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Investigating parameters affecting the indoor temperature drop after a power cut -In-situ measurements and simulations

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ABSTRACT

When looking at energy supply on a larger scale than to a single building, such as to a neighbourhood or a city, the combined effects of peak power demands can be seen to cause problems on the production side. These can be both economic and environmental and lead to the emission of greenhouse gases when fossil fuels are used to meet these peaks. Encouraging the demand side to reduce their power demands at these time could be one way of dealing with this issue. This paper investigates the temperature drops after a power cut both through measurements in the field and comparisons of these results to simulations. A single-family dwelling in use and a multi-family dwelling about to be decommissioned were studied. The comparisons showed that the rates of the temperature drops in reality were slower than in the simulation models. A parametric study of the variables affecting the temperature drops, such as furniture, showed that they might explain these differences.

1. Introduction

When looking at energy supply on a larger scale than to a single building, such as to a neighbourhood or a city, the combined effects of peak power demands can be seen to cause problems on the production side. These can be both economic and environmental and lead to the emission of greenhouse gases when fossil fuels are used to meet these peaks. Scheduling intermittent power supplies might be one way for the demand side to contribute to the much larger energy system of a district or a city, in order to reduce the total demands. The actual timing would depend on when difficulties on the production side occur or on the fluctuation of energy costs. The main condition for allowing a power reduction on the demand side, with a resulting lower indoor temperature, is that the indoor climate remains at an acceptable level. . Field studies have shown promising results. Kensby, Truschel and Dalenback [1] performed a pilot test where different types of apartment buildings were tested regarding the ability to use the building thermal mass. By modifying the outdoor temperature sensor, which in turn govern the supply temperature of the water to the heating system, it was possible to either charge or discharge the thermal mass. This was made by changing the outdoor temperature perceived by the sensor in the direction preferred. Different cycles of charging and discharging were tested, mainly in cycles of 9 h, for a number of weeks with simultaneous measurements of the indoor temperature in selected apartments. Weekly averages of these temperatures showed a maximum impact on the indoor temperature was ±0.5 °C. Another field test in Finland in a dwelling facility for elderly people it was found that the power demand could be cut by 25–30% for 2–3 h if allowing a 2 °C [2]. Werner and Olsson Ingvarsson [3] used a similar approach as Kensby et al. [1] by modifying the outdoor temperature sensor. They also showed that in the residential buildings a large difference regarding indoor temperature existed already between different apartments, up to 3 °C. Reductions were performed for durations up to 48 h with indoor temperature drops up to 2 °C. Wernstedt and Johansson [4] tested a new type of intelligent load control and were able to cut up to 6% of the power without any impact of the indoor temperature. Using the building frame to delay the heating power load demand has also been investigated using simulations for a single-family house [5]. Heat was supplied using a heat pump when electricity prices were most favourable while allowing the indoor temperature to vary within different intervals. Up to 60% peak power

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reductions were obtained if a 4 °C drift was allowed from the design temperature. Arteconi, Hewitt and Polonara [6] investigated using simulations the possibility to turn off a heat pump for 3 h when the electricity prices peaked in a single family dwelling. The case with underfloor heating managed a 3 h cut off but a case with radiators was shown to be in need of a more thermal energy storage such as a water tank if not wanting to risk the indoor temperature to drop too much. However, in order to design or predict the result of demand side reductions, simulations are needed and, to make these simulations as reliable as possible, data from certain parameters connected to the indoor heat balance are needed as input. For older buildings, which the majority of the building stock obviously consists of, much of this data could be lacking or not as comprehensive as one could desire. Original building plans might be available but with the complication that changes might have been made, even during construction or over the years, without any record being made. Older buildings, especially single-family dwellings, are usually naturally ventilated [7] which gives rise to uncertainties regarding the ventilation rate. The control of the heating system might be another uncertainty, compounded by poorly functioning thermostats, valves and sensors. There is also the issue of furniture and indoor materials, which might be seen as variables and would depend directly on the current residents in the building. Assuming that building energy and indoor climate simulation tools are able to accurately simulate physical phenomena and as long as all the inputs sufficiently reflect reality, the values of these inputs become important.

Many field tests have shown good results, with short-term cuts in heating power having only limited and acceptable effects on indoor temperatures. However, when considering applying this new approach, i.e. the use of intermittent power supplies to a building, it would be of great interest to be able to simulate these effects. This paper aims to identify, with relatively simple measurements and simulations, key parameters affecting temperature drops after a power cut.

