

The impact of the behaviour of individual users in single-family households on the values of internal heat gains in a building

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Abstract

The aim of this study is to analyse the presence and activity of users in individual households by means of quantitative and qualitative research – questionnaires and interviews. The users' behaviour has a significant impact on the thermal-flow processes taking place in the building, so their verification, ultimately, makes it possible to reduce the difference between the calculated and actual energy consumption of the building. The literature review revealed a lack of updated building occupancy schedules, which changed significantly after the COVID-19 pandemic. Based on the data collected, 6 household occupancy profiles were proposed, which, when combined, form a model describing behaviours (occupancy profile, profile of electrical appliances, lighting, natural ventilation, heating installations and supporting appliances). The model took into account the effect of internal heat gains on the energy balance of the building, including the working system – home office mode. The collected data was fed into a reference building model and an hourly dynamic simulation was carried out using commercial DesignBuilder software. Using outdoor climate parameters for selected cities, the reference building's annual heat demand was demonstrated and an assessment of the building's indoor microclimate was provided. The multi-criteria empirical approach resulting in a set of revised data can be generalised and adapted to a larger group of actors, a selected area and a building.

Keywords: Human behaviour; Schedules; Heat-flow processes; Heat demand

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1. Introduction

The construction sector is widely recognised as one of the most energy-intensive [1]. In 2020, electricity and heat consumption in the residential sector in the European Union (EU) was 714 TWh, which amounts to 1.6 MWh (1595 kWh) per capita. The correct application of methodologies for determining the energy performance of buildings influences the accuracy of the scale of the

problem and the improvement in their energy efficiency [2]. Static methods are subject to a large calculation error, and the use of dynamic methods, which give more accurate results, requires the introduction of a large number of parameters in complex calculation procedures [3]. Modelling these parameters is very labour-intensive, so many researchers use simplified static methods and, in the case of dynamic methods, parameter values derived from outdated literature data. The rapid development of technology has

Nomenclature

d – permissible error, %
 m – fraction size
 n – population size
 n – sample size
 u_α – value resulting from the adopted confidence level, %

Abbreviations and Acronyms

ASHRAE – American Society of Heating, Refrigerating and Air-Conditioning Engineers
 Cfb– C = warm temperate, f = fully humid, b = warm summer
 Dfb– D = continental, f = fully humid, b = warm summer

Dfc – D = continental, f = fully humid, c = cool summer
 DHW – domestic hot water
 DOE – Department of Energy
 EPW – energy plus weather
 ET – E = polar, T = tundra
 EU – European Union
 HDD – heating degree day
 HDI – human development index
 HVAC – heating, ventilation, air conditioning
 IEA – International Energy Agency
 MOTIE – Ministry of Trade, Industry and Energy
 NOAA – National Oceanic and Atmospheric Administration
 TMY – typical meteorological year

resulted in human dependence on appliances, which is why electricity consumption has increased very strongly in recent decades [4]. Consequently, the consideration of internal heat gains has become an important element in determining the thermal load of residential buildings.

Many researchers stress the importance of using the most realistic model of occupant presence and activity to perform dynamic energy analyses of buildings [5]. Despite this, authors still typically adopt the ASHRAE 90.1 standard in their energy analyses [6]. Lee et al. [7] conducted an analysis of the effect of internal heat gain levels on the determination of building envelope insulation standards for a large-scale office building. Although the analysis carried out was very detailed, the modelling of internal heat gains was based on standards and literature data: Department of Energy (DOE), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Ministry of Trade, Industry and Energy (MOTIE). Literature data on European electrical and hot water load profiles by the International Energy Agency (IEA) [8] were also used by Ampatzi and Knight [9]. In their work, the authors included patterns of daily electricity consumption to model internal heat gains, which have important implications for the performance design of solar thermal systems in multifamily buildings. Ferdyn-Grygierek et al. [10] included values of internal heat gains in their validation studies of daily heat demand, where for a school building, the values were adopted according to ASHRAE recommendations [11], and for a multi-family building, random tests were performed. On the basis of the results from random tests, the authors assumed constant heat gains, which is a major simplification with a high risk of calculation error with regard to performing dynamic simulations [11]. The results of the analysis of the influence of static and dynamic internal heat gains on heat demand by Elsland et al. [12] show that the static values used in the study are underestimated. In comparison with the existing knowledge, Firląg et al. [13] also showed that the standard values of internal heat gains differ from the actual measured values.

