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Wood burning habits and its effect on the electrical energy demand of a retrofitted Norwegian detached house

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Abstract. Using firewood as a space heating source is a popular solution in Norwegian housing and can significantly reduce the electrical energy demand of houses. This study analysed habits and reasons for using a wood stove from survey data. From this, typical behaviour patterns were defined. These patterns were imported into a building performance simulation model of a typical Norwegian single-family detached house to evaluate the impact of the stove user behaviour on the electrical energy demand and on the overheating risk. Results showed that up to 32% of the electrical energy demand for space heating can be saved using a wood stove. The number of overheating hours increased when the wood stove was used more frequently. However, it decreased after full renovation because the stove is used less often, as the total space heating demand decreases and the indoor temperature drops less often below the temperature set-point when the stove is started. Active use of the wood stove is effective as retrofitting measure when the aim is to save electricity or fossil fuels. Nevertheless, if the stove power is not adapted to the building, it can be challenging to maintain a comfortable temperature in the room.

1. Introduction

Retrofitting the existing building stock has the potential to improve the overall energy efficiency and reduce CO₂-emissions [1]. There is a significant energy saving potential in upgrading housing as around 75% of the building stock is residential [2]. About 40% of the houses in Norway are detached single-family houses built before 1990 [3]. These houses typically have a wood burning stove in addition to electric heaters to cover the space heating demand. This makes it possible to use a renewable energy source for space heating and biofuel currently covers around 16% of the national energy consumption for households [4]. In addition, a wood stove improves the flexibility of the heating system (i.e. the possibility to choose between two heat generation systems) and decreases the dependence on non-renewable resources. Norway wants to increase its use of bioenergy by 2020, and firewood is the most promising bioenergy resource for both small houses and existing buildings without a water-borne heating system [5]. In the building code of 1969, small houses, if not connected to a central heating system, were required a chimney



so that a wood stove could be installed [6]. TEK17, the building code valid today, states that small houses must be built with a chimney unless they have a water-borne heating system or reach passive house requirements [7].

Regarding the indoor environment, a potential concern is that wood stoves produce pollutants and CO₂ emissions that could affect the indoor air quality. Hamon et al. [8] found that the emitted particles and CO₂ concentration in both old and new houses stayed below the maximum permitted levels. However, a significant drop in humidity was found when the wood stove was used. Another concern is the increase in room temperature when using a wood stove. Studies showed that the nominal power of typical wood stoves can be oversized for buildings with high-performance envelopes, which can pose a risk for overheating [9, 10, 11]. The installation of a wood stove without the proper nominal power can lead to similar overheating behaviour in less insulated buildings, as studied by Skare [11] and Thalfeldt et al. [12].

Past studies focused mainly on overheating and the modeling of the indoor thermal environment of buildings heated by wood stoves and less on user behaviour [13, 9, 10]. Finstad et al. [14] conducted a survey about fireplace behaviour in Norway in 2003. In Trondheim 27% of those who use a fireplace or wood stove used it as a primary heating source during the winter of 2002/2003. In Trondheim and Oslo, 10% and 44%, respectively, used it only for coziness. Most people used their fireplace during the evening (79-85%), followed by the late afternoon (35-73%), though the results vary a lot depending on the location. The main reasons for using the fireplace more often than the previous year were colder outdoor temperatures and a higher electricity price. However, this study is not recent and it is not possible to identify behaviour patterns from the results. Kipping et al. [15] analyzed the electric consumption of Norwegian dwellings using smart meters measurement and user surveys. They showed that using firewood for space heating can result in a significant reduction of the hourly electricity consumption. Kipping and Trømborg [15] found that 60% of the investigated households with electric heaters say they used firewood as their primary heating source during the winter and 30% used it as a supplementary heating source. Less than 10% used it for coziness only. Except Kipping et al. [15], none of these studies discussed how user behaviour may affect the electricity consumption and indoor comfort. Skare [11] investigated the effect of several energy related user behaviors related to stoves on the space-heating needs, such as the set-point temperature, the stove power modulation, batch load and internal door opening in the building. However, this study did not focus on different user customs (i.e. why and when the stove is used) which is the aim of the present work. Georges et al. [13], analyzed the space-heating needs in passive houses using the wood stove as primary heating source. In reality, it can be challenging to provide heating to the whole house using a wood stove only. In housing with a low space heating demand, such as passive houses, it was possible to cover most of the demand with the wood stove though it depends on the effectiveness of the heat distribution in the house and the desired indoor temperature in the bedrooms. If relatively warm bedrooms were required, extreme weather conditions resulted in unacceptable temperatures in parts of the house. Therefore, the wood stove should be complemented by another heating source, especially in poorly insulated buildings.

