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# UTILIZING FLEXIBILITY OF ELECTRIC HEATING IN DEMAND SIDE MANAGEMENT PROGRAMS IN FINLAND IN 2050

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**ABSTRACT**

Driven by climate change concerns, our energy system has been under steady change. Renewable energy sources are increasingly used to decarbonize our energy system, making it also more decentralized. At the same time, information and communications technologies (ICT) are enabling smart services for consumers, offering financial benefits through demand side management (DSM) programs. This study investigates various DSM solutions for a detached house in Northern Finnish conditions in 2050. A thermal model is used to model the thermal behavior of the building and test out DSM programs in direct electric space heating and underfloor heating alternatives. The 2050 scenarios are created from climate change projections, existing data on electricity generation and from projections on the future energy system and cost of electricity. The results indicate that load shifting with photovoltaic (PV) generation is a potential way of reducing costs and $CO_2$ emissions both today and in 2050, but it lacks economic feasibility due to long payback times of the investments. Cost optimized direct electric space heating and underfloor heating are both able to provide economic and environmental benefits when compared to manually controlled heating. The scenarios presented in the paper suggest that 95-96% emission reduction can be achieved; however, the electricity cost of households is expected to increase by 174-253%. At the same time electricity consumption from the grid is expected to reduce by 3-10% in all the scenarios.

**Keywords:** demand side management, electric space heating, future energy system, optimization, smart energy services, decarbonization

## 1. INTRODUCTION

Climate change, increasing renewable electricity generation and the development of information and communications technologies (ICT) have a major impact on our energy system today and in the future. Climate change mitigation requires us to reduce $CO_2$ emissions through decarbonizing our society. One option is to increase the amount of electricity generation from renewable sources such as wind and solar, which are intrinsically variable in their electricity generation creating mismatches between supply and demand of electricity. ICT technology allows us to utilize new smart functions allowing e.g. shifting the demand of electricity of a building. This enables the utilization of demand side management (DSM) programs, which aim at modifying the demand of electricity according to the state of the power system. DSM programs have been further divided into services and measures improving energy efficiency of the system, and to programs aiming at shifting consumption patterns through electricity pricing models, such as real-time pricing (RTP) or time-of-use tariffs (ToU), or by providing economic incentives for the use of service [1]. This way, DSM programs can improve the state of the system and allow integration of variable renewable energy sources by better matching demand with supply.

The residential sector has multiple potential sources for providing DSM, such as washing machines which are considered to be deferrable loads, and heating as temperature-based load, which can utilize e.g. the thermal inertia of the building. Conversely, there are also loads that are not suitable for DSM in the residential sector, such as lighting and cooking appliances [2]. Heating in particular has been studied to provide flexibility to the electricity network. Rautiainen et al. [3]

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found that aggregated electric space heating is suitable for frequency control, and Lu [4] that aggregated heating loads can provide balancing in the network. For a single household, DSM programs can help in improving the utilization of local electricity generation [5], or providing financial gains or reduction of $CO_2$ emissions [6]. Therefore, DSM programs seem to provide benefits in the current network but, due to the change in the energy system and the impact of climate change on the energy demand of buildings, DSM methods should also be studied in the future network.

This work aims at investigating the potential of electric space heating providing flexibility to the future electricity network through utilizing DSM methods. The objective is to optimize electric space heating, using electricity costs and $CO_2$ emissions as parameters for the model of a single building in the 2050's network. For this purpose, a thermal model [7] is used to simulate the thermal behavior and the electric space heating system of the building with different DSM programs, including use preferences and willingness to participate in DSM programs. Future conditions are simulated through creating prospective weather files, approximated national electricity generation, and real time pricing profiles.

