Archetype EnergyPlus Models for Verifying the Thermal Performance of Danish Office Buildings

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Abstract

This paper presents the research efforts that seek to improve the efficiency of conducting advanced thermal simulations in the detailed design stage of the design process. A prototype for an application that facilitates a quick and inexpensive setup of EnergyPlus (EP) models of Danish office buildings was developed in a co-creation process involving simulation practitioners. The prototype is designed to mitigate barriers to migrating from current tools to EP; however, further research is needed to investigate this aspect.

Introduction

The Danish building regulation requires that the thermal indoor climate in rooms where persons stay for a longer period must be satisfactory in terms of health and comfort (BR18, 2018). The fulfilment of this requirement must be documented for so-called 'critical rooms' in a calculation using the Danish design reference year as weather data input. For office buildings, the building regulation guideline state that the requirement is usually considered fulfilled if the operative temperature is not exceeding 26 °C for more than 100 hours and 27 °C for no more than 25 hours. The current practice is to document the fulfilment of this guideline by conducting a simulation of the intended building design in an advanced physics-based thermal building simulation tool. This documentation rarely happens until very late in the design process leaving only very few expensive design options to fix any oversteppings of the guideline. Previous studies have indicated several reasons – barriers – for this late entrance of thermal building simulation tools in the building design process, see e.g. Attia et al (2009), Kanters et al. (2014), and Petersen et al. (2014). The main barriers found in these studies can be summarised as: 'Tools are too complex', 'Tools are too expensive', 'Tools are not integrated into drawing software', 'Tools take too much time', and 'Tools not integrated into workflow' (Petersen et al., 2021). Literature holds many different suggestions on how to eliminate these rather diverse barriers, see e.g. Purup and Petersen (2020a) for a recent overview. The vast majority suggest redefining the workflow of the design process to align better with how tools work but the practical uptake of these suggestions – no matter how obviously more efficient they might seem to be in relation to obtaining better building performance – is rare. Purup and Petersen (2020b) therefore argue that the research community maybe should start focusing on developing tools that fit current design activities and processes instead of proposing activities that fit tools.

Following this line of thought strictly, the workflow of the current Danish design practice is not to be changed; applying advanced physics-based thermal building simulation tools will happen late in the design process and (hopefully) verify that an almost finished design fulfils the building requirement. Assuming this to be the case, researchers should focus on how to improve the efficiency of conducting this specific task as bottom-up modelling in advanced thermal simulation tools is a time-consuming process requiring expert knowledge, skills, and experience to minimize input errors, ensure a model of appropriate quality, critical interpretation of the simulation results, and prepare simulation output communication to project stakeholders. The task is therefore expensive in terms of salary; on top of this, many tools have expensive annual licenses.

This paper presents the research efforts that seek to improve the efficiency of conducting advanced thermal simulations late in the design process. The outcome is a prototype for an application that facilitates a quick and inexpensive setup of EnergyPlus models of Danish office design proposals. The paper is structured as follows: The method section provides a brief overview of the co-creation process used for developing the prototype followed by an elaborate result section explaining the outcome of the co-creating process, ending up with a presentation of the before-mentioned prototype. Finally, discussions and conclusions are provided based on the findings of the studies.

Method

A previous study by Petersen (2011) showed that providing models where all inputs were pre-set to simulate the performance of typical thermal systems of Danish buildings reduced the time that the tool user had to use on setting up the system significantly – let alone the time used for debugging the model. The intention of the study reported in this paper was therefore to engage with simulation professionals to co-create an application that facilitates a quick and inexpensive setup of advanced thermal simulation models of Danish office design proposals. The concept of the application is that the user can choose from a series of different predefined and quality-assured archetype build-ups of typical Danish building enclosures and HVAC systems, and add them to the geometry of their building design. After simulation in EnergyPlus, the application display whether the building design fulfils the guideline of the Danish building requirements regarding thermal indoor climate.

