



# Analysis of heat use profiles in Norwegian educational institutions in conditions of COVID-lockdown

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## ABSTRACT

The COVID-19 pandemic at the beginning of 2020 has significantly affected the energy demand in Norway. In order to avoid unnecessary energy use and ensure the proper functioning of buildings, it becomes essential to have a better understanding and planning of heating use for different building types under possible pandemic conditions. Despite this fact, the literature review showed a lack of awareness about heating system performance in buildings during the COVID-lockdown. This article addressed the problems of heat use profiles analyses and scenario development for schools, kindergartens, and university campuses in Norway. The comparison of heat use profiles in these educational institutions during both the previous year and the COVID-lockdown showed that the operation of the heating system remained on the same level, although the occupancy was largely reduced. Moreover, the month after the reopening of the buildings was characterized by a remarkable increase in heat use, regardless of the warmer weather conditions. For heat use planning in educational institutions, the following scenarios were developed: Scenario 1 – operation according to a normal year setting; Scenario 2 – reducing the heating to the level of the night heat use; and Scenario 3 – using settings that were applied during the lockdown. The results showed that the application of Scenario 2 might allow us to save 21 kWh/m<sup>2</sup> per year.

## 1. Introduction

COVID-19 is a potentially fatal coronavirus disease that may cause severe problems with the human respiratory system [1]. Since the beginning of 2020, this disease has begun to spread rapidly around the world [2]. In March 2020, the World Health Organization (WHO) declared that COVID-19 outbreak is a global pandemic. Social distancing and personal hygiene are proved to be the primary measures that may help to prevent the spread of COVID-19 [3]. Therefore, in order to avoid people gatherings and crowds, most countries have imposed a partial or full lockdown of educational institutions and commercial and industrial companies. Many people were compelled to stay at home and work remotely. Such drastic changes in the behavior of energy users have a significant impact on energy demand and lead to substantial problems in the energy sector. Some crucial problems and challenges for energy systems are discussed in the publications below.

Several authors investigate the problems related to changes in energy loads of the energy system during the COVID-19 pandemic. The weekly electricity loads in the Brazilian power system and its subsystems (Northeast, North, South, and Southeast-Midwest) are compared in the

periods before and after the isolation [4]. Statistically, significant decreases are observed in the levels of electricity use. The average daily electricity loads in 26 cantons in Switzerland are analyzed in Ref. [5]. In these cantons, the reduction of energy use was varying and reached a decline up to -16.5% of the energy use compared to the previous year. The analysis of the hourly electricity loads amidst the pandemic in Ontario, Canada, is performed in Ref. [6]. The electricity loads show a noticeable curve flattening during the pandemic, especially during the peak hours of from 7:00 till 11:00 o'clock in the morning and from 17:00 till 19:00 o'clock in the evening. The effect of restrictions on energy demand in the EU countries is investigated in Ref. [7]. The EU countries have individually approached the restrictions associated with the COVID pandemic. The analysis of energy use showed that countries that imposed stricter restrictions experienced a higher reduction in energy demand.

A regression model is used to forecast the peak electric load in the Kuwaiti power grid according to climatic data [8]. The influence of the pandemic on the power grid in the Kuwaiti power grid is investigated by comparing the actual demand during 2020 with the predicted demand for the same year in normal conditions. The full lockdown resulted in

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17.6% drop in energy use compared to the 2020 prediction. A comprehensive review of the electricity use in Italy, Japan, USA, and Brazil shows that the pandemic leads to uncertainty in the electricity demand and causes problems for the system operators [9]. To conclude, changes in the energy demand profiles during the COVID period creates difficulties for accurate load forecasting.

The investigation of power system operation in Ref. [10] states that during the COVID-lockdown, the total electricity demand in many countries reduced by around 10–30%. A set of recommendations should be introduced to overcome the current crisis and achieve a sustainable operation of the power systems. Governmental policies and actions considering the discounts for electricity bills in commercial and residential buildings in G20 countries were investigated in Ref. [11]. The authors argue that in addition to the applied discounts, it is necessary to provide energy users with guidance on energy conservation for the pandemic outbreak and especially lockdown.

The impact of corona lockdown on energy systems and pricing in Italy is evaluated in Ref. [12]. The energy generation systems in this country faced problems related to the regulation capabilities and flexibility. Combined heat and power plants were compelled to work close to the minimum. A nearly doubled increase in the ancillary market costs for system operations during the last week of March 2020 was observed in Italy [12]. The global renewable energy sector was also affected by pandemic restrictions and experienced additional difficulties and risks related to the operation of existing installations, as well as the implementation of new projects [13]. The additional expenses during the COVID-19 pandemic are related to the need for the energy systems to achieve load balancing, frequency control, and to reserve margins formation.

The negative influence of COVID-19 pandemic on the energy sector can be mitigated by ensuring the energy efficient functioning of end-users, better energy planning, quick adaptation to new conditions and introduction of proper operation measures. The deployment of demand-side management for the residential, commercial, and industrial energy users is essential to ensure a smooth operation of the power system in the pandemic period [9,10]. Energy use profiles provide us with valuable insights to analyze changes in energy use and take actions to respond to these changes. Moreover, the regimes of work of residential energy consumers are different from non-residential consumers, and therefore pandemic affected them differently. Thus, the ability to isolate residential from non-residential electricity profiles during COVID-19 is considered as an essential aspect for planning and operation of the electricity systems. For this reason, it is necessary to understand the changes in energy use profiles related to COVID-19 that occurred in each category of energy users.

The comparison of the energy use profiles before and after the COVID-19 pandemic was performed publications [14–18]. The main results of these studies are presented below.

In a study [15], data obtained from energy management systems (HEMS) in 632 apartments in New York were used to investigate the dynamics of energy use patterns during the COVID pandemic. The research is based on the comparison of the energy use profiles in the same months between the normal time and the COVID lockdown [15]. The authors found that the morning peak of energy use was shifted later, and the previous energy decrease during daytimes became non-existent. Moreover, most of the residents are experiencing much higher electricity use than before [15].

During the COVID-19 pandemic, the energy demand in the industrial and commercial sectors showed a significant decrease, while in the residential buildings, an increase in energy use was observed [16]. For example, energy use in residential buildings in the USA rose by 6–8% [16]. Similar to the article [16], research is performed for Southeast Asia [17]. The investigation in Ref. [17] finds that the lockdown measures reduced the energy needs in the industrial sector and increased the energy demand in the residential sector. In addition, the daily energy demand in these Asian countries has been found close to the Sunday

electric load curve.

The electricity load profiles for residential, commercial, and industrial consumers are respectively shown under three cases: 1) business-as-usual case without a lockdown; 2) the case of a partial lockdown; 3) the case of a total lockdown in Ref. [18]. The research in the mentioned study is performed based on data from 259 electrical energy users located in the Lagos metropolis, Africa. Compared to the business-as-usual case, no change in the percentage of electricity demand by sectors under a partial lockdown case was detected. However, under the total lockdown, the authors discover a sharp increase of electricity demand in the residential sector, a 6% decrease in the industrial sector, and almost no changes in the commercial sector [18].

