Do the customers remember?

The fade-out effect from the demand response applied in the district heating system in Denmark

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Do the customers remember? The fade-out effect from the demand response applied in the district heating system in Denmark

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Abstract. Buildings can deliver short-term thermal energy storage to energy systems. In district heating (DH) systems, it is mainly desk studies and simulations that reveal a large thermal flexibility potential. Knowledge from real-life case studies on how residents participate in demand management campaigns is crucial for the successful utilisation of buildings' flexibility potential for minimizing bottlenecks in the daily operation of DH systems. In the field study including 72 single-family houses connected to the 3GDH network in southern Denmark, the demand response (DR) strategy "night setback" was applied for two heating periods. The houses were equipped with control and monitoring equipment, which allowed the deactivation of the heating system while monitoring the indoor temperature, so it does not drop below the defined value. The occupants controlled the DR events settings and could at any time stop utilisation of the night setback strategy (implicit participation in the DR). All 72 houses applied the night setback during both heating periods. Yet, the participation time decreased from 89% to 81%. The lowest participation rate was noted for the farm house, 60% and 9% of heating periods 1 and 2, respectively. In around 60% of the DR events, the night setback strategy was activated at 20:00.

1. Introduction

The heat demand profile of a building can be modulated by overheating and underheating the building and utilizing the building's thermal inertia (e.g. of the building envelope or liquid-based installations) for short-term thermal energy storage. If aggregated, this storage has the potential to facilitate the transition of the district heating (DH) systems towards low-temperature networks operated on intermittent renewable energy sources (i.e. sun and wind) [1,2]. The concept of modulating the buildings' demand profile according to the energy system needs is called demand side management (DSM) also known as demand-response (DR). Two opposing approaches exist to involve a building and its end-users in activating demand response assets [3]. The users can either be active participants (implicit participation) by adjusting the timing of energy use according to the received signal (e.g. price, CO_2 emissions) or be passive participants (explicit participation), where the change/adjustment of energy use is executed by automatic systems and/or remote control by system operators. These two engagement approaches are recognized by the DH operators as indirect and direct control strategies. They resemble the access and control possibilities of the grid operators to the building installations [4].

A small body of work has focused on field tests of demand response activation/utilization in buildings in the DH systems. Van der Meulen [5] named a field trial in 34 small houses in the Netherlands without providing the details and results. Kensby et al. [6] quantified the thermal storage potential of different construction types in five multi-story residential blocks in Sweden for 52 weeks. Sweetman et al [7] presented a field trial of demand-shifting technology in 28 homes in the UK for four winter months and concluded that PassivSystems' Home Energy Management System (HEMS) led to a reduction in peak demand and an increase in load factor, which is the ration between the mean daily to max daily demand, from 0.29 to 0.44 with only 3% increase in energy cost. Similar results of 85% peak load reduction were reached in a monthly field trial in a multi-family residential building in Copenhagen [8]. The field test in 27 student houses in Finland [9] proved that DR technology is a viable way to save energy and reduce greenhouse gas emissions in DH systems. The field trial in 12 multi-family blocks with 93 residents, who were exposed to load shifts for two weeks during early winter, showed that no statistically significant difference was found in thermal sensation or thermal satisfaction and that perception and acceptance of DSM in residential space heating is subject to four factors: (1) set indoor climate conditions, (2) timing and magnitude of the load shifts, (3) individual control and (4) communication [10]. Christensen et al. [11] showed in a 4-week field trial in three detached houses in Denmark that residents accept changing thermal conditions (temperature boosts) only after additional explanation of the monetary or environmental benefits of such interventions in their typical thermal comfort preferences.

Most demonstration studies have only been carried out as short-term trials (i.e., a few weeks or months) or with very few participants. Therefore, they do not report on how residents' reactions to the DR interventions have changed over a longer time (e.g. two successive heating seasons). Yet, as proven in the DR in electricity systems, implicit participation is often forgotten by residential customers after a short time [12]. Therefore, this paper presents unique insights into the persistence and adjustments to the implicit DR interventions in 72 single-family houses connected to the Danish DH system during a field experiment of 17 months including two heating seasons (2013-2014 and 2014-2015). Two following research questions were formulated: a) how long the occupants participated in the default DR control strategy, b) how they have defined the night setback settings.