Furthermore, the literature shows that internal heat gains have mostly been modelled for office buildings [14]. Liang et al. [15] conducted a prediction of internal heat gains in an office building using artificial intelligence methods. The analysis was performed for an office building in China. The use of artificial

intelligence methods is very time-consuming, and often, engineers do not have the expertise to perform internal heat gain prediction by such means. The use of fuzzy logic methods appears to be a faster and simpler solution for this type of modelling. Samaan et al. [16] built time schedules of internal heat gains using DesignBuilder software, but only for rooms located in the Mansoura University building. The authors focused their attention on the effect of heat gains from population and daylight on the cooling load of the rooms, abandoning any attempt to predict the heat demand due to the location of the building. As a result, it can be assumed that the analysis makes a significant contribution to the area of knowledge studied, but only for buildings located in tropical climates.

Detailed modelling of internal heat gains in relation to single-family and multi-family buildings has been conducted by several authors. Few analyses have referred to modelling the behavioural variables of individual occupants and their impact on the level of energy demand in single-family passive buildings [17]. Given that passive buildings currently do not account for a large share of the total number of households, the model is only applicable to a very narrow group of consumers. Such studies should be carried out for existing buildings that need to be thermally upgraded. Elsland et al. [12] performed an internal heat gain model for single-family and multi-family buildings at different age groups. The base year was 2008 and an electricity consumption projection scenario was considered until 2050. The scenario took an upward trend in electricity consumption into account, especially with regard to the increasing number of mobile devices. The authors subjected a very large survey sample (27 EU countries) to the study, thus giving indicative results. In this article, the patterns of daily electricity consumption were determined on the basis of the quantitative research carried out – questionnaires that were targeted at a smaller group of people. The individual approach allowed internal heat gains to be modelled with greater accuracy. In addition, the dynamic increase in electricity consumption caused, among other things, by the change to a home office system that occurred during the COVID-19 pandemic, and its continuation and trend towards persistence, indicates an update of the existing scenarios. The literature review showed a lack of such analysis in the last decade. Therefore, one of the key objectives of this study was to

present an empirical approach identifying patterns of hourly electricity consumption in single-family buildings and modelling internal heat gains from these.

The analysis was performed in four stages:

- 1) Identify the area, subject and object of research;
- 2) Carry out a survey consisting of an on-site visit to a residential building and quantitative and qualitative research to collect datasets;
- 3) Performing modelling based on the empirical survey data obtained;
- 4) Carrying out dynamic simulations.

The approach presented here aims to build a theoretical database for engineers and researchers in an effort to improve their work. The modelling of behaviours and their variables makes it possible to accurately determine the heat demand of a building and thus to accurately size heating, ventilation and air-conditioning (HVAC) systems. Efficient operation of HVAC systems contributes to lowering the overall energy demand and thus to maintaining environmental sustainability. As a result, the approach presented aims to improve energy efficiency in residential buildings.

2. Method of solving the research problem

With the aim of building an authentic and contemporary model describing the behaviour of individual users in single-family households and determining its impact on the values of internal heat gains and thus on the heat balance of the building, the research was carried out using descriptive-analytical and simulation methods.

2.1. Descriptive-analytical method

The research was conducted in Norway in 2023. The validity of the choice is emphasised by the HDI (human development index) indicators, according to which Norway is the most developed country in the world after Switzerland [18]. The high standard of living of the population is ensured by the effective operation of state instruments for raw material policy. The revenue generated from oil and gas exports allows, among other things, the formation of a welfare state with the main focus on levelling income inequality in the country. The high national income per capita is synonymous with the desire to improve the quality of everyday life through, among other things, the purchase of high-end household appliances. This translates into the result of average electricity consumption in the residential sector, which fell by 18.5% between 2005 and 2020 [19]. However, the potential to reduce total energy consumption in the residential sector is even higher. Thus, the government's efforts are directed towards introducing financial support mechanisms for retrofitting older buildings and the scientific community's efforts to identify the scale and scope of the problem and to search for the best building and architectural solutions to support the government's efforts, which are already seen worldwide as a pioneering energy policy that is a model for many economies around the world.

With this in mind, selected Norwegian cities were taken as the study area in this paper, the subject was single-family households and the subject was Norwegian society. The exact study area was delineated according to the Köppen-Geiger climate classification [20] and the ANSI/ASHRAE 90.1 and 90.2 [21,22] classification system. An analysis of the literature and statistical data together with their interpretation was used to determine the research subject. However, the minimum size of the research subject (research sample) was determined using the following formula [23]:

$$n = \frac{u_a^2 \frac{m}{n} (1 - \frac{m}{n})}{d^2}, \quad (1)$$

where n is the sample size, u_a is the value resulting from the adopted confidence level, m/n is the estimated proportion in the population (m – fraction size, n – population size) and d is the permissible error.

