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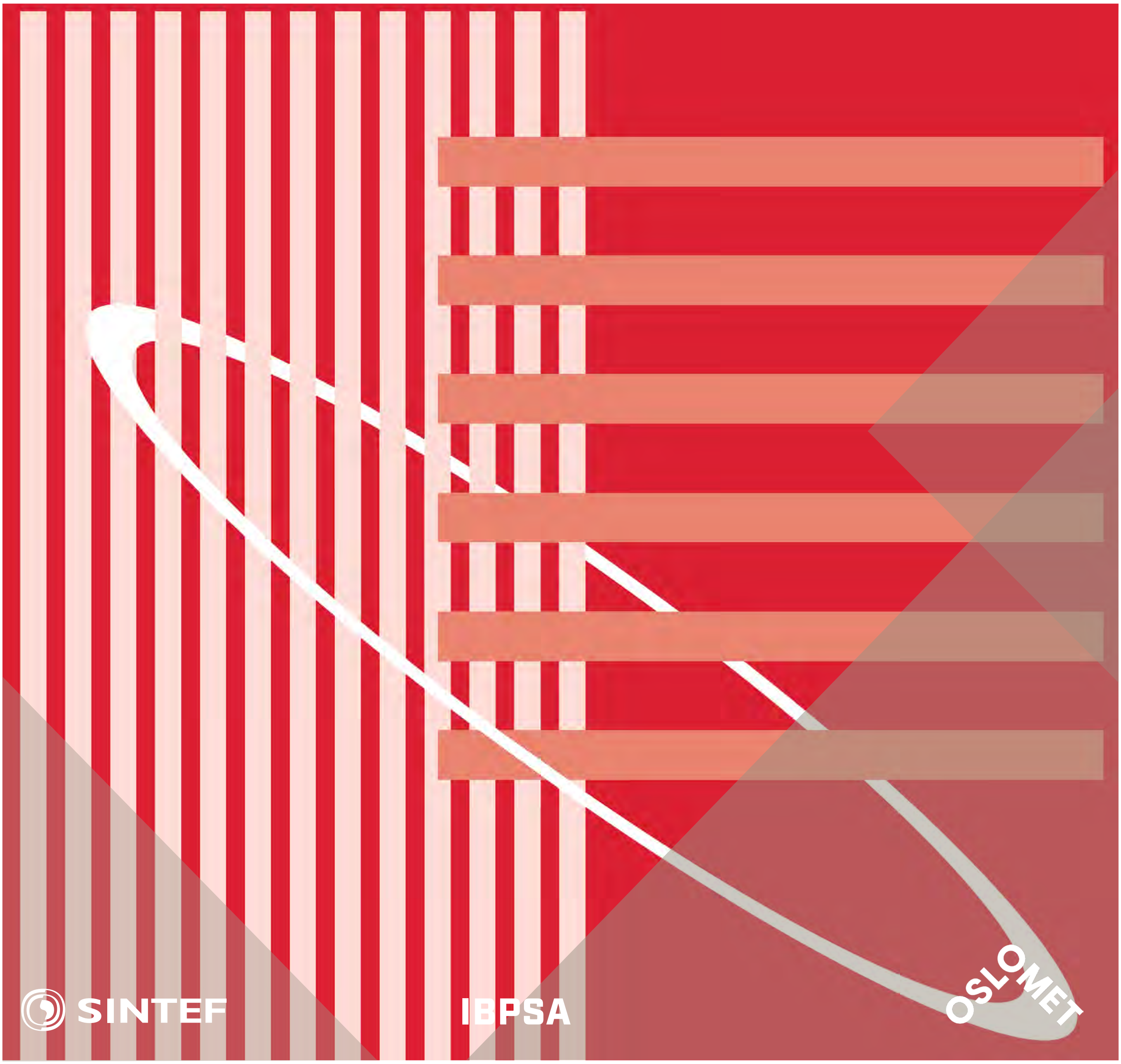

SINTEF Proceedings

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Undefined modelling parameters impact on building simulation results: using IDA ICE according to the Estonian methodology for calculating building performance

Henri Sarevet[1*], Martin Kiil[1], Raimo Simson[1], Martin Thalfeldt[1], Jarek Kurnitski[1,2]
[1]Tallinn University of Technology, Department of Civil Engineering and Architecture, Ehitajate tee 5, 19086, Tallinn, Estonia
[2]Aalto University, School of Engineering, Otakaari 4, 02150, Espoo, Finland
** corresponding author: henri.sarevet@taltech.ee*

