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Efficient Interaction Between Energy Demand, Surplus Heat/Cool And Thermal Storage

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Abstract

This paper describes energy simulations pertaining to a hospital in Norway at latitude 70° North. The recommendations in this paper are aimed at hospitals in northern Europe.

The purpose of the research was to examine the savings potential and verify how to reduce the energy consumption in new hospitals by about 50%.

Heat pump, chiller and thermal storage technologies enable re-use of surplus heat/cool energy throughout the year. Energy supply and demand are typically modelled with separate tools and timescales. Our study developed new methods for interfacing these energy simulation models. These methods allow optimization of hospital energy flows and the design of an integrated thermal energy system.

Our research indicates that it is possible to save between 20-50% of the energy consumption with optimizing the technical installations in Oslo area.

Another benefit of integrated thermal modelling is the reduce the risk of permafrost in ground source heat pump installations. This risk is relevant for large buildings in northern Norway, where annual mean temperatures are below 0°C.

This paper shows how integrated simulation and design can be used to avoid permafrost.

Keywords: Heating, cooling, thermal storage, technical solutions, energy savings

1. Introduction

Buildings account for about 40 % of national energy consumption, and hospitals represent about 6 % of the total energy consumption in public buildings in Norway. Hospitals are the building category with the highest specific energy consumption. A large university hospital uses twice as much energy per square meter compared to commercial buildings. Large university hospitals recently built in Norway have annual energy consumption between 300-400 kWh/m². New national building codes will soon require “passive house” standard for all new hospitals in Norway, and soon after that for retrofitted hospitals as well.

The authors are key members of a research project funded by The Research Council of Norway to examine energy design of new hospital buildings, known as “Low Energy Hospitals” project (www.lavenergisyskehus.no). The main goal of the project is to discover and describe a collection of best-practices which can achieve a 50 % reduction of the total delivered energy to new hospitals.

A breakdown of energy consumption in a typical large hospital is shown in Figure 1. The "Other" category in this Figure represents electricity consumption by medical and office equipment.

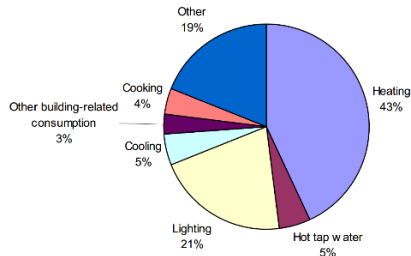


Figure 1. Breakdown of the energy flows in a large hospital

Within each of these categories of energy consumption are thermal energy streams which may be combined and re-used. Our research used interacting simulation models in new ways for integrating and optimizing these different combinations of thermal energy streams.

Conversion and re-use of surplus heat energy are well known energy-efficiency methods, and under constant development. Large buildings complexes, with their many different energy flows for heating and cooling, have a high potential for thermal integration. Large hospitals and shopping centers, for example, have surplus heat/cool energy which can be redirected to reduce overall energy consumption. Nearby buildings may also participate in a coordinated production, storage, and distribution of thermal energy.

Net-zero energy buildings and smart grids will require the development of new tools and design methods in order to optimize surplus heating and, or, cooling throughout different time periods. For example, the various departments in hospitals have very different needs for cooling and heating.

The objectives of the paper is to show the importens of designing the most optimal temperatures for radiator systems and ventilations heating coil and the importants of the design cooling temperature when combining heatpump / cooling machine.

Although our recommendations are aimed at hospitals in northern Europe, they have a general applicability to other types of health facilities worldwide and for other building categories and building complexes with common heating, cooling and ground storage systems. In this paper we have compared simulations for different locations of hospitals in Norway from latitude 60' (Oslo) to latitude 70' north (Vardø).

2. Methods

The research project studied several hospitals built in Norway over the last 10-15 years, looking for examples of typical and best practice with respect to energy performance. The team examined published literature, visited existing hospitals, took energy measurements, reviewed room requirements and building regulations, and created energy simulation models.

Several different software applications were used to simulate factors such as local heating, ventilation heating, local cooling, ventilation cooling, lighting, equipment energy, pump and fan energy, and domestic hot water.

The project developed a simulation tool to analyse interactions between building envelope, climate, local heating, ventilation heating, local cooling, ventilation cooling, lighting, equipment energy, pump and fan energy, and domestic hot water. This tool was an important design aid to maximise the efficiency of combined integrated energy systems.

The simulation model take into account the hydronic design temperature for heating components as radiators and ventilation coils. System solution with series connection between radiators and ventilation coils shown in figure 2 are simulated with outdoor compensated temperature regulation algorithm to optimize the water flow through different valves.