To this end, seven Danish engineering experts in indoor climate and energy simulations with 3-9 years of practical experience from five different Danish consultancies (a mid-size company and four of the top-five largest consultancies in Denmark) accepted to participate in workshops. The workshops were conducted with one expert at a time to ensure a confident and open discussion. The intention of the workshops was to identify any barriers to the concept as well as co-creating the form and content of the application. Several iterations on the latter activity were conducted to increase the likelihood that the application and its options are relevant and useful to the building industry.

Results

The following sections provide a description of the outcome from the steps taken in the co-creation process leading to a prototype of the suggested application.

Initial interview and workshop

In the interviews leading up to the first workshop regarding the form and content of the application, it was found that none of the five companies represented in the interviews were currently using EP for advanced thermal simulations. All companies used either BSim or IES-VE, or both. All interviewees believed that there were significant barriers to the proposed concept but that these barriers were only related to the migration from their current tools to EP. The barriers mentioned were mainly related to low-practical concerns and uncertainties of consequences related to abandoning any current practice, such as the cost of training many employees to use the "new" tool, lack of confidence in the usability and validity of the "new" tool, potentially increase of complexity in modelling procedures, and using a "new" tool that no one else in the Danish industry is using. However, the interviewees indicated that there are practically no barriers to the concept of providing pre-set quality-assured templates of typical building enclosures and HVAC systems. On the contrary: The concept was well-received. Two of the interviewees stressed that the templates must be completely open making it possible to quality-assure the inputs and make any changes to the template at will.

In a subsequent workshop following the initial interviews, the interviewees were asked to provide input on the form and content of the application. Figure 1 is an example of the outcome of such a workshop. The participant was asked to provide their professional opinion on how the application should communicate simulation output (Figure 1, left) as well as outline their wishes for the specific content of pre-set templates for building enclosure elements and HVAC systems (Figure 1, right). A wish expressed by all interviewees was to have HVAC schedules that follow the guidelines in Vorre et al. (2017).

The feedback from the practitioners encouraged the authors of this paper to develop an application that facilitates a quick and inexpensive setup of EP models of Danish office design proposals. The idea was to leverage the template concept to overcome some of the identified barriers to the migration to EP.

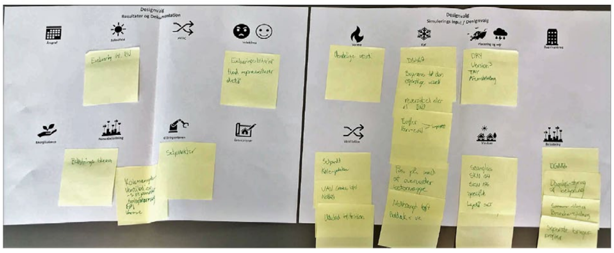

Figure 1: Example of workshop outcome.

Feedback on mock-up

A digital mock-up of the input interface was developed based on the interpretation of the outcome of the initial workshop (Figure 2).

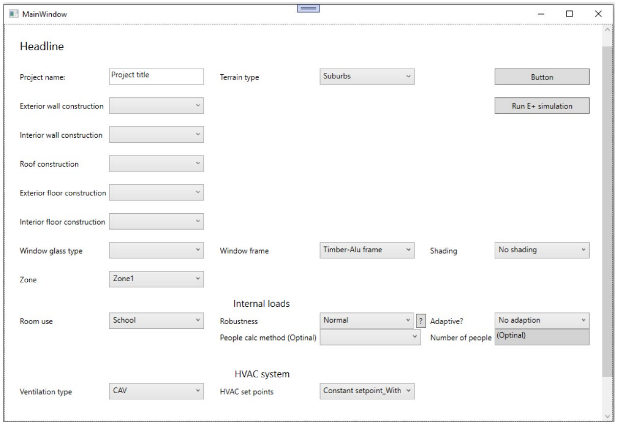

Figure 2: Digital mock-up of application interface.

The intention of the mock-up was to get feedback from potential end-users before prototyping the actual application. The mock-up was functional in the way that the potential end-user could interact with the input dropdown menus which had meaningful content (see figure 3).

