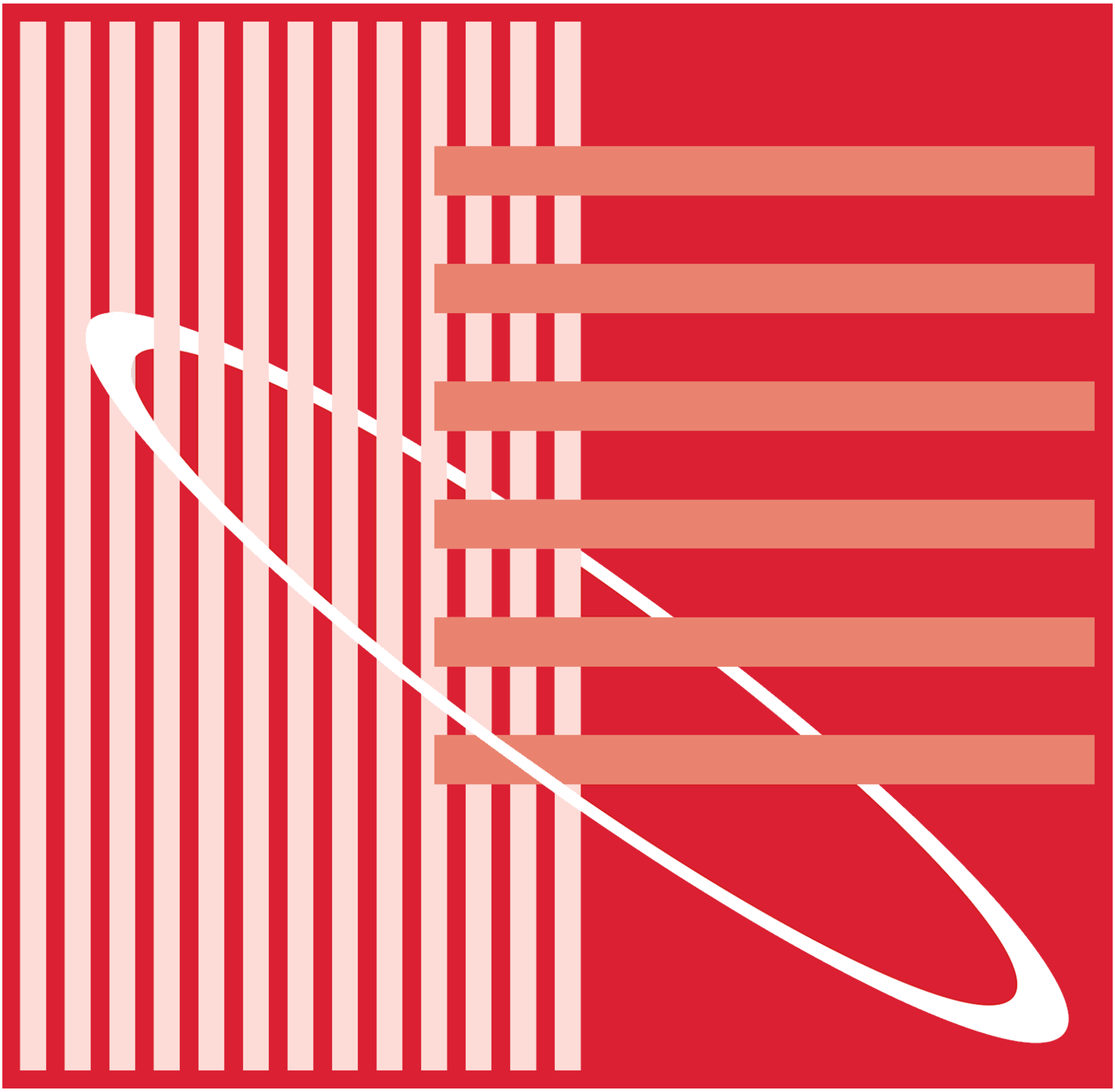
International Conference Organised by
IBPSA-Nordic, 22nd–23rd August 2022,
Technical University of Denmark

BuildSim-Nordic 2022

Technical papers



Editors:
Mandana Sarey Khanie and Christian Anker Hviid

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Keywords:
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Fenestration systems
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PREFACE

The BuildSim-Nordic 2022 conference is the second in a series of events with a long-term objective to establish a key biannual international conference in building performance simulation, with a strong focus on Nordic countries. The purpose is to create a platform for exchanging ideas, issues, and research findings that facilitates international collaboration and the meeting of minds between practitioners, researchers, and students.

This book contains technical papers approved by the reviewers and the scientific committee of the BuildSim-Nordic 2022 conference, August 22nd & 23rd 2022. The conference was hosted by Technical University of Denmark in Kongens Lyngby, Denmark, and organized in cooperation between the Nordic chapter of IBPSA, DTU, Molio and Danvak.

All submissions to the conference underwent a review process and presentation type was determined. Two blind reviewers evaluated each paper, a third reviewer was asked for evaluation in cases where the first two reviewers were not in good agreement. The selected full papers are of a high quality theoretical (scientific) nature.

IBPSA-Nordic is a regional affiliate of IBPSA, the International Building Performance Simulation Association, for four countries: Denmark, Finland, Norway and Sweden. IBPSA-Nordic is linked to IBPSA-World association but acts as an independent organization.

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Contents

TRNSYS model with 3-way valve for heat carrier temperature control of solar thermal collectors integrated into district heating system

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Abstract

TRNSYS and TESS component libraries do not have a valve with flow control dependent on system pressure and valve hydronic characteristics. To analyze the influence of valve Kvs coefficient, actuator time constant, hysteresis and inherent characteristics on heat carrier flow and temperature fluctuations in a short period (0.1 s), a Fortran code of "three-way valve with actuator" from TRNLIB was modified and adapted to TRNSYS 18. The model with solar thermal collectors connected to the district heating system was developed and tested by using data about the heat demand, supply/return temperature and pressure fluctuations from the district heating system.

Introduction

The total operating district heat (DH) pipelines in Europe are growing by 3 thousand km each year (IEA, 2020). The majority of the Latvian residents receive heat supply using district heating. Responding to decarbonization and energy efficiency policy, the system continues to transform, considering different development scenarios (Zajacs et al., 2021; Zajacs and Borodiņecs, 2019).

Currently, in Latvia, many boiler houses operate on natural gas with high efficiency and convenience but considering the climate change, political, economic and safety risks, the topic of green energy is becoming more and more relevant. Gradual transition to the 4th or 5th generation district heating (Lund et al., 2021) with solar thermal energy integration (Winterscheid et al., 2017) seems to be the next logical step. Connecting thermal solar collectors to the existing district heating system in parallel through a heat exchanger and without a local heat accumulation tank (Figure 1) is a way how to increase solar collector efficiency by avoiding collector stagnation and overheating and decrease natural gas consumption.

As the solar radiation intensity during the day is not stable, the heat carrier supply temperature and flow might significantly fluctuate. It is important to achieve robust supply temperature control to improve overall system efficiency, because too high heat carrier temperature increases heat losses, too low temperature increases flow rate and pressure drop in the system, but temperature fluctuations increase the maintenance costs compared to stable operations (Agner et al., 2022; Bergsteinsson et al., 2021; Lennermo et al., 2019; Zajacs et al., 2022).

In the case of developing a computer model to study temperature control strategies, it is important to have a three-way mixing valve model with accurate physical characteristics which is a challenge (Fürst et al., 2020).

In this paper, the results of simulations based on the developed TRNSYS model by using data about the heat demand, supply/return temperature and pressure fluctuations from existing district heating system with the heat load of 1.3 MW during summer weather are reported. Different cases were investigated, by changing three-way valve hydraulic and control characteristics.

The aim of the paper is to present the developed TRNSYS simulation model and show the influence of different "Three-Way Valve with Actuator" component parameters and control algorithms on the heat carrier temperature fluctuations and amount of produced heat energy in a small district heating system during a cloudy summer day.

Methods

The model (Figure 2) with a solar thermal collector, circulation pumps, heat exchanger and three-way valve with actuator was created with the dynamic simulation computer software TRNSYS 18 to analyze the control valve operation influence on the solar collector system supply temperature to the network.

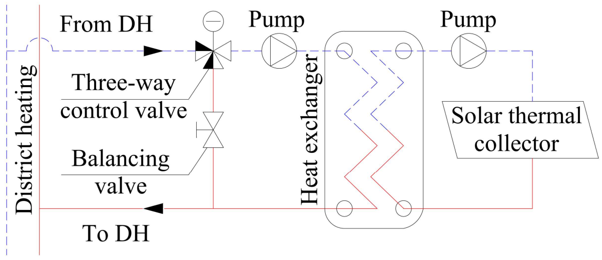

Figure 1: Principle drawing of the studied system.

The three-way valve position is controlled by two components Type1233 (Figure 2) which compare the actual heat carrier temperature with the specified temperature and send the signal to open or close the valve considering the three-way valve's real response speed, which determines for how long time the signal is transmitted for opening the valve and the waiting time between two consecutive opening / closing signals (Figure 3). The response speed is a part of the control algorithm and does not depend on specific valve physical characteristics.

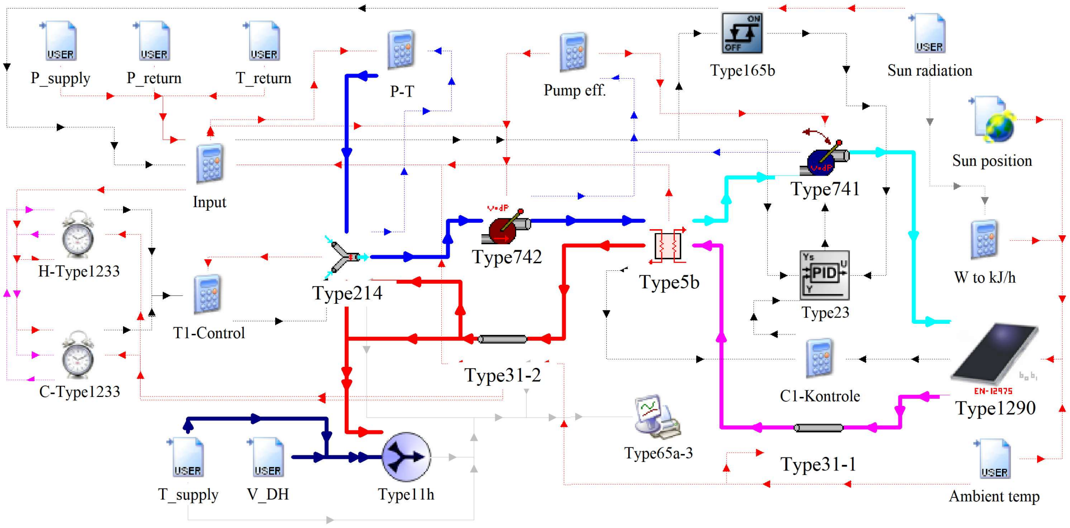

Figure 2: The TRNSYS model of the studied system.

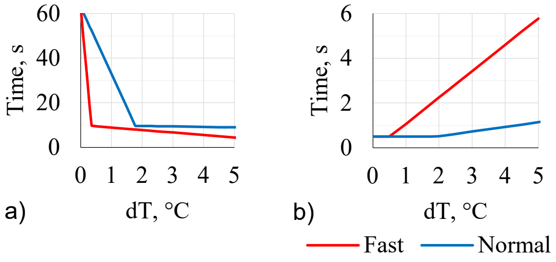

Figure 3: Control signal (a) waiting time and (b) run time depending on the temperature difference between actual and specified heat carrier supply temperature.

The three-way valve component (Type 214) is developed based on the "Three-Way Valve with Actuator" Fortran code from (TRNLIB, n.d.). The original Type was written for TRNSYS 15 which has different coding requirements and is not compatible with TRNSYS 18.

Type 214 parameters:

- K_1 and K_2 – valve coefficients at ports 1 and 2 ($K = 1/Kvs^2$, $Kvs = m^3/h$ at pressure drop 1 bar);
- y – leakage [m^3/h] then the port is fully close, needed to prevent from infinite pressure drop;
- Toll – actuator time constant (time for the output to reach 63.2% of the new steady-state value);
- hys – hysteresis, a fraction of actuator's range over which valve position remains constant when actuator's direction of travel reverses;
- Mode – port 1 / port 2 inherent characteristics: 0 = linear / linear; 1 = linear / exponential; 2 = exponential / linear; 3 = exponent. / exponent.

Type 214 inputs:

- P_1, P_2, P_3 – pressure in ports 1, 2 and after valve [bar];
- T_1, T_2 – temperature in ports 1 and 2 [°C];
- C – desired valve position (1 = port 1 is fully opened);
- Ci – initial valve position.