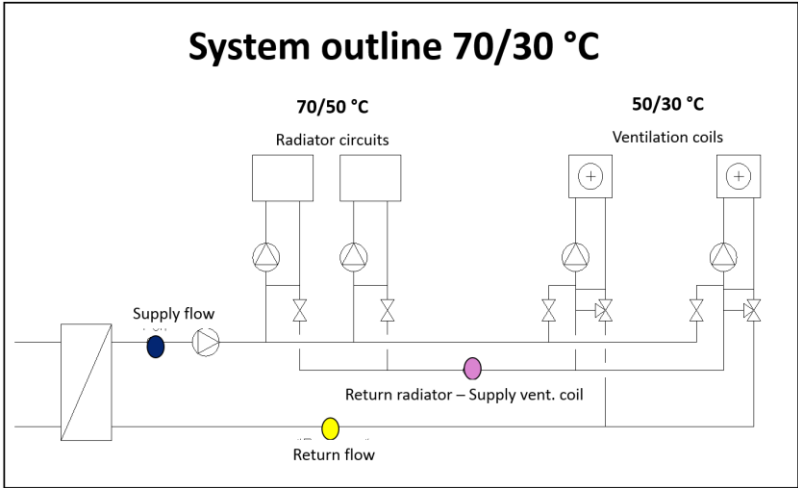


Figure 2. Serial connection - schematically shown

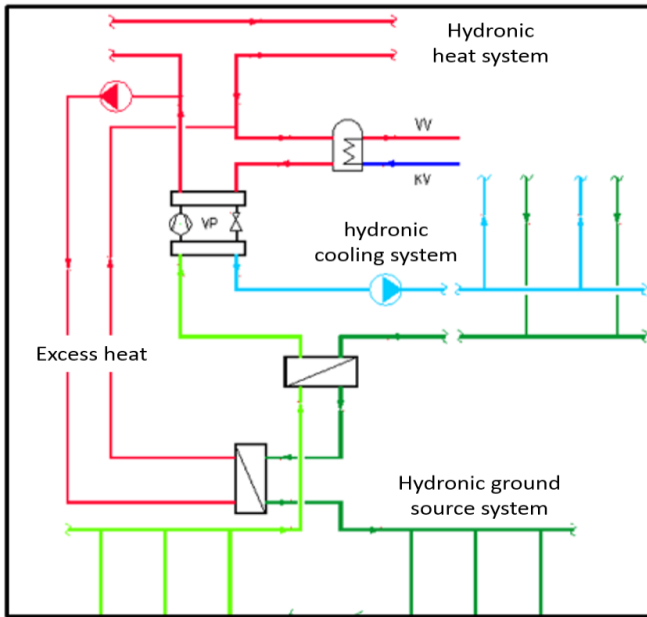


Figure 3. Normal solution to integrate heating, cooling and storage system, which the simulation model is based on

Figure 3 shows a schematic of the central plant with integrated heating and cooling circuits, and ground source storage system which was used in our simulation model.

A hospital consists of very different types of areas, depending on the clinical function and users needs and equipment. The varying working conditions must be considered from the perspective of employee, patient and visitor. Each of these conditions must be treated as a separate design case. A successful design methodology depends on close cooperation with hospital personnel, especially within the surgery department, to achieve optimal solutions for technically complex installations.

A reference hospital was used as the baseline energy model for our project. The reference hospital was divided in 10 different departments as listed:

- Bed ward
- Public area
- Day treatment area
- Operation room
- Office and administration area
- Polyclinic area
- Imaging area
- Lab area
- Patient hotel
- Acute area.

Each area has different uses and internal thermal loads. Using the baseline simulation model, we then varied the heating and cooling system layout, including the pipeline connections and couplings. Further, the design temperatures for radiators, cooling coils and heat pumps were varied. Finally, we varied the outdoor temperature compensation curves.

3. Results

Potentially valuable surplus heat/cool in large hospitals is created from internal loads like equipment, lighting systems, irradiance, related to occupancy and transferred by refrigeration or ventilation systems. For building types such as hospitals the need for heating and cooling are high and do not necessarily match the surplus heat and cool energy at any given time. Thermal storage combined with heat pump / chiller units allow surplus heat/cool to be recycled.

Research on thermal storage solutions for hospitals has so far focused on storage technology without considering interactions between the different energy subsystems. Our analysis looked at different temperature levels for supply and return heating water system as a function of outdoor temperature, different temperature levels for chilled water supply and return, and design parameters for geothermal storage. Overall system efficiency is not optimal if interdependence between these subsystems are neglected.

Results from the simulations in our model, with all the different departments included, are listed in the table above (table 1). In this study we simulated the hydraulic

system for radiators and ventilation coils in a serial connection (see figure 2). Our research found energy savings between 10-30% for this special connection. With all the measures in the table, the total savings are 52%. The savings here come from improved plant efficiency: from the heat pump operating at higher Coefficient of Performance (COP_{hp}), and with less supply from the relatively inefficient peak boiler. The COP_{total} in this case means that total energy to heating divided to electrical energy to heat pump and extra energy for peak load.

