreased 75 % in the last five years, mainly due to high oil prices [2]. The houses fully or partly being heated by a heat pump was 40 % in 2008 [2]. This figure increased rapidly in the 90’s and early 2000’s, but the increase has now leveled off [2]. In Table 1 the distribution of different heating systems in detached houses from 2006-2008 is shown. Looking at the data, electricity for heating, either by itself or in combination, is used in more than half of the detached house but has decreased since 2006. The amount of detached houses with heating systems using biofuels to some extent has remained almost constant around 40 % while district heating has increased and oil has decreased.

Table 1. Distribution of heating systems for detached houses [2]. Air/air heat pumps count to direct electricity (d) and air/water heat pumps to waterborne electricity (w).

<table>
<thead>
<tr>
<th>Heating source</th>
<th>2006 Percent</th>
<th>2007 Percent</th>
<th>2008 Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only electricity (d)</td>
<td>12.2</td>
<td>12.4</td>
<td>12.6</td>
</tr>
<tr>
<td>Only electricity (w)</td>
<td>10.4</td>
<td>10.5</td>
<td>10.1</td>
</tr>
<tr>
<td>Only biofuels</td>
<td>6.5</td>
<td>11.1</td>
<td>11.4</td>
</tr>
<tr>
<td>Only district heating</td>
<td>7.3</td>
<td>7.5</td>
<td>9.6</td>
</tr>
<tr>
<td>Only ground/earth/lake heat pump</td>
<td>4.6</td>
<td>8.2</td>
<td>6.8</td>
</tr>
<tr>
<td>Only oil</td>
<td>2.5</td>
<td>2.5</td>
<td>2.1</td>
</tr>
<tr>
<td>Biofuels + electricity (d)</td>
<td>16.7</td>
<td>17.0</td>
<td>15.4</td>
</tr>
<tr>
<td>Biofuels + electricity (w)</td>
<td>16.6</td>
<td>12.7</td>
<td>13.1</td>
</tr>
<tr>
<td>Oil in combination</td>
<td>9.3</td>
<td>5.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Other</td>
<td>13.9</td>
<td>12.4</td>
<td>14.0</td>
</tr>
</tbody>
</table>

For multi-dwelling houses the total energy delivered for heating and hot water in 2008 was 25.7 TWh, which has been steadily decreasing in recent years (30.5 TWh in 2003) [3]. District heating is the dominating way of heating with 92 % of the total heating demand being supplied by district heating and the remaining heat being supplied by electricity (5 %), oil (2 %) and biofuels, natural gas or other (1 %) [3]. The majority of the multi-dwelling buildings are larger than 1000 m², with 31 % being larger than 3000 m². Of all dwellings in multi-dwelling houses 85 % are situated in southern Sweden and 15 % in northern Sweden (roughly north of Stockholm). The energy purchased for heating and domestic hot water is also
similarly distributed with 83% being used in southern and 17% in northern Sweden [3]. The figures are similar for detached houses with 77% of the houses in southern Sweden and 23% in northern Sweden with 75% of the purchased required for heating and hot water allocated to the south and 25% to the north [2]. This shows that the purchased energy per dwelling (or house) is almost the same both in northern and southern Sweden despite the fact that the climate is much colder in the north. There can be several reasons for this and the truth is most likely a combination of factors. Possible explanations could be that the buildings are better insulated in the north or maybe that people tolerate a slightly lower indoor temperature, both resulting in a lower energy use for heating purposes. Other possible reasons could be that the market share for heat pumps is larger in the north (although this is not shown in statistics) or that for example wood log stoves and boilers not part of the statistics are more frequent in the north, resulting in similar figures for purchased energy but a higher energy use in reality.

One important key figure for the energy demand in buildings is the average supplied energy per area for heating and domestic hot water, here expressed as kWh/m² for the year 2008. In detached houses the average use of energy for heating and hot water was 121 kWh/m² for all buildings, while the same figure for buildings constructed between 2001-2007 was 79 kWh/m² [2]. The reduction in the average use of energy in detached houses started in the 90’s and has continued since then, largely because of the increased popularity of heat pumps in newly constructed houses, lowering the need for purchased energy. The majority of the buildings however (over 80%) are constructed before 1980 and 30% are constructed before as early as 1940 [2]. There should therefore be a large saving potential in older detached houses with a high energy demand. For multi-dwelling buildings the average use of energy for heating and hot water was 145 kWh/m² for all buildings, and 116 kWh/m² for buildings constructed after 2001 [3]. Many of the multi dwelling buildings were constructed during the 1960’s due to the housing shortage at that time, also resulting in a large amount of buildings with a high heating demand and a large potential for energy savings.