The first objective of this paper was to analyse habits and reasons for using a fireplace or wood stove as a heating source in Norway and to identify typical behaviour patterns. The second objective was to evaluate the effect of these patterns on the electrical energy demand for space heating and on the indoor comfort (i.e. overheating hours) of a typical Norwegian single-family house. The paper is organized as follows. First, the methodology is explained. Then, survey results and identified behaviour patterns are presented, followed by energy performance and indoor climate results. Finally, limitations and suggestions for future work are discussed.

2. Methodology

2.1. Survey design

An online survey about fireplace behaviour was designed to provide insight in how and why fireplaces are used in Norway and how different groups use them. In the survey and in sections 2.1 and 3.1, 'fireplace' refers to any type of wood burning place, such as open fireplaces and wood stoves. The survey was sent out in February 2019 and was available for 6 weeks. The first part of the survey contained questions about the characteristics of the participant and their house. After this, the survey focused on characteristics of the fireplace and fuel. The final part focused on the importance of a fireplace, how and why it is used (or not used) and indoor climate satisfaction. It should be mentioned that personal and professional networks were used to distribute the survey. Therefore, the survey sample cannot be considered representative for all of Norway.

2.2. Data analysis

A total of 645 valid responses were obtained and analyzed with SPSS Statistics [16]. For this paper, only the results from those with one or more fireplaces were analyzed (N=509). The association between monthly use, hours of use, and time period of use and reasons of using the fireplace was investigated. Because all dependent variables for defining behaviour patterns were categorical, Chi-square tests of independence and Cramer's V were used to find correlations. The former is used to conclude if there appears to be a relation between two variables ($p < .05$ for a significant association). The latter is used to identify the strength of the relation (weak=.15 to .20; moderate=.20 to .30; strong=.30 to .50).

2.3. Simulation-based impact assessment

The case study is a typical Norwegian detached single-family house [17], placed in the climate of Trondheim, Værnes. The house was modeled as a simplified multi-zone model in IDA-ICE [18] with five zones: the living room and kitchen, all rooms south of the living room, all rooms north of the living room, the stairs and the whole ground floor (see Figure 1). Standardized input values from NS 3031 [19] were used for occupancy and internal gains. The simulation model was validated by comparing results from the model to reference values for the same building category [20]. Blind control and window opening were added to simulate real user behaviour and to provide free cooling. Windows are opened for 30 minutes when the temperature exceeds 24°C. The blinds go down for 4 hours when the temperature exceeds 23.5°C. The doors inside the building are kept closed.

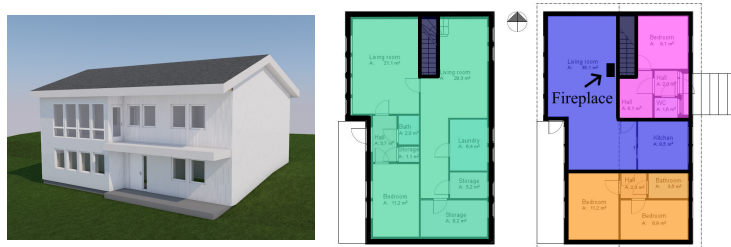


Figure 1. Appearance of a typical single-family house (built 1970-85) and layout with zoning.

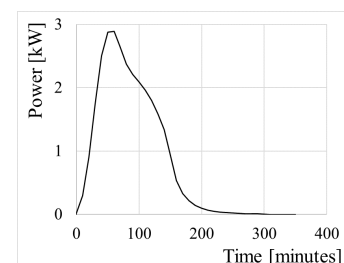


Figure 2. Combustion profile of a 6 kW stove [11]

The house is heated by electric heaters and a wood stove, which is located in the living room on the first floor (i.e. the blue zone in Figure 1). For the sake of the simplicity, this wood stove is implemented as an electric radiator where the time-varying emitted power corresponds to a

wood stove. A realistic wood stove control strategy developed and implemented by Skare and Thalfeldt [11] was used. This control imposes the power emitted by the stove inside the room (i.e. the net space-heating power) and not the combustion power. The nominal power of the wood stove was selected to be 6 kW [11] and without additional thermal storage (see Figure 2). A combustion cycle starts when the temperature drops below 22.1°C, just above the NS 3031 set-point of 22.0°C for the electric heaters, and when a schedule (i.e. behaviour pattern) is active. Because most fireplaces are only used during the winter [14] and to avoid the effect of overheating during the summer, the simulation period is taken as the heating season. This is from the day the average daily temperature drops below 11°C until springtime when the outdoor temperature exceeds 9°C. In Trondheim, this is from the 6th of September to the 24th of May.

