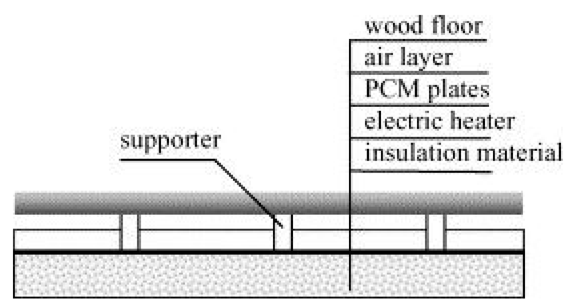
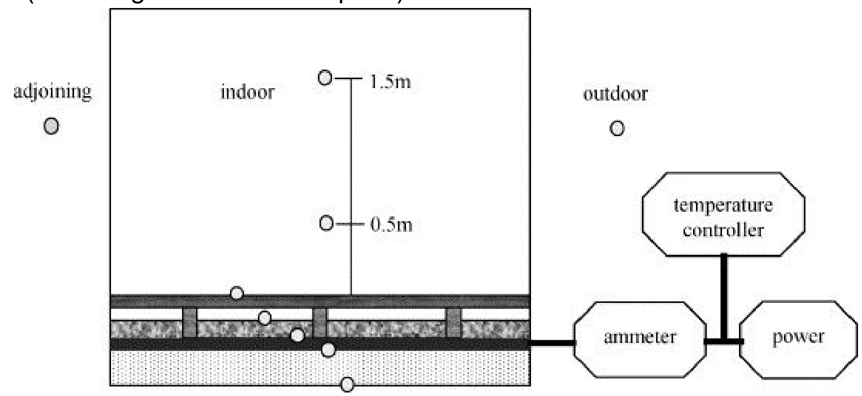
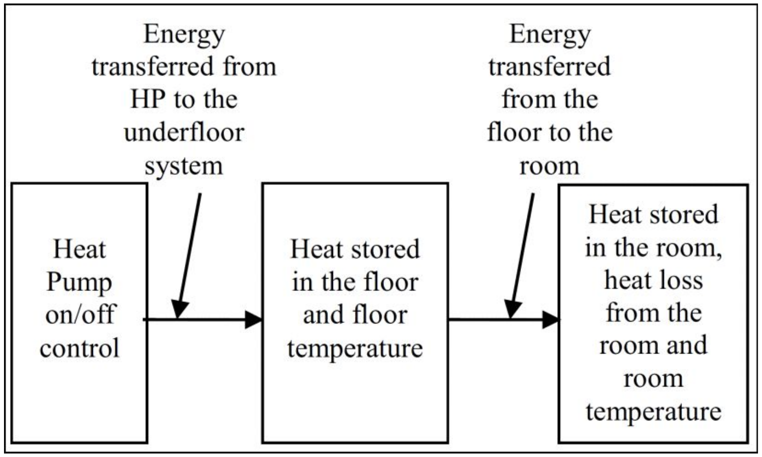
Project: Underfloor heating as power reserve

Litterature study done for the project “Underfloor heating as power reserve” (Dnr 2017-002309 projectnr 44366-1)

Article Title & Link	Notes
Modeling and simulation of under-floor electric heating system with shape-stabilized PCM plates http://www.sciencedirect.com/science/article/pii/S0360132304001271	● Mathematical model of PCM underfloor heating ● Considers radiation between surfaces around the air layer ● Also considers heat transfer through window ● Used different experimental setups to simulate different climate regions ● Used Medpha to generate climate data
Experimental study of under-floor electric heating system with shape-stabilized PCM plates http://www.sciencedirect.com/science/article/pii/S037877880400180X	● This is the experimental model used to validate this system^ ● Dimensions: 3 m (depth) × 2 m (width) × 2 m (height); 1.6 m × 1.5 m double-glazed window facing south, covered by black curtain. The roof and walls were made of 100 mm-thick polystyrene wrapped by metal board. The under-floor heating system included 120 mm-thick polystyrene insulation, electric heaters, 15 mm-thick PCM, some wooden supporters, 10 mm-thick air layer and 8 mm-thick wood floor  ● The experiments aimed at determining the thermal behavior of the heating system and indoor temperature of the room. The following apparatus were applied for measuring. ○ Dataloggers (for recording data). ○ Computer (for processing the data).