**Non-residential premises**

In Sweden in 2007 there was a total of 130.7 million square meters of non-residential premises in 62,700 buildings, excluding industrial and farming premises [4]. The distribution of the area to different types of premises for the years 1991 and 2007 is shown in Figure 1. The three largest groups of premises are schools, offices and health care and interesting to note is that the area distribution within these three groups has changed significantly between 1991 and 2007. The area allocated to schools has more than doubled, while it has been reduced by almost 30 percent for offices.

![Figure 1. Distribution of the total area for types of premises in Sweden for 1991 and 2007 [4].](image)
The energy used for heating and hot water in premises in 2007 was 18 TWh. Of this 12.9 TWh was district heating, 2.8 TWh was electricity and 1.3 TWh was oil and the remaining 1 TWh being biofuels, natural gas and other [4].

The total cooling need for premises (including district cooling and electricity for comfort cooling, but excluding electricity used for process cooling), was 901 GWh (purchased energy) in 2007 [4]. The total electricity purchased for cooling (including electricity for both process and comfort cooling) was 379 GWh in 2007 [4]. Looking at the specific cooling need in different types of premises and their construction year, a large part of the cooling is used in offices, hotels and restaurants constructed since 1991. For example office buildings constructed since 2001 use an average of 31 kWh/m², yr for cooling, while the average for all office buildings is 15 kWh/m², yr [4]. The largest average specific cooling need for all construction years belongs to round the clock health care with 16 kWh/m², yr, with the most being for buildings constructed in the 1960s (average of 40 kWh/m², yr) [4]. Comparing this with the results in Figure 1, it can be concluded that two of the premises types with the largest total area also have the largest specific cooling use (offices and health care).

Of the entire premises area around 20 % is situated in northern Sweden. The purchased energy for heating and hot water in the same region is 22 % of the total amount [4], showing that the amount of purchased energy for heating and hot water in premises is roughly the same per area both in northern and southern Sweden, which also was the case for residential buildings. The average energy purchased for cooling in premises however is three times as high in southern Sweden; 51 kWh/m² compared to 17 kWh/m² in the north [4]. According to predictions made by the Ministry of the Environment, the electricity needed for cooling will increase to 2.0 TWh for residential buildings and 2.5 TWh for premises until 2020 [5]. This is only taking climate change into account, considering today’s building stock and efficiencies for cooling.

Looking at key figures for the average heating use (heating and domestic hot water) for premises in 2007, the average for all premises was 131 kWh/m² and for premises constructed after 2001 the same figure is 105 kWh/m² [4]. Also for premises a large portion is constructed in the 60’s, with a rather high heating demand of 137 kWh/m² [4].