Abstract

The Nordic countries have taken important and strict steps moving towards reducing building energy consumption. Energy performance estimation by dynamic building simulation has become a crucial part of the building design. The performance assessment methodology including pre-determined standardised input parameters vary from country to country. The purpose of this study was to analyse the impact of modelling parameters which are not pre-defined but influence the result, and define specific values to be used in the methodology to reduce the uncertainty and variations in the results. The assessed parameters include the definition of the first day of simulation, e.g. startup date, weekday and calendar year, startup pre-simulation specifics and simulation splitting. The simulations were conducted using dynamic simulation software IDA ICE. Calculations were carried out according to the Estonian national methodology for calculating energy performance of buildings. The study analyses the impact of modelling input data parameters which are not pre-defined in the methodology. The effects of these parameters are illustrated by modelling and simulating multiple typical 5-day usage office buildings. The results show that the startup date can affect the results of the net ventilation heating energy, net ventilation cooling energy or energy performance value over 1 kWh/(m²×a). This study highlights the importance of the initial modelling parameters determination on the building energy consumption calculation results.

Introduction

Building energy efficiency importance and implementation in European Union member states and the need for dynamic simulations, in case of nearly zero energy building (nZEB) and low-energy buildings the detail of the simulations can have large effect on the energy performance assessment results. Although not all the member states require a dynamic simulation to prove compliance with national requirements, experienced clients and developers could be interested in vital information regarding simulations in the early stages of the design. In addition, the decisions for mechanical, electrical and plumbing system (MEP) selection criteria in these buildings is more and more dependant on the cost-benefit analyses. Complex technical systems, including heating, ventilation and air conditioning sub-systems require comprehensive and precise simulations. Mastery of dynamic simulation software is a common part of a heating, ventilation and air conditioning (HVAC) engineer on building energy performance specialist. However, simulation software are useful tools for the user, not giving out answers by itself.

There are many variables and parameters in simulation software tool that are not predetermined by the national regulations and can be chosen freely by the energy efficiency specialist who conducts the calculations. These parameters can have large impact on the simulation results and influence the design decisions regarding building systems and renewable energy production systems in order to achieve nZEB energy performance levels.

In the Estonian energy performance regulations for buildings (Ministry of Economic Affairs and Communications 2018), a detailed methodology is given with specific parameters for building modelling and dynamic simulation creation (Ministry of Economic Affairs and Communications 2015b).

In this paper we have addressed these research questions:

- in what extent the startup date, pre-simulation and simulation splitting affect the results of energy consumption or energy performance calculations;
- which is the most affected of the net room heating and cooling, net ventilation heating and cooling, delivered heating energy and electricity and *EPV* in general.

Methods

In this section, the input, modelling, simulation model creation, simulations and analysis steps of the study are described. The undetermined simulation parameters analysed in this study are not defined by regulations (Ministry of Economic Affairs and Communications 2015b). For running simulations in IDA ICE, the user must choose the calendar input, such as start-up date, weekday and calendar year. Therefore, seven different options for the weekday are available. Secondly, user can define the custom startup length. In this study, we have used 14-day length startup for all the default simulations and compared it with 0, 1, 7 and 31-day pre-simulation options. Finally, we ran simulations with multiple parallel processes, as the simulation was split into 6 sub-simulations (one year into six months). Flow chart of undetermined modelling parameters are seen on Figure 1. Thus, first day of simulation is labelled as P1, startup pre-simulation as P2 and simulation splitting as P3.

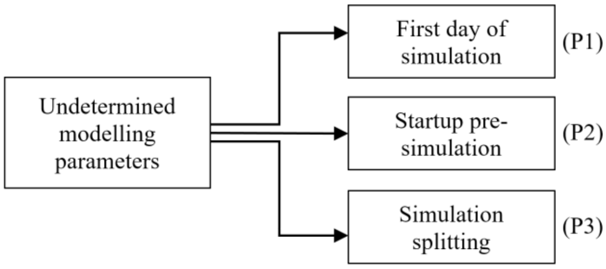


Figure 1: Flow chart of undetermined modelling parameters.