## 2. MATERIALS AND METHODS

### *2.1 Thermal Model*

The study utilizes a thermal model developed earlier [7] and an existing smart house model [8] to simulate the impact of DSM methods and the flexibility of the electric space heating to optimize the system by cost and environmental indicators using various heating technologies. The simulation is carried on an hourly basis. The flow chart describing the main idea behind the thermal model is presented in Fig 1, which shows what is included in the model and the main sources of the used calculation methods. The flow chart considers that the information passed to the process earlier is available later as well. Furthermore, the forecasts are calculated similarly than the hourly values, only considering weather forecasts instead of measured values. Finally, the nodal temperatures are passed back to the inputs for calculating the future temperatures and for the control of the used building automation and for manual control of venetian blinds. All the parts of the thermal model are described in more detail in [7], with following modifications made to the model:

*i)* the heat demand is calculated as described in ISO 52016-1 and [9].
*ii)* The operation of the venetian blinds is bounded to the general cooling limit temperature.
*iii)* The thermal comfort limits are covered with fixed temperature set-points of 21°C for lower heating limit, 25°C for the upper heating limit with estimation of ~1.0 clo and category I for residential building from standard EN 15251, and 27°C for the cooling limit as stated in Decree 1010/2017.
*iv)* The convective fractions of heating devices are extracted from Finnish national standard EN 15316-2 and are used directly in ISO 52016-1.

The existing smart house model is used to create the electricity consumption profiles of the appliances, to calculate the solar irradiance to vertical surfaces and transparent materials, and to calculate the local electricity generation from photovoltaic (PV) panels [8]. The inputs to the model are the same as in [7].

### *2.2 Heating technologies*

The study considers a selection of 5 different electric space heating alternatives to provide heat in the building: constant temperature setting, manually controlled heating, cost optimized heating, underfloor heating utilizing cheapest charging hours and load shifting with 2 $kW_p$ PV panel system. These heating systems, their operations and electricity consumption calculations are described in thermal model [7] with the following changes made to the model:

*i)* Energy demand for constant temperature setting, and future indoor temperature calculation in cost optimizes heating is calculated through ISO 52016-1. Additionally, the current model considers also an estimation of constant heat gains from appliances and inhabitants from the legislation (Decree 1010/2017), and solar heat gains from the models' calculation methods and global irradiance values as hourly average values from Test Reference Year 2012 (TRY2012) monthly [10].
*ii)* Manually controlled heating is controlled by the lower and upper heating temperature set-points presented in section 2.1, instead of the thermal comfort limits calculated originally in the model. Furthermore, if indoor temperature drops under 18°C the heater is considered to operate at full power until the indoor temperature has reached 18°C to prevent the building from cooling down too much.