The fireplace behaviour patterns were combined with four retrofitting packages. These are not optimized for the house, but based on standards. Package R0 is the house before retrofitting. In package R1 only the windows are replaced. Package R2 represents retrofitting to TEK 17 [7]. In package R3, the envelope is retrofitted to meet Norwegian passive house criteria [21], though other energy performance requirements, such as maximum space heating demand and share of renewable energy, are not considered.

Table 1. Energy performance characteristics in the four renovation packages.

	R0 - no renovation [19]	R1 - minimum	R2 - moderate [7]	R3 - major [21]
U-value basement wall [W/m ² K]	1.0	1.0	0.18	0.10
U-value basement floor [W/m ² K]	0.5	0.5	0.10	0.08
U-value timber frame wall [W/m ² K]	0.6	0.6	0.18	0.10
U-value roof (loft insulation) [W/m ² K]	0.6	0.6	0.13	0.08
U-value windows [W/m ² K]	2.8	1.2	0.8	0.8
Air leakage at 50 Pa [h ⁻¹]	6.0	1.4	0.6	0.6
Norm. thermal bridge value [W/m ² K]	0.07	0.07	0.05	0.03
SFP [kW/(m ³ /s)]	2.0	1.5	1.5	1.5
Heat recovery [%]	0	80	80	80
Ventilation system	Mech. exhaust	Balanced	Balanced	Balanced

3. Results and discussion

3.1. Fireplace behaviour patterns

Associations between use characteristics (e.g. how often it is used and when) and five reasons for using the fireplace were found (for coziness, because it is cheap, because it is fast, because it is environmentally friendly, and because it heats up the whole house). These five reasons are further referred to as pattern variables. Table 2 presents the patterns that were identified based on associations between the pattern variables and how often the fireplace is used. Figure 3 shows the time periods (i.e. when during the day) associated with the pattern variables. These were converted to input schedules for the wood stove control in IDA-ICE. If no specific correlation was found, the mean value was assumed.

The data shows that when a fireplace is used for coziness or because it is a fast heating source, it is used for a couple of hours per day (i.e. one combustion cycle). When a fireplace is actively used as a main heating source or because it is environmentally friendly, it is used from the morning or early afternoon to the evening. It was not possible to find how often a pattern occurs in the population from the survey results. Figure 4 gives an indication of which defined patterns are more popular, and therefore may occur more often in this population. The grey bars show how many participants agreed the pattern variable was their reason for using the fireplace. The green bars show their level of agreement to statements about using the fireplace

for each pattern variable. Interestingly, over 50% replied that one of the reasons why they used their fireplace was because it is cozy, though around 20% used it only for coziness. Most people (>75%) agreed that the fireplace is a fast way to heat up their house.

Table 2. Fireplace behaviour on weekdays (wd) and weekends (we) and weekly use patterns associated with the pattern variables, derived from the survey data.

	Cozy	Environment	Cheap	Fast	Main heat
Use per week	3-4 days $\chi^2(6)=53.931$, $p=.000$, $\varphi_c=.326$	Daily $\chi^2(6)=27.595$, $p=.000$, $\varphi_c=.233$	5-7 days $\chi^2(6)=58.562$, $p=.000$, $\varphi_c=.339$	5-6 days $\chi^2(6)=64.356$, $p=.000$, $\varphi_c=.356$	5-7 days $\chi^2(6)=63.078$, $p=.000$, $\varphi_c=.352$
Use hours (wd)	2-4 hours $\chi^2(6)=26.669$, $p=.000$, $\varphi_c=.229$	10-20 hours $\chi^2(6)=29.850$, $p=.000$, $\varphi_c=.242$	2-4 hours $\chi^2(6)=21.831$, $p=.001$, $\varphi_c=.207$	2-4 hours $\chi^2(6)=50.676$, $p=.000$, $\varphi_c=.316$	4-6 hours $\chi^2(6)=28.956$, $p=.000$, $\varphi_c=.239$
Use hours (we)	2-4 hours $\chi^2(6)=42.315$, $p=.000$, $\varphi_c=.288$	10-15 hours $\chi^2(6)=16.233$, $p=.013$, $\varphi_c=.179$	4-6 hours $\chi^2(6)=25.812$, $p=.000$, $\varphi_c=.225$	0-2 hours $\chi^2(6)=34.418$, $p=.000$, $\varphi_c=.260$	6-10 hours $\chi^2(6)=40.342$, $p=.000$, $\varphi_c=.282$