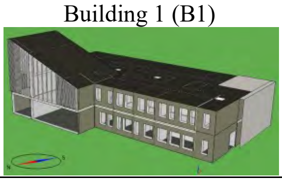
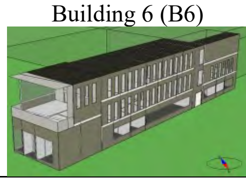
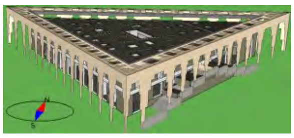
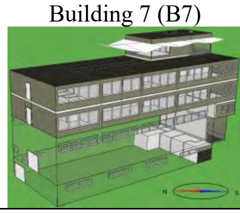
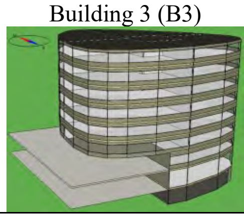
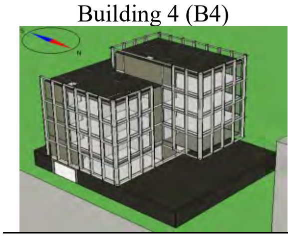
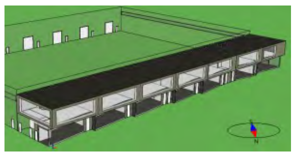
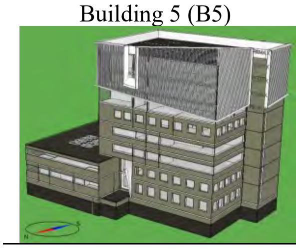
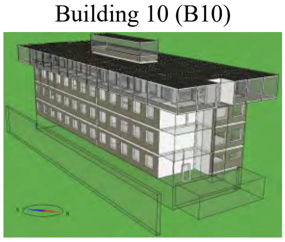
Flow chart of research methodology is seen on Figure 2. Simulation input data is the set of buildings used in this study. To investigate undetermined parameters on the same set of buildings, the main criteria for the buildings is the 5-day usage per week. Otherwise, the first day of simulation impact would be questionable. Therefore, according to Estonian regulation (Ministry of Economic Affairs and Communications 2015b), 5-day usage must be used in energy calculations for office, educational, preschool institution, healthcare and industrial buildings. However, in a multi-purpose building, the *EPV* corresponding to each purpose shall be assigned separately, if heated net floor area exceeds 10% of the total heated floor area (Ministry of Economic Affairs and Communications 2018). Whereas, depending on the remaining building part purposes' efficiencies, single parts of the building can also be below the required criteria independently as the overall *EPV* is decisive.

In this study, we have analysed five office buildings (B1-B5) and five office parts of the buildings (B6-B10), designed between 2015 to 2020. The second criteria were the requirement for at least low-energy building ("B") as *EPV* criteria or the significantly reconstructed building value ("C") (Ministry of Economic Affairs and Communications 2015a). According to issued *EPV* certificates, B1 and B2 met nZEB criteria ("A") and B3 the low-energy ("B") building *EPV* criteria. B4 and B7 were significantly reconstructed to *EPV* corresponding value "C". B5, B6, B8, B9 and B10 to *EPV* corresponding value "D". 3D views of the analysed buildings are provided in Table 1.

Reference buildings are situated in Tallinn or near the capital of Estonia. The highest reference building has eight floors and the lowest has two. The largest analysed office building or part of the building as office is 6890 m² and the smallest is 810 m² by heated net floor area. The reference building MEP system initial data used in analysis includes HVAC information given in the : Building HVAC system information of the analysed office buildings and office parts of the building., domestic hot water information, lighting and appliances energy consumption values (Table 4). In Table 2, heating column consists of heat source and conversion factor values, building heating system and efficiency factor values and heating auxiliary devices' electricity consumption. The ventilation column includes ventilation supply air temperature, type of the air handling unit heat recovery with efficiency, frost protection temperature, air exchange rate and specific fan power of the air handling units. The cooling column consists of could source with efficiency factor, type of cooling system regarding the room units and condensation losses of the cooling process. The indoor temperature setpoint for heating period is +21°C and for cooling period is +25°C.

Domestic hot water consumption is a default value 6.0 kWh/(m²×a). Default lighting installed power wattage per m² is 10, yet may be varied as other values regarding wattages are allowed to be used, if lighting calculations are conducted in conjunction with the *EPV* evaluation process. Appliances are calculated with default value 12 kWh/(m²×a). Internal gains and schedules are listed in Table 4.

Table 1: 3D views analysed reference office buildings and office parts of the buildings in IDA ICE.

Office buildings	**Office parts of the building**
Building 1 (B1) 	Building 6 (B6) 
Building 2 (B2) 	Building 7 (B7) 
Building 3 (B3) 	Building 8 (B8) 
Building 4 (B4) 	Building 9 (B9) 
Building 5 (B5) 	Building 10 (B10) 