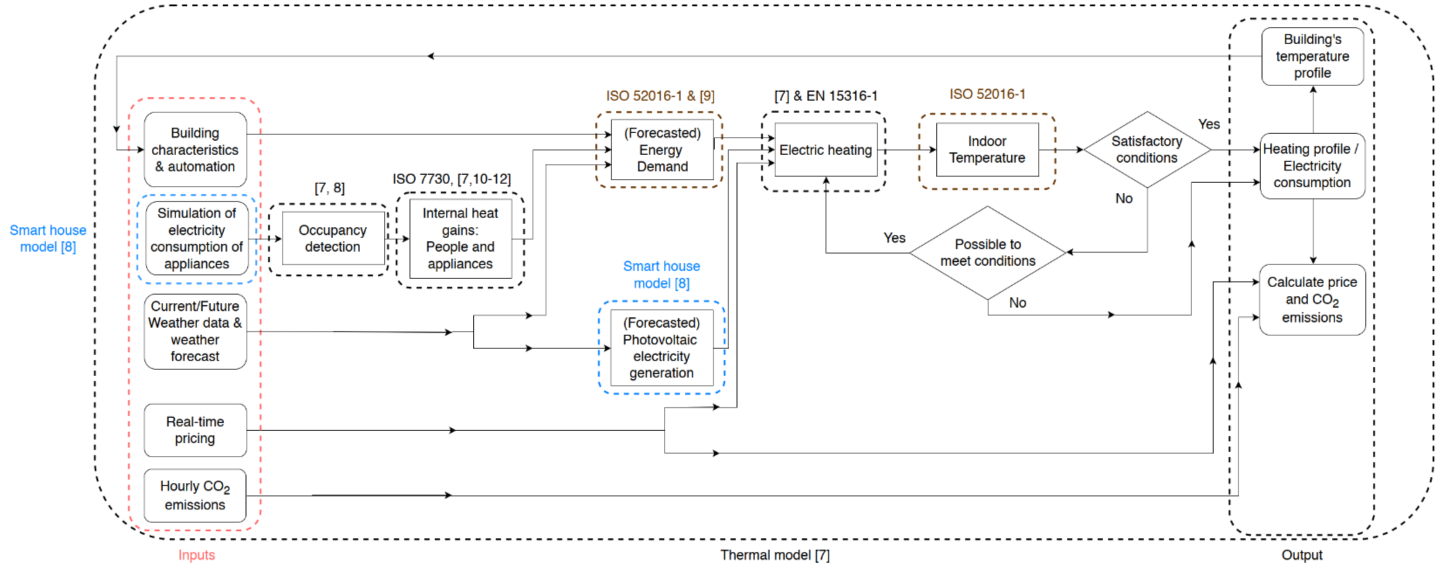


Fig 1 Flow chart describing the model and what is consists of. Blue parts are from the smart house model [8], red parts are inputs to the system, brown parts are calculated according to ISO 52016-1 and [9], electric heating consists of [7] and EN 15316-1, internal heat gain calculations ISO 7730 and [7,10–12] and the rest is according to methods presented in [7].

*iii)* Load shifting with PV panel generation utilizes the lower and upper heating limits from chapter 2.1, instead of the temperature limits presented in the original model. The thermal comfort is covered with the lower and upper heating temperature set-points.

Furthermore, the input values for PV panel generation are the same as in [7] for the system of the same size. Space cooling is currently neglected in the model.

### *2.3 House types and location*

The simulations are conducted with the house type equal to the current legislative limits in Finland (house type 2018 from Decree 1010/2017), having balanced ventilation with air-to-air heat exchanger and located in Oulu. The used weather files are TRY2012 for the Oulu area [13] for today and the weather files for the climate change projection scenarios of B1, A1B, A2 (Special Report on Emissions Scenarios (SRES) models), and RCP 4.5 and RCP 8.5 (Representative Concentration Pathways (RCP) models) as created in [9]. The dimensions of the building, selected appliances and other inputs to the system are the same as in [7]. Hourly emission profile is created with assuming fixed fuel usage in thermal power plants by their annual usage of fuels, by calculating the emissions by produced electricity using standardized emission factors as provided by Statistics Finland and using hourly generation profiles from Fingrid for 2016. The electricity price for TRY2012 scenario is Finland's hourly real-time pricing for 2016 from Nord Pool.

### *2.4 Hourly electricity profile and real-time price in 2050*

To run the simulations for the future environment, artificial hourly profiles were created for the electricity generation based on the hourly generation profile from 2016 in Finland, and by utilizing the annual electricity generations from a projection scenario 'Growth' within the VTT-TIMES model for 2050 [14]. The current hourly electricity generation profile by technologies was normalized to an annual generation of 1 TWh, which was used with the annual values from [14] to create an approximated generation profile for the future. This profile was then used to create an hourly real-time pricing profile for the created generation profile by utilizing levelized costs of electricity (LCOE) by the generation method for 2050 from [15]. The creation of the future profiles are discussed and presented in detail in [7].

## 3. RESULTS & DISCUSSION

The annual price of electricity, emissions and the electricity consumption of the heating system are all presented for a single building and for all the scenarios in Fig 2 and Table 1. The results show that for the created scenarios the price of heating will become 174-253% higher, emissions ~95-96% lower and electricity consumption 3-10% lower in all scenarios. Therefore, the created hourly scenario increases the electricity price and decreases the emissions regardless of the selected heating system. This is mainly due to the projected electricity price expected to raise by 2050. When comparing the heating systems and DSM methods, the