The confidence level was assumed to be 99% as the survey is targeted at a specific audience. The size of the fraction was assumed to be 50%, assuming that half the respondents may be users of single-family dwellings and half are not. The size of the survey population was calculated using statistics from Statistics Norway 2021. A margin of error of 5% was assumed for the survey sample selection [23].

In the next stage of the research, the data sets necessary to carry out energy simulations and thus determine the scale of the problem – the amount of energy demand in the selected households – were collected. The geometric and technical data sets of the building were constructed using the results from the site visit. On the other hand, the dataset describing the uses of the building was created using the results of quantitative (questionnaires made using Google Forms) and qualitative (interviews) research. Based on the collected dataset from the empirical research, a reference single-family residential building was modelled and a model was created to describe the behavioural patterns of the building's occupants. Modelling was carried out in the commercial simulation software DesignBuilder [24]. Simulations of the dynamic distribution of internal heat gain values were performed using hourly weather data. A set of 8760 data records containing meteorological parameters, being a typical meteorological year (TMY), was downloaded from the international EnergyPlus database [25]. The EnergyPlus Weather (EPW) files in the repository were developed based on the methodology in ISO 15927-4:2005 [26] and weather data provided by the NOAA (National Oceanic and Atmospheric Administration).

3. Course of research

The course of the research consisted of identifying the research area, subject, and object. The research area was defined based on the Köppen-Geiger climate classification. Four main climate zones were distinguished, considering the significant impact of varying solar radiation gains and modeled internal lighting (dependent on daily solar insolation) on the amount of internal heat gains in buildings. Next, the subject of the research was defined,

focusing on single-family residential buildings, which are characterized by the highest electricity consumption within the residential sector. In the final stage, the research sample (research object) was selected for survey distribution in order to develop a model describing the users' behavioral patterns.

3.1. Research area

Four major cities in Norway, located in four different climate zones – Bergen, Oslo, Tromsø and Vardø – were selected for the study. The weather conditions in these cities according to the Köppen-Geiger classification [20] were defined as oceanic climate (Cfb), continental, warm, humid climate (Dfb), subarctic climate (Dfc) and tundra climate (ET), respectively. The affiliation of these cities to climate zones according to the division by ASHRAE [27] is shown in Table 1.

Table 1. Division of Norwegian climate zones according to ASHRAE [27].

City	Climate zone	Description	Criteria
Bergen	5A	cool - moist	$3000 < HDD_{18^{\circ}C} \leq 4000$
Oslo	6A	cool - moist	$4000 < HDD_{18^{\circ}C} \leq 5000$
Tromsø	7	very cold	$5000 < HDD_{18^{\circ}C} \leq 7000$
Vardø	8	subarctic	$HDD_{18^{\circ}C} > 7000$

*HDD – heating degree day.

3.2. Subject of the study

On the basis of the literature data, the residential buildings with the highest energy consumption were singled out. These are single-family households built before 1960 [28]. Their share of the total set of single-family households located in Norway is 30%, which means that this group has a significant impact on sectoral energy consumption and the level of emissions from energy consumption [29]. A detailed summary of the results from the analysis of statistical data on the number of single-family households built before 1960, relative to 2021, in the identified study area is presented in Table 2.

In order to collect geometrical and technical data, an on-site visit was made to a reference building, built before 1960, with a typical Norwegian timber-frame construction. The total volume of the building is 279 m³, of which only 91 m³ is the usable

Table 2. Study subject selection - analysis of the number of single-family dwellings by year and locality [29].

Area	Number of single-family houses built before 1960	Number of single-family houses built between 1960 and 2021
Norway	380 819	1 284 892
Oslo	9407	27 210
Bergen	11647	36 008
Tromsø	2254	15 605
Vardø	365	787

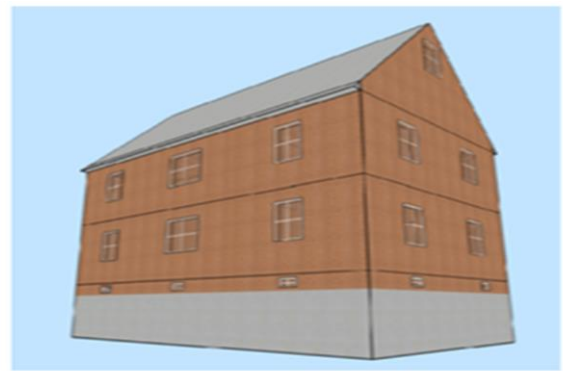


Fig. 1. The building under consideration. This model was created with DesignBuilder software.