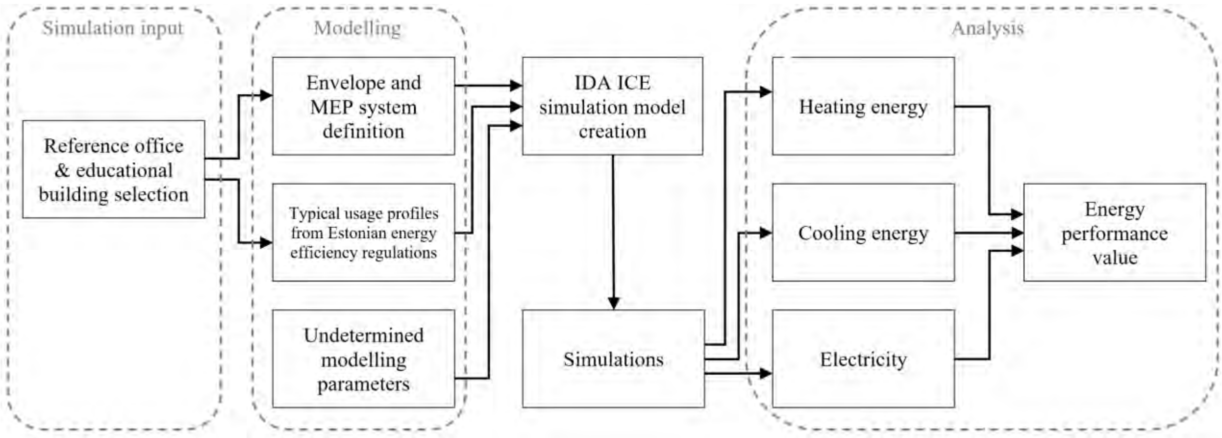


Figure 2: Flow chart of research methodology.

Table 2: Building HVAC system information of the analysed office buildings and office parts of the building.

	Heating			Ventilation					Cooling		
B	**Heat source/ conversion factor**	**Heating system/ efficiency factor**	**Heating aux. dev. electricity kWh/(m²xa)**	**Supply air temperature °C**	**Heat recovery**	**Efficiency**	**Frost protection**	**Air exchange/ *SFP***	**Could source/ efficiency factor**	**Cooling system**	**Condensation losses**
1	district heating 1.00	underfloor heating 0.92	1.0	20(w) 18(s)	plate heat exch.	0,84/ 0,80	0	2.0 1.78	compressor-driven cooler 3.5	fancoil	0.3/0.2
2	district heating 1.00	underfloor heating 0.92	1.0	18	rotary heat exch.	0.78	-5	2.0 1.80	compressor-driven cooler 3.5	fancoil	0.3/0.2
3	effective district heating 0.90	radiator heating 0.97	0.5	18	rotary heat exch.	0.80	-5	2.0 1.80	compressor-driven cooler 3.9	chilled beam	0.3/0.1
4	district heating 1.00	radiator heating 0.97	0.5	19	rotary / plate heat exch.	0.80	-5/ 0	2.0 1.80	compressor-driven cooler 3.5	fancoil	0.3/0.2
5	gas cond. boiler / AWHP 0,95 / 2,7 / 2	underfloor /radiator heating 0.97	0.5	18	rotary / plate heat exch.	0,80 / 0,84	-5/ 0	2.0 1.30	compressor-driven cooler 3.5	chilled beam	0.2/0.1
6	district heating 1.00	radiator heating 0.97	0.5	18	rotary heat exch.	0.80	-5	2.0 1.80	compressor-driven cooler 3.5	chilled beams	0.3/0.1
7	gas cond. boiler 0.95	underfloor heating 0.93	1.0	18	plate heat exch.	0.80	0	2.0 1.80	split 3.5	fancoil	0
8	gas cond. boiler 0.95	underfloor heating 0.96	1.0	18	plate heat exch	0.80	0	2.0 1.80	compressor-driven cooler 3.5	fancoil	0.3/0.2
9	gas boiler 0.85	radiator heating 0.97	0.5	18	rotary heat exch.	0.80	-5	2.0 2.14	compressor-driven cooler 3.5	chilled beam	0.3/0.1
10	gas. cond. boiler 0.95	underfloor / radiator heating 0.97	1.0	18	rotary heat exch.	0.80	-5	2.0 1.70	compressor-driven cooler 3.5	fancoil	0.3/0.2

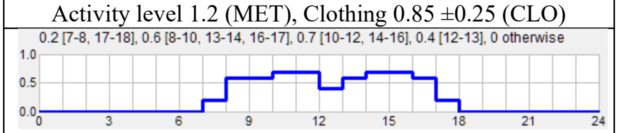
Table 3: Building envelope information of the analysed office buildings and office parts of the building.

B	A m²	*H/A* W/(K×m²)	*H/V* W/(K×m³)	A_{env}/V m	*WWR*	*WFR*	U_{wall} W/(m²×K)	U_{roof} W/(m²×K)	U_{floor} W/(m²×K)	U_{door} W/(m²×K)	U_{window} W/(m²×K)	*SF* Shading
1	1276	0.43	0.12	0.47	0.36	0.24	0.12	0.09	0.09/ 0.15	0.9	0.9	0.45, shading E, S, W
2	1329	0.50	0.14	0.58	0.39	0.27	0.10	0.10	0.11	0.8	0.8	0.50 -
3	6890	0.31	0.10	0.24	0.51	0.24	0,15/ 0,10	0.10	0.11/ 0.15	1.4	0.65	0.23 0.41 -
4	810	0.84	0.23	0.49	0.33	0.34	0.23	0.13	0.11	1.0	1.0	0.45 -
5	999	0.53	0.16	0.44	0.35	0.29	0,15/ 0,23	0.11	0.19	1	0.83	0.25/ 0.30/ 0.40 -
6	1889	0.60	0.18	0.39	0.55	0.42	0.17	0.12	0.12/ 0.22	1.2	0.8	0.25 -
7	1613	0.41	0.12	0.46	0.32	0.14	0.17	0.09	0.11	-	0.8	0.30 -
8	1739	0.59	0.15	0.40	0.65	0.29	0.17	0.10	0.08	1.0	1.0	0.50 -
9	5413	0.56	0.16	0.29	0.34	0.21	0.40	0.11	0.19/ 9.40	1	0,9 / 1,53	0.48 -
10	2190	0.50	0.17	0.35	0.57	0.33	0.16	0.12	0.16	-	0.9	0.31 -