Data from 3.8 million electricity users in Illinois, USA, was examined in Ref. [14]. This study shows that the onset of COVID-19 shifted weekday load profiles for residential buildings was similar to weekend profiles from previous years.

The literature review [14–18] shows that efficient energy use in buildings becomes a crucial problem during the COVID-19 pandemic. The study [19] is dedicated to the prior cases of pandemic diseases and challenges that they brought to society. It shows the results similar to publications [14–18] and emphasize that the COVID measures will lead to more attention to sustainable and energy efficient solutions in buildings design and operation. The post-COVID recovery agenda is developed by the International Renewable Energy Agency (IRENA) [20]. This report states that in the post-COVID period buildings are expected to receive the most significant share of energy efficiency investment [20].

Mostly, the articles [14–18] demonstrate that currently the existing publications are focused on the residential buildings, while research on non-residential buildings is lacking. For the educational institutions, office buildings, and other commercial buildings that experienced lockdown, it is usually assumed that the demand profiles for weekdays during the pandemic are similar to weekends of the reference week in 2019 [7]. However, the data-based evidence for energy use profiles in these types of buildings is missing.

In order to achieve efficient energy use in buildings during the COVID-19 outbreak and the post-pandemic period, it is necessary to understand and forecast the changes in energy use in the main technical systems of buildings. Out of all the technical systems in buildings in the EU, space heating (SH) and domestic hot water (DHW) are often the most significant consumers of energy. According to Ref. [21], before the pandemic, SH and DHW heat use together has accounted for more than 20% of the total EU energy demand annually. The heat use profiles in normal conditions are well established and presented in Ref. [22]. However, the building heat use has been significantly affected by the pandemic. For instance, the energy data from 352 households in a Chinese region which had a similar energy composition to the EU before the pandemic, showed a 60% increase in cooling and heating demand during the lock-down [23]. The current heat use profiles for normal conditions are not descriptive in pandemic circumstances. Nevertheless, the heat use in buildings during the COVID-19 pandemic is not studied enough, especially for non-residential buildings. Currently, there are only a few publications that give some information or recommendation for heat use in buildings in pandemic time.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) presents guidance [24] for buildings operation in epidemic conditions. This guidance does not recommend to completely shut off HVAC systems in a temporarily unoccupied building. It proposes to use the special “Unoccupied Mode” that maintains the building within a reasonable range of temperature and humidity conditions, while reducing energy use during the shutdown. For example, the number of operating boilers should be reduced to the minimum needed. However, to avoid further problems with the system operation, the boilers and DHW circulation systems should operate at least once per week for a minimum of 1 h in a normal regime.

In [25], several conditions of energy use in a typical household in

Serbia are considered: S1 – Reference case, S2 – Mild protection measures, S3 – Semi-quarantine measures, S4 – Complete quarantine. The numerical modelling for the household is performed in EnergyPlus. As an input for the simulation model, the occupancy profiles in the building for the considered scenarios were used. The simulations show that an increased presence of inhabitants in their households during the corona pandemic has led to an increase in heating use. In normal conditions before declaring the state of emergency, the energy use for heating in March was 3414 kWh. However, in conditions of mild protection measures, semi-quarantine measures and complete quarantine, it could be increased to 4509 kWh, 4487 kWh and 4465 kWh, respectively. In total, heating energy demand reached up to 62% of the total demand [25].

Our study aimed to improve the existing knowledge about heat use in buildings in Norway during the period of the COVID-19 pandemic. The literature review showed a lack of awareness about the changes in heat use in non-residential buildings. Among non-residential buildings, the performance of educational institutions was highly affected by the pandemic. Therefore, this research was focused on the analysis of heat use in educational institutions: schools, kindergartens, and universities. First, our study compared profiles in buildings during the COVID-lockdown and the post-lockdown period with the profiles obtained before the pandemic. The second part of the study was devoted to the development of scenarios for heat use in buildings in conditions of the pandemic lockdown. The following scenarios were considered: 1) Scenario 1 – Modelling based on behavior in a normal year (i.e. the previous year), 2) Scenario 2 – Modelling based on heat use in night hours, 3) Scenario 3 – Modelling based on the current settings that were used in the buildings during COVID-lockdown. The proposed scenarios represented the different settings for the heating systems and gave important information for further efficient utilization of heating systems in buildings. Such a study creates the basis for achieving energy saving in the educational building in Norway.

The paper was structured as the following. Section 2 introduces the methods for the scenarios-based modelling of heat use during the COVID-19 pandemic. Section 3 explains the main characteristics of the buildings that were used for the analysis in our study. In Section 4, the methodology was implemented on the real data, and the main results of this investigation were presented. The profiles of heat use in periods before the pandemic, during the COVID-lockdown, and the post-lockdown were compared. The adequacy of heating systems settings in buildings during lockdown was checked. The scenarios for heat use in Norwegian educational buildings were proposed. Finally, the limitations and conclusions of the study were highlighted in sections 5 and 6.

## 2. Methods

Due to the high activity of the younger generation, educational institutions belong to the type of buildings where restrictions are primarily imposed. During the lockdown, all educational activities are carried out remotely. The educational buildings are closed, and the employees have limited access to these buildings at the same time. The need for heating and DHW in buildings in this period reduces. Consequently, the heating system's exploitation in a way as before the lockdown, becomes excessive and inefficient. Unnecessary energy use can be avoided by applying the proper settings to the buildings' heating system in adjustment to these demand changes. In order to select proper settings and estimate the benefits of their implementations, scenario-based modeling should be performed. In addition, the potential for energy savings can be assessed by comparing a scenario that represents the behavior of heating use under normal conditions with alternative scenarios for the lockdown period. Therefore, this chapter presents the approaches for modeling three different scenarios of heat use in buildings during the lockdown. This chapter consists of three subsections. Each subsection presents the methods for developing a particular scenario of heat use in buildings during the pandemic. Subsection 2.1 considers Scenario 1 when the settings of the heating system did not change and remain the same as for

the normal year. Subsection 2.2 shows Scenario 2, where the heating system was set to the night heat demand of the normal year. Subsection 2.3 shows Scenario 3 when the settings that were applied during the lockdown in March–April 2020 were used for the entire year heat use prediction.

### 2.1. Scenario 1 - Modelling heat use for based on behavior in a normal year

When the building is operating in a regular regime, not affected by unexpected changes in occupancy, the outdoor temperature may be treated as the main factor that explains the variation of heat use in buildings [26]. The model that expresses the relationship between the heat use in an observed building and the outdoor temperature is called the Energy Signature Curve (ESC) [27]. The ESC is widely used for energy planning in buildings [28]. Usually, the ESC contains two sub-models divided by the change point temperature (CPT). The CPT is a critical temperature that sets the boundary between the start and the end of the heating season. Piecewise regression is a method that can be used to build the ESC model. By piecewise regression method, the two separate sub-models for ESC are identified by using the following:

$$f(x) = \begin{cases} \beta_0 + \beta_1(x - CPT) + \varepsilon & \text{If } x < CPT \\ \beta_0 + \beta_2(x - CPT) + \varepsilon & \text{If } x > CPT \end{cases} \quad (1)$$

where  $f(x)$  is a model for the ESC,  $x$  is the outdoor temperature,  $\beta_0$ ,  $\beta_1$ ,  $\beta_2$  are the coefficients of the piecewise model, and  $\varepsilon$  is the residual error.

