Graduation plan P2 - Building Technology

Personal information

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Studio

Theme:	Green Building Innovation
Teachers:	
1st mentor	Peter Luscuere
2nd mentor	Wim van der Spoel
Argumentation of choice of studio:	Research on the integration of low energy climate concepts and building services in architectural design.

Title

Title of the graduation project:	Comparative analysis of short term storage systems for low quality heat in Dutch dwellings

Problem statement

Most renewables do have an intermittent nature, causing a mismatch in time between demand and supply.

Currently, the low-quality heating and cooling demand in the built environment is met with high quality energy resources e.g. gas or electricity and our dependency on fossil fuels is only increasing. Alternatives to fossil fuels could be: renewable energy sources, natural (ambient) heat and cold and waste heat. Besides active solar thermal and Combined Heat and Power, heat pumps provide a mature and efficient technology for an increased contribution of renewables. The International Energy Agency expects that the application of heat pumps for domestic space and water heating will dramatically increase, from circa 800mln installed heat pumps today to 3.500mln by 2050[1]. Currently, ground source heat pumps are most common, but air-source heat pumps are a potential competitive variant since there more easy installation and the fact that they don't need underground heat exchangers reduces investment costs.
Natural and renewable resources (e.g. desirable ambient air temperatures or sun) are intermittent though. This means energy is not always available, or could not always be efficiently produced under most optimal circumstances, immediately at the moment of demand. Storage for a short term could shift peak loads to moments of supply surplus, which could improve the performance of an air source heat pump, and in general support the integration of intermittent renewables in the power grid.

Research question

What could be the potential of short term storage of low quality thermal energy applied in a contemporary Dutch dwelling with an air-source heat pump, considering the exergy principle?

[1] Technology Roadmap IEA 2011

Sub questions
1. How could the selected thermal energy storage options be integrated in an energy system design for a typical Dutch residential building?
2. What is the influence of each storage option on the total energy consumption and installed system power that is necessary to meet the heating load?
3. How could the storage options adjust the daily heating demand profile in such a way that the heating demand is met with minimum amount of work?
4. What is the environmental impact of the storage options considering their complete life cycle?

General objective

The goal of this graduation project is to assess the potential of short term energy storage in meeting the low temperature heating or cooling demand in a residential building with an air-source heat pump. A software model will be constructed, in which different storage technologies can be compared on their impact on energy and exergy performance, but also on environmental costs. Building characteristics associated with different heating demands will be assessed, which can give insight in relation between (the performance of) building services and architectural aspects. The storage systems should reduce the high quality energy consumption necessary to meet the heating demand.

Boundary conditions

- short term storage: maximum of one week;
- building physics characteristics (insulation, thermal mass, dimensions) and building services associated with three annual heating demands of resp. passiv-haus standards, a new built dwelling and a dwelling according to standards several years ago[2], i.e. 15 kWh m^{-2}, 25 kWh m^{-2} and 35 kWh m^{-2};
- for simplification reasons, no PV or solar thermal collectors will be included in the model;
- storage on secondary (demand) side of the energy generation;
- generation system: combi air-source heat pump, calculating with real COP performance;
- installed power depends on DHW demand, simulate three different DHW-draw patterns according to CW klasse 2,4 en 6 (NEN 7120);
- focus on performance in the Dutch climate, but results might be valid for many other countries.

Method description

<u>Literature study</u>
1. advanced study low temperature storage options
- theory and previous research outcomes
- energy, exergy, LCA studies in dwellings
- commercial applications
- basic heat and mass transfer theory
2. thermal mass
- studies on effect of thermal mass on temperature regulation / energy consumption in dwellings
3. Air-source heat pumps
- performance state of the art heat pumps
- application in dwellings (system analysis)
- foreseen improvements/current research
- heating demand profile dwellings (ventilation/occupancy/appliances)

<u>System development</u>
- development energy system reference cases (heating demand, components)
- development energy systems for energy storage options

[2] Estimates PeGo 2007 and Referentieraming energie en emissies 2010-2012, ECN 2010

Comparative analysis

- calculation software

Using dynamic simulation software (Matlab) and a Life Cycle Assessment

- software model

A model will be constructed using the input- output approach, in which the energy and exergy losses in each component of the energy system chain are assessed. This includes:
1 Resources (primary energy, renewable energy)
2 System components (conversion, storage, distribution, emission)
3 Demand (space heating and cooling, DHW)