Fig. 2. Layout of zones on the first floor. This model was created with DesignBuilder software.

area of the heated part of the building. The basement level is unused, only one room is developed – the boiler room, where the electric hot water heater is located. The second storey is an enclosed, unheated area that serves as a utility room. The third storey is a usable, heated area which includes a kitchen, bathroom, hallway, living room and two bedrooms. The third storey is connected to the attic. The attic is occasionally used and heat is provided by convection. The measures for separating the unheated zone (basement, ground floor) and the heated zone (1st floor) aim to reduce the heat demand. A model of the building is shown in Fig. 1 and Table 3 summarises the parameters of the zones located on the first floor, which constitute the heated floor area (Fig. 2).

Table 3. Area of usable space.

Zone	Purpose	Area of the room (m ²)
Corrido	Corridor	19.1
Bathroom	Bathroom	3.1
Kitchen	Kitchen	12.5
Living room	Living room with dining area	24.8
Bedroom 1	Parents' bedroom	13.2
Bedroom 2	Children's bedroom	18.3
Total usable area	Usable, heated	91.0

Table 4. Building envelope data. Infiltration is 10 air changes per hour at a pressure difference of 50 Pa.

Partition type	Building material	Unit (W/m ² K)
External wall	- exterior wood cladding (spruce) - unventilated air void - tar paper (windproofing) - timber frame construction (trusses) - interior wood cladding (spruce)	1.45
Inner wall	- wood cladding (spruce) - wooden construction - unventilated air void - wood cladding (spruce)	2.17
Exterior doors	wooden double doors	4.92
Floor on the ground	compacted threshing floor	3.13
Foundation wall (basement)	- clinker brick - plaster	3.57
Exterior windows	single pane	5.00
Lower internal ceiling	- wooden ceiling joists - unventilated air void - wooden planks - joists - clay - floorboards (spruce)	1.53
Internal upper floor	- wooden ceiling joists - unventilated air void - wooden planks - joists - clay - floorboards (spruce)	2.14
Roof	- slate - tar paper - unventilated air void - timber frame construction - interior wood cladding (spruce)	2.83

A technical and structural inventory of the residential building under study was carried out in order to determine the measurement of all structural elements that are a source of heat loss and gain (Table 4). On the other hand, the heat transfer coefficients for windows and doors were adopted on the basis of data and information from the European building classification database TABULA – EPISCOPE [28].

In addition, on the basis of a site visit and an interview with the users of a reference residential building, the following relationships were introduced into the model:

- 1) The building is supplied with electricity from a single-phase low-voltage network – 230V IT system;
- 2) The primary source of heat is 5 electric radiators, supporting an air conditioner with heating function and a wood-burning fireplace; in the bathroom the source of heat is electric underfloor heating made of heating cables;
- 3) A water heater located in the basement (unheated zone) is used to cover the domestic hot water (DHW) demand, so the total heat transfer coefficient between hot water and air was assumed to be 2.6 W/K;
- 4) The building has natural displacement ventilation (duct in the chimney), exhaust grilles in the bathroom and a 120 m/h exhaust package in the kitchen. Local fresh air supply is provided by window leaks.

Quantitative research – questionnaires – and qualitative research – interviews – were carried out to build a model describing the behaviour of users located in the reference building, the subject of this study. The size of the research sample was calculated according to Eq. (1). Current statistics from Statistics Norway [30] were used in the calculations. Based on these data, it was assumed that there are two adults per household. Also, taking into account data on the number of buildings built before 1960 in Oslo, Bergen, Tromsø and Vardø (Table 2), the population size was calculated to be 47 346 people. A margin of error of 5% was assumed for the survey sample selection. An anonymous survey was conducted among 654 people, using Google Forms. The questions on the form were structured to build a model describing behaviour consisting of six areas based on their answers:

- 1) usage profile that affects human heat gain,
- 2) usage profile that affects heat gain from lighting,
- 3) usage profile that affects heat gains from electrical appliances,
- 4) usage profile that has the effect of reducing electricity and heat demand as a result of lowering the setpoint temperature,
- 5) usage profile that affects the ventilation of the premises,
- 6) usage profile that affects the heat gain from burning wood in a fireplace.