It is well known that heat use in buildings also varies depending on days of the week and hours of the day [22]. Due to the diverse schedules of work, in working days at hours when the main activities are held, the heat use in educational buildings is much higher comparing to the rest of the time. For this reason, in order to plan the heat use in a regular regime, we developed the separate ESC models for each hour of the weekdays and weekends. In such a way, based on the data obtained for 2019, we developed the 48 ESC models that explained how the heat use in a building would behave if the settings of these considered buildings remain the same as before COVID-19 pandemic.

In order to formulate heat use in Scenario 1, the outdoor temperature data for the typical cold and warm meteorological years (TMY) were applied as an input to the ESC models. The temperature data for the typical meteorological years for different locations may be found at the website of the European Commission information system [29]. The temperature data is produced by choosing each month with the most "typical" conditions out of the last 10 years [29]. By this means, using the typical cold and warm temperatures allowed us to obtain expected boundaries of heat use for each hour of the typical year in Scenario 1 (i.e. for normal conditions when no changes were made in the operation of the building heating system).

### 2.2. Scenario 2 – Modelling based on hours of night heat use

Compared to Scenario 1, Scenario 2 considered better operation settings for the heating system during the lockdown. In this scenario, it is assumed that during the lockdown, the buildings' heat use should be kept at the level of night heat use under the normal pre-pandemic conditions. In the educational institutions, the lowest heat use can be usually observed at the night time from 1:00 o'clock to 5:00 o'clock in working days, when there are no people in buildings and the heating system is working with the minimum energy load required to maintain the lowest acceptable temperatures.

In order to express the possible reduction of heat use in the buildings, the ESC model based only on nighttime heat use was developed. After that, in a similar way to Scenario 1, the ESC model was applied to the outdoor temperature data for the typical cold and warm meteorological years. In such a way, possible boundaries of the heat use for each hour of the typical year in Scenario 2 were obtained (i.e. for conditions when the

heating system was operating at the night level).

### 2.3. Scenario 3 – Modelling based on current settings that were used in the buildings during COVID-lockdown

Scenario 3 was intended to explain how building heat use would behave if the settings that were actually applied to the heating system during the COVID-lockdown in Norway would be continuously used to the typical year. Scenario 3 was developed based on the average monthly heat use that was observed before and during the COVID-19 pandemic. The flowchart of the algorithm applied to Scenario 3 is shown in Fig. 1.

The detailed algorithm for determining boundaries of the heat use under Scenario 3 was as the following:

*Step 1. Identify the model that reflects the relationship between the monthly heat use and the outdoor temperature in normal conditions.*

It is well known that monthly heat demand in buildings varies throughout the year due to changes in the outdoor temperature [28]. The average monthly heat use and the outdoor temperature are linearly dependent as stated in Ref. [30]. In order to explain these relationships, a linear regression model was developed based on data from 2019.

*Step 2. Based on the identified model in Step 1, calculate expected monthly heat use for the typical cold and warm years.*

At this stage, the average monthly outdoor temperatures for typical years were used as the input to the regression model (see Step 1). Thus, the values of the expected monthly heat use for a typical cold and warm years were obtained.

*Step 3. Calculate the monthly variation factors for the typical years.*

In accordance with the expected monthly heat use for a typical year, the monthly variation factors for the heat use was calculated as:

$$K_i = E_{t,i} / \bar{E}_t \quad (2)$$

where  $K_i$  is the monthly variation factors for  $i$ -th month,  $E_{t,i}$  is the expected heat use for  $i$ -th month of the typical year,  $\bar{E}_t$  is the average monthly heat use for the typical yearly.

*Step 4. Identifying the average monthly heat use for the COVID-lockdown months.*

Relying on data in 2020, the actual monthly heat use when the COVID-19 lockdown occurred were identified. The analysis showed that

the difference between the monthly outdoor temperatures in March 2020 and the typical warm year was only 0.4 K. On the contrary, in the outdoor temperature in 2020 April was closer to the cold year with the temperature difference of 1 K. For this reason, it was assumed that heat use in March for a typical warm year was equal to heat use in March 2020, and heat use in April for a typical cold year was equal to heat use in April 2020.

*Step 5. Extrapolating the heat use for the rest of the year based on the monthly variation factors.*

By using the monthly variation factors, the average monthly heat use when the COVID-19 lockdown occurred were extrapolated for the typical cold and warm years. In such a way, we obtained boundaries of the average monthly heat use in Scenario 3 (i.e. for conditions when the heating system was expected to operate under settings that were used in the buildings during COVID-lockdown).

### 3. Description of the observed educational buildings

The investigations in this article were performed based on data obtained from educational institutions located in Trondheim, Norway. University buildings are presented by the Geology and Mineral Resources Engineering building at the campus of Norwegian University of Science and Technology (NTNU). This building was built in 1953 and it underwent several renovations afterwards. It has an area of 3516 m<sup>2</sup>. A more detailed description of the buildings properties and energy use at the entire NTNU campus are given in Ref. [31]. The heat use data for this building were collected from the energy management system of NTNU. The information of the heat use in eight kindergartens and 12 schools were obtained from the energy monitoring platform of the Trondheim municipality. Among these schools, nine schools are for junior pupils, two schools are secondary schools, and one is the mixed school. The area of kindergartens are within 779–2086 m<sup>2</sup>, and the area of the schools are within 3206–8449 m<sup>2</sup>. All the buildings in the analysis are using district heating system (DH) as the main heating supply carrier. In order to compare buildings of different characteristics, the average heat use per heating area (per m<sup>2</sup>) was used as a physical indicator.

The influence of weather conditions on heat use was considered in the investigation. For this purpose, data obtained from the nearest meteorological station located in Trondheim were used [32].