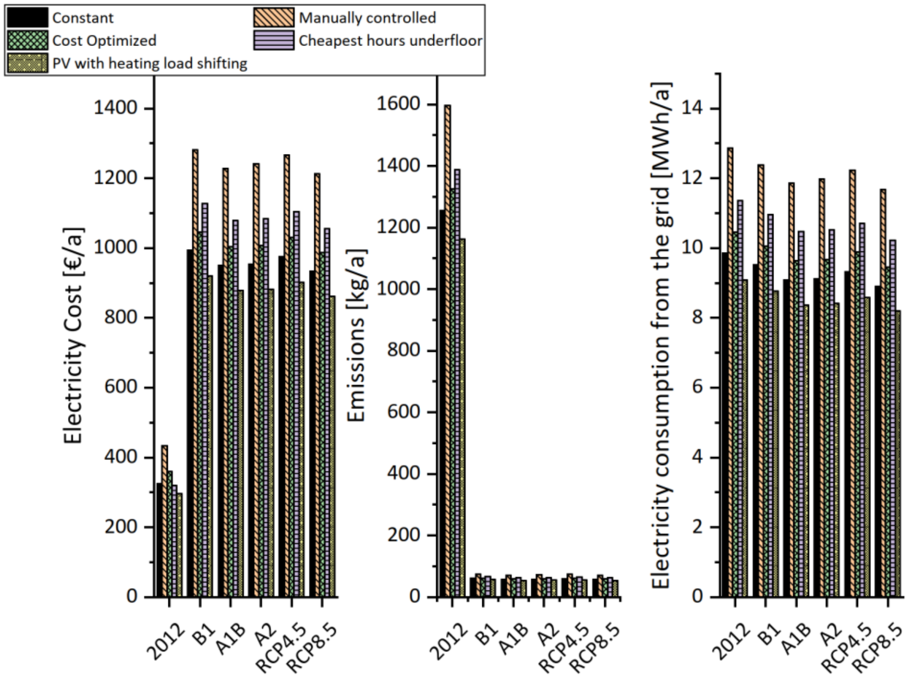


Fig 2 The electricity costs, $CO_2$ emissions and electricity consumptions from the grid of the DSM and climate change scenarios.

manually controlled heating has the highest costs, $CO_2$ emissions and electricity consumption of the selected scenarios, which can also be traced to the nature of the used rules, which makes the system aim for higher indoor temperature than other systems. Conversely, PV system with heating load shifting seems to have the lowest costs (-8-47%), $CO_2$ emissions (-6-37%) and electricity consumption from the grid (-8-42%) out of the scenarios, which is related to the ability to use local generation to have cost and emission free electricity. Constant temperature setting results in 5-10% lower price, 3-5% lower $CO_2$ emissions and 5-6% lower electricity consumption than cost optimized heating, since it has the lowest indoor temperature out of the scenarios. Comparing constant temperature setting to underfloor heating, the cost in underfloor heating is 1.7% lower in TRY2012 scenario but 12% higher in SRES and RCP scenarios. Similarly, the $CO_2$ emissions are ~9-10% higher with underfloor heating than with constant temperature setting in all scenarios. This is likely related to the lower electricity consumption with constant temperature setting (8.9-9.9 MWh/a) compared to the underfloor heating (10.2-11.4 MWh/a). Yet, the constant temperature setting scenario has an ideal thermostat without any dead band or other inefficiencies, making the results here unrealistically good for the constant temperature setting.

Both cost optimized heating and underfloor heating with the cheapest charging hours utilize real-time pricing to take decisions on the electricity consumption from the grid, and this resulted in a 12-26% lower electricity costs than in manually controlled heating. Their mutual rating on the other hand varies by the variable and selected scenario. In the TRY2012 scenario underfloor heating has 13% lower electricity costs, but 5% higher $CO_2$ emissions than cost optimized direct electric heating space heating. Conversely, in 2050 scenarios the underfloor heating becomes the more expensive heating technology, having ~7% higher costs than cost optimized direct electric space heating. This is likely related to the generated real-time electricity price scenarios having lower price volatility in in 2050. The underfloor heating will also have 6-7% higher $CO_2$ emissions and ~8% higher electricity consumption compared to cost optimized direct electric space heating. Furthermore, considering the feasibility of the solutions, their payback times can be calculated from the amount of saved money they provide and the investment costs. The saved money from the PV system is calculated from the money saved using the PV system instead of buying the same electricity from the grid. The money saved in TRY2012 scenario is 28 €/a and in 2050 between 72-79 €/a, whereas the investment cost of PV system is on average 1650 €/kW$_p$ [16]. This results in payback times of 118 years in the TRY2012 scenario and 42-46 years in the 2050 scenario, disregarding the distribution costs and taxes from the costs of electricity, meaning that the PV system is not itself profitable, even though it showed good results in terms of cost and $CO_2$ emission reductions. Comparing cost optimized and underfloor heating scenarios to manual heating, the