4. Results

4.1. Results of the descriptive-analytical study

On the basis of a preliminary analysis of the results from the environmental survey, a study group was identified, with the subjects being traditional Norwegian families with a size of 2+2. In turn, assumptions were made about the timing of daily activities, based on the findings, which are necessary for modelling the usage profiles.

4.1.1. Usage profile 1

Assumptions:

- 1) From Monday to Friday, both adults work. One works remotely (at home) from 8.00–16.00, while the other works at the company's premises (away from home) from 8.00–18.00;
- 2) From Monday to Friday, three people are in the kitchen from 7.00–8.00;
- 3) From Monday to Friday, two children are in school from 8.00–16.00;
- 4) Monday to Friday, after school and work, from 16.00–18.00, one adult and two children stay in the kitchen;
- 5) Every weekday from 18.00 to midnight, two adults stay in the lounge;
- 6) Every weekday from 18.00 to 8.00, two children are in bedroom 2;
- 7) Every weekday from 0.00 to 8.00, two adults stay in bedroom 1;

Table 5. Usage profiles for calculating human heat gains.

Usage profiles (human heat gains)					
Hours of use		Zone	Value		Purpose
Monday to Friday	Saturday and Sunday		Monday to Friday	Saturday and Sunday	
8 h (8.00–16.00)	10 h (8.00–18.00)	Lounge	0.25	1.0	Inactive rest
1 h (7.00–8.00)	0	Kitchen	0.75	0.0	Active relaxation
2 h (16.00–18.00)					
6 h (18.00–24.00)	6 h (18.00–24.00)	Lounge	0.50	0.5	Inactive rest
7 h (24.00–7.00)	7 h (24.00–7.00)	Bedroom 1	0.50	0.5	Sleeping
9 h (18.00–7.00)	9 h (18.00–7.00)	Bedroom 2	0.50	0.5	Sleeping

- 8) On Saturday and Sunday, the whole family is in the lounge from 8.00–18.00;
- 9) On Saturday and Sunday, the kitchen is not in use.

Based on the assumptions quoted, a usage profile schedule was constructed and tabulated (Table 5).

4.1.2. Usage profile 2

In order to build a second occupancy profile that influences the heat gain from lighting in each of the zones analysed, time slots were defined in the separate cities in which people are simultaneously present and using lighting that imitates daylight. A schedule (Table 6) was constructed based on the hours of occupancy in each room (Table 5) and based on an analysis of hourly reports showing typical weather conditions for Oslo, Bergen, Tromsø and Vardø. This analysis made it possible to extract the dependent variables – the hours of sunrise and sunset and the number of hours of sunshine – which, in combination with the occupancy schedule, determine the duration of lighting use during the day.

The modelled profile was also supplemented with information resulting from the quantitative survey, participatory observation and the technical and structural inventory. Based on the collected research material, assumptions were made, stating that:

- 1) More than half of the respondents surveyed are away from work and school during their free period (lasting at least 3 days);
- 2) 70% of these people declared that the period falls during the Easter holidays, during the May holidays enacted as public holidays and during the summer holidays. According to respondents, the most common month for summer holidays is July, with the holiday itself lasting 3 weeks. In order to input this data into the simulation software, these periods were assumed to fall on the following dates:
 - 14.04 – 18.04,
 - 03.06 – 06.06,
 - 04.07 – 24.07;
- 3) The majority of the Norwegian population has lights on in the corridor 24 hours a day, as a result of the habits they have retained;
- 4) The density of lighting power installed in each room is:
 - in the living room: 1.00 W/m²,
 - in the corridor: 0.27 W/m²,
 - in the kitchen: 0.63 W/m²,

- in bedroom 2: 0.28 W/m²,
- in bedroom 1: due to the usage profile, the lighting density is 0,
- in the bathroom: the density of the luminous flux falling on the surface is negligible and has therefore not been taken into account.

4.1.3. Usage profile 3

The third use profile refers to the schedule of hours of use of electrical appliances (Table 7). The operation of these units results in heat exchange through the movement of gas streams (convection) creating heat gains, which are important in the energy balance of a building. By implementing the first schedule, which describes the occupancy profiles at specific time intervals in specific rooms (Table 5), it can be concluded that:

- 1) Throughout the living room, individual users use electrical appliances;
- 2) Between 7.00 and 8.00, individual users use a kettle and microwave;
- 3) During the two-hour period (16.00–18.00), the family uses the induction hob and oven in the kitchen. During this time, individual users programme the automatic switching on of the washing machine, dryer and dishwasher during the night time interval (0.00–3.00), due to the financial savings resulting from the lower price of electricity in the night zone;
- 4) The washing machine and dryer are located in the hallway. The washing machine operates from 0.00–01.00, while the dryer operates from 1.00–3.00;
- 5) The family does not use electrical appliances in the bedrooms and bathroom.