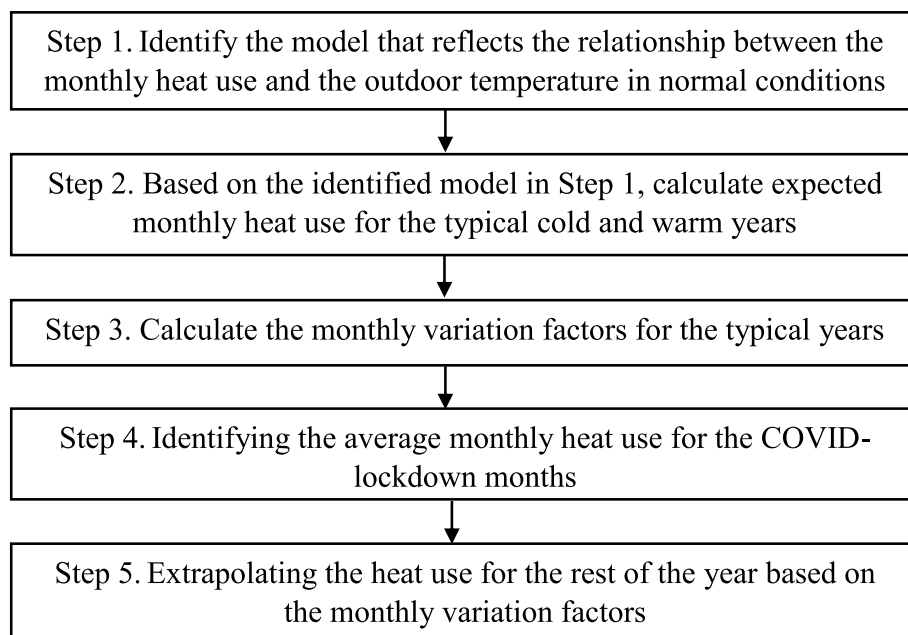


Fig. 1. Flowchart for the algorithm for determining the heat use in Scenario 3.



## 4. Results

This section is divided into two subsections. The analyses of heat use profiles before and during the COVID-19 restrictions is given in Section 4.1. The several scenarios for heat use in the educational institutions are shown in Section 4.2.

### 4.1. Analysis of heat use profiles in educational institutions before and during the COVID-lockdown

Norway is among the countries that had imposed strict restrictions when the COVID-19 pandemic began to spread in early 2020. One of these restrictions was the temporary lockdown of educational institutions. Following the recommendations of the government, schools and kindergartens were closed from March 13th to April 23rd 2020. The universities in Norway also stopped their regular operation starting from March 13th. Unlike schools and kindergartens, classes at the university buildings were resumed only from August 2020. However, a significant share of employees returned to physical presence on campuses in May 2020. Accordingly, this chapter is focused on comparing heat use in March, April, and May 2019 and 2020. In addition, in our investigation, March and April included only days when the lockdown was imposed.

Energy use profiles are a powerful instrument that allow us to display the changes in heat use at different time intervals. In our work, the profiles were used for the analysis of heat use variability before and during the COVID-19 pandemic. Although the outdoor temperature influence heat use [28], it was decided to compare the real profiles rather than the temperature adjusted values in this work. This enables us to focus on real data without making any biased suggestions. The temperature adjustment of heat use was introduced in the scenario analysis (See Chapter 4.2). Nevertheless, in the analysis of the profile, the outdoor temperatures in 2019 and 2020 were considered. It was considered that the average outdoor temperature in March 2019 was 0 °C, and in March 2020 it was 1.7 °C. In April 2019, the outdoor temperature was 7.2 °C, and in April 2020 it was 3.9 °C. Whereas in May 2019 it was 7.9 °C, and in May 2020 it was 6.4 °C. As it may be noted, April and May in 2020 had slightly colder temperatures than in 2019, while March a bit warmer.

Since weekdays and weekends have different patterns of heat use, their profiles were considered separately. The average daily heat use profiles for kindergartens, schools, and university campus of 2019 and 2020 are compared in Figs. 2-4, respectively. In Figs. 2-4, WD denotes working day and WE denotes weekend, and the dashed lines stand for 2019 and the solid lines for 2020. Typically, on weekdays, the main

heating load follows the opening hours of the educational institutions. The heat use generally increased from 7:00 to 16:00 o'clock with the peak of the heat use at 9:00 o'clock, and a significant heat reduction persists from 20:00 to 6:00 o'clock next morning. From Figs. 2-4, it may be observed that the shape of the heat use profiles before and during the pandemic in educational institutions remained almost the same. The profiles show that for kindergartens, this working schedule did not change during the COVID-lockdown in 2020. For schools, there was a slight change of the peak load that was shifted backwards by an hour in March and April 2020 and forward by an hour in May 2020. For the university campus, the peak heat was moved backwards by an hour in April and two in May, while much lower heat demand during the off-work time in March 2020 was noticed.

In Norway, teaching activities are not carried out in educational institutions on weekends. Thus, the heat load on weekends was much lower than on weekdays and is more in line with the heat load on weekdays at night. In Figs. 2-4, it may be noted that the minimum heat use on weekends was from 12:00 to 20:00 o'clock. It is likely that during this period, the heating system was operating at the minimum load, and the indoor temperature in the building was maintained mainly by thermal inertia.

Figs. 2 a)- Fig. 4 a) show that during the weekdays in March 2020 heat use was reduced compared to the same period of 2019. However, unlike the assumptions made in Ref. [7], the profiles in the working days 2020 were not identical to the weekends. One of the reasons for this could be that some institutions may have operated during the COVID-lockdown. In order to support parents who are working in the critical positions such as medical systems, transportation, police stations, and others, kindergartens and junior schools (See Appendix Fig. A1) remained open during the pandemic. On the other hand, our analysis also showed that some buildings were using energy inefficiently and did not reduce heat use, regardless of the transition to distance learning. For example, the profiles for the secondary schools (See Appendix Fig. A2) showed that they did not decrease heat load in the buildings.

Despite the lockdown, in April 2020, the heat use was slightly higher than in April 2019. This fact can be explained by several reasons. Firstly, from April 18th to 22nd 2019, there were public holidays in Norway, and most educational buildings were closed in these days. The second reason is that April 2019 was warmer than April 2020, which led to less energy use in 2019. The third reason is preparation for buildings reopening at the end of April 2020. For example, it required cleaning and disinfection work, and testing of the heating system performance, which resulted in increased heat use.

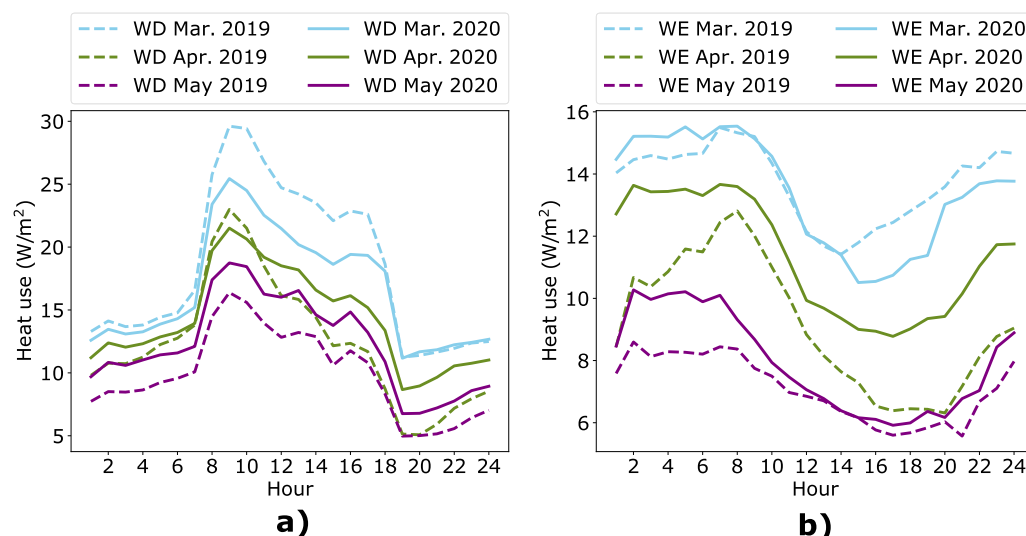


Fig. 2. Heat use profiles for kindergartens, where: a) profiles for weekdays, b) profiles for weekends.