Type 214 outputs:

- Ca – actual valve position;
- W_1, W_2, W_3 – flow in ports 1, 2 and after valve [m^3/h];
- T_3 – temperature after valve [°C].

Input values

The simulation was performed for one day – 02.06.2021 from 7:00 till 19:00. The simulation step is 0.1 s.

The outdoor temperature and the solar radiation intensity on the tilted surface during a day (Figure 4) are taken from the measurement data, values between input data are linearly interpolated. The sun position from Meteonorm data for Riga on a relevant day.

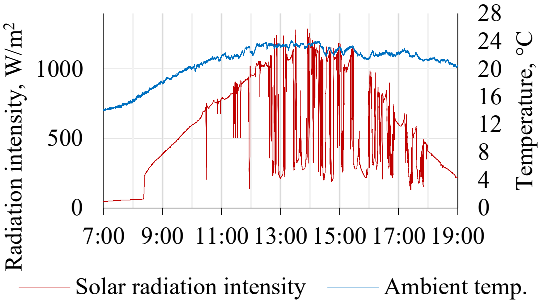

Figure 4: Weather data, measured data, step 2 sec.

The heat network parameters are taken from the existing district heating system. The system pressure fluctuations (Figure 5) are measured and handled data, average supply pressure 4.8 bar, average return pressure 2.9 bar.

During the period, heating power demand changes in the range 893 – 1338 kW, system flow 29.6 – 44.6 m^3/h, supply pipe heat carrier temperature 68.7 – 70.1 °C, return pipe heat carrier temperature 40.1 – 43.9 °C.

Flat plate solar collector (Type1290) area (total) = 200 m^2; efficiency = 0.712; $\alpha_1 = 3.18\ W/m^2K$; $\alpha_2 = 0.01\ W/m^2K^2$; beam IAM Coeff. $b_o = 0.09$; heat capacity = 6.3 kJ/m^2K.

The inclination of solar collectors: 45°; south direction.

At the ambient air temperature of +25 °C, heat carrier temperature of +70 °C, and solar radiation on the surface of 1000 W/m^2, the simulated solar plant (200 m^2) may produce 110 kW of heating energy.

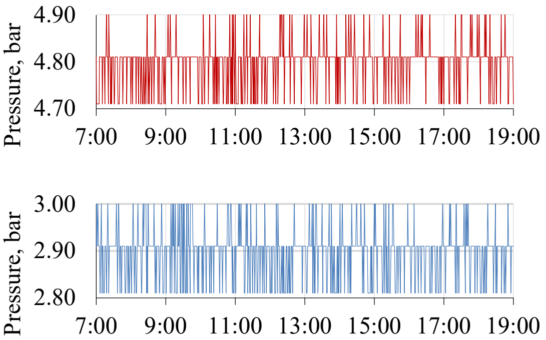

Figure 5: Supply and return pipe pressure in time (h), normal fluctuation, step 1 min.

For the normal pressure fluctuation (Figure 5), in the supply pipe pressure fluctuate in the range 4.71 – 4.91 bar with standard deviation (SD) = 0.05 bar; in the return pipe 2.81 – 3.01 bar with SD = 0.06 bar. For the large pressure fluctuation in the supply pipe pressure fluctuate in the range 4.15 – 5.35 bar with SD = 0.32 bar; in the return pipe 2.39 – 3.49 bar with SD = 0.28 bar.

Table 1: Cases description used in the TRNSYS model

Case	Pressure fluctuation	Response speed (Fig. 3)	Valve hysteresis	Actuator time constant	Valve Kvs value	Port (from DH) characteristics
0	normal	normal	5%	60 s	16 m^3/h	linear
1	**large**	normal	5%	60 s	16 m^3/h	linear
2	normal	**fast**	5%	60 s	16 m^3/h	linear
3	normal	normal	**1%**	60 s	16 m^3/h	linear
4	normal	normal	5%	**15 s**	16 m^3/h	linear
5	normal	normal	5%	60 s	**4 m^3/h**	linear
6	normal	normal	5%	60 s	16 m^3/h	**expon.**

Results

There is a relatively high (1.2 °C) temperature difference between district heating temperatures with and without solar collectors at the beginning of the day (Figure 6) that might be explained by the solar collector system's heat inertia. From 12:45 to 16:00 the temperature fluctuations are higher than from 10:00 to 12:45 which correlates with solar radiation fluctuations (Figure 4). The statistical analysis for all simulated cases is represented in Table 2.

Results in Figure 7 show how different control valves and algorithm choices may influence the small district heating system heat carrier temperature.

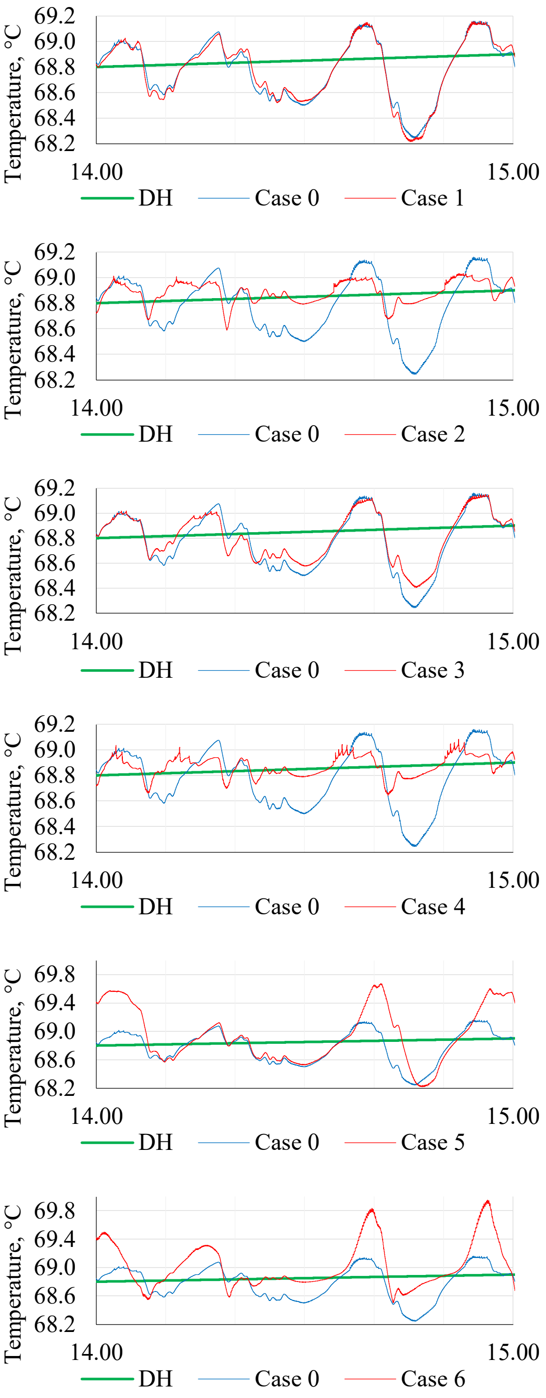

Figure 7: Simulated supply pipe temperature in the district heating system without solar collectors (DH) and with installed 200 m^2 solar collector plant in 0-6 cases.

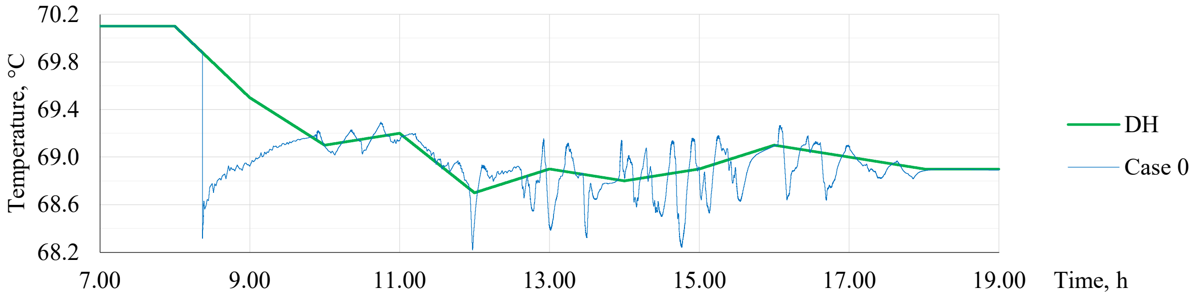

Figure 6: Simulated supply pipe temp. without solar collectors (DH) and with solar collectors (Case 0).

The amount of useful heat energy produced by solar collectors 02.06.2021 from 7:00 to 19:00 for Cases 0 – 5 is in the range from 428.0 kWh (Case 2) to 435.0 kWh (Case 1). For Case 6 it is smaller – 419.4 kWh.

From 14:00 to 15:00 solar collectors produced only 7.5% (higher rate) of the whole district heating system energy demand but the heat carrier temperature fluctuates in the range of 0.45 °C (Case 2) – 1.47 °C (Case 5), so with larger installed solar collector capacity, the difference between Cases will be greater.

Table 2: The statistical analysis of the supply temperature deviation from initial district heating (DH) temperature in the period from 9:00 till 18:00

Case	Maximal deviation, °C	Minimal deviation, °C	Range, °C	Standard deviation, °C
0	0.34	-0.63	0.97	0.16
1	0.33	-0.66	0.99	0.17
2	0.21	-0.58	0.79	0.11
3	0.29	-0.47	0.76	0.12
4	0.23	-0.58	0.81	0.11
5	0.86	-0.76	1.62	0.23
6	1.06	-0.42	1.48	0.17

The standard deviation is selected as one of the major criteria for the analysis because this parameter is closely related to the data dispersion. The higher the standard deviation of data sets is, the higher the temperature fluctuations are. Cases 2 and 4 have the lower temperature fluctuation (Table 2), Case 5 has the higher fluctuation.

Conclusion

The TRNSYS model of decentralized solar thermal collectors integrated into a small district heating system was developed and the three-way control valve characteristics were analyzed to find out their influence on the district heating supply temperature.

In this paper, only one day during the summer weather is analyzed and the total solar fraction is low (3.6% during the studied period) but anyway the inappropriate control valve choice may negatively influence the district heating system parameters – increasing the range of temperature fluctuation and decreasing heat energy production by 2%.

Simulation results show that district heating system large pressure fluctuations have a minor influence on the studied system temperature fluctuations. The temperature fluctuations might be reduced by increasing the control valve response speed and decreasing the actuator time constant. Decreasing control valve hysteresis also decreases the temperature fluctuations but the influence is not significant. Choose the undersized control valve (with a low Kvs value) or the valve with exponential inherent characteristic instead of linear characteristic significantly increase the temperature fluctuations.

Additional analysis with different solar collector areas and district heating system parameters is going to be done in further research to make a general conclusion about solar collector influence on the district heating system.

Acknowledgement

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Data-driven modelling of the KU Leuven data centre

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Abstract

Despite continuous operational improvements, data centres consume a large and rapidly increasing share of energy in many countries across the globe. Driven by ongoing digitization of society and intensifying data processing needs, a better understanding of how energy is used in data centres is key to optimizing their performance. In light of these realizations, an internal project was launched in 2021 to investigate the performance of the central KU Leuven data centre and further optimize it, if possible. This is a complex endeavour theoretically, especially because the energy flows into and out of the data centre take on many forms. More concretely, a task scheduler attempts to maintain the CPU load on the computational servers as high as possible, thereby limiting any potential flexibility. At the same time, heat flows are optimized by existing heat exchangers, which means that excess heat from the data centre is used to heat neighbouring buildings. Drawing appropriate system boundaries in developing a model for the data centre is therefore critical. In the first phase of this project, we model the data centre using data from on-site temperature sensors and the HVAC loads etc. Developing such a model will not only enable us to optimize its operation, it will also help raise alarms in case of anomalous behaviour.

Introduction

Driven by increasing digitization, data centres represent one of the fastest growing energy demand sectors. According to a recent IEA report, global data centre electricity use in 2020 was 200-250 TWh, or around 1% of global final electricity demand. Despite continual efficiency improvements, the overall electricity demand of data centres is expected to grow further in the coming years. As such there has been increasing emphasis on better understanding their performance and further optimizing it - both in the provision of core computational services and in the maintenance of stable operating conditions. This can further reduce their operational energy and carbon footprint, as well as enabling design improvements for the future.