	○ Copper–constantan thermal couples (for measuring temperature). ○ Temperature controller (for controlling on–off of the electric heater). ○ Thermal radiometer (for measuring solar radiation). ○ Ammeter (for noting electric consumption). 
Modeling a radiant floor system with Phase Change Material (PCM) integrated into a building simulation tool: Analysis of a case study of a floor heating system coupled to a heat pump http://www.sciencedirect.com/science/article/pii/S0378778811006323	● Model for simulating radiant floor system with PCM for load shifting to off-peak hours ● Validated model by comparing results to those given by Energy Plus ● PCM floor system is fed by heat pump which operates during night time ● Radiant floor heating systems are compatible with low-grade energy sources (and have better efficiency) ● Model meant to be integrated within building simulation program (EnergyPlus) ● The building simulation model is based on a finite volume approach ● No analytical solution for relevant heat transfer problems (conduction in floor slab, radiation exchange between floor surface and other internal surfaces, heat transfer in floor piping) so finite difference and finite element methods are used ● Two types of validation test: free floating interior temp and ideal loads calculation ● Experimental cubicle setup: PCM integrated into radiant floor by being embedded in concrete material of the slab, 5.87m x 2.38m x 2.31m ● “With PCM” compared to “Without PCM” achieved cost savings of 17.9%
Modelling and Simulation of Underfloor Heating System Supplied from Heat Pump http://ieeexplore.ieee.org.focus.lib.kth.se/document/7796	● Underfloor heating system w/ heat pump in REL at Queen’s University Belfast ● Underfloor heating allows storage of cheaper electricity in form of thermal energy ● Heat pumps are considered non-essential load that can be switched off during emergency conditions ● Experimental setup: ○ 10-kW (heat output) air source heat pump coupled with underfloor heating ○ 13 x 5 x 4m , with a concrete floor with underfloor heating covering 12 x 2.5 m

715/	○ LabView to acquire data from thermocouples ○ Ambient temperature recorded from Weatherlink station above laboratory ● Temperature reduction of only 4ºC during 24-hour time with heat pump off ● Two-stage model: thermal storage capacity of floor and of building itself ● Subtract heat loss using a feedback loop ● Use experimental results for thermal capacity of structure (*how can they validate?)* ● Reference temp of 20ºC and dead band of +/- 0.5ºC ● Experimental setup was not tested against for validation ● Experimented with Economy 7 tariff (cheap electricity between 12:00 - 7:00) ● Results: the thermal model developed can be used to schedule heat loads to meet the heat demand determined from the generation scheduling process. The inside temperature of a house can also be determined from the model 
Domestic Electrical Space Heating with Heat Storage http://journals.sagepub.com/doi/pdf/10.1243/0957650991537455	● Investigates the potential of using a phase-change material placed between the heating surface and the floor tiles to increase the thermal mass of the floor ● For purpose of shifting load to off-peak time ● Large heating surface of floor allows lower heat fluxes (100 W/m^2) ● Normally tiles don't have enough storage to only charge during off-peak (that's what PCM tries to fix) ● Assumed constant room temp (20ºC) ● Used paraffin wax as PCM