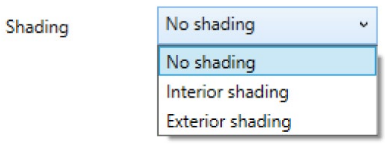

Figure 3: Example of drop-down in interface.

Once the potential end-user had chosen input in all dropdowns, the "Run E+ simulation" button could be pushed, and a mock-up of a suggestion for how simulation results should be presented opened (see Figure 4 and 5).

The mock-up was presented to one of the participants in the initial interview and workshop as they were potential

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end-user; however, it was not unfortunately practically possible to engage with the remaining participants from the initial round.

The participant approached the input mock-up in Figure 2 as one would read an article formatted in columns (like this paper). The participant wanted better descriptions of inputs to better understand what the inputs were supposed to represent. A good feature highlighted by the participant was the displaying of a visual representation of the occupancy schedule chosen in the drop-down. Another remark was to split the input up into sub-interfaces for room level and building level input, respectively. Furthermore, there was a range of suggestions on minor rearrangements and more direct availability of certain inputs currently hidden away in the HVAC templates.

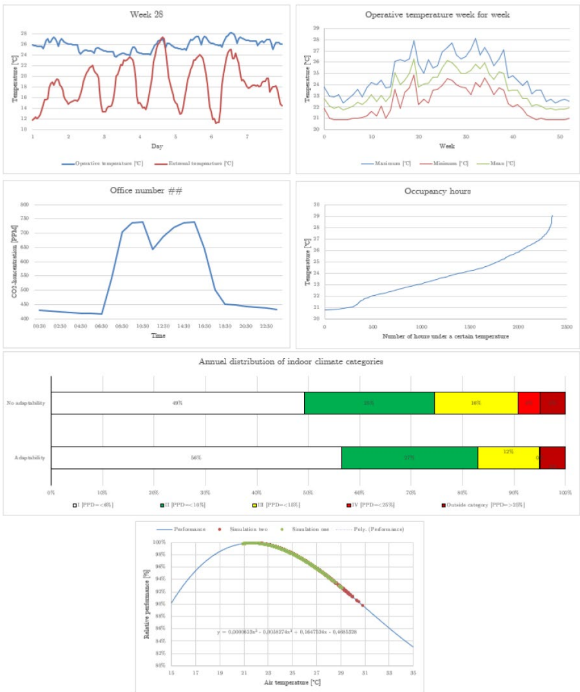

Figure 4: Suggestions for graphical presentation of output.

Min. class	II	17,0%
	Adaptability	
Category	Hours	% of time
I [PPD=<6%]	1325	56,4%
II [PPD=<10%]	624	26,6%
III [PPD=<15%]	281	12,0%
IV [PPD=<25%]	4	0,2%
Outside category [PPD=>25%]	115	4,9%
Total hours	2349	100,0%

Over stepping (O)	115	4,9%
Under stepping (U)	0	0,0%

Temperature overstepping	Not dependent	Dependent
t_o>	Hours	Hours
>25	603	815
>26	345	340
>27	141	94
>28	32	14
>29	4	0
>30	0	0

Max temp.
29,1

Min. class	II	25,5%
	No Adaptability	
Category	Hours	% of time
I [PPD=<6%]	1155	49,2%
II [PPD=<10%]	594	25,3%
III [PPD=<15%]	384	16,3%
IV [PPD=<25%]	99	4,2%
Outside category [PPD=>25%]	117	5,0%
Total hours	2349	100,0%

Over stepping (O)	117	5,0%
Under stepping (U)	0	0,0%

Maximum air volume	[m³/h]	[l/s·m²]	[h⁻¹]
Southern office	620	5,1	5
Northern office	370	3,1	3

Service hours of sunshading device	[%] of occupancy hours
Southern office, with low g-value	12%
Southern office, with normal g-value	28%
Northern office	-
Meetingroom	-