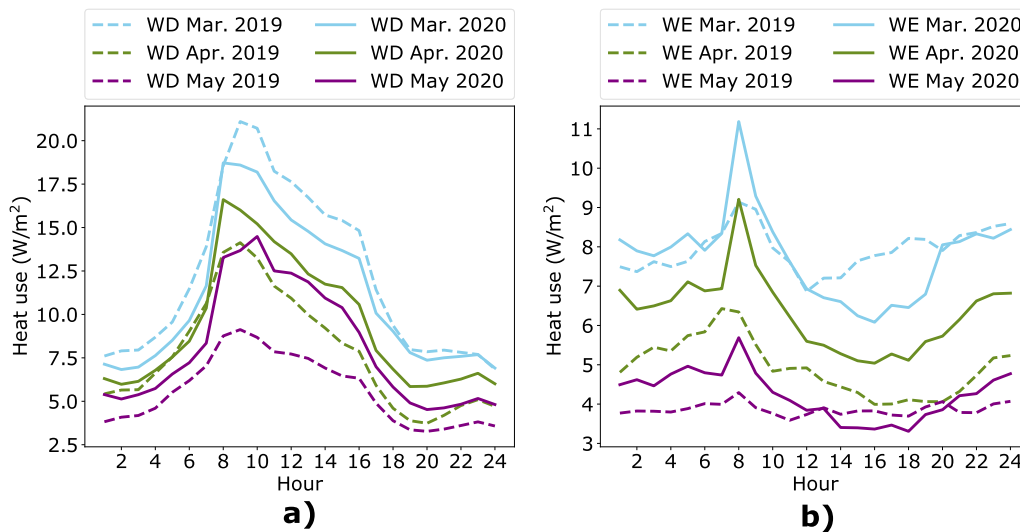


Fig. 3. Heat use profiles for schools, where: a) profiles for weekdays, b) profiles for weekends.

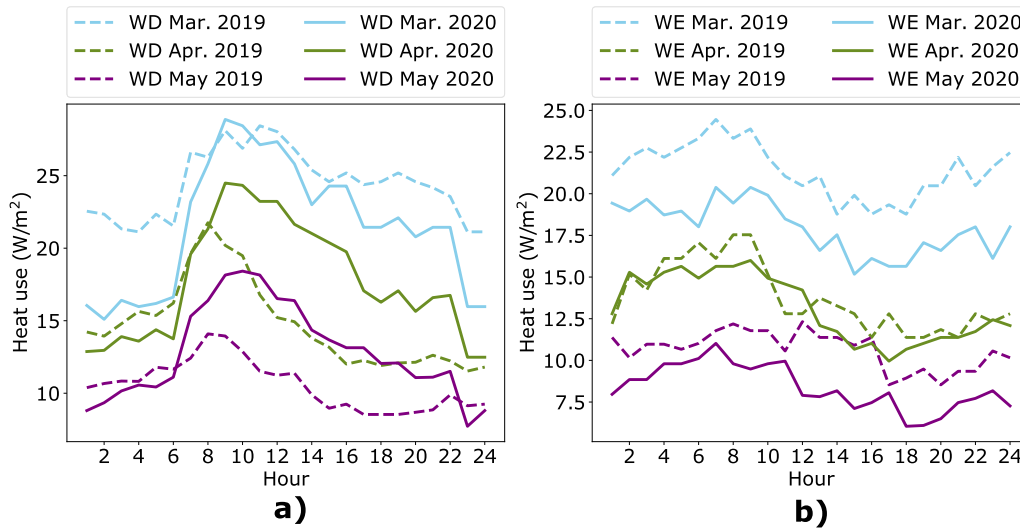


Fig. 4. Heat use profiles for the university campus, where: a) profiles for weekdays, b) profiles for weekends.

After buildings reopening in May 2020, we can observe an increased heat use comparing to May 2019. This phenomenon may be associated with an increase in DHW use for regular disinfection of buildings and personal hygiene.

For many buildings, the profiles showed that the operation of heating systems during lockdowns should be changed to be more efficient. In order to achieve this goal, it is therefore necessary to develop recommendations and scenarios for operation of heating systems in various conditions.

#### 4.2. Analysis scenarios of heat use in educational institutions

This chapter explores three scenarios for the operation of the heating system in educational institutions during the pandemic. All the scenarios were developed by employing real statistical data obtained from schools, kindergartens and university campus.

Scenario 1 investigated the heating system operation in the same regime as before the pandemic. This scenario was developed based on the method presented in Section 2.1. The ESC models for every hour on weekdays and weekends were developed with the data for 2019. Thus, the heat use for each building type was represented by 48 ESC models.

For all these ESC models, the CPT of 14 °C showed the best approximation.

An example of the ESC models for the heat use at the 13-th hour in kindergartens is shown in Fig. 5. For a more detailed analysis, the actual heat use in 2019 and during the lockdown in 2020 was also plotted in Fig. 5. As it may be seen from Fig. 5, the heat use during the COVID-lockdown lies close to the pre-pandemic data and models. This fact proves that the operation of heating systems in kindergartens remained practically unchanged during the lockdown in 2020. For other educational institutions, the ESC models demonstrated similar results.

It should be noted that at certain hours on weekdays, the line after CPT had a slight positive slope (See Fig. 5 a)). From a theoretical point of view, with an increase in outdoor temperature, heat use should decrease. This positive slope can be explained by the use of the cooling system during the hot days.

Table 1 shows that the application of 48 ESCs allowed us to obtain quite accurate models for normal conditions of the heat use. For kindergartens and schools, the  $R^2$  was around 0.94, while for the university campus  $R^2$  was 0.83, meaning that all met the requirement of ASHRAE guidelines for achieving a satisfying regression model. In order to develop Scenario 1, the outdoor temperatures for the typical cold and

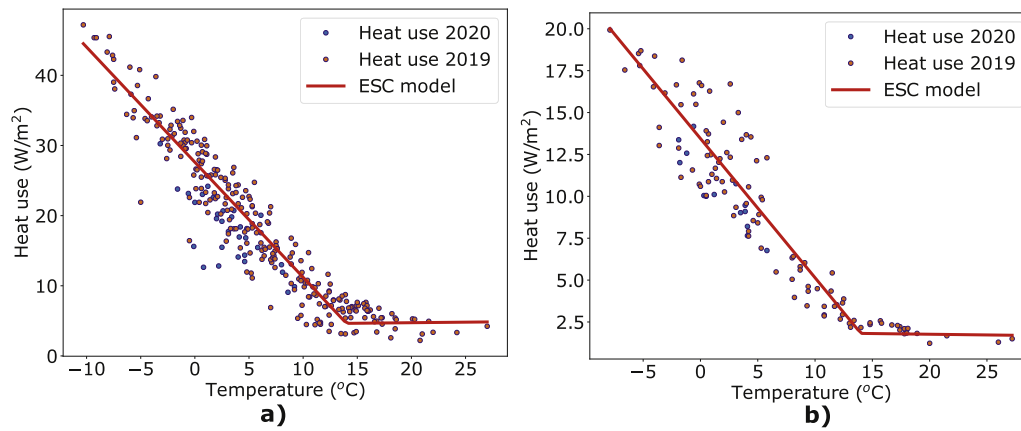


Fig. 5. ESC models for 13-th hour for kindergartens, where: a) ESC for weekdays, b) ESC for weekends.