However, many such efforts are marred by data retrieval and quality issues (henceforth referred to as data integration), even before the modelling or optimization stages can begin. This integration exercise includes gathering data from several independent streams, including ambient weather conditions, operating conditions and physical layout of the data centre, constraints on safe operational limits, HVAC system operation and scheduling of loads on the data centre. Furthermore, oftentimes the system boundaries extend beyond the data centre itself as its residual heat can be reused to heat neighbouring buildings etc. Once this data has however been integrated, it can be modelled using a variety of white-, grey- or black-box techniques (Kazmi, 2020). Finally, this model can be used in an optimal decision-making tool to minimize the energy demand of the data centre, for instance by improved scheduling of cooling or computational tasks or recommending investments in improved insulation etc. (Zhang, 2016).

This paper details our preliminary experiences with modelling and optimizing the KU Leuven data centre, where we encountered many of these data integration issues, with several semi-structured streams containing necessary data, in addition to model selection challenges. More concretely, the KU Leuven data centre is used in two main ways. On the one hand, a low-density compute room is used to provide core IT infrastructure services (e.g. email, web services etc.). On the other, a high-density compute room is used by researchers at the university to run complex simulation and modelling tasks, including potentially the modelling of the data centre itself.

Data integration and system boundaries

The residual heat from the data centre is reused to heat surrounding campus buildings. However, this was excluded from the system boundary and the focus was on the thermal response of the data centre itself. More concretely, this involved learning a function of the form $y=f(x)$, where y is the temperature at the various racks and servers in the data centre, and x is a set of input features used to predict this:

- Power of in-row cooler
- Airflow through the in-row cooler
- Chilled water flow through the cooling coil of the in-row cooler
- Chilled water valve position [%] of the in-row cooler (=control variable to alter the water flow)
- Power provisioned to the rack by two different PDU’s (every rack has two PDU’s)
- CPU usage [%} of all nodes in a rack
- Internal temperature readings corresponding to the racks

The function f refers to the model, which we describe next.

Modelling and optimization

Once the data had been collected and integrated into a usable form, a forecast model, f, was created which could then be further used in a downstream optimization task. We used the Darts library to fit several models to the observed data, and the final model was chosen using backtesting, a form of cross validation for time series. This model minimizes the prediction error over the given time horizon, and aims to predict the indoor temperature (and various quantiles of it) as accurately as possible. As alluded to previously, this task is complicated by the fact that there are several racks and servers in the data centre, and all of them display temperature variations, which are extremely localized in nature, as shown in Fig. 1. Learning a model for just the mean temperature is therefore obviously not sufficient to understand the data centre behaviour as a whole. Consequently, we considered models which could predict the quantiles of the temperature distribution.

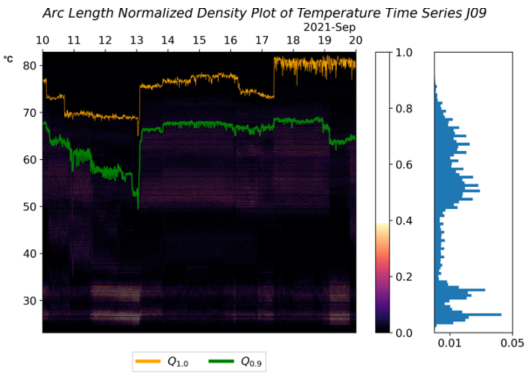

Fig. 1: A visualization of all the temperature readings for a single rack, shown for a ten-day subset. The colours represent the relative frequency of occurrence of a particular temperature at a particular time. The 100% and 90% quantiles are also highlighted, while the right histogram plots the density

The models were trained using data for several months from 2021, and the forecast time horizon was six hours. All models were benchmarked against a simple baseline (naive persistence model, which assumes a perfect past-predicts-future strategy). In our experiments, a linear model with L1 regularization (LASSO model) outperformed several alternatives, including tree-based methods such as LightGBM and random forest. At the same time, this model was roughly 15% better than the previously mentioned baseline at a six-hour time horizon. At the same time, it was quite obvious that the model performed much better for short-term forecasts of the temperature in the data centre when compared to multi-hour forecasts, as shown in Fig. 2.

The most accurate model created using this approach can then be used in a downstream optimization task. As the cooling power of the HVAC system is one of the inputs of the model, it can be modulated to ensure that the best trade-off between safe operating conditions and energy efficiency can be obtained. At the same time, the same model can also be used to detect anomalous values (or behaviour) in the data centre which is arguably an even more important service for the low-density compute room where tasks cannot be rescheduled and operating conditions are much more stringent (breakdowns in email communication are, in general, much more serious than slight delays in simulation results).

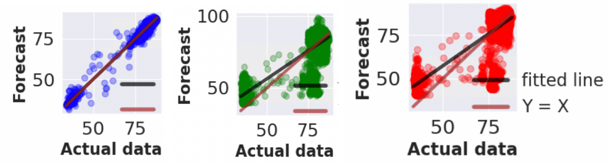

Fig. 2: A visualization of forecast temperature against observations for three different time horizons (5 minutes, 3 hours and 6 hours); the R^2 falls rapidly with increasing horizon

Conclusion

This ongoing project to optimize the behaviour of a moderately sized data centre has raised some interesting challenges. These range from issues with obtaining the relevant data (complicated by the fact that different teams using different software are responsible for the organization's and management of the data centre) to modelling the data centre. Due to random fluctuations caused by unobserved variables, it is naturally difficult for a black-box model to map the spatiotemporal temperature variations with high fidelity. However, given the importance of data centres in modern life, this work will only assume greater importance in the future. In addition to energy efficiency, the energy demand of the data centres can also be made flexible in response to grid and market-based signals. This energy flexibility is a function of existing HVAC loads, the computational load scheduling, and the possible presence of any backup generation or storage system in the data centre. In this case, backup is provided by a small UPS system and a (seldom activated) diesel generator which cannot be called upon to provide flexibility.

Acknowledgement

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A bottom-up approach for building performance evaluation -BREEAM?
BuildSim-Nordic 2022, Copenhagen

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Abstract

Commercially available building performance evaluation methods, such as BREEAM (Building Research Establishment Environmental Assessment Method), is considered nowadays as essential and powerful tools towards sustainable buildings (Hasan Haroglu,2013). In Norway, there exist more than 300 registered BREEAM-NOR projects, of which the integrated building performance are performed by BREEAM. However, the lack of multidisciplinary communications amongst stakeholders with various professional backgrounds (engineers, designers, and architects etc.) along the BREEAM implementation process is proven to be problematic (Schweber, Libby and Haroglu, Hasan,2014). For instance, the existing nine environmental indices within BREEAM are interrelated and even paradoxical for some criterium such as definition of relevant areal for daylighting simulation, indoor climate analyses, CO_2 emission and energy use. The intertwined relationship is commonly accepted as one of the most challenging aspects of BREEAM certification system. Therefore, it is important and required to pay more attention to deepen engagement refer to potential gaps along the whole process of project.

This study aims to justify the need for a bottom up approach- dialogue based process for improving multidisciplinary communications or engagement towards sustainable buildings by means of case studies. Interviews will be carried out and further analysed before and after the BREEAM process, in order to identify the difficulties, causes, and solutions.

Introduction

Nowadays sustainability has become a highly influential concept and a decisive factor in economic, social, and environmental decisions of developed countries. Buildings, which serves as an important component in the society, have a prevailing role as a hub for the realization of sustainable development. In order to better facilitate and implement sustainability in both building and use the building, advanced assessment methods such as BREEAM have been developed by Building Research Establishment (BRE) since 1990 in the UK. Relying on dedicated criteria and specified processes, multidisciplinary teamwork towards sustainable development can be coordinated and realized (Lowe, Watts, Jack, Norman, 2011). As shown in Figure 1, the framework of BREEAM can promote integration of diverse knowledge and knowhows from different experts. However, it is often lack of communications among experts during different stages of the construction process. This will potentially lead to risks for total contractor when meeting the requirement of certification level of BREEAM. In addition, the ambiguity of technical definition such as daylighting/indoor climate simulation areal increases the risk level.

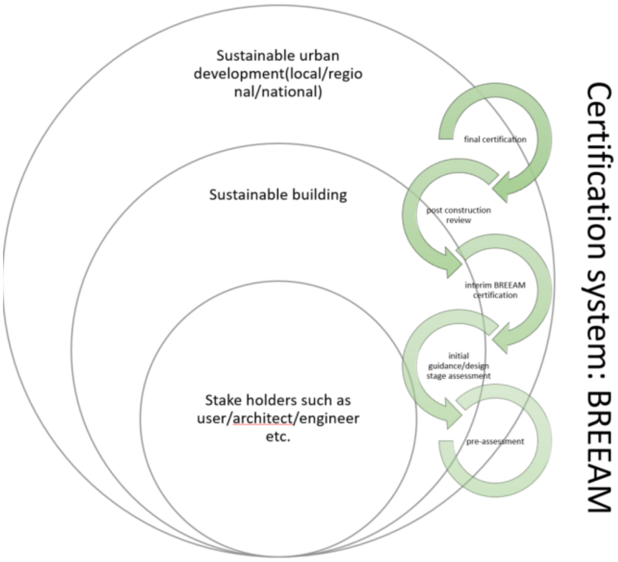


Figure 1, diagram elucidating how BREEAM works

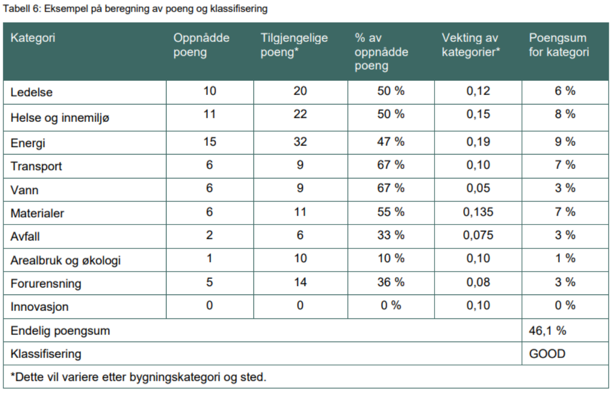
In section one we introduce the certification systems in Norway-BREEAM NOR. Section two presents the case study which use the above certificate systems. Section three illustrates the findings from the case study: gaps within the certification systems, while section four concludes the paper.

Main body

BREEAM (Building Research Establishment Environmental Assessment Method) NOR is the Norwegian adaptation of BREEAM as a toolset for sustainability assessment and documenting quality for buildings in Norway. The Norwegian Green Building

Council is the responsible organisation to operate and manage BREEAM certification in Norway.

BREEAM embodies various criteria, such as metrics under nine weighted environmental categories (energy, water use, health and well-being, pollution, transport, materials, waste, ecology and management processes). The building performance can be put into different levels (6 BREEAM certification levels: Outstanding, excellent, very good, good, pass and unclassified (Outstanding (>85%), Excellent (>70%), Very Good (>55%), Good (>45%), Pass (>30%), and Unclassified (<30%)). The value of grading is a sum of the resulting score of each criteria, as exhibited in Figure 2 below.



Tabell 6: Eksempel på beregning av poeng og klassifisering

Kategori	Oppnådde poeng	Tilgjengelige poeng*	% av oppnådde poeng	Vekting av kategorier*	Poengsum for kategori
Ledelse	10	20	50 %	0,12	6 %
Helse og innemiljø	11	22	50 %	0,15	8 %
Energi	15	32	47 %	0,19	9 %
Transport	6	9	67 %	0,10	7 %
Vann	6	9	67 %	0,05	3 %
Materialer	6	11	55 %	0,135	7 %
Avfall	2	6	33 %	0,075	3 %
Arealbruk og økologi	1	10	10 %	0,10	1 %
Forurensning	5	14	36 %	0,08	3 %
Innovasjon	0	0	0 %	0,10	0 %
Endelig poengsum					46,1 %
Klassifisering					GOOD
*Dette vil variere etter bygningskategori og sted.					

Figure 2, example on calculation of points and classification (BREEAM NOR 2016 manual, Page 13)

BREEAM NOR 2016 process is undertaken in 5 stages based on bygg 21 fasenorm: pre-assessment, initial guidance/design stage assessment, interim BREEAM certification, post construction review, and final certification.

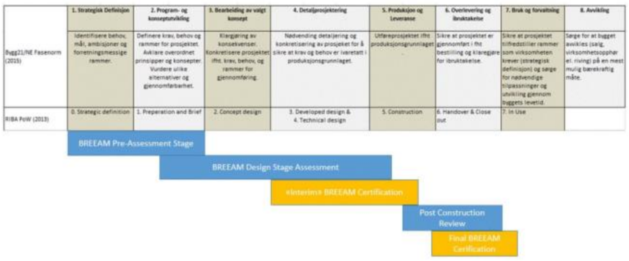


Figure 3, BREEAM-NOR assessment and certification stages in relation to the project work stages according to Bygg 21 fasenorm. (BREEAM NOR 2016 manual, page 12)

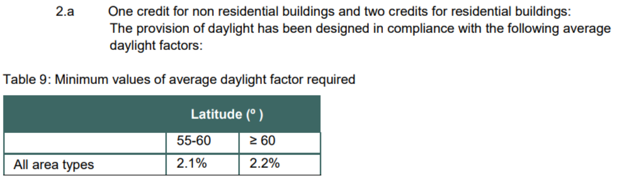
The BREEAM coordination/training is undertaken by BREEAM accredited professional and assessed by independent licensed assessors .