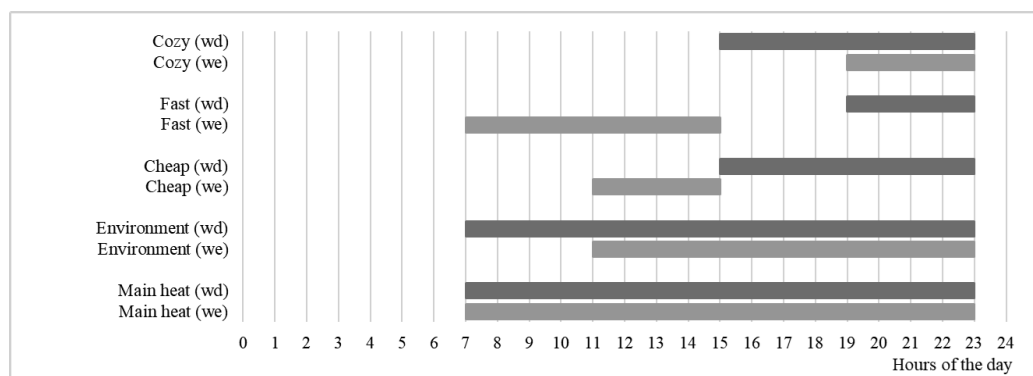


Figure 3. Time periods of use associated with the pattern variable.

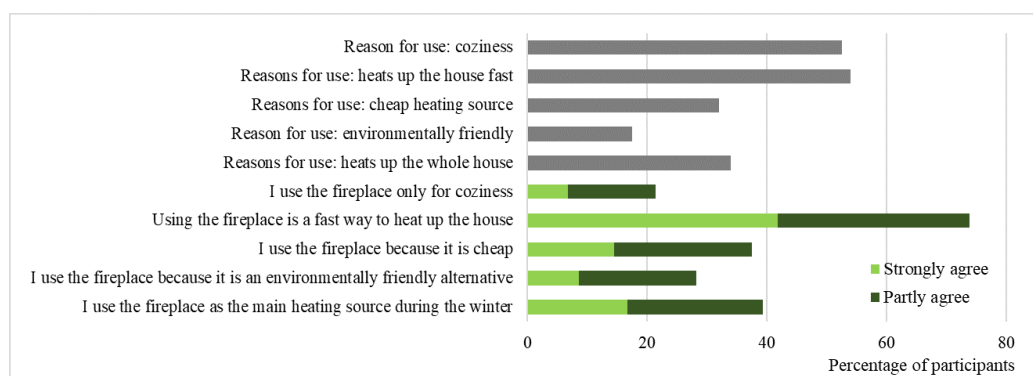


Figure 4. Percentage of participants that answered positive (i.e. ticked off an answer or agreed to a statement) to questions regarding use of the fireplace or wood stove.

3.2. Electrical energy savings

This section analyzes the effect of different time schedules for the stove operation on the space-heating demand. Other energy-related user behaviors are kept unchanged, such as the start set-point temperature and the door opening. Figure 5 shows the results of the space heating

demand in kWh/m² per year (heating season). The total space heating demand increased when the wood stove was used, but electrical energy savings were achieved (see Table 3). The space heating demand covered by the wood stove and the achieved electrical savings were similar in the patterns 'cozy', 'cheap' and 'fast' and were similar in the patterns 'environment' and 'main heat'. The potential electrical energy savings [%] are calculated as [11]

$$E_{\text{saved}} = 1 - \frac{Q_{\text{SH,wood stove}} + Q_{\text{SH,electric}}}{Q_{\text{SH,ref,total}}} \quad (1)$$