By changing different parameters, their impact on the storage performance can be investigated and the different strategies can be developed further. Following storage strategies are subject of comparison:

Cases	**Reference**	**Storage option 1**	**Storage option 2**	**(if possible) Storage option 3**
Single family 15 kWh m^{-2}	- common thermal mass - buffer tank for DHW - emission: floor heating, LT	- larger buffer tank (active sensible storage) - emission: floor heating, LT	- PCM in HVAC - buffer tank for DHW - emission: air (+ radiators LT)	- PCM in floor system (active) - buffer tank for DHW - emission: floor heating
25 kWh m^{-2}	“	“	“	“
35 kWh m^{-2}	“	“	“	“
(if possible) apartment complex 15, 25, 35 kWh m^{-2}	“	“	“	“
	“	“	“	“
	“	“	“	“

Finally, these storage options are compared on: total energy consumption, total exergy consumption, required installation power and environmental costs

- Exergy principles

Exergy analysis reveals thermodynamic losses that would not be revealed in energy analysis. Storage should enable a heating demand profile with minimal exergy factors/maximum COP (“exergetic optimized profile”). This will reduce the primary energy (electricity) consumption.

- Sensitivity analysis

Possible consequences of change in input variables different from expectation (e.g. different DHW-draw profiles or ventilation rates) on the system and output will be investigated. This will give insight in the impact of building characteristics and design variables too.

Relevance

Societal relevance

Well designed thermal energy storage systems can improve the energy efficiency and comfort level in a building, resulting in significant cost savings and a promising payback period. Most currently built dwellings contain balanced ventilation systems, and the application of air-source heat pumps is foreseen to increase[3].

Scientific relevance

This study investigates how integrated short term energy storage could help to meet a dwellings heating demand with minimum amount of work. PCM investigations emphasis on cooling applications in offices, while it is interesting to investigate if the low temperature heating demand in different dwellings typologies with user-control could also benefit from active heat accumulation.

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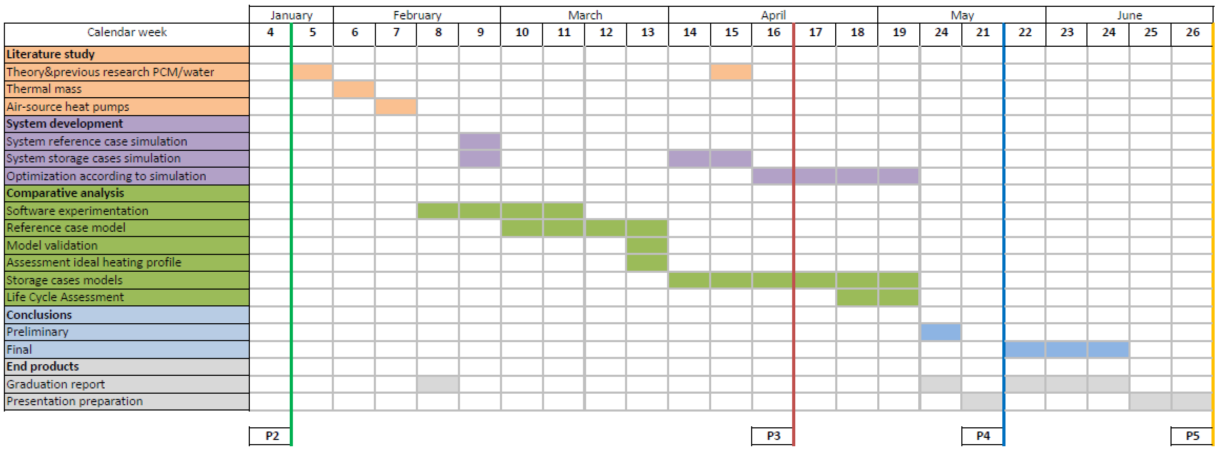
[3] Technology Roadmap IEA 2011

Time planning



Literature and general practical preference

<u>Energy storage/PCM</u>

Articles

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<u>Exergy</u>

Jansen, S.C., Luscuere, P.G., van der Linden, A.C., 2011. *Exergy demand of heating in buildings – steady state versus dynamic approach.* TU Delft.

Jansen, S.C., Luscuere, P.G., Teres-Zubiaga, J., 2012. *The exergy approach for evaluating and developing an energy system for a social dwelling – Part 1: Concept development.* TU Delft.

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