In the case study, we present one secondary school (ungdomsskolen) project which followed BREEAM NOR 2016 manual, aiming to reach BREEAM EXCELLENT. The project is set as a pioneering building (passive house and zero-emission building (ZEB-OM) with extensive use of cross-laminated timber/massive wood in the region. The following issues has been located and discussions initiated towards possible proposals:

- Ambiguity of simulation areal *vs.* Point requirement

Daylighting simulation:

The goal was to achieve one credit point based on criteria 2a-Hea01, a minimal 2,1% of average daylight factor (DF) for relevant area.



2.a One credit for non residential buildings and two credits for residential buildings:
The provision of daylight has been designed in compliance with the following average daylight factors:

Table 9: Minimum values of average daylight factor required

	Latitude (°)	
	55-60	≥ 60
All area types	2.1%	2.2%

Figure 4, criteria 2a from Hea 01 visual comfort. (BREEAM NOR 2016 manual, page 51)

Daylighting simulation was proceeded in the design phase according to CN9 (see below), after which it was concluded that the building as a whole meets the daylight requirements as 80% of the total relevant area has DF>2.1% for the building.

CN9 from Hea 01: “*Where the compliance requirement specifies that a percentage of floor area must be adequately daylit, it refers to the percentage of the total floor area of all the rooms in relevant building areas (cf. CN 2). If, for example, a development has 6 rooms that must be assessed, each 150 m^2 (total area 900 m^2) and 80% of this floor area must meet the criteria, then 720 m2 must comply with the criteria; this is equal to 4.8 rooms. The number of rooms that must comply must always be rounded up; therefore, in this example, five rooms must have an average daylight factor of 2.1%/2.2% (depending on the latitude) or more (plus meet the other criteria) to achieve the credit.”* (BREEAM NOR 2016 manual, page 55).

It was not clearly explained in CN9 on if the relevant areal is refer to the whole building or the room type. The ambiguity of explanation of relevant areal was later clarified at the construction phase relying on knowledge base - KBCN0471 and FAQ from Norwegian green building council where followed:

“……

Whereas a building often contains various types of areas depending on usage, the 80% minimum floor area must be calculated within each area type as defined. For example, a multi-residential building that contains kitchen areas and living room areas, would need each one of these areas to comply with the 80% minimum floor area requirement, respectively.

………..”

This gap has rendered that the predefined criteria are impossible to achieve since the relevant areal is defined by room types. All the meeting rooms in the project are designed in the centre and none of these rooms have achieved average daylighting factor over 2,1%.

Furthermore, according to Norwegian building code (TEK 17 (§ 13-7 3), definition of relevant areal (rom for varlig opphold) does not differentiate between different room functions as long as the rom serves as work or public rooms.

“*rom for varig opphold: rom for varig opphold i arbeids- og publikumsbygg er arbeidsrom og publikumsrom. Lagerrom, korridor, gang, garderobe, toalett, dusjrom og lignende er ikke rom for varig opphold*”

- byggteknisk-forskrift-tek17/1/1-3

Indoor climate simulation:

It was predefined to achieve 2 credit points from criteria 1-4 of Hea03 thermal comfort in the design age. The aim turned out to be very challenging. There are designed large window areal to satisfy the daylighting requirement. This in turn contributes to passive heat gained from the windows areal and unsatisfied predicted percentage dissatisfied (PPD) according to BREEAM requirement related to criteria 1-4 of Hea03.

The ambiguity of definition leads to risky for total contractor who is supposed to fulfil the daylighting and indoor climate point. In extreme case, it might lead to risky that it cannot reach the BREEAM level in case of little margin.

- Energy supply study *vs.* Profitability assessment in reality

In combination of criteria 1 from Ene 04 (see below), energy feasibility study was analysed concluding that heat pump together with solar panel and solar collectors are chosen as the energy supply solutions based on calculations in the design stage.

Criteria 1 from ENE04: “*A feasibility study has been carried out by an Energy specialist (see relevant definitions) to establish the most appropriate local (on-site or near-site) low or zero carbon (LZC) energy source for the building/development*”. (BREEAM NOR 2016 manual, page 117).

However, it is on the other hand proved to be less profitable compared with heat pump plus only solar panel on the roof due to better return on investment at the construction phase.

The profitability assessment shows that the energy supply solution with solar panel and collector has the net present value with 87 559 Norwegian kroner, while energy supply solution with only solar panel has the net present value with 869 455 Norwegian kroner. In addition, it is more profitable in terms of maintenance and drift.

The findings suggest that there was a high chance lacking efficient communications between experts from the design stage and construction stage, which will lead to the potential discontinuities of sustainable design quality.

The early engagement of experts to define the BREEAM level is very effective to set up the framework and common goals. The widespread criteria under the 9 environmental categories and involvement of stakeholders such as client, total contractor, architect and engineers, material producer etc supply common framework towards sustainable building by considering of social, economic and environmental issues (Cole, 2005). The represent of total contractor of case study stated that ‘I have learned a lot from the process by means of BREEAM meetings’. The results further suggest that BREEAM requirements needs more dialog to have the common understanding. For instance, the daylighting credit might be conflict with the indoor climate credits. Furthermore, the CO_2 commission credits might be paradoxical with the energy performance credit.

In the case study, the early engagement of experts to define the BREEAM level is very effective to set up the framework and common goals. However, there is various understanding on the technical concept from the BREEAM manual from the design stage to the construction stage. It was found that the impact of engaging BREEAM accredit professional (AP) and assessor at the early stage of the process is significant, and deemed crucial to set the right framework at the right time. As the BREEAM AP stated ‘the communication with BREEAM accessor has constituted right direction for AP and other expert towards the right explanation of BREEAM criteria’.

Conclusion

The finding from this short paper draw attention to potential gaps in the BREEAM process, which could result in discontinuities of sustainable design quality. It is clear that BREEAM as a hub could promote sustainable development. However, the lack of bottom-up approach into improving multidisciplinary communications of diverse stakeholders can lead to ambiguity of technical definitions of criteria are concluded as barriers to promote better sustainable development.

Future research can be designed and performed to seek to identify how the BREEAM assessment process could be better developed into dialogue based communicational process among stakeholders.

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A BEE process for BIM Energy–Environment

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Abstract

BIM (Building Information Model) lacks effective frameworks for energy and environmental studies. The BEE (BIM Energy Environment) process consists in a few steps to process BIM data of a building for thermal analysis and LCA (Life Cycle Analysis). The method to obtain the adapted geometry is detailed in this article. An experiment was done on cases of IFC (Industry Foundation Classes) files to assess the performance of the process. We notice better results by carrying out energy and environmental studies in a single process, in accordance with the evolution and the issues of the energy-carbon framework in the building field.

Introduction

BIM is an important technology that aims to collect and centralize a very large amount of building data for experts of various domains in the building sector. Many engineering fields can potentially access all required BIM data: thermal, electrical, mechanical structures, etc. An expectation for many experts in the various fields is to use BIM data to carry out technical analysis, to improve the performance and reduce study time thanks to this technology (Pereira et al., 2021; Azhar et al., 2012). The various approaches range from a simple extraction of BIM data to carry out a single study, to advanced interactive processing between the BIM data and the analysis model. A common analysis with BIM is for instance the treatment of MEP networks in integrated tools (Wang et al., 2016; Singh et al., 2018). The purpose is to allow the integration of design methods for the building networks (plumbing, electricity, etc.).

If the BIM technology is promising for architects and building engineers, reality shows a current lack of use for technical applications, in particular for energy and environmental calculations (Elagiry et al., 2020). For all the concerned experts, such as architects or energy and environmental engineers, the use of BIM for technical applications does not create an effective framework for energy and environmental studies. Various obstacles seem to prevent the technical use of BIM. A first obstacle is technical: a lack of effective methods and tools for fast and safe BIM process to build an energy-environment model. For example, if errors or defects occur in the BIM model, the time required to correct the model is slower compared to a new study with common software or calculation tools. The effectiveness of technical BIM is therefore not guaranteed. A second obstacle comes from the cooperation between experts for the management and the transfer of BIM data (Gregorio, 2020). Complex work processing makes the consistency of BIM data difficult to maintain, for instance the interactions between an architect and a building engineer to undertake local corrections of the model. The level of details of a thermal model requires dedicated BIM objects that mostly concern engineers: layers of the walls, spaces, 2nd level space boundary, etc. This leads to clarify rules in order to make the BIM process more reliable. IFC-type standard exchange formats have been able to adapt to technical requirements for the fields of energy and environment. For instance, the IFC 4 format (ISO 16739-1, 2018) contains 2nd level space boundary (in the IFCRelSpaceBoundary class) which is essential to carry out the division of spaces and to produce a thermal model of the building. However, available software for the design of BIM models have not necessarily adapted their method to the technical requirements of standard for energy models. This does not guarantee the availability of essential information for energy and environmental calculations. We aim to improve the use of BIM data to carry out energy and environmental analysis. We propose a framework to undertake energy-environment analysis in a single BEE process. The BEE process can use BIM models from IFC files of average quality, according to the requirements of energy modeling. Models from IFC 2x3 format, without 2nd level space boundary, can also be used. The BEE process can structure BIM data sets according to the requirements for the technical data of energy and environmental analysis, making possible analysis and simulations from a single BIM data input. First, this article presents the methods used for the BEE process. Then, we show the results of an experimental approach to assess our method.

The BEE process in this article allows to treat data from a single BIM model in order to undertake energy and environmental analysis. A common energy-environment framework for buildings engineering is explained by the recent changes that have taken place in this field. The successive regulatory frameworks, for instance the French thermal regulations: RT2005, RT2012 had an evolution towards a conjoint study of the energy and environmental performances, as appeared in the latest French RE2020 environmental regulation. Similar evolution happens in many countries. This shows that the choice of building elements (walls, insulation, windows, joinery, etc.) will be made as much for the properties of energy performance as for their carbon footprint (EN 15978, 2012). The method we propose must allow the characterization of the elements of a building for both energy-environment objectives of performance.

The objective of the BEE process is to create a corrected model adapted for energy and environmental analysis. In order to improve a reliable use of BIM, the BEE process is also aimed at users with few skills in both BIM and thermal engineering, so that IFC files with lower levels of detail can be used. Other methods exist to solve the issues from the step of conversion of BIM data to energy model. Existing methods are based on the IFC standard, with methods for generating, verifying and correcting geometries (Elagiry et al., 2020; Reynders et al., 2017; Giannakis et al., 2019). The IFC 4 standard contains a number of essential objects characterized in the classes of the IFC format: volumes of spaces (IFCSpace), walls (IFCWall), 2nd level space boundary (IFCRelSpaceBoundary). These data should be required to generate an equivalent thermal model. However, as mentioned in the introduction, the cases of complete IFC 4 input files are unfortunately not common in reality. Some of the research works undertaken in Lilis et al. (2018) manage to bypass the lack of 2nd level space boundaries by converting the input BIM data into a topology, which makes possible to reconstruct 2nd level space boundaries. Other problems can be encountered with IFC standards for other object classes. For instance, many errors are encountered with IFCSpace such as wrong definitions of the volume of spaces. This suggests probably algorithm errors in BIM design software when creating output IFC export files. In addition, the IFC 2x3 format is still very common in reality. The latter format remains the most widely used standard among building thermal engineers. All of these observations show that the generation of a thermal model limited to reading or treatment of IFC file contents is difficult for a sufficiently stable step for a BEE process. Other methods also allow to process CSG (Constructive Solid Geometry) trees or to use geometric methods (Jones et al., 2013; Maile et al., 2013)

An approach based on generation of geometry

The features and choices of the BEE process are shown below. Only the energy part of the process is explained in the article. The BEE process is first aimed at an energy process due to the difficulty to convert BIM data into an equivalent thermal model of the building. The BEE process adds also the integration of an environmental process. The whole process is summarized in Figure 1. For the energy process, ENERBIM had developed an advanced method to extract a description of the BIM data of the building. The algorithm uses optimized methods of raytracing and voxels (Horna et al., 2015; Huber et al., 2011) in order to generate step by step: spaces, sets of walls and linear thermal connections of the building. The principle of analysis is to disconnect from the IFC objects for geometry, because IFC objects are considered as the roots of many problems in practice: incorrect geometry from exported IFC files, not enough detailed geometries, bad junctions between IFCWalls or ceilings, lack of elements such as IFCSpaces, etc. We want a common approach that would allow the use of either a complete IFC 4 model or a moderately informed IFC 2x3 model.