2. Field study

The described field trial was a part of the *Smart Energi I Hjemmet* (SEIH) project conducted in southern Denmark in the years 2012-2015. Houses with different heat sources (i.e. oil boiler, gas boiler and district heating) participated in the experiment of implicit DR action aimed to reduce the energy use for space heating during night time (i.e. the night setback) [13]. All participating households were required on a convenience basis as a response to the invitation letter sent by the local municipality.

In this study, only the trial cohort of 72 single-family houses connected to the DH network is described and analysed. The homes that comprise the cohort were built before 1990 and covered a range of sizes and typologies from 80 m^2 row houses to 250 m^2 detached units. Table 1 provides an overview of trial cohort characteristics. The participating households were all owner-occupiers and in full-time use. Each home in the trial was equipped with flow and temperature sensors at the DH substation unit to monitor energy use for space heating in the house. Moreover, one temperature sensor was placed on the wall in the living space out of direct sunlight to monitor the indoor temperature. The data collected by the sensors were fed into the PassiveSystem control system located in each home to send a communication signal to close or open the supply of heat from the DH network. The occupants had access to monitored data and control options via SEIH homepage, where each house had a user account and control settings could have been modified according to individual household preferences (e.g. change of the night setback start and finish hour and/or definition of the minimum indoor temperature below which the heating system should be turned on again).

Table 1. Characteristics of the 72 houses participating in the DR events.

Typology		Size of household [person]		Area [m^2]		Construction year	
Detached house	47	**1**	6	**<= 90**	3	**< 1950**	33
Town house	15	**2**	31	**91-120**	23	**1951-61**	8
Row house	7	**3**	16	**121-150**	19	**1962-73**	28
Farm house	2	**4**	9	**151-180**	19	**1974-85**	3
Other	1	**5+**	10	**>=181**	8		
Total	72		72		72		72

3. Data and methods

The flow and temperature data were logged every two minutes for 17 months proving a range of data points for analysis. The data collected during the field trial were 98% complete, so very limited cleaning was carried out. The analysed sample included data from two heating periods (HP), which were January-April 2014 (120 days) and November 2014 – April 2014 (181 days). The HSs were analysed separately. Data from each house were analysed separately (local analysis) and the whole trial cohort of 72 houses was analysed to identify the global tendencies.

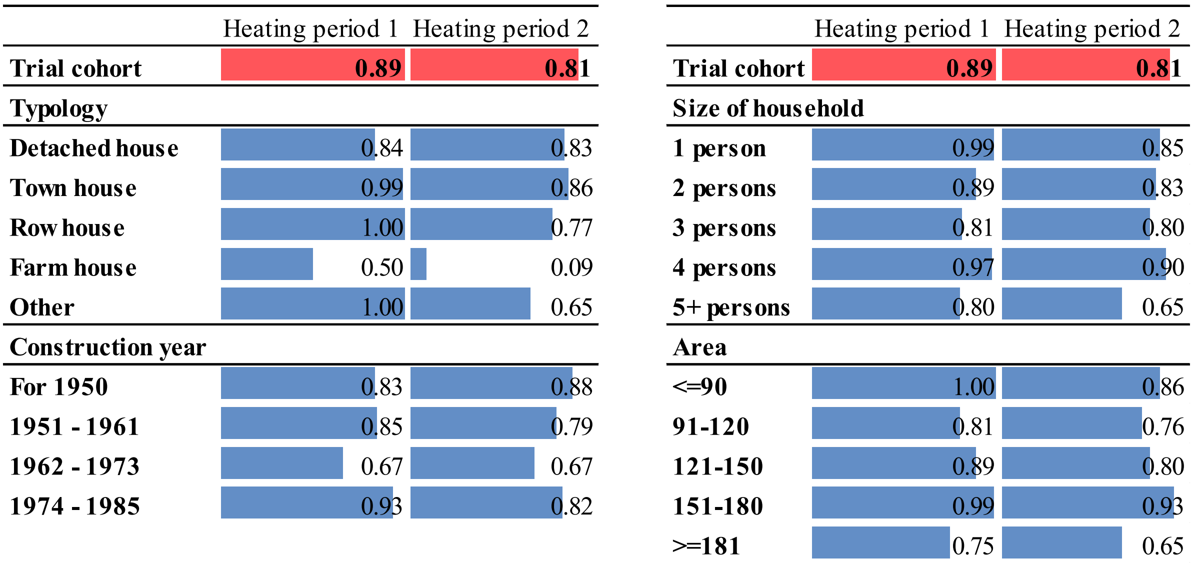
The used data sample includes only the indoor temperature readings from living spaces. The temperature data were interpolated to 1-hour values by calculating the mean value over this time slot. The weekdays and weekends were grouped to identify the impact of working and non-working days. The nighttime was defined as hours from 20:00 to 8:00 (12h) during weekdays and from 20:00 to 10:00 (14h) during weekends. For each home, for each time slot between 20:00 and 24:00, a maximum temperature and its timestamp are found. This timestamp is considered the starting point of the night setback. The end of the DR intervention is the timestamp where the indoor temperature increases more than 0.1 K between it and the following timestamp. The length of the time slot between start and end timestamps is the length of the DR intervention.