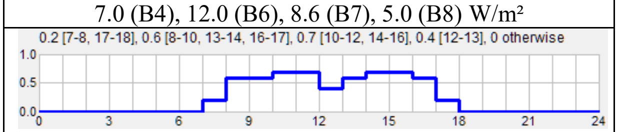
The building envelope information is provided in Table 3. Thermal bridges and infiltration parameters for reference buildings are not brought out in this paper as they are partly different from the regulation-based default values. However, these values are included in the values of *H/A* W/(K×m²) and *H/V* W/(K×m³) with thermal transmittance values indicate the building heat resistance. A_{env}/V ratio represents the compactness of the building. Window-to-floor (*WFR*) and window-to-wall (*WWR*) ratios illustrate the window proportions of the envelope. In addition, window solar factor (*SF*) values and option of shadings are listed in Table 3.

Table 4: Office building internal gains parameters and schedules.

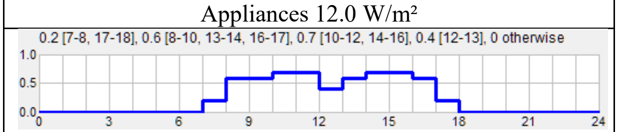
Occupants 5.0 W/m²
Activity level 1.2 (MET), Clothing 0.85 ±0.25 (CLO)



Lighting 10.0 (B5, B9, B10), 9.5 (B1), 7.0 (B2), 4.9 (B3), 7.0 (B4), 12.0 (B6), 8.6 (B7), 5.0 (B8) W/m²



Appliances 12.0 W/m²



The internal gains and parameters of the reference office buildings are provided in Table 4. Building envelope and MEP system data in this study is provided from the reference building energy performance certificates. Firstly, the energy calculation results are split into net heating, ventilation, cooling, domestic hot water, lighting and appliance energy consumption. Secondly, using heat and cooling source conversion and heating and cooling system efficiency factors, delivered energy is calculated. Finally, the *EPV* is found using primary energy conversion factors. Currently, Estonian regulation sets the *EPV* requirements for nZEB, low-energy building and significantly reconstructed office building as (Ministry of Economic Affairs and Communications 2015a).

- "A" ≤ 100 (nZEB)
- 101 ≤ "B" ≤ 130 (low-energy building)
- 131 ≤ "C" ≤ 160 (significantly reconstructed building)

Therefore, the gap between high efficiency *EPV* for office buildings is 30 units. The simulations were conducted according to the current building energy performance regulations in Estonia (Ministry of Economic Affairs and Communications 2018). Worth noting, that currently, in Estonia, the simplified verification method with a specific energy efficiency calculator for small individual houses is allowed. As an exception, energy calculation software BV² is allowed to use in case of major reconstruction of a small individual house, apartment building or barracks.

Estonian local climate data used in this study is based on Estonian test reference year (Kalamees and Kurnitski 2006). The office building models were composed and the simulations were conducted using well validated (Kroph and Zweifel 2002) building simulation software IDA ICE, version 4.8 SP1, EQUA Simulation AB, Stockholm, Sweden (EQUA 2019).

Results and discussion

In this paper, undetermined simulation parameters, such as first day of simulation, startup pre-simulation length and simulation splitting to sub-simulations was analysed.