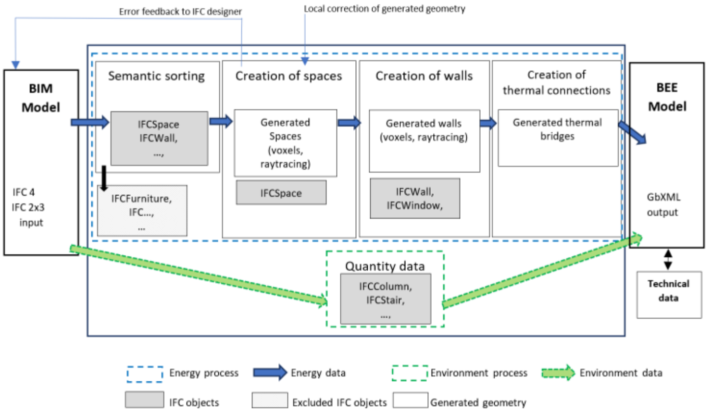

Figure 1: Diagram for steps inside the BEE process. blue arrows: process for energy data. Green arrows: process for environmental data.

To structure the energy model of the building, this method consists of generating spaces, instead of using the IFCSpaces from the IFC files. The thermal model is generated from the successive steps: (i) semantic sorting of IFC objects (ii) creation of spaces, (iii) creation of walls, (iv) creation of thermal connections. The successive steps of the process are as follows:

(i) Semantic sorting of IFC objects: input of the IFC file and storage of geometry – surfaces and volumes, from the IFC objects. This step also allows to fix semantic errors in the IFC model, such as structural elements (walls, slabs) that were drawn with improper tools, and are seen by the IFC with the wrong class.

(ii) Creation of spaces: this step generates spaces from new volumes and detected volumes from IFCSpaces. Generated volumes rely mostly on combined methods of ray tracing and voxels. A matching is done with the IFCSpaces to keep the links with BIM data. This allows to maintain data structures even for the cases where the IFCSpaces are poorly defined. This accounts for instance IFCSpaces not existing at the location of the detected volume, several IFCSpaces located for a single detected volume, modeling errors such as: lack of ceiling under attic, which generates a single IFCSpace in the last level under the attic. This step takes into account closing volumes in the case of open space problems (usually due to modeling problems or erroneous 3D IFC exports). The detection concerns both indoor volumes (spaces) and outdoor volumes (external envelope of a building). Edition tools have been developed to create local surfaces inside the generated geometry to enclose spaces: slabs, ceilings, etc. This avoids to modify the model in the initial BIM software. Many problems can be solved with this tool, however some cases require feedback to the designer to correct the initial BIM model.

(iii) Creation of walls: this step is for the generation of walls and boundaries between volumes, openings and joinery: a ray-tracing method is used again to detect walls and boundaries as well as the various elements in compound walls. The layers of the walls are not detected at this step and are treated later. A matching is also done from generated walls and IFCWalls from the BIM model to keep the data links from IFCWalls, IFCWindows, etc.

(iv) Creation of thermal connections: the last step consists in the generation of the thermal bridges in the new model. They are generated from spaces and walls, independently from the initial IFCRelSpaceBoundary objects.

The environmental process is not described in details in the article. It consists in the transfer of useful IFC objects useful for carbon accounting, i.e. that contain information about quantities of materials. This includes any objects from the geometry: IFCWall, IFCWindow, etc. Additional elements from the structure of the building are also considered, such as IFCColumn, IFCStair, etc.

At the end of the BEE process, the BEE model consists in the thermal model, enhanced with links with technical data and IFC object links. A GbXML output file is available with all required data (Figure 2).

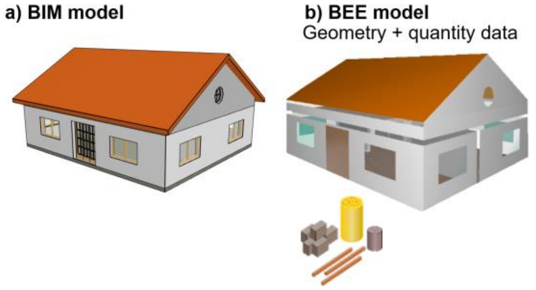

Figure 2: Models before/after the BEE process. a) initial BIM model b) BEE model with energy-environment associated data model, with GbXML output file.

Once the BIM data have been processed and the entire BEE model has been generated, the BEE process allows coordination between the BIM data and the technical data to carry out the various energy-environment analysis: regulatory thermal calculations from dynamic energy simulation, analysis of thermal bridge with finite element method, carbon accounting of the elements of building envelope and structure.

Experimentation and discussion

An experimentation consists in applying the BEE process to around twenty digital models from IFC files, not formatted for the technical applications of BEE. IFC files have been designed by various partners of the project: building design offices, engineering companies or universities. The performance of the BEE process was targeted to test the main weak points from the initial geometry: IFCSpaces and IFCWalls, as the most common objects used to compose a building geometry. A comparison with a so-called "classic" algorithm is based on the simple reading of IFC 2x3 or IFC 4 input files without further examination of the models. The classic IFC reading is notably limited by the IFC exports algorithm from BIM modeling software. It is likely that these problems are encountered for most analysis tools, as reported in several articles discussing tests on IFC mockup cases (Reynders et al., 2017; Giannakis et al., 2019). The panel consists in three types of building in the IFC models: detached houses, residential buildings and tertiary buildings (Figure 3). The upper limit for the size of the buildings is around a hundred rooms on ten levels. The cases show various problems, notably with IFCSpaces: non-existent matches (IFCSpaces not at the expected location), multiple matches (several IFCSpaces for a single volume), non-enclosed spaces (for example open kitchens). Residential facades also contain classes of unwanted IFC objects, considered as IFCWalls. A noteworthy problem is the detection of spaces under roofs, due to the complex enclosed geometry around attics (a). Poor definition of the attics inside the BIM files can generate indoor space closure problems, even for simple detached houses. Tertiary buildings usually contain many rooms (from a few dozen to a few hundred rooms) and complex building shapes (b). That increases the chances of finding wrong IFCSpaces. Curtain wall facades are reasons of wrong modeling or wrong IFC objects definitions. Their geometric description is generally complex, not necessarily stuck to a wall in the modeling. They are also composed of a several hierarchical sub-components not necessarily very well ordered (c). A hall with several floors also creates multi-level indoor spaces with many sources for misinterpretation, as an architect's IFCspace is not strictly similar to a thermal volume.

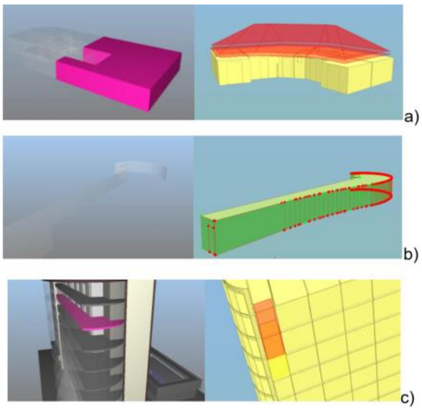

Figure 3: Comparisons of cases with : classic IFC file reading (1st column) and BEE process (2nd column).

By comparison with the classic IFC reading method, the BEE process allows a better adaptability to average/low quality IFC files using voxelization and ray tracing. For houses with attics (a), the BEE process generates new spaces with correct ceiling, slabs and thermal connections. For complex wall shapes (b), curved slabs could be detected, with correct definition of surface normal. For multi-leveled spaces (c), the correct thermal volume could be generated. Concerning the performances of following simulation tools, from output GbXML files: either for the energy or the environmental aspects, improvement of the joint BEE approach makes the process more reliable. For the energy analysis, the performance criteria: speed and precision, relies on the evaluation of the simulation tools themselves (STD calculation engine, calculation with finite element method). For the environmental analysis, treatment of quantities from BIM data did not create further stability issues, once the BEE model was well established. However, the evaluation of the accuracy of the LCA must be considered from the choice of filtered IFC objects. An analysis of classes of IFC objects to consider remains to be done, in order to improve the accuracy of carbon accounting. Last, some features of the BEE process need to be improved, such as the reliability of data transfer from BIM, the management of BIM file versions or the development of semi-automatic tools to facilitate the coordination with technical data.

Conclusion

We have shown the usefulness of a single BIM process to undertake energy and environmental calculations. The process has shown a significant efficiency and a better stability. These results encourage the use of BIM to solve issues related to the evolution of the various energy-environment regulations. This experience opens the possibility of exploiting BIM data for advanced technical uses, adapted to the needs of the building energy–environment field. We hope that this process helps the field of BIM suitable for energy-environment engineering.

Acknowledgments

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Simulation and optimization of data management through parallel computing and multithreading

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Abstract

This paper presents a case study on the optimization of a building simulation software, BPC® Workflow Pedersen and Rasmussen (2019) within the Python language. The BPC® Workflow is developed with the intended use of evaluating the performance of solar shading systems and has an extensive database of solar shadings, which is continuously increasing. To counter this it is necessary to optimize the BPC® Workflow to handle more simulations within a reasonable amount of time. Therefore, the tool is assessed in terms of time to detect where optimization is most beneficial. The investigation showed that the effort to optimize software has resulted in an increase of 3.5 times more simulations per minute.

Introduction

The global building industry is changing due to enhanced building directives and an increasing focus on carbon reduction, energy consumption and indoor climate. Solar shadings pay a key role as they provide a passive solution to control the heat at the façade and limiting the use of energy for cooling. The BPC® Workflow has been developed to provide an easy-to-use and fast tool to evaluate solar shadings in a holistic perspective taking energy consumption, indoor climate, daylight and view out into consideration. The BPC® Workflow is a coupled workflow, which means that it uses the same assumptions for both energy/indoor climate and daylight calculations. The results from BPC® Workflow are collected in a database, that forms the building section of the online simulation tool SimShade®. See Figure 1. SimShade® intends to advise industry professionals, such as architects and engineers, to model solar shading systems accurately.

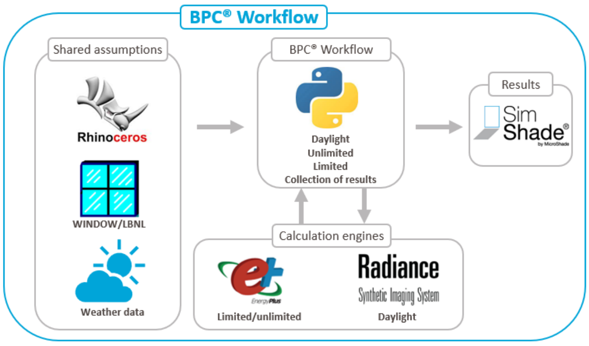

Figure 1: BPC® Workflow and the integration with SimShade®

SimShade® needs to cover the most typical solar shadings in a number of different markets. Therefore, the number of different shading solutions considered in the BPC® Workflow is increasing, resulting in increased simulation time as well. It is, therefore, necessary to optimize the BPC® Workflow to keep the simulation time within an acceptable range.

BPC® Workflow

The BPC® Workflow is developed by MicroShade A/S and is written in Python Van Rossum and Drake (2009). The software consists of four steps; 1. Daylight simulations in Radiance Ward and Shakespeare (1998), 2.Energy and indoor climate simulation with unlimited cooling capacity in Energy+ US Department of Energy (2018), 3. Energy and indoor climate simulation with limited cooling capacity, and 4. collection of data from each simulation. See Figure 2.

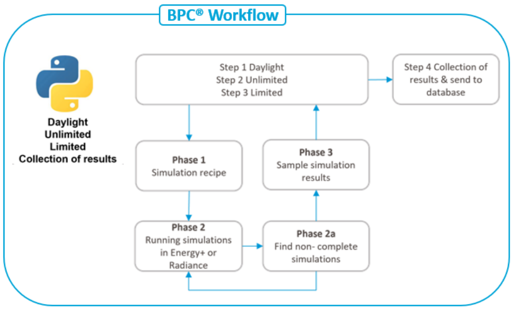

Figure 2: BPC® Workflow step overview

The input variables in the software consist of shadings, building types, window floor ratio, orientation, and locations (Figure 3). 112 different geometries can be constructed with 276 different shadings varying from passive to active solutions. The simulation of the different scenarios is simulated for 150 cities with a growing number of shadings.