4.1.4. Usage profile 4

Based on the quantitative study carried out – a questionnaire, addressed to a selected sample of the Norwegian population, living in single-family households built before 1960, it can be concluded that the respondents surveyed are highly consumer-conscious people. Almost 70% of the respondents answered that, during a prolonged absence, the set temperature, which is 20°C, is lowered to 16°C, in each room. A prolonged absence was defined as the absence of all occupants of a household during the Easter holidays, the May break and the holiday season. Based on these assumptions and the geometry of the building, the occupancy profile presented in Table 8 was constructed.

Table 6. Usage profiles for calculating heat gains from lighting.

Usage profiles (heat gains from lighting)					
Hours of use Monday to Sunday*					
Month	City				Zone
	Oslo	Bergen	Tromsø	Vardø	
January	10 h (8.00–9.00 & 15.00–24.00)	10 h (8.00–9.00 & 15.00–24.00)	16 h (8.00–24.00)	16 h (8.00–24.00)	Lounge
	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	Kitchen
	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	Bedroom 2
February	24h	24h	24h	24h	Corridor
	8 h (16.00–24.00)	9 h (8.00–9.00 & 16.00–24.00)	11 h (8.00–9.00 & 14.00–24.00)	12 h (8.00–9.00 & 13.00–24.00)	Lounge
	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	Kitchen
	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	Bedroom 2
March	24 h	24 h	24 h	24 h	Corridor
	7 h (17.00–24.00)	6 h (18.00–24.00)	8 h (16.00–24.00)	9h (15.00–24.00)	Lounge
	1 h (17.00–18.00)	0 h	2 h (16.00–18.00)	2 h (16.00–18.00)	Kitchen
	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	Bedroom 2
April	24h	24 h	24 h	24 h	Corridor
	4 h (20.00–24.00)	4 h (20.00–24.00)	5 h (19.00–24.00)	5 h (19.00–24.00)	Lounge
	0 h	0 h	0 h	0 h	Kitchen
	0 h	0 h	1 h (19.00–20.00)	1h (19.00–20.00)	Bedroom 2
May	24 h	24h	24 h	24 h	Corridor
	3 h (21.00–24.00)	3 h (21.00–24.00)	2 h (22.00–24.00)	3 h (21.00–24.00)	Lounge
	0 h	0 h	0 h	0 h	Kitchen
	0 h	0 h	0 h	0 h	Bedroom 2
June	24 h	24 h	24 h	24 h	Corridor
	2 h (22.00–24.00)	2 h (22.00–24.00)	0 h	0 h	Lounge
	0 h	0 h	0 h	0 h	Kitchen
	0 h	0 h	0 h	0 h	Bedroom 2
July	24 h	24 h	24 h	24 h	Corridor
	2 h (22.00–24.00)	1 h (23.00–24.00)	0 h	0 h	Lounge
	0 h	0 h	0 h	0 h	Kitchen
	0 h	0 h	0 h	0 h	Bedroom 2
August	24 h	24 h	24 h	24 h	Corridor
	3 h (21.00–24.00)	2 h (22.00–24.00)	1 h (23.00–24.00)	2 h (22.00–24.00)	Lounge
	0 h	0 h	0 h	0 h	Kitchen
	0 h	0 h	0 h	0 h	Bedroom 2
September	24 h	24 h	24 h	24 h	Corridor
	4 h (20.00–24.00)	4 h (20.00–24.00)	4 h (20.00–24.00)	5 h (19.00–24.00)	Lounge
	0 h	0 h	0 h	0 h	Kitchen
	0 h	0 h	0 h	1 h (19.00–20.00)	Bedroom 2
October	24 h	24 h	24 h	24 h	Corridor
	6 h (18.00–24.00)	5 h (19.00–24.00)	6 h (18.00–24.00)	7 h (17.00–24.00)	Lounge
	0 h	1 h (7.00–8.00)	0 h	1 h (17.00–18.00)	Kitchen
	2 h (18.00–20.00)	1 h (19.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	Bedroom 2
November	24 h	24 h	24 h	24 h	Corridor
	8 h (16.00–24.00)	8 h (16.00–24.00)	10 h (14.00–24.00)	11 h (13.00–24.00)	Lounge
	2 h (16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	Kitchen
	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	Bedroom 2
December	24 h	24 h	24 h	24 h	Corridor
	9 h (8.00–9.00 & 15.00–24.00)	10 h (8.00–9.00 & 15.00–24.00)	16 h (8.00–24.00)	16 h (8.00–24.00)	Lounge
	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	3 h (7.00–8.00 & 16.00–18.00)	Kitchen
	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	2 h (18.00–20.00)	Bedroom 2
	24 h	24 h	24 h	24 h	Corridor

*On Saturday and Sunday, the number of hours the kitchen is lit is 0 h.