where Q_{SH} is the energy demand for space heating. The savings presented in Table 3 are in comparison to the reference case (i.e. no wood stove) for each retrofitting package. Using a wood stove can result in up to 32% savings of the electrical space heating demand. Pattern 'environment' resulted in most savings (21-32%) while pattern 'cozy' resulted in the lowest amount of savings (6-11%). The highest reductions were achieved in the moderate retrofitting package (R2), closely followed by retrofitting package R3. Figure 5 and Table 3 show that the relative space heating demand covered by a wood stove increased after renovation, though the absolute values decreased. This is because less energy is needed to heat up the house after retrofitting and the indoor temperature drops less often below the set-point for space heating.

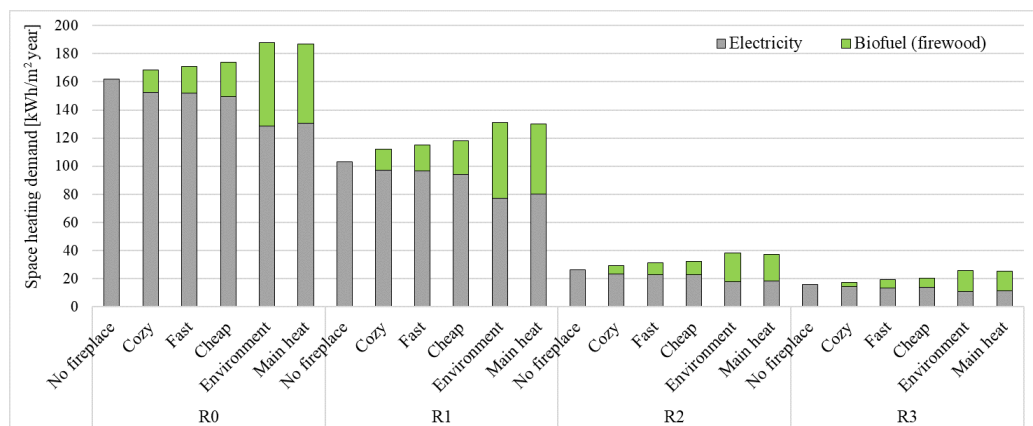


Figure 5. Space heating demand covered by electricity and biofuel in the four retrofitting packages and for the fireplace behaviour patterns.

Table 3. Electrical energy savings achieved in comparison to the reference case (i.e. no wood stove) within each retrofitting package.

	R0 - no renovation	R1 - minimum	R2 - moderate	R3 - major
Cozy	5.9%	6.0%	11.1%	10.4%
Fast	6.2%	6.2%	12.7%	14.6%
Cheap	7.9%	9.0%	13.5%	11.5%
Environment	20.8%	25.2%	32.3%	31.9%
Main heat	19.4%	22.5%	30.6%	29.6%

3.3. Overheating

The thermal comfort was assessed in terms of occupied overheating hours. Figure 6 shows the number of occupied hours in the living room (where the wood stove is located) when

the temperature exceeds 24, 25 and 26°C, respectively. The percentage of occupied hours over 25°C decreased after full retrofitting, which is in agreement to results from Skare [11]. After retrofitting, the number of occupied hours over 24°C increased when no wood stove was used, though it stayed the same in 'cozy', 'cheap' and 'fast' and decreased in 'environment' and 'main heat'. Figure 7 shows the relation between the number of hours above 26°C and the wood stove use (i.e. space heating demand covered by firewood). There is a clear positive correlation between the two, indicating that the number of overheating hours increases when the wood stove is used more often. It also shows that when the space heating demand is lower (after retrofitting), it results in less overheating hours. The control strategy of the wood stove starts a combustion cycle when the pattern is active and when the temperature drops below 22.1°. As explained by Skare [11], after increasing building insulation levels, the living room temperature drops less often below the start set-point temperature and the wood stove is used less often. The results also showed that due to local temperature peaks when using the wood stove, the humidity levels dropped, as pointed out by Hamon et al. [8]. When the wood stove was not in use, the humidity levels were significantly more stable.