Table 1

Accuracy of the model based on 48 ESC for Scenario 1.

Building type	CPT (°C)	R <sup>2</sup>	MAE	MSE
Kindergarten with DH	14	0.94	1.04	4.38
Schools	14	0.94	1.68	11.15
University campus	14	0.83	2.28	20.03

warm meteorological years were applied as the input to the 48 ESC models. In such a way, the possible boundaries of the heat use in buildings for Scenario 1 were identified.

The boundaries of the heat use in Scenario 1 for the schools, kindergartens, and university campus are shown in Fig. 8-10. The potential of energy savings can be assessed by comparing Scenario 1 with the other scenarios that represent more efficient settings of the heating systems.

Scenario 2 assumed that during the lockdown, the heat use in the buildings should be kept at the level of night setting under normal conditions. The heating system operation under such conditions may be explained by the ESC model determined based on the heat use in 2019 at the nighttime. An example of the ESC model for the kindergartens is shown in Fig. 6. This model represents periods when the heating system was operating at the minimum load due to the low occupancy in the buildings.

The accuracy criteria for the ESC models in Scenario 2 are given in Table 2. They indicated that the models explained the heat use reasonably well. For instance, for the kindergartens R<sup>2</sup> = 0.93, for the schools R<sup>2</sup> = 0.88, and for the university building R<sup>2</sup> = 0.78. The typical cold

Table 2

Accuracy of the ESC models based on night heat use for Scenario 2.

Building type	CPT (°C)	R <sup>2</sup>	MAE	MSE
Kindergartens	14	0.933	0.83	1.99
Schools	14	0.883	0.66	1.29
University campus	14	0.78	2.28	16.27

and warm temperatures were applied to the ESC models in order to identify possible boundaries of heat use in Scenario 2. The heat use over the entire year for this scenario is presented in Figs. 8-10. Comparing to Scenario 1, Scenario 2 presented a reasonable approach to reduce heat use during the lockdown when buildings are not occupied.

Scenario 3 demonstrated the average monthly values of the heat use in conditions when the heating system was operated under the settings that were really applied during the COVID-lockdown in March-April 2020. Similar to the previous scenarios, Scenario 3 was adjusted with the typical cold and warm years. For the development of Scenario 3, the monthly heat use model for 2019 was determined. The study revealed that the relationship between the average monthly heat use in educational buildings and the outdoor temperature could be described by a linear regression model, as shown in Fig. 7. Table 3 shows the validation criteria for the monthly heat use models. The R<sup>2</sup> criteria in Table 3 were from 0.94 to 0.98. These values indicated that models were accurate enough to be used for the investigation.

The average monthly outdoor temperatures for typical cold and warm years were used as the input to the model for Scenario 3. In such a way, the expected monthly heat use for typical years was determined. After employing Equation (2), the monthly variation factors of heat use

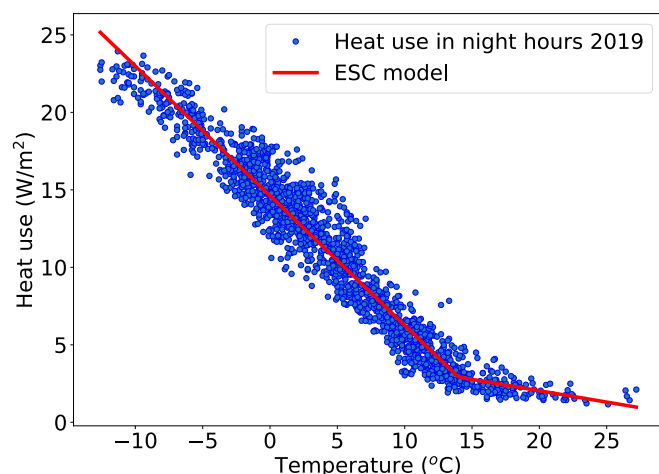


Fig. 6. ESC for kindergartens for night settings of heat use.

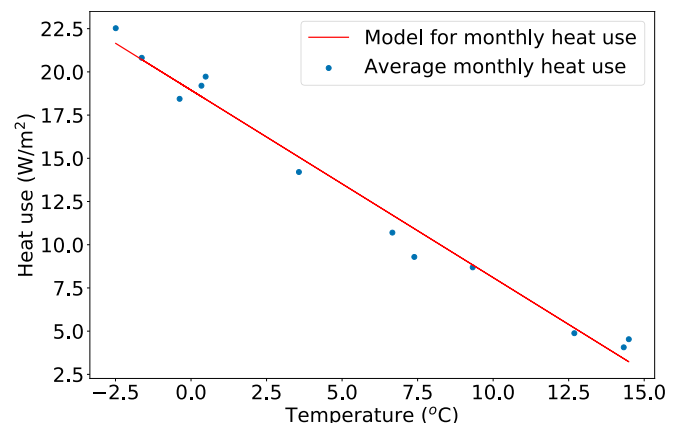


Fig. 7. Monthly model of heat use for kindergartens.

**Table 3**  
Accuracy of the monthly heat use model for Scenario 3.

Building type	R <sup>2</sup>	MAE	MSE
Kindergartens	0.98	0.87	0.87
Schools	0.97	0.56	0.58
University building	0.94	1.85	5.85

were identified. The variation factors for the typical cold and warm years are presented in Tables 4 and 5.

The monthly variations factors present the seasonality of the heat use. They showed that the highest heat use in the educational buildings occurred in January, March, and December. The lowest heat use was observed in the summertime, when space heating system was not used, and DHW use reduced due to summer holidays. For a typical cold year, the difference between the heating season and the summer months was more significant than for a typical warm year. This phenomenon may be explained by the fact that the heat use was significantly affected by the outdoor temperature and the DHW use due to the colder inlet water temperature. Therefore, the warmer outdoor temperatures caused lower heat use in buildings and vice versa.

The boundaries of the heat use under Scenario 3 for schools, kindergartens, and the university building are presented in Figs. 8–10. Scenario 3 indicated also months that have the highest variation of the heat use between the typical cold and warm year. Among these months January, October, and December were the most noticeable ones, which may be seen with the large shadowed squares in Figs. 8–10.