2. Method

Two buildings were investigated. One was a single-family dwelling built in 1956, located in the south of Sweden [Latitude 56, Longitude 13]. This was a building in use, with furniture and people present during the tests. The second building was a multi-family dwelling built in 1966, located in the north of Sweden [Latitude 68, Longitude 20]. This was a decommissioned building that was about to be demolished. The reason for deconstruction was not that it had come to the end of its service life but due to the expansion of a nearby iron ore mine.

The two different building types investigated were therefore tested differently. In the single-family dwelling the heating was turned off during one night, for approximately 8 h. The temperatures in the multi-family dwelling were measured from when the heating supplies to the buildings were permanently cut off and for a cooling period of about two weeks. Due to the different building sizes and the number of sensors used, one in every room compared to one in each apartment, two different levels of accuracy were achieved.

The commercial building energy simulation software IDA Climate and Energy (IDA ICE) was used for the simulation [8]. The software had gone through comparative testing in which it was compared to other similar software with respect to EN and ASHRAE standards [9,10]. Also in an Annex [11], simulations were performed using a test house as a basis for comparing measured values with simulated results. In order to run the systematic parametric analysis efficiently, a second commercial programming software, MATLAB, was used to handle the parameter inputs, to start the energy simulations and to gather the output results. This is exemplified in Fransson, Bagge and Johansson [12].

2.1. Case 1 single-family dwelling

2.1.1. Building properties

A single-family dwelling located in the south of Sweden in the town of Ängelholm [Latitude 56, Longitude 13] was investigated. The house was constructed in 1956 and had an area of 106 m^2 divided between two floors. The upper floor had a sloping ceiling and there was a basement beneath the whole ground floor. The layout of the house and the connected unheated buildings, a garage and a conservatory, can be seen in Fig. 1. Each room has been modelled as a separate zone in the simulation model. There can be no air movement inside a zone but the heat and are can be transferred between the zones. The house had not been subject to any major refurbishments to increase the thermal insulation level of the exterior envelope. The load-bearing frame of the building was made of bricks (interior walls), concrete (floors) and lightweight concrete (exterior and interior walls), the latter also serving as the insulation of the exterior walls. The properties of the building envelope are summarized in Table 1. The material properties were those included in the simulation software and the properties of the layers of the different envelope parts were gathered from the existing building plans. Thus, the values in Table 1 might not fully represent reality due to differences in material properties, the degradation of insulation materials or other imperfections. Translating reality into a simulation model also introduces inconsistencies, as simplifications always have to be made. The air value regarding air leakage, thermal bridges is gathered from Ref. [13] as the values are not measured. The air leakage is distributed proportionally to the exterior envelope area connected to each zone.

Hydronic radiators supplied the heat to the rooms and this secondary system was the one originally installed. However, the primary heating source had changed from an oil-fired boiler to district heating. The radiators had no thermostatic valves, only manually operated valves. The temperature of the water leaving the primary system depended on the outdoor temperature and, presumably, on the difference between the indoor temperature measured at one location in the middle of the house and the desired temperature. The device measuring the indoor temperature was also the device by which the design, or preferred, indoor temperature was selected. In this test, it was used to turn off the heat by reducing the setpoint from 21 to 10 °C. The building was naturally ventilated, and therefore the input data from the ventilation was unknown. In the simulations, a ventilation rate of 0.23 l/s·m^2 was chosen. This is the mean ventilation rate of Swedish single-family dwellings from this period, determined through a nationwide investigation of the Swedish building stock [7].

2.1.2. Measurement set-up

The test was performed in March, during the night, with an average outdoor temperature of about 0 °C. Temperature loggers (HOBO U12 -012, ±0.35 °C temperature accuracy) were placed in each main room (not every small closet) and set to log the temperature every minute. To record the local outdoor temperature, one logger was placed on the north façade of the house. Climate variables needed for the simulations and not measured at the location of the house, such as wind speed, wind direction, and diffuse and direct solar radiation, were obtained from measurements taken at the Swedish Meteorological and Hydrological Institute (SMHI) climate station located 19 km away [14,15]. There were four residents living in the house during the test, two adults and two children (6 months and 5 years old). The only active electrical goods during the test were the fridge and freezer.