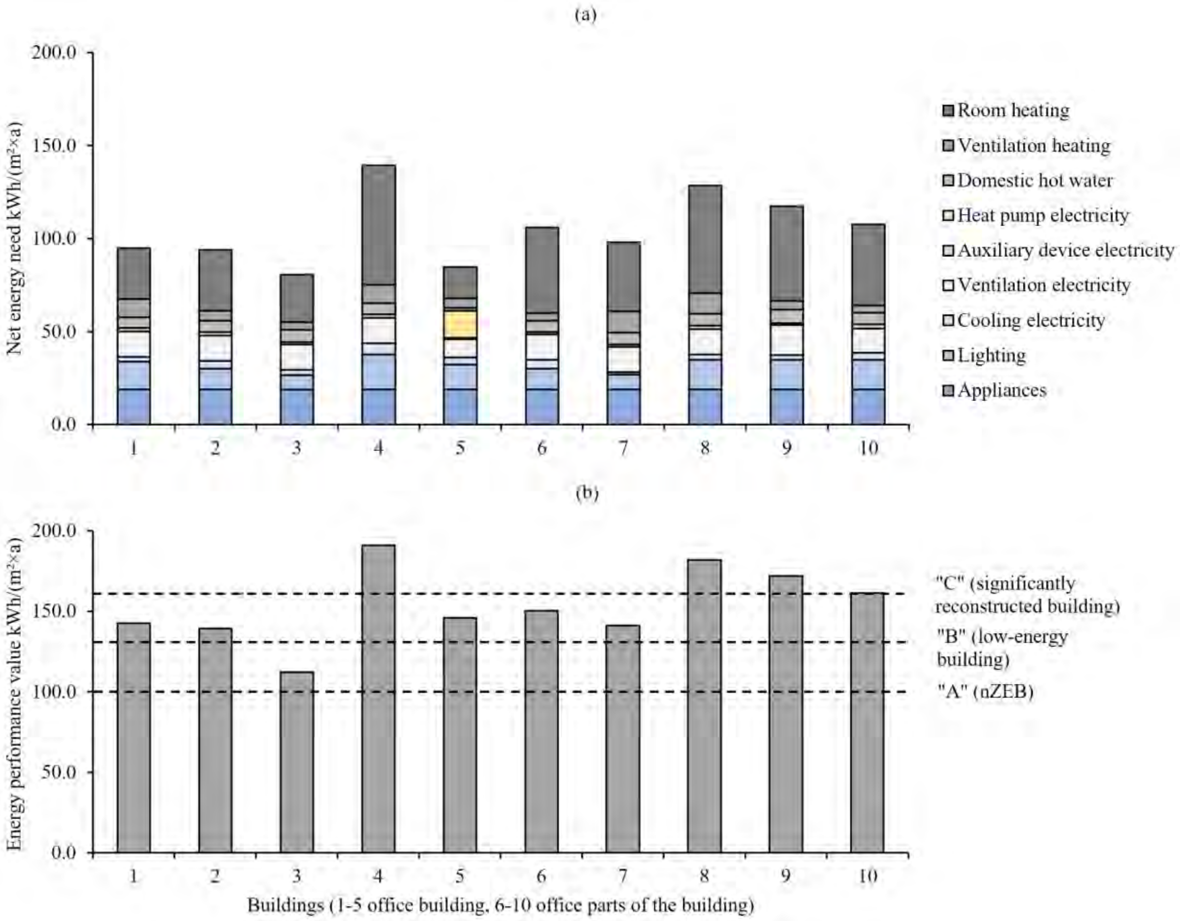


Figure 3: Comparison of base model (a) net energy need kWh/(m^2×a) and (b) energy performance value kWh/(m^2×a) for reference buildings. EPV is presented without on-site produced energy.

The base model is defined as a year starting with Thursday, using 14-day startup pre-simulation without simulation splitting. The results for each reference building are provided in Figure 3. On the upper part of the figure, the components of net energy need are provided and on the lower part of the figure the *EPV* is presented. For comparison, the on-site produced energy is excluded.

Firstly, room heating and ventilation heating net energy consumption was assessed. The variation of the results is presented on Figure 4. The maximum difference between starting weekday simulation is 0.37 kWh/(m^2×a) for room heating and 1.18 kWh/(m^2×a) for ventilation heating as the mean values for the reference buildings are 0.08 and 0.43 kWh/(m^2×a). For the startup pre-simulation, the maximum differences are 0.52 and 0.04 kWh/(m^2×a) and the mean values 0.28 and 0.01 kWh/(m^2×a). Regarding simulation splitting, the results vary up to 0.39 and 0.02 kWh/(m^2×a) with the mean values of 0.21 kWh/(m^2×a) for room heating and for the ventilation heating the difference is close to zero. Ventilation heating has the highest impact, when weekdays for the start of the simulation is exchanged, but obviously insignificant for the startup or the simulation splitting, as the external air temperature is not affected by the building. Opposite to ventilation heating, the room heating is more varied by startup and simulation splitting.