TES used in Swedish buildings today
The most common way of actively storing heat in Swedish buildings is in domestic hot water tanks, which are used in nearly all dwellings where heat is supplied by electricity. This helps in evening out peak loads in the hot water preparation. Another common way of storing heat, especially in single family houses, is by using a water storage tank in combination with a boiler (often pellet or wood logs). Especially for wood boilers, a heat store is an essential part of the system, since one batch of wood roughly produces the amount of heat used in a whole day. Without a storage tank the boiler has to run on very low power, often with the wood just glowing, with high emissions as a result. A storage tank is therefore crucial, increasing running times with full power and lowering emissions. For pellet boilers the emissions are highest during start and stop [6] and the number of start and stops can be reduced with a storage tank also resulting in lowered emissions. Another increasingly popular way of reducing emissions is by installing solar collectors, which also requires a storage tank allowing solar energy to be stored for later use. According to Statistics Sweden, in 2008 the number of detached houses equipped with solar collectors were around 28,000, a figure doubled since 2006 [2]. There is however a large uncertainty in this number and it is somewhat doubtful whether the actual number is that high. For example, Solar Energy Association of Sweden [7] reports the number of solar heating systems to be around 15,000 with a yearly increase of about 2,000 systems per year.
Heat pumps using boreholes as energy source are widely used in Sweden, with around 25 % of all boreholes for geothermal energy in the world being drilled here [8]. Many of the drilled holes are however strictly speaking not energy storage systems in the sense that they are only intended to provide buildings with heat, with no active recharging in mind. Most common are boreholes for single family houses, but several larger systems for borehole thermal energy storage (BTES) also exist. One example is the university in Lund where heating for 2 buildings and cooling for 3 buildings is supplied from 153 wells at a depth of up to 230m [9]. One example from the residential sector is a BTES system built in Anneberg in Sweden. The system comprises 100 boreholes at 65 m depth and the 60,000 m³ rock storage is supplied with heat during the summer from 2,400 m² of solar collectors [10]. The heat loss from the rock storage is estimated to be about 40 % of the stored solar heat and the solar fraction is estimated to be 70 % after 3-5 years of operation [10]. Another way of using ground heat is through aquifer thermal energy storage (ATES). The world’s largest ATES is operating since summer 2009 at Arlanda airport in Stockholm. It is providing heat and cooling for the airport and is expected to reduce the electricity use by 4-5 GWh per year and the district heating use by 10-15 GWh per year with a heating and cooling capacity of 8 MW [11].

Using heavy constructions to increase a building’s thermal inertia and passively store thermal energy is not something that has been used deliberately in Sweden to any large extent. There has however been some research on this topic showing that the use of heavy constructions can lower a building’s energy use, but the penetration to the building sector is low. Norén et al. [12] used simulation and calculation models to investigate the impact of the construction on the energy demand of a building. The studied building was a 6 apartment building with three different constructions; a light weight construction, a medium weight construction in massive wood and a heavy weight construction using concrete and brick. The results showed that the building using massive wood construction required 9-12 % less bought energy, depending on the calculation method, when compared to the light weight construction and that the building with the heavy construction required between 14-18 % less. Not only the heating requirement can be lowered by increasing thermal inertia in buildings, but also the need for cooling. This can become more and more important with an increasing interest in low energy buildings and the potential problem with overheating in the summer.

One method making use of heavy constructions already used today in many offices and larger buildings, mainly to reduce the cooling load, is by using hollow core concrete slabs as ceilings/floors in buildings [13]. In summer the slabs are cooled during the night using cold outside air and during daytime the ventilation air passes through the hollows thus being cooled down before entering the room. At the same time excess heat from people and equipment can be absorbed into the slabs. In the winter excess heat during the day is stored in the slabs to be released during the night, lowering the need for space heating after office hours. According to Engström and Andersson [13] an average of around 40-50 % of the required cooling energy can be saved compared to a normal HVAC system.

Latent heat thermal energy storage (LTES) is not used to any large extent in Swedish buildings at present but some examples can be found. One example with snow as phase change material (PCM) is found in the hospital in Sundsvall where snow collected in the winter has been used for cooling since 2000. The system is described in [14-15] and consists of a snow mound insulated with wood chips, and heat exchangers to transfer the cold from the melting snow to the hospital. The results from the first year of operation show that the summer cooling load of 655 MWh with a maximum cooling power of 1366 kW was covered to 93 % by snow stored from the winter [15]. There is also an example from a Swedish library where PCM in bags in the ventilation system were installed in 2003 to help preventing overheating in the building during summer [16]. During the night, cold outside air
is transported into the building using fans and cold is stored in both the PCM bags and the
structure and furniture to be used during the day.