Table 1: Results from simulations with hospital placed in Oslo with an annual mean temperature at +5 °C.

No	ALTERNATIVE SYSTEM INPUT	SYSTEM COP	SAVINGS (%)
1	Reference 80/60 °C – heat pump	2,31	0
2	Reduced return temperature ventilation coil 40 °C	2,44	5
3	Reduced return temperature ventilation coil 30 °C	2,48	7
4	Reduced return temperature ventilation coil 25 °C	2,50	8
5	Dimension temperature ventilation coil 45/25 °C	2,54	9
6	Return temperature radiator 50 °C	2,78	17
7	Return temperature radiator 45 °C	2,86	19
8	Return temperature radiator 65/45 °C	2,82	18
9	Dimension system temperature 70/50 °C	3,68	37
10	Reduced condensation temp. heat pump from 53 to 50 °C	3,20	28
11	Dimension system temperature: 60/40 °C	4,17	45
12	Return temperature radiator 55/35 °C	4,17	45
13	Improved heat pump A++	4,81	52

Each of the numbered simulations in table 1 are explained below:

Simulation no1;

Reference case with typical design temperature levels for the radiator system and ventilation coils supply/return 80/60 °C ; no savings.

Simulation no 2-4;

Show savings from a lower return temperature on the ventilation coil and a series connection between radiator and ventilation coil (see figure 2, other temperatures) for each department. Here we simulate design return temperatures from 40 to 25 °C.

Simulation no 5:

Reduce the design supply temperature for the ventilation coil to 45 °C.

Simulation no 6-7;

Reduce the design return temperature from the radiator system to 50 and 45 °C.

Simulation no 8;

Reduce the design supply temperature for the radiator system to 65 °C.

Simulation no 9;

Reduce the system supply temperature for design condition to 70 °C

Simulation no 10;

The maximum condensation temperature for the heatpump is reduced from 53 to 50 °C.

Simulation no 11-12;

Reducing the system supply temperature to 60°C, and the design temperatures for supply/return of the radiator system 55/35 °C.

Simulation no 13:

In this simulation we show the effect of choosing heat pump with internal performance at energy efficiency rating A++.

The results from table 1 show significant savings from introducing a serial connection between radiator and ventilation coils. The reference case is based on the standard design from existing hospitals of today, with design supply/return water temperatures of 80 °C / 60 °C. Simple adjustments to this circuit show a heat saving potential between 10 and 30 %.

The interconnections in this system allow the heat pump's evaporation temperature to be increased. For an increase from 8 to 10 °C our preliminary results shows show an extra energy saving of 3,6 %.

Table 2 shows results from a change in climate when our reference hospital is moved from Oslo to a more northerly location.

Table 2: Results from simulations with hospital placed in Vardø and Kautokeino with an annual mean temperature at 0 °C and -2,5°C.

No	Simulations hospital placed in <u>Vardø</u> and <u>Kautokeino</u> North in Norway	SYSTEM COP	<u>SAVINGS</u> (%)
14	Hospital moved to <u>Vardø</u> – North in Norway – Annual mean temperature 0 °C.	3,75	- 28
15	<u>Vardø</u> – Change dim. <u>crit. vent.</u> coil to 40/25°C (45/25)	3,76	0*
16	<u>Vardø</u> – Change dim. <u>crit. radiator</u> to 60/40°C (55/35)	3,72	- 4
17	Change <u>central</u> supply temperature to 65°C (60)	3,29	-18
18	Increase heat pump <u>condence</u> demand to 500 kW (400)	3,35	-16
19	Hospital moved to <u>Kautokeino</u> - Annual mean temp.-2,5 °C	2,24	-138
20	Increase heat pump to 600 kW (500)	3,11	26*
21	Increase heat pump to 800 kW (600)	3,39	32
22	Increase heat pump to 1000 kW (800)	3,40	32

* compared to the above row results

We hereby summarize the simulations in the table above:

Simulation no14;

The hospital is moved from Oslo to Vardø; uses 14 % more heating energy t

Simulation no15 and 16;

Change in design temperatures for radiators and ventilation coils; increases the heating energy with 4 %

Simulation no17;

Change central plant supply temperature to 65 °C (60); increased heating energy with 14% (18-4)

The subsequent simulations investigate the successive effects of increasing heat pump condenser loads:

Simulation no18;

Increased heat pump condenser load to 500 kW (400); reduced the total heat energy delivery by 2% (18-16).