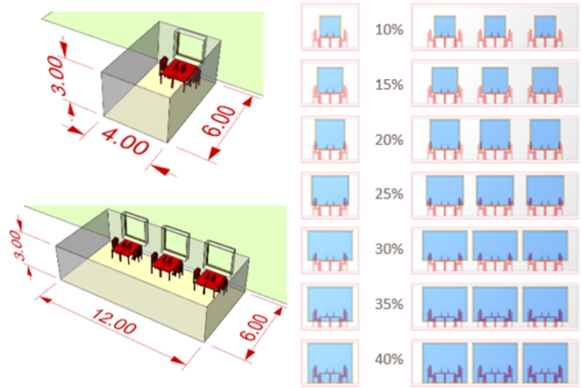

Figure 3: BPC® Workflow: Two building types, 7 WFR options and 8 Orientations.

The BPC® Workflow simulates all scenarios through the four steps of the software to provide full validation of a given shading system. The output from the simulation is spatial daylight autonomy according to EN17037 European Standard (2018), overheating hours according to EN16798-1 European Standard (2019), ideal heating and cooling demand and activation time and weighted view out. The three simulation steps, daylight, unlimited and limited, consist of three phases. Phase one collects and creates the simulations recipe to make a simulation in either Radiance or Energy+. The subfiles, for creating the recipe for a simulation, are stored in the program and are composed according to the predetermined variables for the simulation. Phase two initiates the simulation in either Radiance or Energy+ through a series of bat files. However, the control of the simulation is lost in this transition to the Energy+ program, which means that there is no information regarding when a simulation is completed. Therefore, a bat file is constructed with a timer that shuts down the simulation after a predefined time. This timer must be very accurate, so the simulation does not take an unnecessarily long time. Phase three is the collection of results from each simulation. The collected results are processed into the desired results and stored in the program until all steps are completed. In the last step of the whole simulation all results are compiled and send to the SimShade® database for easy comparison between the solar shadings.

The limited simulation is further subdivided into two sections, calibration of the cooling capacity and the limited cooling capacity calculation. The calibration calculates the cooling capacity required to maintain maximum 100 hours above 26 degrees for a specific shading system, according to EN16798-1 European Standard (2019). The cooling capacity required is used in the limited simulations to set the cooling capacity for all other shading systems to be able to compare the effect of the shading on indoor climate.

Case study: Optimizations in BPC® Workflow

The BPC® Workflow has been optimized to handle the increasing numbers of shading systems. This case study focus on optimization of the calculation time, as it will allow the software to run more simulations faster without using more powerful hardware. The three steps with the calibration section are initially measured in percentage of the whole simulation time. See Figure 4. Since the unlimited and limited calculations (incl. calibration) are the most time consuming the case study will focus on those.

Four optimizations will be described: reuse of calibration results, implementation of directories, shutdown timer and CSV reader.

The case study was performed on an PC with the specification listed below:

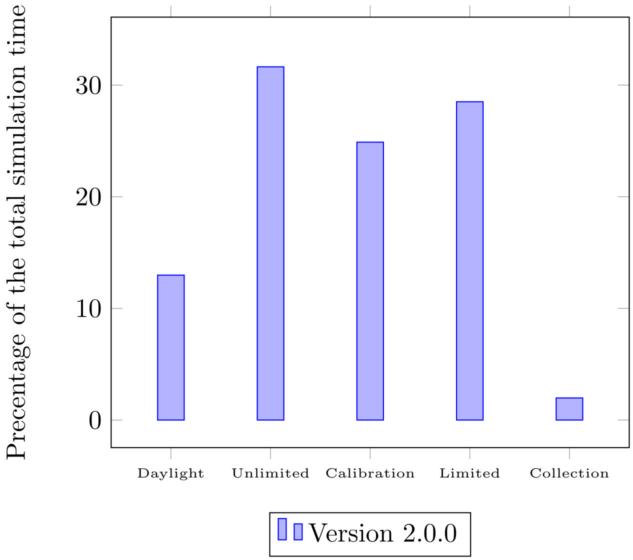

Figure 4: The percentage for each step in the simulation of the total simulation time. Where Calibration is divided from limited simulation.

- RAM 8 GB
- Processor Intel® Core(TM) i5-8250U CPU@ 1.60GHz 1.80GHz
- 4 Total Cores - 8 Total Threads

Reuse of calibration results

In version 2.0.0 it was found that the calibration of the cooling capacity was a significant part of the simulation time (25%). The calibration of cooling capacity is performed for every location and it was found that locations were closely related in terms of cooling capacity required. Therefore, a code segment was developed to store the calibration results for later use. The stored calibration results resulted in a more precise estimate of the cooling demand for a specific location. Since the initial guess was more close this improvement resulted in fewer simulations to calculate the needed cooling capacity and hence a shorter simulation time. The code was implemented in version 2.1.0.

Directories

Version 2.1.1 time optimization featured a more general code cleaning. The different code segments were reanalyzed to check for unnecessary time-consuming code elements. This included cleaning loops and functions that could be accomplished through new python functions and the introduction of dictionaries instead of lists. The dictionaries were introduced in the recipe reading, where all information regarding a shading type and building type was stored. The directories enables the BPC® Workflow to find specific shading and building information without the need for multiple loops through lists to find a particular piece of information. This was, for example, implemented in the creation of IDF files, where information needed to create the IDF files could now be found through and searched in the created dictionary instead of using multiple loops in different lists to find the specific information.

Shutdown Timer and CSV reader

The version 2.2.0 investigations showed that the unlimited simulation was the most time-consuming step in the software, with approximately 25 hours of the whole simulation time of 56 hours. Where the limited simulation took approximately 17 hours. The investigations found, that the running of the Energy+ files and specifically the shutdown timer of the bat file was the most time-consuming part. As running the Energy+ simulations have the same practice for the unlimited and limited steps a general replacement was investigated.

The running of the Energy+ simulations starts with a collection of IDF files created for the different solutions, and a master bat file is sent to the Energy+ program. However, this practice could not measure when the simulations are completed. Therefore, an open-source plugin called Eppy Philip, S. (2021) was tested. Eppy is an Energy+ scripting language programmed in Python. The Eppy plugin program has several functions: navigating and modifying Energy+ files, running Energy+ simulations, and reading output files of an Energy+ run. Furthermore, it can run multiple IDF files in parallel, which is an important feature to be able to run many simulations simultaneously.

The implementation of Eppy meant, that the timer could be discarded along with the bat file generator. This feature improves the time spent between each simulation because the simulations do not have to wait for the predefined timer to run out. Furthermore, the program will wait for slower running simulations instead of restarting them.

The initial investigation showed, that the data collection after ended simulation was highly time consuming as the data harvesting for unlimited and limited metrics took approximately 5 hours. This is primarily due to the large number of CSV files produced after an Energy+ calculation, that needs to be read into the software to harvest the results of the simulations. The data collection plays a central role in reading and transforming the raw results into the final results. In the initial software the Pandas package McKinney et al. (2010) is used to read the CSV results. The Pandas package has a large pool of options for CSV file management, making result management easy in many aspects. The CSV file reading was achieved through a parallel loop facilitated by the Python package Joblib Joblib Development Team (2021).

In the investigation for a replacement of the CSV reader three different CSV readers were tested for performance, including a modified version of function in the Pandas packages. The study showed that the Dask reader Rocklin (2015) was significantly faster than the other options.

1. Pandas took 0.106 seconds
2. DictReader took 0.219 seconds
3. Pandas modified took 0.057 seconds
4. Dask took 0.012 seconds

Dask was selected to further develop and integrate into the software. Dask has various options for handling large amounts of data. The Dask Dataframe used in this project has an API closely related to Pandas. The Dask Dataframe is a large parallel Dataframe consisting of a series of smaller Pandas Dataframes, divided along the index. Data loaded through Dask is stored as lazy data, which means that it can compute a larger amount of data, than the memory capability of a single computer allows. The parallel load is achieved through a predefined thread scheduler from Dask, which optimizes the data loading. The implementation should allow multiple files to be managed simultaneously with a lower CSV read time. The use of multithreading instead of multiprocessing has been chosen because the task is highly I/O bound, where multithreading often achieves a faster completion time.

Dask is implemented in data collecting and processing in the unlimited and limited steps instead of the previously used Joblib multiprocessing.

Results

To measure the time consumption of version 2.1.1 and version 2.2.0, a full simulation with 60033 different scenarios was started. The time consumption for each part is illustrated in Figure 5. The time consumption for the whole simulation is improved by 12 hours. The most significant improvement was seen in the unlimited simulation with an improvement of 9 hours. This suggests that the introduction of the Eppy package significantly improves the calculation time. However, this tendency cannot be seen in the limited simulation, where the time consumption has only been improved by 10 minutes. The difference is due to the unlimited simulations had several individual simulations that went overtime in version 2.1.1, which meant they needed to be simulated again. However, this did not occur in the limited simulations. Therefore, the time difference is more significant in the unlimited step than in the limited step. This supports the benefit of using Eppy, which can self-control the time of each simulation.

The collection of results after ended simulation was improved with one hour in both the unlimited and the limited step. However, in the precious study of Dask, it was found that the CSV reading was the primary time consumer and that the Dask reader was approximately 5 times faster. Therefore, the Dask implementation should be further investigated either in the standard multithread scheduler currently in use or in the results management. Moreover, there is still an opportunity to explore how the modified Pandas without Dask could do in an entire simulation, as this options also showed promising CSV read speed.

As illustrated on Figure 6, the effort in time optimizations has been proven beneficial as the latest version of the software performs 3.5 times faster than version 2.0.0. For each new version of the software, the calculations per minute were increased by approximately 5.5. The most significant increase in calculations was between version

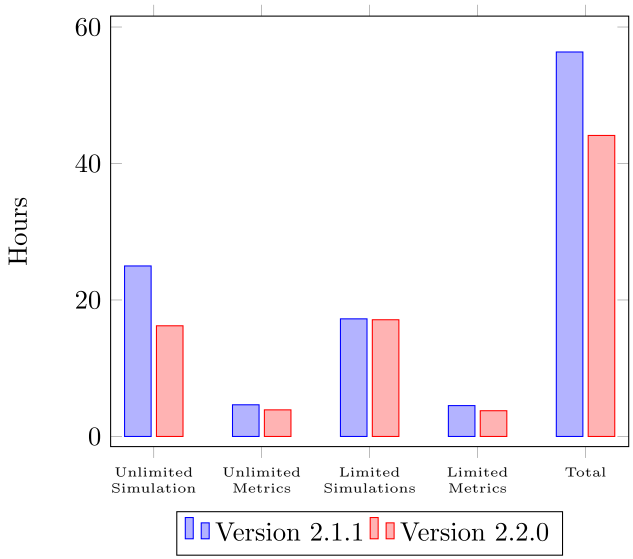

Figure 5: Time comparison of version 2.1.1 with the improved version 2.2.0. The comparison is split in unlimited simulation, unlimited metrics, limited simulation, limited metrics. The total time of the simulation is a sampling of the steps in question and the general code.

2.0.0 and 2.1.0, where the calibration results were stored and reused. The calibration isolated has been improved from 29 calculations per minute to 394 calculations per minute in version 2.2.0. The lowest change in the calculations per minute is the newest actions where Dask and Eppy were applied. However, the recent improvement of the shutdown timer has shown that the expected time for the simulation to be completed is now more accurate as there will be no re-simulations caused by the predefined timer.

Conclusion

Time optimization of BPC® Workflow is an essential part of the software development as it allows to perform more simulations in a shorter time. Furthermore, it has proven that faster simulations are possible without faster computers.

The study showed that since version 2.0.0, the simulation per minute has been increased by approximately 3.5 times. Each action towards faster simulation has demonstrated significant improvement, especially the storage of calibration results has proven to be substantial. The investigation also showed that each slight improvement in cleaning the script and minimizing the use of loops could significantly reduce simulation time. The latest optimization of the shutdown timer and the CSV reader is a significant time optimization observed in the unlimited simulation. However, the limited simulation did not show the same trend. This was caused by the predefined timer, where every simulation was completed in time in the limited step but not in the unlimited step. Therefore, it can be concluded that the introduction of Eppy is a considerable improvement as the program will complete all simulations without any re-simulations. In calculating the results, an improvement of 1 hour could be observed in both steps. However, this should still be investigated further, as we expected a more significant decrease in time consumption.