**Interesting technologies for future TES in Swedish buildings**

As mentioned earlier, a common way to store heat in smaller houses is by using a water
storage tank. This is something that could be expanded to larger buildings like offices or
public buildings. It is then important to consider the placement of the tank to be able to use
heat losses from the tank as efficiently as possible. Results from one such building is
presented by Wagner in [17] where a round office building equipped with an 87 m$^3$ water
storage tank for seasonal storage being heated by solar collectors and a ground heat
exchanger. One important thing to take into account when constructing buildings in this way,
however, is the problem with overheating in the summer. To minimize the contribution from
the storage tank to this problem, the tank in the building described in [17] is insulated with
five layers of insulation resulting in an estimated heat loss of only 900 W for the entire tank
(fully mixed at 95 °C). A similar concept but for a residential multi-dwelling building was
presented at Eurosun 2008 [18]. The market and potential for this type of storage in Sweden is
not very big however, considering that a very large portion of both multi-dwelling houses and
premises are connected to the district heating network. For the district heating though, large
water storage tanks are often used as a buffer between the heat cogeneration plant and the
heating networks. When only heat is produced the tank serves mainly as a buffer to handle
peak loads in the heat demand, but another example is a company in Sweden who instead take
advantage of the store connected to a cogeneration plant to be able to produce large amounts
of electricity during times when the spot price for electricity is very high and then use the
storage tank to dump excess heat.

LTES is an increasingly popular field of research worldwide with many areas of
use that could have great potential also in Sweden. A state-of-the-art for LTES in buildings is
shown by Zhang in [19], focusing on how to incorporate PCM into the walls, floors and
ceilings. Making use of PCM in buildings this way can be an alternative or a complement to
using heavy construction materials for passive storage. PCM can also be used in active TES
systems and, for example, replace systems with a lower specific storage capacity. An
experimental product with a storage capacity of around 100 kWh/m$^3$ that can be used for solar
hot water systems is shown in [20]. Given time, this kind of product can replace hot water
stores where, for example, either a store with a larger capacity is needed or where space
restrictions prevent the use of conventional products. Similar systems for comfort cooling will
become more important as long as the need for comfort cooling in buildings increase, and
advantages and disadvantages using salt hydrates in cold thermal energy storage systems is
discussed in [21]. Free cooling systems with PCM using cold night time air is also interesting
and one such system was designed and evaluated in [22]. Seasonal storage using PCM is also
something that could have very large potential in Sweden, making storage of solar heat from
summer to winter a viable option, even for smaller systems. One problem still, however, is the
lack of appropriate and cost effective PCM and more research in this field is needed. One
currently ongoing project within IEA ECES (Energy Conservation through Energy Storage)
in relation to these aspects is Annex 24, where the aim is to develop PCM for improved
thermal energy storage. Also, EU has recently started a new platform for renewable heating
and cooling [23] where TES is one of three focus groups within the Cross Cutting Technology
Panel. Focusing more on energy storage in low energy buildings, IEA ECES Annex 23 is also
in its starting phase where focus will be on how to integrate energy storage into sustainable
building design.
DISCUSSION & CONCLUSIONS

A large portion of the Swedish building stock is constructed during or before the 1960’s resulting in many buildings with a relatively high energy consumption. Figure 2 shows the average energy used for heating and hot water with respect to building type and construction year. For premises also the average specific cooling need, including district cooling and electricity for comfort cooling, is shown. It is interesting to note that the buildings with a construction year before 1961 have a similar specific energy use regardless of building type, while detached houses have the lowest specific energy use for newer buildings.

Figure 2. Average energy use for different building types and construction years [2-4].

Large saving potential exists, in the residential segment mainly to reduce heating demand in the winter and in premises both heating and cooling demand could be lowered. Looking at Figure 3, a more detailed summary of the cooling need (district cooling and electricity for comfort cooling) for selected types of premises is shown. Generally, the cooling need is increasing in newer buildings indicating that cooling systems are installed to a larger extent here. Incorporating suitable PCM in buildings during renovating is one way of increasing the thermal mass in a building, leveling out temperatures and, maybe more importantly, eliminating a future need to install cooling equipment in buildings not yet equipped.

Figure 3. Specific cooling need for premises type and construction year [4].

For residential detached houses the majority is still heated with electricity, either alone or in combination, while almost all multi-dwelling houses use district heating. Adding solar collectors to new and already existing buildings to lower the need for purchased energy has great potential but also requires efficient ways of storing the solar energy. When fitting existing buildings with solar collectors there might be problems finding suitable space for the required storage. This can open up opportunities for new storage types with higher specific
storage capacity to minimize the space required. Seasonal storage may also have potential, but costs are still very high compared to alternatives.

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