Simulation no19;

Moving hospital to even colder Kautokeino; increases the total heat energy requirement by with 122% (138-16). – Annual mean temperature -2,5 °C.

Simulation no 20;

Increase heat pump condenser load to 600 kW (500); reduces the total heat energy delivery by 26%.

Simulation no 21;

Increase heat pump condenser load to 800 kW (600); reduces the total heat energy delivery by 6% (32-26).

Simulation no 22;

Increase heat pump condenser load to 1000 kW (800) – No Change.

Ground thermal storage model

Our reference hospital has a gross floor area of 22 000 m², divided into 10 different departments described above. The thermal energy storage system (TES) is a borehole field with either 50 or 100 boreholes, at a distance of 10 and 20 meters and depth of 200 meters each.

To optimize the cooling system we have designed the cooling coil for ventilation with a temperature fluid supply temperature at 14 °C and high return temperature at 21 °C.

To analyse the temperature fluctuations we have plotted 2 different temperatures in the ground with a distance of 1,5 meter and 5 meter from the borehole. We have also plotted the return fluid temperature from the borehole.

The relative high design temperature for the ventilation coils shows that we can use "free cooling" for the ventilation system the whole year. In our simulations we have also included fancoils for local cooling in the different hospital areas.

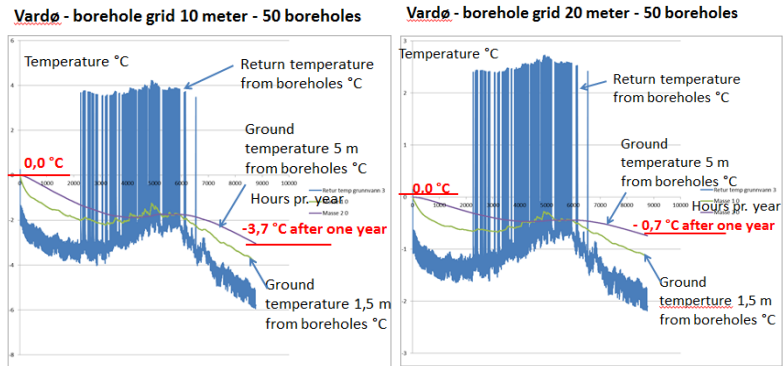


Figure 4. Temperature fluctuation through a year for ground 1,5 and 5 meters from the borehole and the return temperature from the borehole - northern Norway.

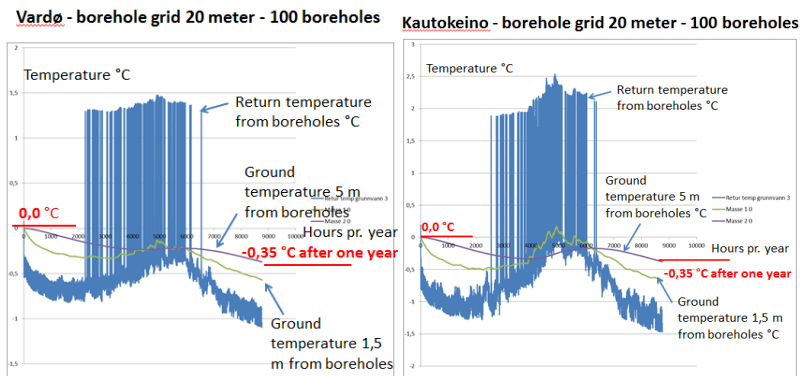


Figure 5. Temperature fluctuation through a year for ground 1,5 and 5 meters from the borehole and the return temperature from the borehole.

4. Conclusions

The most important findings of the research is that it is possible to save more than 50 % energy to heating hospitals just by changing the layout and design supply and return temperatures of radiator system and ventilation coils. Interdisciplinary design and engineering with focus on design criteria for the heat pump are also very important.

The design of hospitals in the cold climate of 70 degrees latitude requires careful sizing of the ground source to the heat pump system. It is important to analyze the temperature fluctuations in the ground and to strive for a design which balances heat extraction and heat rejection (from cooling) to achieve balance over the year.

Without heat balance, our test case showed that the temperature in the ground in a few years results in permafrost in a cold climate. In such a case it is important to use surplus heat, such as cooling heat rejection in summer, to balance the boreholes.

Through the simulations and modelling we find that using the water twice, or serial connection for heating solutions, we can optimize the use of heatpump and reduce the energy consumption significantly. High design temperature for ventilation cooling coil and local fan coils can optimize the borehole specification.

Further we find that interactions between building envelope, climate, local heating, ventilation heating, local cooling, ventilation cooling, lighting, equipment energy, pump and fan energy, and domestic hot water, and optimizing the combinations of integrated energy systems will give a reduction of the total energy consumption of 20-50% in a new hospital.

Acknowledgement

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