		NORTHERN OFFICE	SOUTHERN OFFICE With low g-value	SOUTHERN OFFICE With normal g-value
WINTER (nov.-mar.)				
under	21.0 °C	0 Hours	0 Hours	0 Hours
over	25.5 °C	0 Hours	0 Hours	0 Hours
over	24.5 °C	0 Hours	0 Hours	0 Hours
TRANSITION (apr. and oct.)				
under	21.0 °C	0 Hours	0 Hours	0 Hours
over	26.0 °C	0 Hours	3 Hours	2 Hours
over	27.0 °C	0 Hours	0 Hours	0 Hours
SUMMER (may-sep.)				
under	22.0 °C	0 Hours	0 Hours	0 Hours
over	26.0 °C	78 Hours	80 Hours	85 Hours
over	27.0 °C	0 Hours	1 Hours	2 Hours
Max. CO_2-concentration		900 PPM	900 PPM	900 PPM
Service hours of sunshading device		-	12%	28%

Figure 5: Example of text-based output.

The comments from the participant on the various proposed outputs can be summarised in the following suggestions for useful output:

- A "traffic light" bar chart evaluating temperatures according to EN 16798
- A bar chart presenting loads from both internal and external heat gains
- Displaying values of "hours above" temperature thresholds and max. indoor temperatures
- A graph displaying the trajectory of the indoor temperature in the "warmest week"
- A graph presenting the maximum, minimum, and average temperatures of all weeks
- The maximum CO_2 concentration in ppm
- Fraction of time with activated solar shading
- The maximum air volume used in case of VAV system

Development of prototype

The information from the initial interview and workshop as well as the feedback on the mock-up was used to develop and C# programming a fully functional prototype for an interface that facilitates setting up multi-zone EP models of office buildings using typical Danish enclosures and HVAC systems (Figure 6). All enclosure components and HVAC systems accessible in the interface have undergone an extensive input-output analysis that verifies that the models perform as expected – see Figure 7-9 for examples.