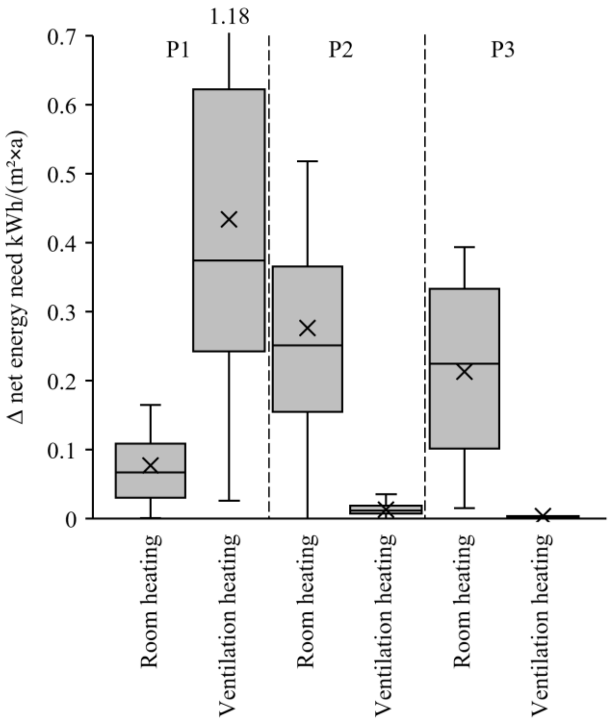


Figure 4: Room heating and ventilation heating net energy need variation with parameters 1 to 3.

Secondly, room cooling and ventilation cooling net energy consumption was assessed. The variation of the results is presented on Figure 5. Similarly, to ventilation heating, the ventilation cooling impact has the highest impact with up to 0.95 kWh/(m²×a) with the mean value of 0.37 kWh/(m²×a). The same results for room cooling are 0.17 and 0.04 kWh/(m²×a). Other simulated parameters do not have any significant effect on the results, except minor effect for room cooling with simulation splitting with the highest and the mean values of 0.08 and 0.03 kWh/(m²×a). Startup simulation does not affect room cooling or ventilation cooling, since simulations were started in the beginning of the calendar year in January. Similarly, to ventilation heating, ventilation cooling is not varied, as the building does not affect the external air temperature.

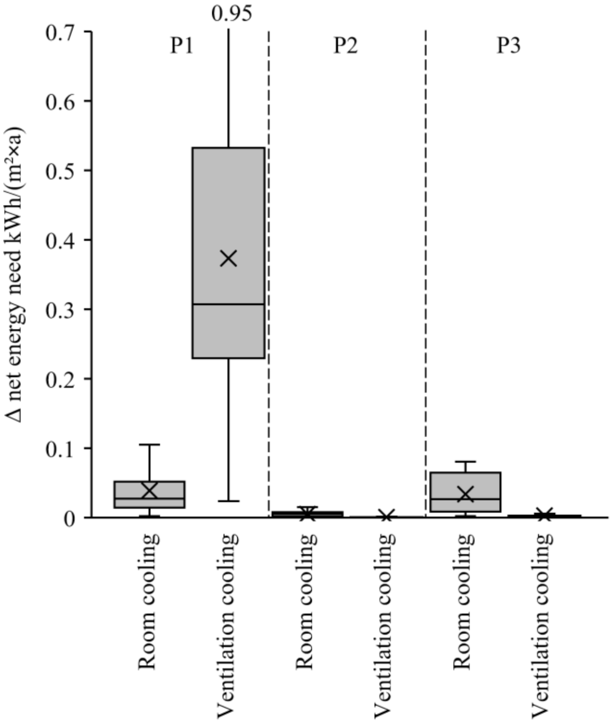


Figure 5: Room cooling and ventilation cooling net energy need variation with parameters 1 to 3.

Finally, delivered heating energy and electricity with *EPV* variation was analysed. For the delivered heating energy, the maximum values are up to 1.19 kWh/(m²×a) for weekday selection, up to 0.58 kWh/(m²×a) for startup pre-simulation comparison and up to 0.41 kWh/(m²×a) for simulation splitting into sub-simulations. As for the electricity, the results are less affected, due to the non-weather-related consumers, such as lighting fixtures and appliances. The effect with startup or simulation splitting is insignificant. The maximum impact regarding start of the simulation weekday comparison results with 0.37 kWh/(m²×a) with the mean value of 0.16 kWh/(m²×a). However, due to the lower impact of the electricity impact, the *EPV* results are correlating with the delivered heating energy. If reference building were more reliable on electrical sources of heating, e.g. heat pump systems, the results would be more diverse. The maximum impact on EPV is 1.05 kWh/(m²×a) with start of the simulation day comparison with the mean value of 0.45 kWh/(m²×a). Startup comparison shows 0.56 kWh/(m²×a) for the maximum and 0.29 kWh/(m²×a) for the mean *EPV* variation. Simulation splitting has the lowest effect on the *EPV*, as the maximum difference is 0.39 kWh/(m²×a) with the mean difference of 0.21 kWh/(m²×a). The results of delivered heating energy, electricity and *EPV* variation with parameters 1 to 3 are shown on Figure 6.