Scenario 3 was created using the monthly average values, and therefore, it was not as accurate as Scenarios 1 and 2 with the hourly values. This issue is discussed in Section 5. However, when considering the average monthly values, Scenario 3 would require higher heat use than Scenario 2, because it did not follow the advantageous energy-saving setting of the heating system.

The proposed scenarios can be used for planning the heat use and estimating the potential energy savings. For example, the analysis showed that application of night settings as in Scenario 2 during the lockdown in March might allow us to save 79 Wh/m<sup>2</sup> per day for kindergartens, 72 per day Wh/m<sup>2</sup> for schools, and 80 Wh/m<sup>2</sup> per day for university building. In normal conditions, the specific annual heat use in kindergartens was 102 kWh/m<sup>2</sup> per year, in schools 63 kWh/m<sup>2</sup> per year, and in university 123 kWh/m<sup>2</sup> per year. Therefore, if annual heat use is considered, for kindergartens, the application of Scenario 2 may save 20.2 kWh/m<sup>2</sup> per year, for schools –17.7 kWh/m<sup>2</sup> per year, and for university building 21 kWh/m<sup>2</sup> per year. By applying the proper setting of the heating system during a pandemic is expected to reduce energy use and save money.

##### 5. Discussion and limitations of the study

The COVID-lockdown in the educational institutions in Norway lasted for about two months. In this regard, the amount of the data collected over this period was limited for a comprehensive analysis. The comparison of the heat use profiles in this work was performed only for March, April, and May. The analysis of the annual data would be more useful and provide a better understanding of changes in the heat use. Due to the lack of data, it is challenging to forecast the heat use for the entire year. Furthermore, due to restrictions that were gradually

**Table 4**  
Monthly variation factors for a typical warm year.

Building type	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Kindergartens	2.1	1.63	1.42	0.9	0.66	0.6	0.35	0.29	0.41	1.14	0.98	1.48
Schools	2.22	1.7	1.48	0.9	0.62	0.56	0.28	0.21	0.34	1.16	0.98	1.54
University building	2.35	1.78	1.53	0.88	0.59	0.51	0.2	0.13	0.27	1.17	0.98	1.59

imposed, the patterns of the heat use may be changed several times during and after the lockdown. For this reason, this work focused on developing different heat use scenarios during a pandemic. These scenarios were adjusted to the outdoor temperatures of the typical cold and warm meteorological years. Typical temperatures are an approximation for the last 10-years and therefore may differ from the actual temperatures in subsequent years. Accordingly, they can be used only for estimation of possible boundaries of heat use in buildings rather than accurate forecasting. Scenarios 1 and 2 were developed based on actual heat use for the entire 2019. No noteworthy assumptions were made in these scenarios. Contrarily, Scenario 3 was based on monthly heat use in March and April 2020 that was extrapolated for the typical cold and warm years. Such extrapolation was based on several assumptions. First, it was expected that monthly variation factors identified based on the data from 2019 would be applicable for the pandemic conditions. Despite the consistency of this assumption, it is impossible to confirm it with the available data. The second assumption used the fact that the monthly outdoor temperatures in March and April 2020 were close to temperatures for the same month in the typical years. However, even due to minor differences in the temperatures, the particulate inaccuracy of Scenario 3 might occur. For this reason, if the additional data could be collected, further work shall be performed for improving Scenario 3. In addition, better scenarios may be identified.

The analyzed buildings in this study are using DH as the main heating supply method and electricity for electric appliances. Meanwhile, there are also many Norwegian buildings having electricity as the main energy supply method, including electric heating without submeters. It would be interesting to investigate the energy changes of these buildings during the lockdown or other circumstances in further research.

##### 6. Conclusions

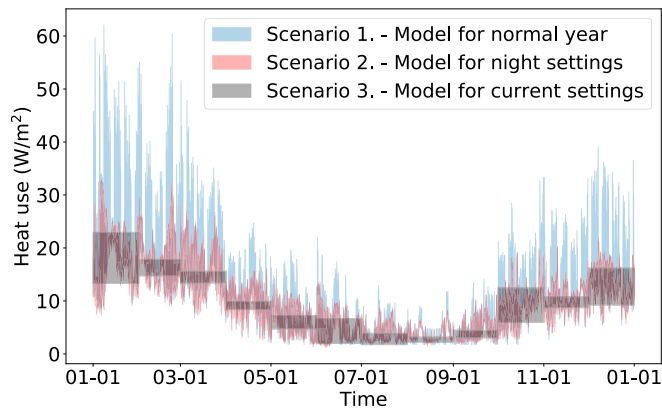
The COVID-19 pandemic poses significant challenges to the energy sectors both in Norway and many other countries. These challenges are primarily related to fluctuations in energy use of buildings caused by restrictions that aim to stop spreading of the infection. The operation of educational institutions was significantly affected by lockdown in March–April 2020 and other restrictions. Understanding the changes in energy use triggered by the pandemic is essential for further energy planning, avoiding excessive energy use, and ensuring the proper operation of buildings. Among all technical systems in buildings, the heating system is the biggest energy user in Norway. Despite this fact, the literature review showed that the operation of heating systems and the heat use in educational buildings during and after the COVID-lockdown is not investigated enough yet. This article highlights the issue of the analysis of the heat use profiles and scenario development for schools, kindergartens, and university buildings in Norway.

Many publications assume that during the lockdown, the operation of educational institutions would follow the weekend patterns. However, our research rejected this hypothesis. The investigation found that the shape of the heat use profiles on weekdays before and during the pandemic remains almost unchanged and differs significantly from the weekend profiles. The profiles revealed that in March 2020, the heat use was lower than in the same period of 2019. In April 2020, the heat use was slightly higher than in April 2019. Differences between the profiles in March and April were mainly influenced by changes in the outdoor temperature, instead of changes in the heating system settings.

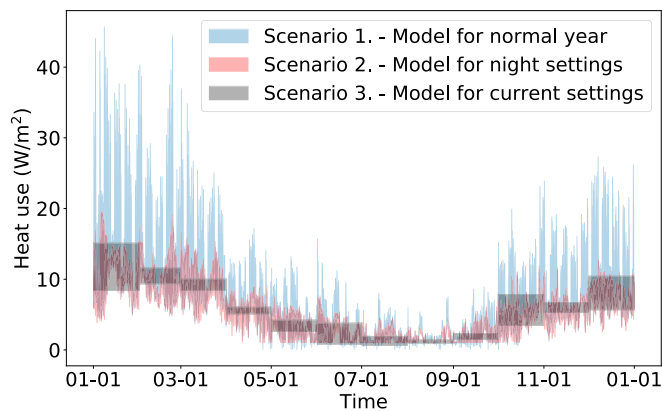


**Table 5**  
Monthly variation factors for a typical cold year.

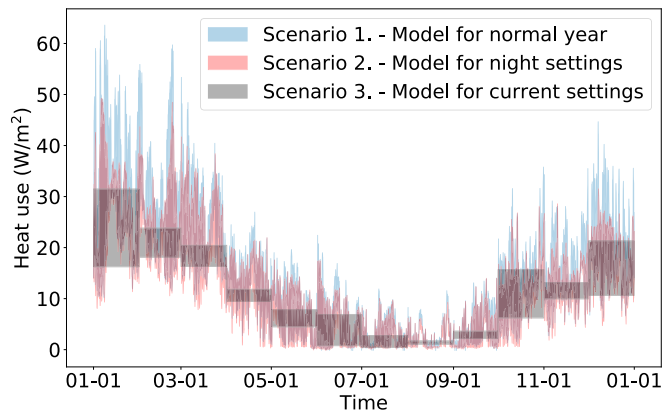
Building type	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Kindergartens	1.83	2.02	1.84	1.14	0.64	0.27	0.23	0.3	0.41	0.82	1.20	1.27
Schools	1.93	2.14	1.94	1.16	0.6	0.18	0.14	0.21	0.34	0.79	1.22	1.29
University building	2.03	2.27	2.04	1.18	0.55	0.1	0.06	0.13	0.27	0.78	1.24	1.33