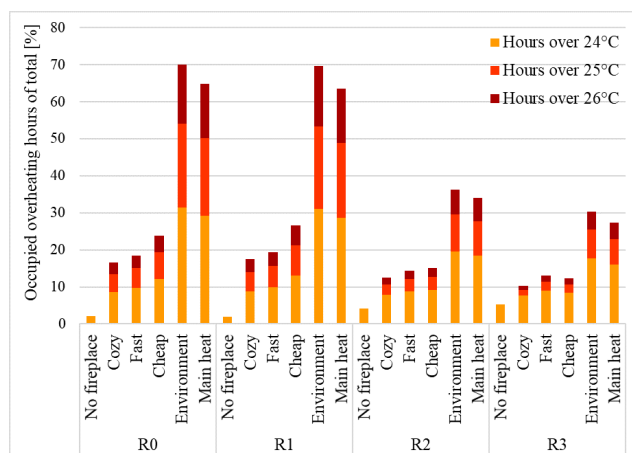


Figure 6. Number of occupied overheating hours over 24, 25 and 26°C in the living room for the five fireplace behaviour patterns.

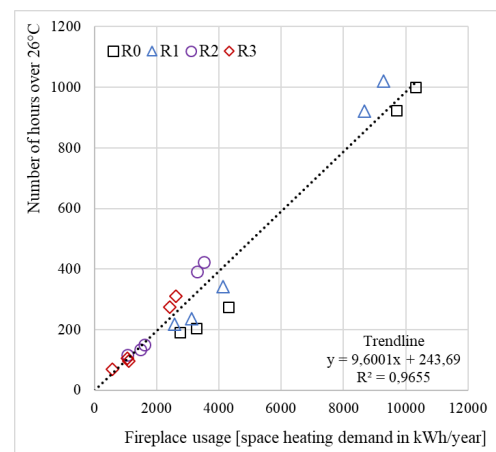


Figure 7. Number of hours over 26°C as a function of wood stove usage (space heating demand covered by firewood)

4. Limitations and future work

The survey sample in this study was not random because of how the survey was distributed. Therefore, results cannot be assumed representative for all of Norway. It was not possible to identify how often the defined patterns are used from the collected data. After completing the data analysis, it was found that some questions may not have been precise enough or that more information should have been asked. For example, clear definitions should be provided for the pattern variables. It could also be interesting to investigate how much fuel people typically use for one combustion cycle and how often they refuel. For future work it is suggested that the survey is revised and randomly distributed.

For the sake of simplicity, this work modeled the fireplace as an electric radiator implemented in a single-family house located in Trondheim. Other types of fireplaces, housing types and climate zones were outside the scope of the present study. In the future, a more realistic model of the stove heat emission can be considered. Indoor comfort was only assessed by evaluating overheating hours, but other thermal comfort criteria could be used. Future work

may include assessment of humidity levels and indoor air quality. The standard room air model in building performance simulation packages, such as IDA ICE, assumes well-mixed air with uniform temperature and concentration of pollutants and does not compute the airflow inside the room. The limitations of this modeling approach to assess the indoor thermal environment of building heated by wood stove has been investigated by Georges et al. [10] using field measurements. It is shown that the thermal stratification can significantly impact thermal comfort. To investigate this effect, alternative room air models should be considered such as zonal models [22] or CFD [23]. The retrofitting packages were not optimized for the housing type and no alternative combinations of heating sources were included. The nominal power of the stove and its thermal storage should also be adapted to the building thermal properties, such as the insulation level and thermal mass [12]. Savings in terms of fuel cost and CO₂ emissions could be investigated as well.

5. Conclusions

Using firewood in addition to electricity is a common space heating solution for residential buildings in Norway. A survey was designed and sent out to investigate how and why fireplaces and wood stoves are used. Five fireplace behaviour patterns were defined from the survey data and were implemented in a simulation model. Depending of the building insulation level and fireplace behavior patterns, simulation results showed that using a wood stove can result in up to 32% savings on the electrical space heating demand. Pattern 'environment' resulted in most savings (21-32%) while pattern 'cozy' resulted in the lowest amount of savings (6-11%). The highest relative reductions were achieved in the moderate retrofitting package, closely followed by the major retrofitting package. Results showed that the number of overheating hours increased when the wood stove covered more of the space heating demand and that the number of overheating hours decreased after full renovation of the building envelope. Active use of the wood stove is effective as retrofitting measure when the aim is to save fossil fuels or electricity. However, the nominal power of the wood stove and its thermal storage should be adapted to the building thermal properties in order to maintain a comfortable temperature in the room.

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