*In the periods: 14.04–18.04 (Easter holidays), 3.06–06.06 (Pentecost), 4.07–24.07 (holiday period) the residential building is unoccupied, heat gains are 0 h.

Table 7. Usage profiles for calculating heat gains from electrical appliances.

Usage profiles (heat gains from electrical appliances)					
Hours of use		Zone	Electrical equipment	Total power of appliances in the room (W)*	
Monday to Friday	Saturday and Sunday			Monday to Friday	Saturday and Sunday
8 h (8.00–16.00) 6 h (18.00–24.00)	10 h (8.00–18.00) 6 h (18.00–24.00)	Lounge	Laptop TV	315	315
3 h (7.00–8.00 & 16.00–17.00)	0	Kitchen	Kitchen appliances	3800	100**
3 h (24.00–01.00 & 01.00–03.00)	0	Corridor	Washer and dryer	1500	100**

* Power of equipment is based on specifications provided by the manufacturer.

** Assuming that only the fridge works for 24 hours on Saturday and Sunday.

Table 8. Usage profile, which influences the reduction in electricity and heat demand as a result of lowering the set-point temperature.

Room	Setpoint temperature (°C)	Set-back temperature (°C)
Lounge	20	16
Kitchen	20	16
Bathroom	24	16
Corridor	20	16
Bedroom 1,2	20	16

4.1.5. Usage profile 5

The interdependence of the presented schedules and the assumptions derived from them also has a significant impact on the effectiveness of the natural ventilation. For the purpose of the simulation, it was assumed that the presence of any of the individual users in the building is equivalent to the operation of the natural air exchange system. A study involving participant observation showed that, when present, the individual users ventilate the building by opening the windows, provided that the outside air temperature is not below 10°C. Based on Table 5, it can be concluded that at least one individual user is in the household 24 hours a day, except during holidays and vacation periods.

4.1.6. Usage profile 6

The technical and structural inventory carried out showed that an additional supporting heat source is the fireplace. Due to its sporadic operation depending directly on usage, a schedule of operation for this heat source was developed at the input stage.

A review of weather data from meteorological files (Oslo, Bergen, Tromsø, Vardø) showed that the winter period runs from 1 October to 30 April. According to a schedule defining the hourly range of individual users in the room, and according to the conclusions presented from the participatory observation, assumptions were extracted regarding the fireplace use profile. According to this, the fireplace is used for two hours from 18.00–20.00 in the living room, by two people, during the winter period.

As assumed by the manufacturer, the nominal power of the fireplace used by individual domestic users is 6000 W. Based on the assumptions outlined above, it can be inferred that this fireplace is operating at around 50%, thus showing that the final power is 3000 W. To simplify the model, the chimney loss was assumed to be approximately 30%, meaning that the usable power is 2100 W. According to the calculation methodology for combustion heat gains contained in DesignBuilder, in which the radiant factor is 0.3 W, it can be tentatively concluded that the radiant power that influences the level of warm comfort and the heating of the walls, located in the vicinity of the fireplace, is 630 W. From this assumption, on the other hand, it follows that the convective power that heats the air is 1470 W.

4.2. Results of the hourly building energy simulation study

All the data and assumptions collected through the empirical studies carried out were entered into DesignBuilder and energy simulations were then carried out on the reference building. The results are shown in Tables 9–12.

Table 9. Annual contribution of gains and losses to the annual heat balance – Oslo.

Profit and loss statement – reference building in Oslo			
Heat gains	Value (kWh)	Heat losses	Value (kWh)
from lighting	102.7	through transparent partitions	–6 202.8
from electrical appliances	4 511.6	through the building envelope	–15 975.7
from people	1 778.3	through the ceiling	–12 974.8
from solar radiation	4 823.1	through the floor	–1 462.6
		ventilation	–2 215.2
		infiltration	–5 161.0
Total profits	11 215.7	Total profits	–43 992.1

Table 10. Annual contribution of gains and losses to the annual heat balance – Bergen.