4. Results

This section begins by describing the participation time in DR events during the two heating periods with the indication of the overall trend of the trial cohort and the trends within different groups shown in table 1. HP1 and HP2 had different lengths, therefore, the results are presented as normalized values with 1 corresponding to 120 and 181 days for HP1 and HP2, respectively. The following section explores in more depth the characteristics of the DR events, such as starting time, length, and temperature decrease. This analysis is done only for the whole trial cohort, without division between the different groups shown in table 1.

4.1. Participation time

The participation in the DR program of night setback decreased by 8% from HP1 to HP2. All 72 participants activated the DR event during both heating periods, yet during fewer nights in HP2. The biggest fade-out effect of 41% was in the farm houses. The households with either one or five persons were more reluctant to activate the night setback in HP2 and decreased their participation time by around 15%. The building construction year does not have consistent results. In the oldest houses, which expect to have the worst thermal properties of the building envelope, and therefore, be more sensitive to the space heating turn-off periods than the other buildings, the time with activated night setback increased, while in the other age groups it decreased. The size of the building is not a key building characteristic, as for all sizes the fade-out effect is around 10%. The main reason for the decreased participation time could be the mean outdoor temperature in HP1 and HP2, which was 5.1 C and 4.6 C, respectively.



	Heating period 1	Heating period 2
Trial cohort	**0.89**	**0.81**
Typology		
Detached house	0.84	0.83
Town house	0.99	0.86
Row house	1.00	0.77
Farm house	0.50	0.09
Other	1.00	0.65
Construction year		
For 1950	0.83	0.88
1951 - 1961	0.85	0.79
1962 - 1973	0.67	0.67
1974 - 1985	0.93	0.82

	Heating period 1	Heating period 2
Trial cohort	**0.89**	**0.81**
Size of household		
1 person	0.99	0.85
2 persons	0.89	0.83
3 persons	0.81	0.80
4 persons	0.97	0.90
5+ persons	0.80	0.65
Area		
<=90	1.00	0.86
91-120	0.81	0.76
121-150	0.89	0.80
151-180	0.99	0.93
>=181	0.75	0.65

Figure 1. Participation time in the DR events during HP1 and HP2 of the trial cohort (red) and participating homes grouped according to the four characteristics (blue). (HP1: 1=120; HP2: 1=180)

4.2. DR event features

Table 2 and Figure 2 show that the DR event features have not changed significantly between the heating periods. It is expected that the space heating demand was stopped by the control most often at 20:00 in both heating periods. From the DR event starting hour, the indoor temperature in the living space dropped successively for the period between 2 to 12 hours, with the period of 7h being the most common night setback window during weekdays. During weekends, the occupants had extended the DR event window to even up to 14h. Moreover, the decrease in the indoor temperature during the space heating stop ranges from 0.5 to 4K. This could be interpreted that for the occupants the indoor temperature is the main control parameter for the DR strategy and the length of the DR window is the output of settings for the minimum indoor temperature, the building thermal inertia characteristics and the outdoor temperature.