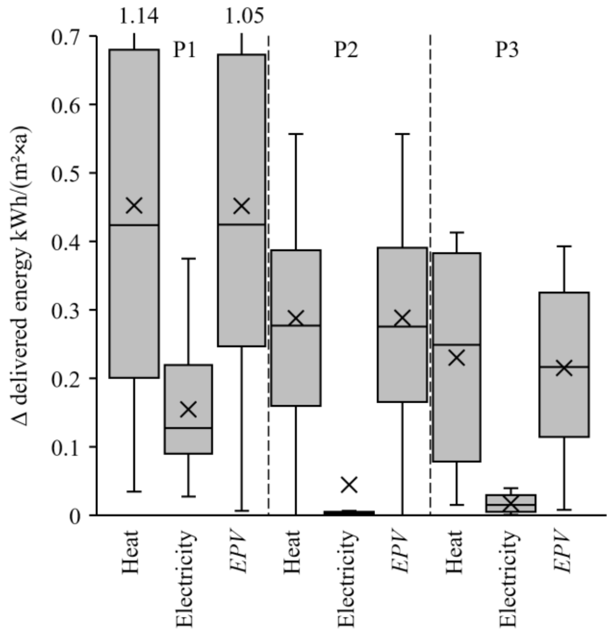


Figure 6: Delivered heating energy, electricity and energy performance value variation with parameters 1 to 3.

The fluctuation of the results shows, that reaching for the higher *EPV* value of the 30-unit gap between the regulation criteria, is approximately 0.5 kWh/(m²×a) on the average (1.7%) and over 1.0 kWh/(m²×a) as the maximum (3.3%) of the analysed buildings. This means, that up to one unit of the *EPV* can be dependant, on the first day of the simulation chosen. Worth recalling, this effect emerges with the 5-day usage buildings. To avoid this uncertainty, the test reference year could be defined to be used with the starting day of Monday as 1st of January for example. Regarding startup length definition and simulation splitting to sub-simulations, the effect on the *EPV* could be up to half of one unit of the *EPV*.

The analysis of this study represents only a few parameters that are undetermined by the local Estonian energy performance regulations. Further studies regarding similar undetermined simulation parameters analysed in this study should include educational and preschool institution buildings, since these buildings are generally half-occupied or empty during the summer holidays. The building energy performance regulations in Estonia guide architects, HVAC engineers and energy performance specialists including developers or building managers to design these buildings without mechanical cooling systems. However, these calculations including passive methods for maintaining required room air temperature levels must be conducted according to regulations methodology. Therefore, the question arises, in which extent the results are varied for the overheating calculations. In addition, the impact of simulating with different time-step options or the leap year could be assessed. Furthermore, in default simulations daylight saving time is used. Hence, simulating only with summertime or correct schedule including both daylight saving time and summertime should be analysed. Additionally, investigating effect on simulations containing demand-based controlled systems, such as variable air flow ventilation system or occupant or natural lighting-based lighting system, the results variations with the same building models could be assumed.

Conclusion

The aim of this paper is to assess the impact of the undetermined building energy related simulation parameters presented in this study, such as first day of simulation, startup pre-simulation length and simulation splitting to sub-simulations. Five office modern buildings and five office parts of the building, situated in Estonia, were analysed.

The first parameter, consisting of the start of the simulation weekday comparison, showed the highest impact to the results. Depending on the weekday chosen, the net ventilation heating energy may vary up to 1.18 kWh/(m²×a) with the mean value of 0.43 kWh/(m²×a) or the net ventilation cooling energy can vary up to 0.95 kWh/(m²×a) (0.37 kWh/(m²×a) on the average). The delivered heating energy may vary up to 1.19 kWh/(m²×a) (mean value 0.45 kWh/(m²×a)) and the *EPV* up to 1.04 kWh/(m²×a) (mean value 0.45 kWh/(m²×a)). Room cooling and electricity consumption as well as definition of startup pre-simulation or simulation splitting is less sensitive to the overall results. In Estonia, the gap between different *EPV* criteria is 30 kWh/(m²×a) for office buildings. Therefore, up to 1.5% of reaching the desired upper *EPV* criteria is based on pre-simulation definition or dividing simulation into smaller sub-simulations. The gap can be over 3% of the desired result depending on the weekday to be chosen for the startup of the simulation. To avoid uncertainty at given extent for the day at the start of the simulation, a fixed weekday for the start of the whole-year simulation could help.

In conclusion, by the means of the analysed 5-day usage-based office buildings undetermined simulation parameters, we found:

- weekday of the first day of simulation to be considered as an additional variable regarding building energy or energy efficiency calculations;
- startup pre-simulation length and simulation splitting to be less sensible parameters compared to first day of simulation impact.

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Nomenclature

HVAC	heating, ventilation and air conditioning
MEP	mechanical, electrical and plumbing system
nZEB	nearly zero energy building
A	net heated floor area m²
A_{env}	envelope area of the building m²
EPV	energy performance value kWh/(m²×a)
H	specific heat loss W/K
SF	solar factor
SFP	specific fan power kW/(m³/s)
U	thermal transmittance W/(m²×K)
V	volume of the building m³
WFR	window-to-floor ratio
WWR	window-to-wall ratio

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