Table 1 The results from the simulations by their respective scenarios.

| | Constant | Manual | Cost Optimized | Underfloor | PV 2kW |
|---|---|---|---|---|---|
| Price [€/a] | | | | | |
| TRY2012 | 324 | 433 | 360 | 319 | 296 |
| TRY2050B1 | 994 | 1281 | 1046 | 1127 | 920 |
| TRY2050A1B | 950 | 1228 | 1004 | 1078 | 878 |
| TRY2050A2 | 954 | 1241 | 1007 | 1084 | 882 |
| TRY2050RCP4.5 | 975 | 1265 | 1030 | 1104 | 901 |
| TRY2050RCP8.5 | 933 | 1212 | 987 | 1056 | 862 |
| $CO_2$ Emissions [kg/a] | | | | | |
| TRY2012 | 1254 | 1596 | 1325 | 1387 | 1163 |
| TRY2050B1 | 60 | 74 | 62 | 66 | 57 |
| TRY2050A1B | 58 | 71 | 60 | 64 | 54 |
| TRY2050A2 | 58 | 72 | 60 | 64 | 54 |
| TRY2050RCP4.5 | 59 | 74 | 61 | 65 | 56 |
| TRY2050RCP8.5 | 57 | 71 | 59 | 63 | 54 |
| Electricity consumption from the grid [MWh/a] | | | | | |
| TRY2012 | 9.9 | 12.9 | 10.5 | 11.4 | 9.1 |
| TRY2050B1 | 9.5 | 12.4 | 10.1 | 11.0 | 8.8 |
| TRY2050A1B | 9.1 | 11.9 | 9.6 | 10.5 | 8.4 |
| TRY2050A2 | 9.1 | 12.0 | 9.7 | 10.5 | 8.4 |
| TRY2050RCP4.5 | 9.3 | 12.2 | 9.9 | 10.7 | 8.6 |
| TRY2050RCP8.5 | 8.9 | 11.7 | 9.5 | 10.2 | 8.2 |

savings in the direct electricity costs are 73 and 114 €/a in TRY2012 scenario, respectively, whereas in 2050 the total savings are between 150 and 236 €/a. If an example price of 1750€ for a load shifting device [17] is considered, the payback time for load shifting device is 15-24 years in TRY2012 scenario and 7-12 years in 2050, without the associated electricity distribution costs and taxes, making load shifting devices more economically attractive.

These results are a representation of one possible future scenario from the electricity generation point-of-view, making the results dependable on the selected scenario and to include the uncertainties associated with the created projections. This means that there is need to test out other projections as well to get comprehensive results on the suitable future decisions and development steps. Moreover, the DSM on electric heating currently consisted only 5 different options, meaning that more options should be simulated to achieve a more profound information on the optimal solutions. Also, the utilization of LCOE in setting the electricity price creates uncertainties related to the cost of electricity as the electricity price in deregulated market is more dependable on the marginal costs of the last cleared generation technology, whereas the LCOE based price considers all the associated costs of the generation [18]. Therefore, LCOE is not able to depict the supply and demand variations of the system but presents an estimation of the price according to the generation technologies. Furthermore, the current lack of cooling capacity in the model restricts the comprehensive analysis of the building's DSM programs. Similarly, the current results are only presented from the consumer's point-of-view, meaning the results from the balancing operators point-of-view also need to be revised to find solutions suitable to all parties.

## 4. CONCLUSION

Electric space heating is a source of flexibility for the electricity system of a single household, as different DSM programs provide different annual costs, $CO_2$ emissions and electricity consumption values from the simulation. Based on the created future scenarios, the cost of electricity for space heating will increase, even though the electricity consumption decreases in all scenarios. Conversely, $CO_2$ emissions can be expected to decrease in the future. Out of the created scenarios, load shifting with PV panels has the least costs, $CO_2$ emissions and electricity consumption from the grid out of the scenarios but is not economically feasible due to its high investment cost and mismatch of generation and energy demand. Cost optimized, and underfloor heating provide also lower costs, $CO_2$ emissions and electricity consumption from the grid than manually controlled heating, while being economically more attractive than PV scenario.


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