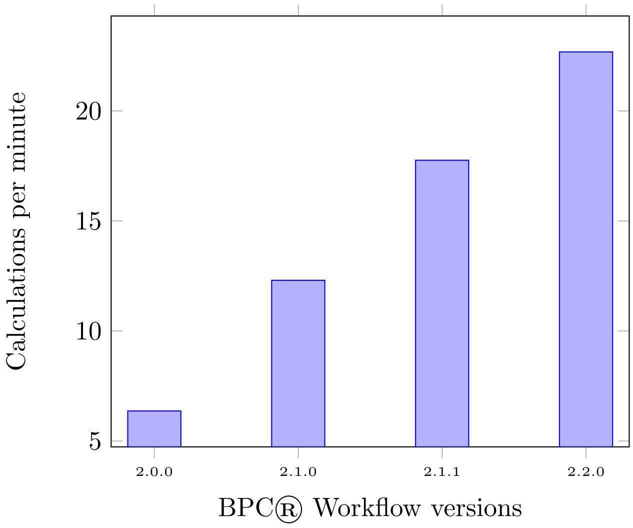

Figure 6: Calculations per minute for the last four versions of the BPC® Workflow

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A Web-based Common Data Environment for Continuous Commissioning of buildings

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Abstract

With ever increasing demands for high performance buildings in the Architecture, Engineering, Construction, and Operation (AECO) industry, a transition towards Common Data Environments (CDEs) is happening. Such CDEs has been created initially to raise the Building Information Modeling (BIM) maturity to level 3. CDEs have been discussed to be the next step of full digitalization of the AECO industry. It is believed, that by creating a CDE as a Single Source of Truth (SSOT) for the BIM model, the AECO industry can minimize the Energy Performance Gap (EPG) from predicted energy performance to measured energy performance. However, most existing CDEs do not involve the Heating, Ventilation, and Cooling (HVAC) model and are not capable of performing advanced hydraulic simulations based on the BIM model. In this article, we discuss the technological changes that need to be made for CDEs to be widely employed within the HVAC industry. We propose a system architecture based on literature, making it possible to perform continuous commissioning of buildings on a digital platform after the building has been built. By introducing a CDE, BIM models will be stored in a centralized database so that all project stakeholders have access to an SSOT.

Introduction

There is a gap in the predicted energy consumption of buildings to the measured energy consumption, and this is called the EPG by De Wilde (2014). Several reasons have been stated for this gap, one of them being that there is a lack of continuous commissioning (Jradi et al., 2018). It should be the original designer of the HVAC system that should perform it. Therefore, we suggest a framework for a CDE to enable continuous commissioning and therefore minimize the EPG from predicted to measured energy performance. Previous work describes parts of the CDE by the authors of this report. A CDE is defined as a web-based collaboration space for all the stakeholders of a construction project (Preidel et al., 2016; Kirby, 2022; BIM Wiki, 2021). The main idea is that all project stakeholders should be able to access the project from anywhere, using a computer, phone, etc. CDEs have been implemented into parts of the AECO industry, but mainly for the design and construction, on large-scale commercial projects. A CDE provides an SSOT of the entire project so that all stakeholders and designing, constructing, and operating the building on the same data foundation. However, few efforts have been made to create a CDE for commissioning of building services. One effort was carried out by Jradi et al. (2018), but while presenting a novel idea on how to utilize a CDE for operation, they did not present a system architecture for others to build upon the idea. This article aims to present the foundation of a CDE and which developments is needed to achieve a CDE for the continuous commissioning of building services. The system architecture has been developed in relation to several unpublished (in review) papers by the authors of this report (Seidenschnur et al., 2023; Fjerbæk et al., 2023; Seidenschnur et al., 2023) and published articles (Kukkonen et al., 2022; Fjerbæk et al., 2022).

Objectives

The objectives of this article is to:

1. To identify what a CDE is
2. To present a system architecture that allows for a CDE capable of making continuous commissioning
3. To identify the IT technological developments needed for CDEs to be used for most building projects

Results & Discussion

Figure 6 shows the system architecture of the CDE. The central BIM-database acts as a SSOT. The database is connected with a backend routing module to the microservices that allows for detailed HVAC simulation, energy and indoor climate simulation, and performance monitoring of the building.

BIM Model requirements

The first part of transferring the data from the Revit model is to ensure that the Level of Detail (LOD) of the Revit model is sufficient to have coherent information about the building and its systems. This subsection lists the requirements for what an HVAC model should include to be transferred as a model to a web-based database. According to United-BIM (2021) there are 6 levels of detail. (1) LOD100 is a purely conceptual model; it contains the spaces in the model with the actual area requirements. (2) LOD200 is the approximate geometry, that is represented with generic models with approximate specifications, quantities, size, shape, location, and orientation. (3) LOD300 is usually used as construction documentation. It contains accurate sizes, quantity, location, and orientation. (4) LOD350 is different because it, on top of LOD300, also supports: interfaces and connections with other building components. (5) LOD400 is a model that is ready to be driven directly into fabrication - it can be handed directly to manufacturers that can supply components based on it. (6) LOD500 is an as-built model. Everything is the same, from the MEP model to the actual building. This means that to be capable of containing the needed information to use the CDE, the BIM model should have an LOD with LOD350 or higher, as the connectivity of the components is necessary. Figure 1 shows an example of an HVAC system modeled to standard LOD350. The figure shows that both the heating, ventilation, and cooling system is modeled with all the components that will be in the system. Furthermore, they are modeled within spaces of a building to provide the connection from system to space.

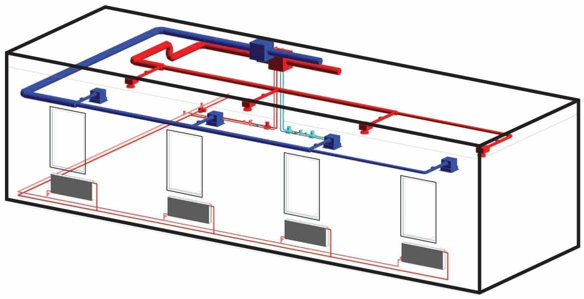

Figure 1: Example of an HVAC system modeled to LOD350, with all components modeled in Revit (unpublished work: Seidenschnur et al. (2023))

However, with current modeling standards in companies, such a transformation is not simple to make. While most companies agree to Information and Communications Technologies (ICT) contracts, stating the LOD for certain phases of the construction process, most of them do not follow the contract meticulously, meaning that often connectivity issues occur. Systems are not classified correctly (supply and return system poorly defined in the model), the flow direction of the system is wrong, etc. Figure 2 shows the level of detail needed for modeling if the desire for the 3D model is to be able to make hydraulic simulations in a Modelica environment.

The model shown in 2 does not constitute the current modeling standards for most companies until very late in the design phase. Therefore, to perform hydraulic simulations in Modelica, companies need to invest time in the 3D model to represent the actual flow system.

Class hierarchy for HVAC systems and spaces

Figure 6 shows both a BIM energy model and a BIM HVAC model. Those constitutes two related object models. To parse the two BIM models, the Revit C# Application Programming Interface (API) was used to serialize a JavaScript Object Notation (JSON) object model to represent the energy model and HVAC model. The JSON object model was initialized using a class hierarchy for HVAC and spaces (energy model), as

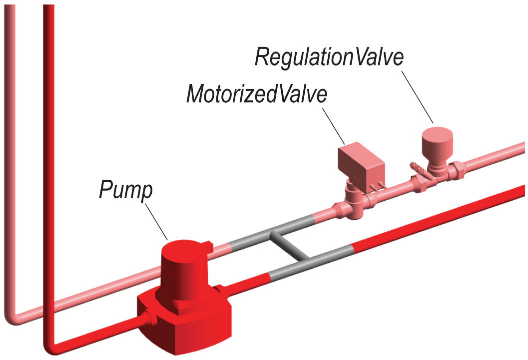

Figure 2: Mixing loop from heating system to ventilation system heating coil, from 3D model shown in 1

seen in Figures 3 and 4. Figure 3 that the container `HVACSystem` contains a dictionary over the `SubSystems`. A `SubSystem` contains a string that describes its type and a list of `Components` in that `SubSystem`. A `Component` acts as a super-class for all possible components in an HVAC system. It contains an Id, Tag, ComponentType, SystemName, SystemType, a list of all components that the component is connected with, and which spaces the component is located in. Below is an example of the C# code that generates the `Component` class. It has been simplified for readability

```
public class Component
  {
     string Id {get;set;}
     string Tag {get;set;}
     string ComponentType {get;set;}
     string SystemName {get;set;}
     string SystemType {get;set;}
     List<Connectors.Connector>
         ConnectedWith {get;set;} =
         new List<Connectors.Connector>();
     List<string>
         ContainedInSpaces {get;set;} =
         new List<string>();

     Component(string id,
               string tag,
               string systemName,
               string systemType)
     {
         Id = id;
         Tag = tag;
         SystemName = systemName;
         SystemType = systemType;
     }
     <Methods not shown for simplicity>
  }
```

The `Component` is a super-class to `FlowSegment`, `FlowTerminal`, `FlowController`, `Fitting`, `EnergyConversionDevice`, and `FlowMovingDevice`. Below is an example of how the `FlowTerminal` inherits the properties and methods from the super-class, `Component`.

```
public class FlowTerminal : Component
 {
     FlowTerminal(string id,
                  string tag,
                  string systemName,
                  string systemType)
        : base(id,
               tag,
               systemName,
               systemType)
     {

     }
 }
```

The same principle applies to all the components that inherit their properties and methods, as shown in Figure 3. However, some classes add extra information to the specific class, such as a pump. The pump contains information that none of the other components contain, such as a power curve and pressure curve.

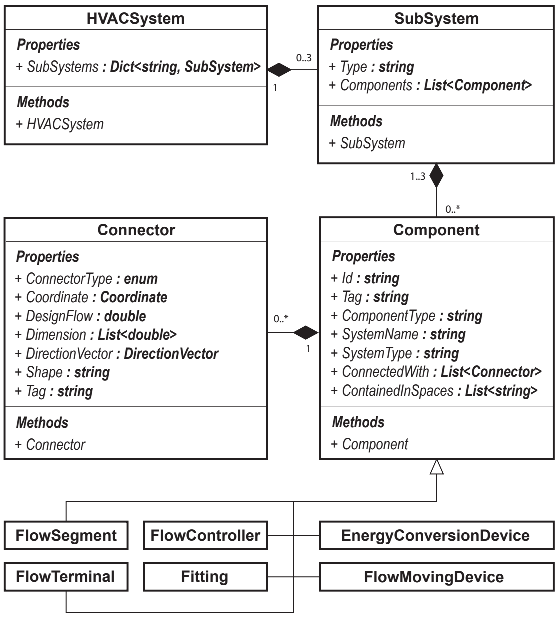

Figure 3: Base classes for a class hierarchy to describe an HVAC system (unpublished work: Seidenschnur et al. (2023))

Figure 4 shows that the container `Spaces` contains a list (`SpacesInModel`) of all spaces in the model. The class `Space` represents the simple features needed to define a space. It contains an Id, Tag, ThermalZone, and SpaceGeometry. The Id and Tag identify the space with a unique id within Revit. The ThermalZone specifies the properties needed to augment the thermal zone with properties related to indoor climate. The SpaceGeometry describes the geometry of the spaces.

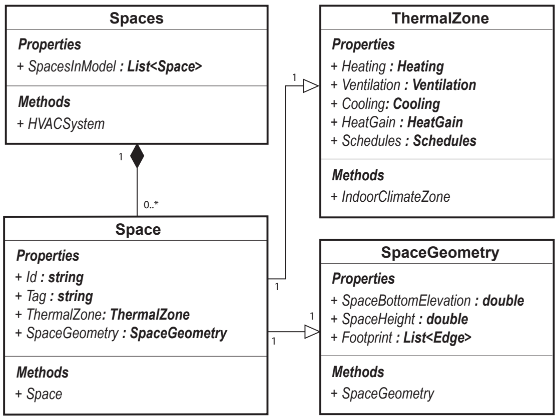

Figure 4: Base classes for a class hierarchy to describe an energy model (unpublished work: Seidenschnur et al. (2023))

Object model generation

In order to generate the FSC object model and serialize it to JSON, a C# script was written, using the Revit API. The C# script was created with an object-oriented approach. First, the Revit API is used to loop through all of the components within the model. While the components are looped, they are mapped down to the correct component, for instance, a pump. After each component of the HVAC model has been looped through and mapped to a FSC component based on the FSC hierarchy, the `HVACSystem` is mapped from a list containing all subsystems and components and serialized into a JSON object. The UI of Revit now creates a prompt window, asking under which projectId, UserId, and Uniform Resource Locator (URL) address the JSON should be sent to. It then sends a response to the endpoint with the above URL to post the data within the MongoDB database.