	- Underfloor heating was simulated by solving the unsteady state heat conduction equation using explicit finite differences - Possible to provide uniform heating throughout the day when heating for only 8 h is applied during the night. This allows the shift of 7.2 MJ/m2 day of electricity from the peak load to the off-peak load
Swedish Energy Agency underfloor heating recommendations http://www.energimyndigheten.se/en/sustainability/households/heating-your-home/heat-distribution-and-control-systems/underfloor-heating/	- Overview of different types of underfloor heating systems - Important considerations including energy consumption and risk of moisture damage
Modelling of Household Electro-Thermal Technologies for Demand Response Applications https://www.research.manchester.ac.uk/portal/files/32297202/FULL_TEXT.PDF	- Introduces a model that aims at creating a deeper understanding of the above features with respect to ETT based heating system modelling for provision of DR - Individual components of the dwelling's heating system are specifically modelled - Used previously validated models for each component - The DR control schemes investigated in this paper are focused on heating units and the signal is considered of a "direct load control" type rather than for optional DR, as the willingness of customers to participate is out of the scope of the paper.
Demand Side Management Potential of Domestic Water Heaters and Space Heaters http://irserver.ucd.ie/bitstream/handle/10197/4728/Qazi_IFAC%202012%20-%20dsm%20potential%20of%20heating%20loads.pdf?sequence=2	- Considers possibility that customer could have a prior agreement to curtail usage (or use at more optimal times) in exchange for a lower overall electricity tariff (would need to aggregate this) - Thermal time constant of 25 hours for building room temp - opps for flexibility - A thermodynamic model for underfloor heating is based on one dimensional heat conduction according to Fourier's law, while also considering the concrete layer heat storage capability. It has been assumed that the heat from the floor is transferred to the room through convection
Calibration of a Commercial Building Energy Simulation Model for Demand	- Calibration of EnergyPlus model for demand response analysis - Calibration: approach to modify and adapt the design case model based on measured data to generate an updated energy model

Response Analysis http://www.ibpsa.org/proceedings/BS2015/p2422.pdf	● Building energy model is required as a virtual test bed to examine different control strategies ● Modelled building at UCL using EnergyPlus; initially calibrated using monthly data and design documentation ● Google Sketch Up for building geometry and AutoCAD for building floors and sections ● HVAC units modeled in EnergyPlus ● Internal gains caused by people, lights and electrical equipment were included in the model ● Building consumes grid electricity at night ● Paper focuses on calibration of electricity demand and zonal parameters using high resolution measured data (15-minute interval granularity) ● Electricity demand profiles, both on a building and zonal level, were created using 15 minute measured and simulated data, so that the model is suitable for DR sensitivity analysis
Modeling Demand Response in the Residential Sector for the Provision of Reserves http://irserver.ucd.ie/bitstream/handle/10197/4757/ODwyer_PES_2012_Modelling%20Demand%20Response.pdf?sequence=2	● In this paper the potential response from the residential sector in a heating dominated climate is estimated by modeling relevant responsive loads ● Paper focuses on incentive-based demand response (as opposed to price-based), looking specifically at the ability of residential loads to provide reserves, through the use of direct load control by a third party aggregator ● Uses bottom-up approach and focuses on interruptible loads ● Refrigeration is considered interruptible load (?) ● Demand for appliances was created using data from Smart A and REMODECE projects ● Different outputs based on demand scenarios ● Expected growth of electric heat pumps ● Model reveals large evening peak ● Lighting is the largest of modeled loads, followed by refrigerators ● In total, interruptible loads account for 50% of total residential load (the rest are considered uninterruptible) ● EU regulations are driving major efficiency improvements ● Total demand in Ireland is seen to fall by almost 5% by 2020 (compared to 2011) ● Paper considers direct load control (historically used for peak reductions in demand) ○ Here, objective is ancillary services for shorter period rather than peak reduction ● Thermal storage capabilities allow power interruptions for short periods of time ● Average of 6% of system demand is available for DR ● Efficiency gains actually reduce amount of interruptible load available by 19% (as does lower overall demand) ● Summer days yield lower interruptible load because most of it comes from heating systems ● Assumes participation rate of 80% based on survey ● At the end of the control period demand spikes will occur as the loads are reconnected and the energy is reclaimed ● It is essential that flexibility is adequately valued in the electricity markets, and that payments for ancillary

	services are sufficient to encourage participation, where it is required