Profit and loss statement – reference building in Bergen			
Heat gains	Value (kWh)	Heat losses	Value (kWh)
from lighting	102.7	through transparent partitions	–5 688.4
from electrical appliances	4 511.6	through the building envelope	–16 517.8
from people	1 783.6	through the ceiling	–12 249.7
from solar radiation	3 389.0	through the floor	–1 307.4
		ventilation	–945.4
		infiltration	–4 735.1
Total profits	9 786.9	Total profits	–41 443.8

Table 11. Annual contribution of gains and losses to the annual heat balance – Tromsø.

Profit and loss statement – reference building in Tromsø			
Heat gains	Value (kWh)	Heat losses	Value (kWh)
from lighting	102.7	through transparent partitions	–8 383.1
from electrical appliances	4 511.6	through the building envelope	–24 131.6
from people	1 786.7	through the ceiling	–16 531.1
from solar radiation	3 565.3	through the floor	–1 568.7
		ventilation	–293.5
		infiltration	–5 949.9
Total profits	9 966.3	Total profits	–56 857.9

Table 12. Annual contribution of gains and losses to the annual heat balance – Vardø.

Profit and loss statement – reference building in Vardø			
Heat gains	Value (kWh)	Heat losses	Value (kWh)
from lighting	102.7	through transparent partitions	–8 157.8
from electrical appliances	4 511.6	through the building envelope	–24 638.3
from people	1 778.3	through the ceiling	–16 603.0
from solar radiation	3 269.7	through the floor	–1 528.2
		ventilation	–175.5
		infiltration	–6 164.3
Total profits	9 672.0	Total profits	–57 267.1

Numerical simulations of heat-flow processes have shown that the energy demand of the reference building in Vardø is the highest at 46 937 kWh (including the heat from burning wood in the fireplace –657.4 kWh). This compares with 32 119 kWh in Oslo, 30 999 kWh in Bergen and 46 234 kWh in Tromsø.

The calculations carried out with an hourly calculation step for the whole year (8 760 hours) also made it possible to determine the technical condition of the residential building under study and to assess the microclimate inside. The simulations carried out showed that there was an air exchange problem in the reference building as a result of the impaired operation of the natural ventilation system responsible for removing excess heat from the building and supplying fresh air to the interior. As a result, there was a loss of thermal comfort for the individual occupants and a decrease in indoor air quality.

5. Conclusions and discussion

The data collected from the empirical research conducted made it possible to build a model to describe the behaviour of individual users, thus reducing the discrepancy between actual and as-

sumed premises. Undoubtedly, the accurately developed model has contributed to results with less calculation error across the entire energy balance. On the basis of the calculations carried out, it has been shown that the percentage of heat gain from people, lighting, appliances and solar radiation in the energy balance, respectively, is for Oslo 20%, Bergen 35%, with reference to Tromsø 32%, while taking into account the climatic conditions in Vardø, the percentage is 22%. Such a high share of heat gain equates to the need for accurate modelling of behaviour. Thus, simplified monthly calculation methods, often used to determine energy characteristics for single-family households, which take into account implicit internal heat gain parameters should not be implemented. As the literature review in the introduction showed, this problem is already known, but researchers are still working to solve it. The model presented in this paper describing the behaviours that influences the level and distribution of heat gains in the energy balance is undoubtedly one solution. It seems that the biggest problem lies with national regulations, which, despite many recommendations, allow the use of monthly methods to calculate annual energy demand. On the other hand, if changes are made to the need for the hourly

method, there is a high risk of job losses for those currently performing energy performance based on basic knowledge and simplified calculation methods.

In highly developed countries such as Norway, people's awareness is at a very high level, so that even though national regulations allow a simplified, monthly method for determining annual energy demand to be used, only software based on the hourly method is used in practice. Therefore, the question arises of whether one solution to the research problem of determining the influence of behaviour on the value of internal heat gains in a building is to raise public awareness of the use of the calculation method.

Furthermore, it should be noted that the use of time-varying internal heat gains that affect the dynamics of the heat flow through the building allows the precise determination of the heating power of the equipment, the selection of which, in actual use, determines its final efficiency and energy performance. Thus, the introduction of accurate data also makes it possible to verify the problems occurring in the heat flow performance of buildings, and thus provides the opportunity to build an appropriately adapted retrofit scenario and avoid a number of mistakes in the future. Although internal heat gains have a significant impact on the selection of heating power of devices, uncertainty in their determination is still caused by future climate changes. The size of the heat demand is largely determined by the parameters of the external climate. Taking into account the lifespan of buildings, the authors also recommend taking into account climate analyses in the selection of heating systems.

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