**Fig. 8.** Three scenarios for the heat use in kindergartens.



**Fig. 9.** Three scenarios for the heat use in schools.



**Fig. 10.** Three scenarios for the heat use in the university building.

Therefore, it can be stated that during COVID-lockdown, the energy system in many buildings was operated inefficiently. After the educational buildings were reopened in May 2020, the profiles showed an increase of the heat use. Such an increase might be explained by introducing strict requirements for regular buildings' disinfection and personal hygiene.

The short-term lockdown in March–April 2020 did not allow us to collect enough statistical data about the heat use. The available data were not adequate for accurate prediction of the heat use. For this reason, instead of performing model prediction, this article suggested scenario-based modelling for possible settings of the heating system. The following scenarios were developed for educational institutions: 1) Scenario 1 – Modelling based on the settings for a normal year, 2) Scenario 2 – Modelling in accordance with night settings of heat use, 3) Scenario 3 – Modelling based on settings that were used during the lockdown. All the scenarios were adjusted with the outdoor temperatures of the typical cold and warm years. The ESC method showed high accuracy in modelling Scenarios 1 and 2. Scenario 3 was developed by monthly variation factors of the heat use. These factors were used in order to project the seasonal variations of the heat use in the COVID-lockdown conditions. The proposed scenario can be used for planning the heat use and estimating the potential energy savings. For example, the analysis showed that application of night setting, Scenario 2 might allow us to reduce daily heat use up to 54% compared to the normal settings, Scenario 1. For kindergartens, it might be reduced up to 261 Wh/m<sup>2</sup>, for schools – 236 Wh/m<sup>2</sup>, and for university building – 248 Wh/m<sup>2</sup>. The methods and outcomes of the study may be applied to similar types of buildings when temporary lower attendance or shutdown will appear.

#### CRediT authorship contribution statement

**Dmytro Ivanko:** Conceptualization, Methodology, Formal analysis, Software, Investigation, Writing – original draft, Visualization, Writing – review & editing. **Yiyu Ding:** Methodology, Formal analysis, Writing – review & editing. **Natasa Nord:** Conceptualization, Methodology, Formal analysis, Supervision, Writing – review & editing.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A

The appendix includes Fig. A1 and Fig. A2, which show heat use profiles for junior and secondary schools during COVID-lockdown in Norway.

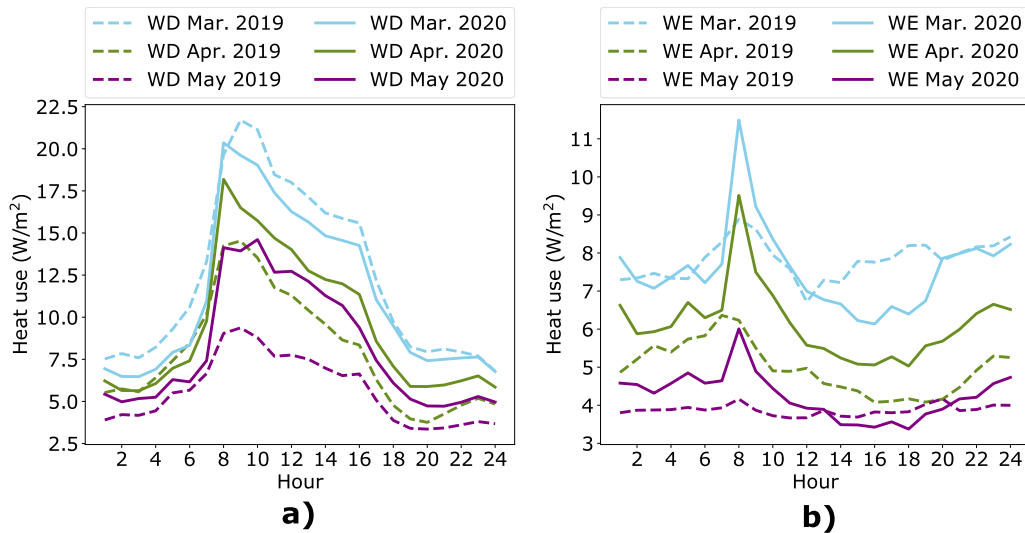


Fig. A1. Heat use profiles for junior schools, where: a) profiles for weekdays, b) profiles for weekends.

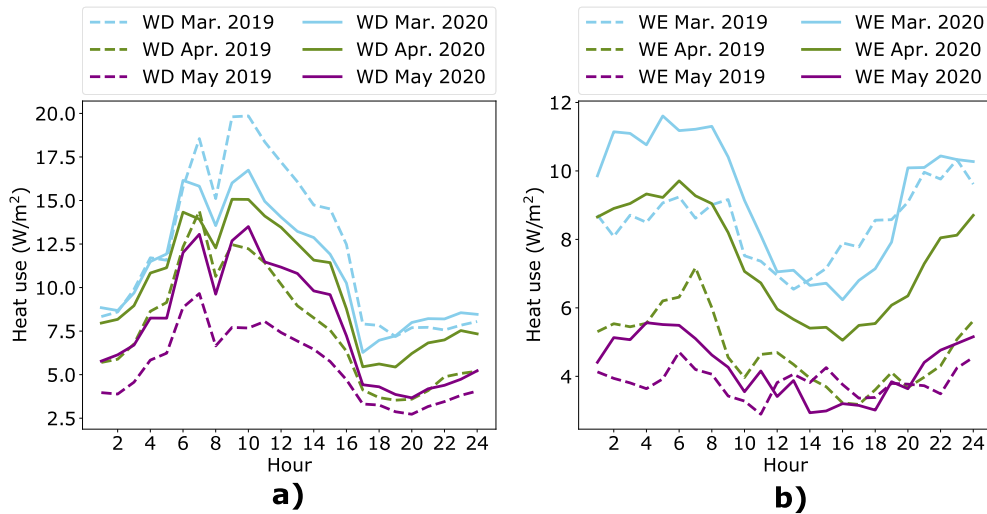


Fig. A2. Heat use profiles for secondary schools, where: a) profiles for weekdays, b) profiles for weekends.

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