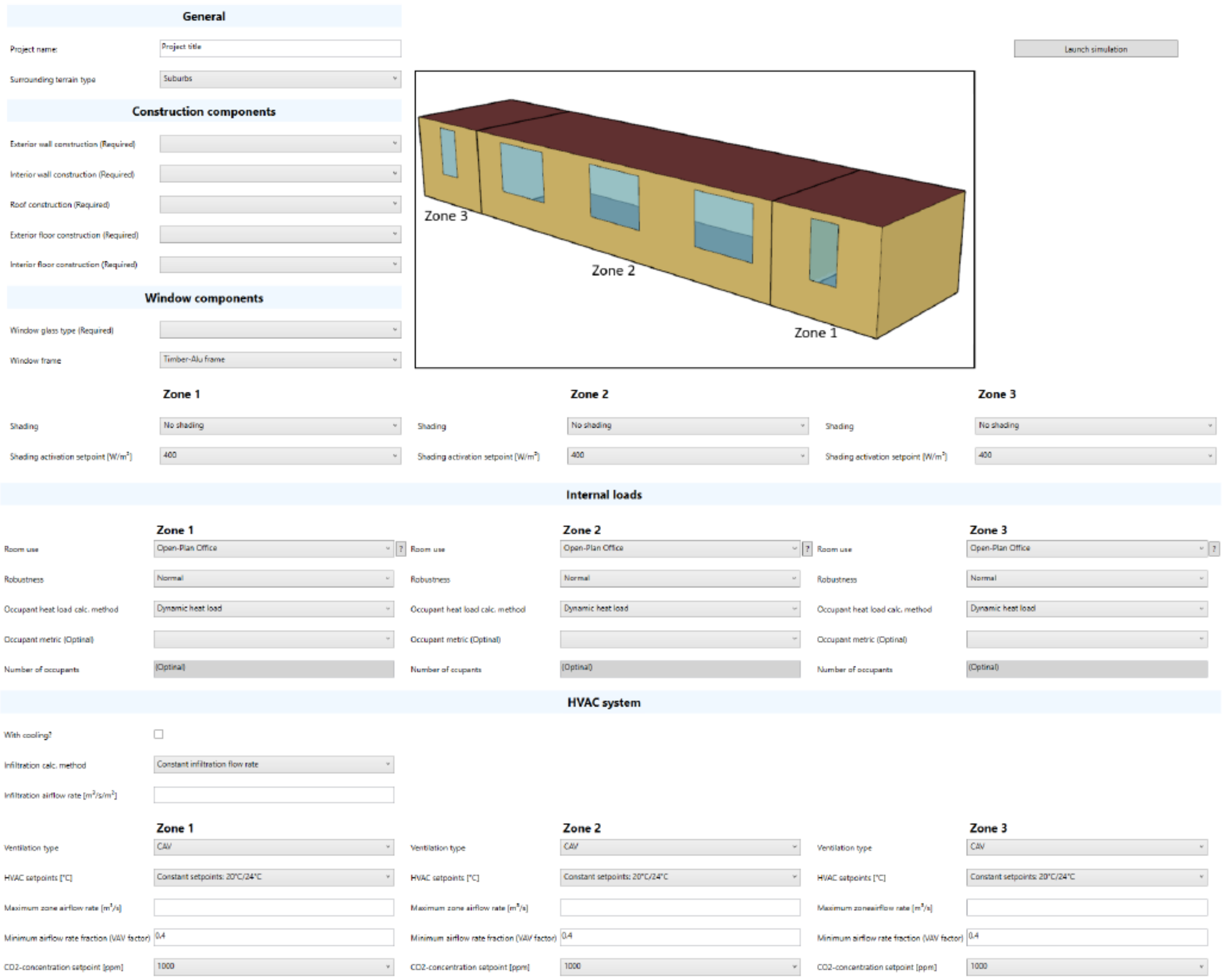

Figure 6: Prototype of interface.

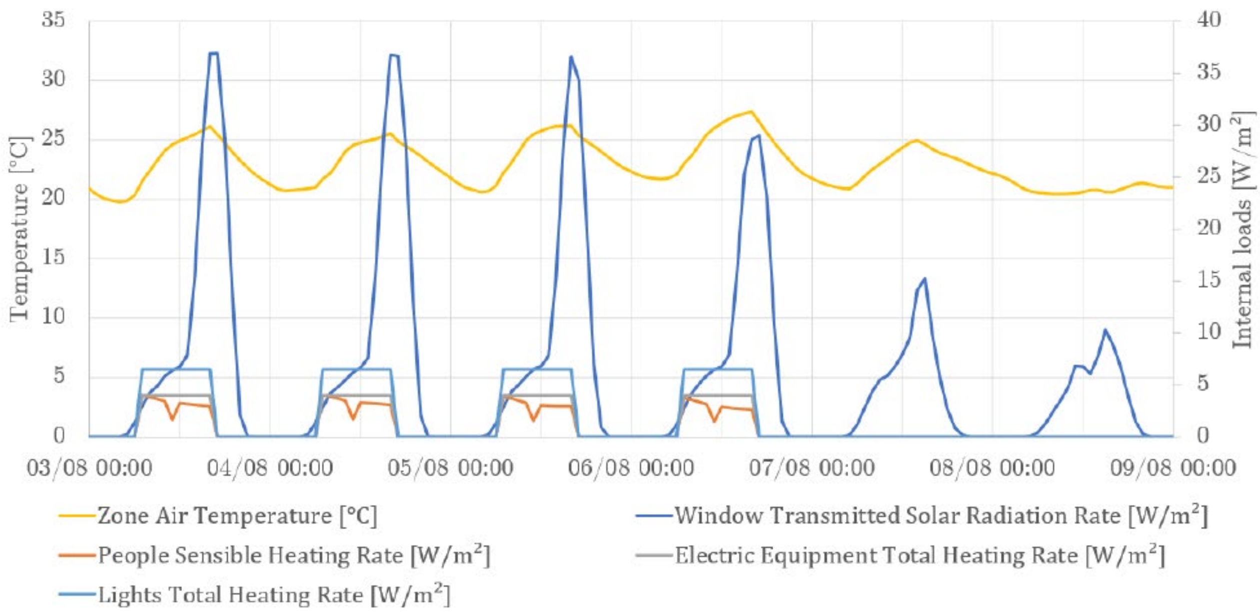

Figure 7: Example of quality assurance of a schedule for an open plan office.