Database infrastructure

The database used for this CDE is called MongoDB. MongoDB is a database following the paradigm of Not only Structured Query Language (NoSQL). NoSQL databases store data non-tabular compared to Structured Query Language (SQL) (relational) databases. The advantage of a NoSQL database is that the schema is more flexible than for an SQL database. Furthermore, a NoSQL database is capable of more easily scaling horizontally rather than vertically. A vertical scale-up means adding extra processing power to the single server but will eventually be limited by the processing power of that server. Horizontal scaling, however, brings in more nodes to distribute the workload of the server - a task that is difficult to perform with relational databases. Finally, MongoDB is compatible with JSON objects, which essentially means that it can take in the JSON that is generated by the C# script from the previous section.

User Interface

Figure 7 shows an example of a user page in CDE. The spaces have been imported from Revit to the central database in the CDE. The top of the figure shows the different types of rooms that the user has generated in the CDE. The bottom shows the rooms that were actually imported from Revit to the database. Each room contains the room number, the name of the room, the function of the room, which level it is located on, what volume the room encloses, the floor area, the type of ventilation, the flow supply, the flow return, and what type of room it is, compared to the mechanical template types, shown in the top of the figure. This makes it possible for the user to select a mechanical template for each room. The engine will automatically calculate the flow supply and return for the given room.

Microservices

With a connection from Revit through an object model to the centralized web-based database in the CDE, the final step is to implement microservices to utilize the object model in the database. Figure 6 shows that the microservices is connected through a routing module within the application. The microservices are created as endpoints in the web framework Flask, which is based on Python, making it easy to develop new microservices. The microservice architecture allows for technologies like Kubernetes to be used for managing containerized workloads and services, making it easy to scale the application to the desired level (horizontal rather than vertical).

The article from Fjerbæk et al. (2022) showed how to transfer an HVAC model from a BIM database into the Modelica-based Dymola environment. In the article, they successfully simulated a small heating system in Modelica and obtained results for the return temperatures of each loop. The setup of this toolchain allowed for easy-to-initiate Modelica simulations of a heating system. This process would, under normal circumstances, be very time-consuming since it is a manual process and the simulations have high complexity. Figure 5 shows the microservice. The microservice receives a post request to perform a Modelica simulation. Step 1 - The FSC object model is translated into a Modelica file (.mo) and stored. Step 2 - The Modelica file (.mo) is simulated, and the results are stored as a Matlab file. Step 3 - the results are read and serialized to a JSON file and then parsed back to the database. Then the results are stored within the original FSC object model for future use.

Conclusion

CDEs will revolutionize the way that the AECO industry works with buildings through the design, construction, and operation phases. If it can be applied to perform continuous commissioning, it has the potential to minimize the EPG from predicted to the measured energy performance of buildings. However, for CDEs to be applicable, the AECO industry must increase the level of BIM maturity from level 2 to level 3. This means that modeling standards need to improve in the industry. The CDE centralizes the BIM model into a database with the applications around it instead of keeping external applications in separated silos. In this article, we have shown examples of the technological advances needed to create a CDE based on microservice architecture for continuous commissioning. In previous work by the authors of this article, a microservice for Modelica was created and used to generate automated detailed simulations of building services together with indoor climate parameters. The next step in the CDE shown in this article is to deploy it within a company structure and use it to ultimately reduce the EPG from predicted to the measured energy performance of buildings. For future work, efforts should be made to prove how a CDE for continuous commissioning can reduce the EPG. Finally, the system architecture created for this article has only been tested in a local testbed, which means that future work will focus on the deployment of the application. Finally, this application has been developed by the authors of this article, who have professional careers as HVAC engineers, meaning that most of the concepts have been developed without any user testing. Future work will involve users in further developing features in the project, improving user-friendliness, etc.

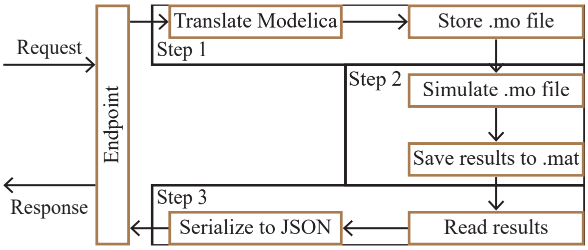

Figure 5: The figure shows the system architecture of the Modelica microservice. (unpublished work: Fjerbæk et al. (2023))

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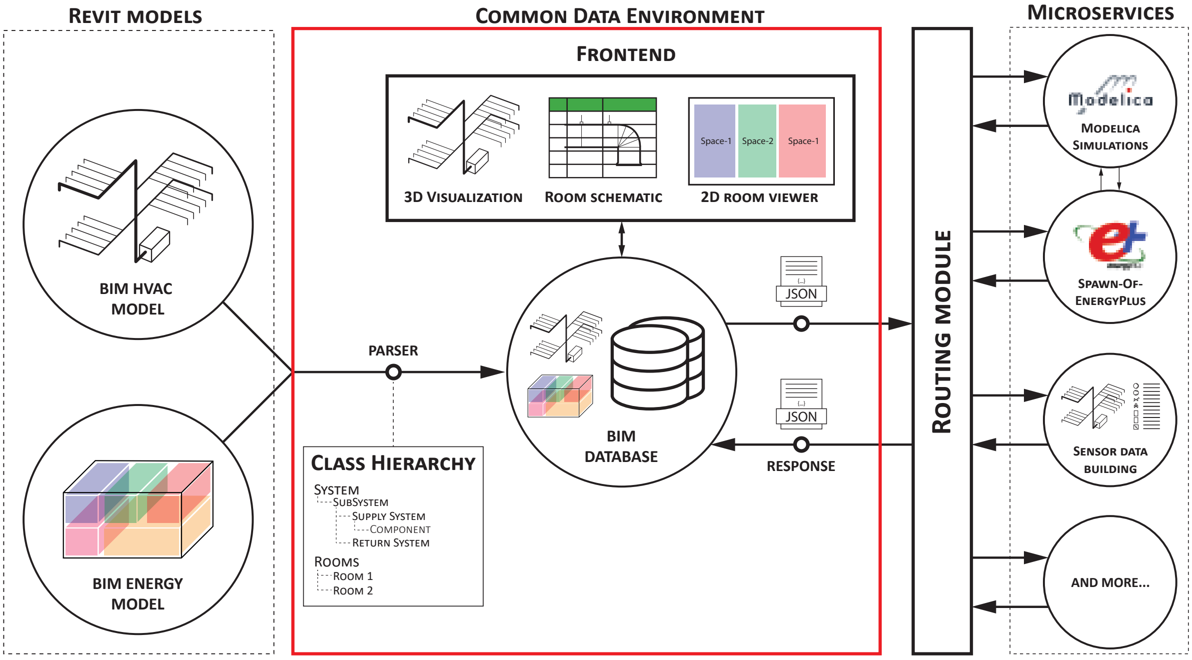
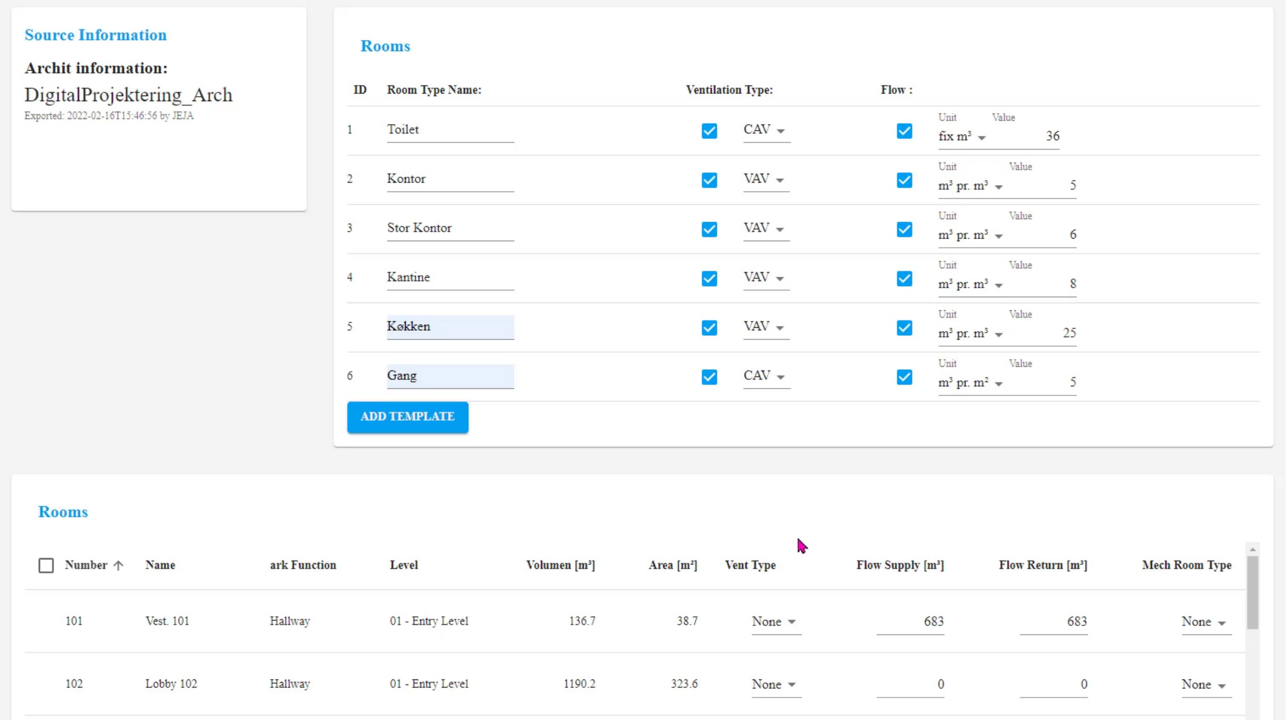


Figure 6: System architecture for the CDE. Data is transferred from the Revit models (left in figure) to the database within the CDE. A frontend is generated (top of figure) to provide insights into the performance of the building. The CDE can now route the information to microservices (right in figure). Among the suggested microservices are Spawn-Of-EnergyPlus with Modelica, a building sensor monitoring module, and potentially many more.



Source Information

Archit information:

DigitalProjektering_Arch

Exported: 2022-02-16T15:46:56 by JEJA

Rooms

ID	Room Type Name:	Ventilation Type:		Flow :	Unit	Value
1	Toilet	☑	CAV	☑	fix m³	36
2	Kontor	☑	VAV	☑	m³ pr. m³	5
3	Stor Kontor	☑	VAV	☑	m³ pr. m³	6
4	Kantine	☑	VAV	☑	m³ pr. m³	8
5	Køkken	☑	VAV	☑	m³ pr. m³	25
6	Gang	☑	CAV	☑	m³ pr. m²	5

Rooms

☐ Number ↑	Name	ark Function	Level	Volumen [m³]	Area [m²]	Vent Type	Flow Supply [m³]	Flow Return [m³]	Mech Room Type
101	Vest. 101	Hallway	01 - Entry Level	136.7	38.7	None	683	683	None
102	Lobby 102	Hallway	01 - Entry Level	1190.2	323.6	None	0	0	None

Figure 7: Mock-up of UI for the CDE

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BUILDSIM-NORDIC 2022

Technical papers

This book contains technical papers from the BuildSim-Nordic 2022 conference, August 22nd & 23rd 2022. Full papers are published online through E3S Conference Series.
The conference was hosted by Technical University of Denmark in Kgs. Lyngby, Denmark, and organized in cooperation between the Nordic chapter of IBPSA, DTU, Molio and Danvak.

The BuildSim-Nordic 2022 conference is the second in a series of events with a long-term objective to establish a key biannual international conference in building performance simulation, with a strong focus on Nordic countries. The purpose is to create a platform for exchanging ideas, issues, and research findings that facilitates international collaboration and the meeting of minds between practitioners, researchers, and students.

IBPSA-Nordic is a regional affiliate of IBPSA, the International Building Performance Simulation Association, for four countries: Denmark, Finland, Norway, and Sweden.

IBPSA-Nordic is linked to IBPSA-World association but acts as an independent organization.
IBPSA-Nordic is a non-profit association.
Four countries form IBPSA-Nordic: Denmark, Finland, Norway, and Sweden.
IBPSA-Nordic was founded in 2011 to promote the science and practice of building performance simulation and to improve the energy, environmental and economic performance of buildings and their systems in the four covered countries.

IBPSA-Nordic provides a forum for exchange of knowledge and coordination between researchers, designers, developers, and practitioners in the field of building performance simulation and related issues in the four covered countries.

IBPSA-Nordic will strive to achieve its objectives on the level of each country and on the regional level through various activities (e.g. meetings, seminars, workshops, publications, education programmes, training, coordinated activities with other associations on national and regional levels and holding the biennial regional technical event).

Affiliate of IBPSA

DTU Construct
Department of Civil and Mechanical Engineering