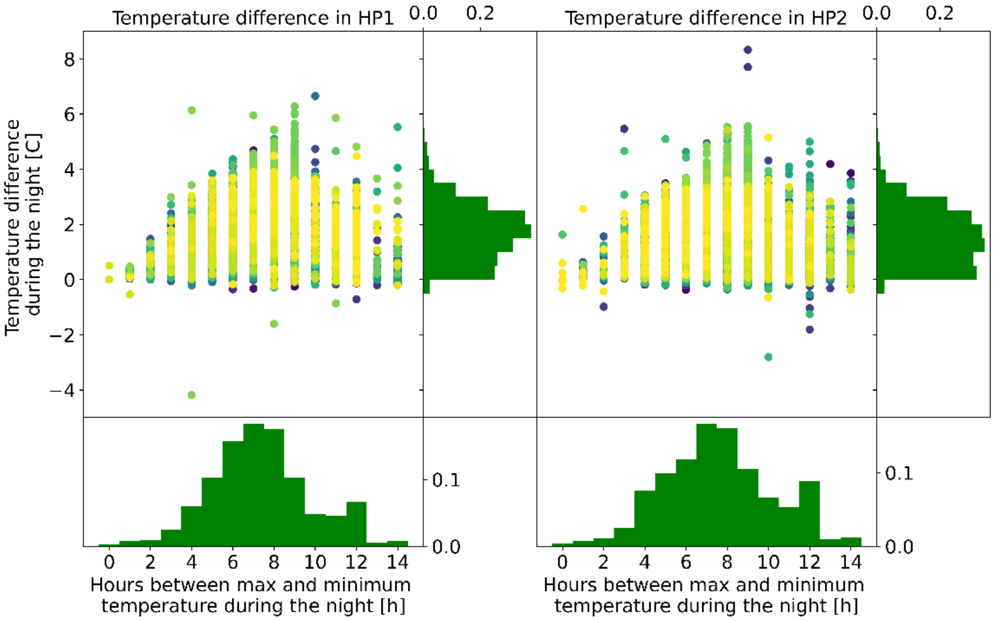


Figure 2. Features of the DR event for HP1 and HP2.

Table 2. DR event starting time for HP1 and HP2

DR start hour	20	21	22	23	24
Heating period 1	0.66	0.22	0.06	0.02	0.03
Heating period 2	0.63	0.22	0.08	0.04	0.03

5. Conclusions

The paper presents some insights into the fade-out effect from the night setback control strategy using the monitored data from 72 single-family houses connected to the DH system in southern Denmark. It shows that participants react differently. Both building and household characteristics, such as typology, construction year and number of occupants, affect the results. All of the 72 participating homes continued to use the night setback during the second heating season, yet with slightly fewer activation nights (a reduction by 8%). Moreover, as indicated by Jensen et al. [13] the applied DR strategy led to energy savings of between 4 and 10 % in the total heat demand of the buildings.

The results contribute to the existing literature on DR application in buildings connected to DH systems by presenting the long-term perspective. Similar to Sweetman et al [7], the modulation of energy use is associated with minor energy savings. The four factors of successful application of DSM in residential buildings connected to DH systems identified in [10], namely (1) set indoor climate conditions, (2) timing and magnitude of the load shifts, (3) individual control and (4) communication, have been indirectly confirmed by our study. The occupants were in full control over the DR events and could easily adjust the DR settings according to the household's demands. This could be the reason why they continued to apply the night setback DR strategy for both heating periods.

The result shows great potential for the application of implicit DR control strategies in DH systems. Moreover, it delivers an important message to the DH utilities that buildings and their occupants should not be considered as a simple load point/demand-side variable but as individuals capable of enabling systemic interventions and delivering short-term storage and/or flexibility, thus speeding up the process towards carbon-neutral systems.

However, this result does not explain the participants' motivations and priorities when it comes to the control of their heating system. For residents, energy is mostly invisible and consumed in the course of performing practices in everyday life. Heating demand response relates to questions of thermal comfort and control of space heating and cooling. Therefore, knowledge of how residents can be engaged is crucial for improving heating control and demand response and its potential for minimizing bottlenecks in the future low-temperature DH system based on intermittent renewable energy sources.

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