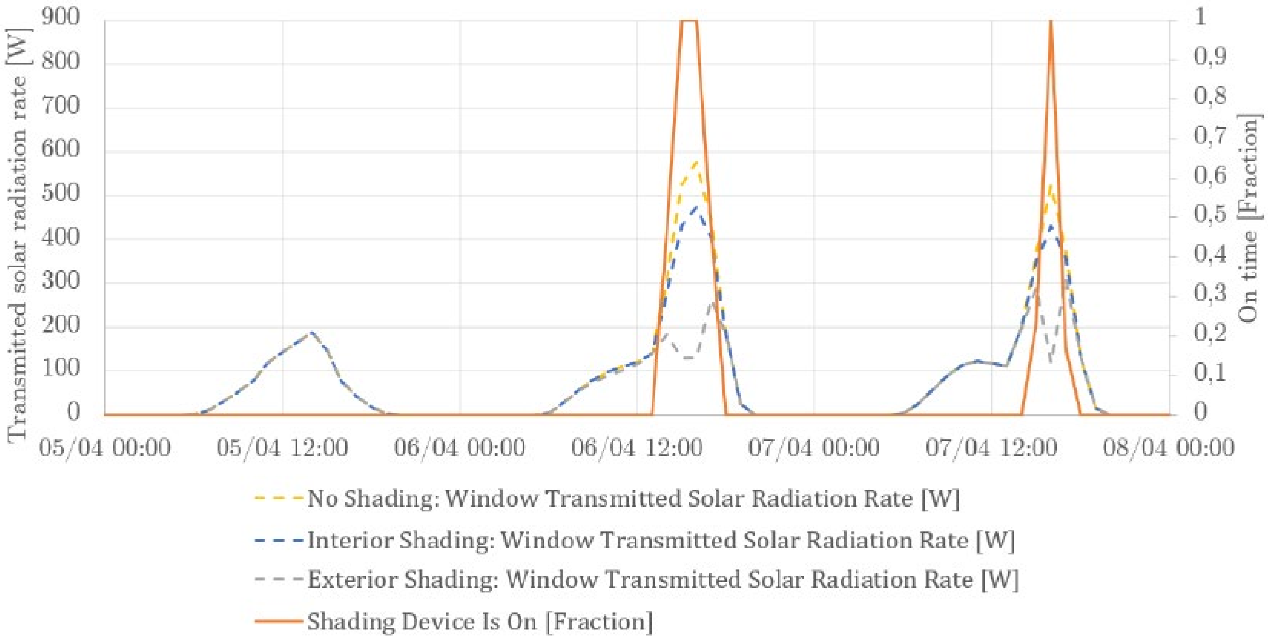

Figure 8: Example of quality assurance of shading activation. The transmitted solar energy radiation is as expected for the different shading types.

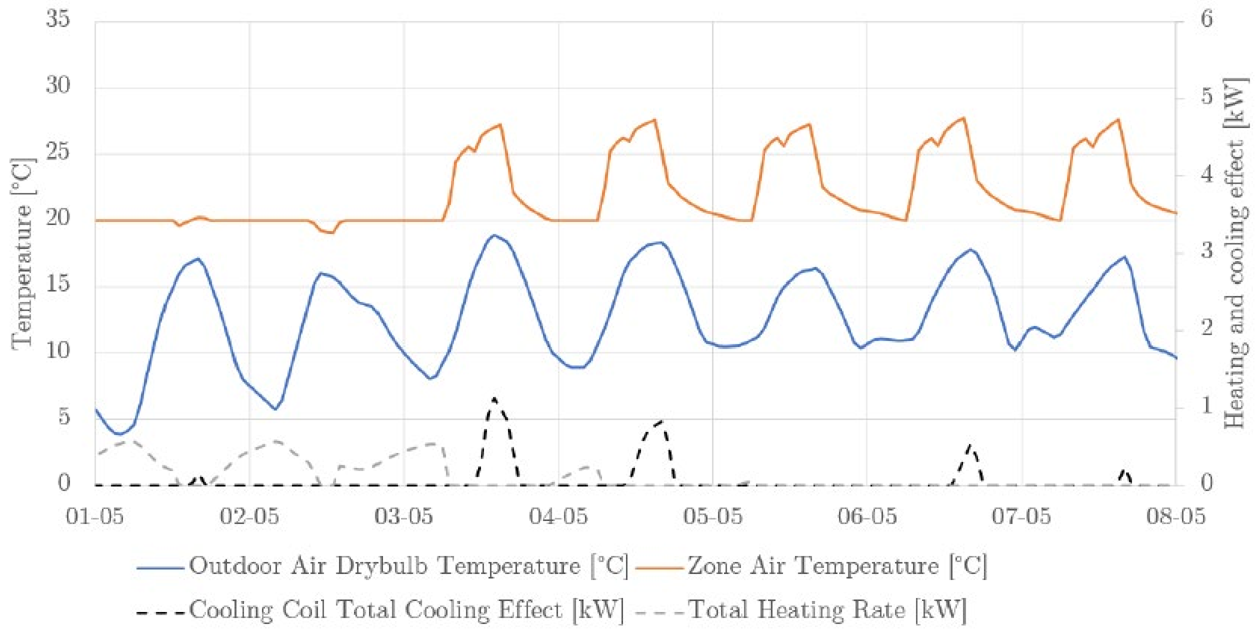

Figure 9: Example of quality assurance of activation of heating and cooling coil in the ventilation system. The coils behave as expected.

The prototype currently contains the following enclosure components and HVAC systems to choose from:

- Two types of exterior walls, roof, and ground decks, respectively
- One interior partition wall
- One interior deck
- Two different 3-layer glazings
- Two different window frames
- One exterior and one interior shading system (simple solar shading coefficient)
- Solar shading activation based on incident solar radiation on glazing (W/m2)
- Occupancy, lighting, and electrical equipment schedules for an open-plan office, a single office, a meeting room, and a classroom for three attendance categories called "robustness" in the interface (high, normal, low). All defined according to Vorre et al. (2017). Occupant heat load can be set as a constant value as per the recommendation in Vorre et al. (2017) or as a function of metabolic rate and clothing as per

the standard method in EP. The number of occupants can be chosen freely

- Infiltration is following a schedule covering the entire year and can be set to a constant value or to be calculated using the BLAST algorithm in EP
- Four ventilation systems: CAV and VAV, with and without cooling. All systems has a heat recovery unit, and heating and cooling coils with unlimited power
- Min. ventilation rate as well as max. ventilation rate and setpoint for CO2 concentration in the case of VAV are user-defined
- Baseboard space heaters with unlimited heat power in all zones
- Heating and cooling setpoint schedules according to Vorre et al. (2017)

The above-mentioned components are merely examples, and the interface is programmed so that other building enclosures or HVAC components defined in EP can be added easily. The prototype does not facilitate setting up the zone geometries; it is currently assumed that the geometry for the EP zones can be defined using simple sketching tools like SketchUp.

Conclusion

The positive feedback from the practitioners on the concept of providing pre-set quality-assured templates of typical building enclosures and HVAC systems encouraged the authors of this paper to enter a co-creation process with the practitioners to develop an application that facilitates a quick and inexpensive setup of EP models of Danish office design proposals. This paper presents the co-creation process up until the proposal and development of a prototype for this application. The prototype has not yet been presented to practitioners leaving the jury out on whether the prototype is in fact a feasible step closer to an application that facilitates a quick and inexpensive setup of EnergyPlus models of typical Danish offices and simulation output communication – let alone whether the prototype would mitigate the identified barriers of migrating from current tools to EP.

Acknowledgement

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