BauSIM2022 in Weimar
20.-22. September 2022
Bauhaus-Universität Weimar
ibpsa

SIMULATION-BASED VULNERABILITY ANALYSIS OF SUMMER HEAT PROTECTION CALCULATIONS IN GERMANY

Luis Enrique Sanchez Vazquez[1*], Arda Karasu[2], Max Bachmann[1], Claus Steffan[2], Martin Kriegel[1]

[1] *Chair of Building Energy Systems (Hermann-Rietschel-Institute), Technical University of Berlin*
[2] *Chair of Building Technology and Architectural Design, Technical University of Berlin*
[*] *corresponding author: l.sanchezvazquez@tu-berlin.de*

Abstract

New buildings must meet summer thermal insulation requirements. However, it is known that there is a difference between planning and reality that can lead to discomfort or increased cooling demand in summer. In this study, the effects of different parameters, such as occupancy profiles, ventilation strategies and weather data, are investigated in a critical room of a building under construction on the campus of the Technical University of Berlin.

For this purpose, several evaluation parameters are adapted to different occupancy profiles. The results show that the normative methods are rather optimistic and can lead to overheating during the lifetime of the building.

Introduction

As described in a previous publication (Inderfurth, et.al., 2017), the University Campus Berlin-Charlottenburg (HCBC) is undergoing a complete retrofitting of its buildings. Currently, an ongoing research project funded by the Federal Ministry of Economic Affairs and Climate Action is dealing with implementation strategies of energy-saving measures. Furthermore, the university will be extended with several new buildings. In the second phase of the project, researchers focus on the evaluation of energy-efficiency proofing methods of new buildings.

Two new buildings on campus (MA and IMoS) are certified to DIN 4108-2 for summer thermal protection, but there is concern that they will overheat in the summer, as many other German buildings have in the past.In this context, it is worth asking what could be causing these buildings to overheat. And why will those buildings pass certification but fail in practice?

For this reason, an investigation into the German certification method (DIN 4108-2) has been conducted. The goals of this case study are to evaluate input parameters for non-residential buildings by means of dynamic thermal simulations and their impact in the evaluation criteria. More importantly, the study intends to give suggestions for users in terms of parameter and profile adaptations to the German summer thermal protection regulations.

Summer heat protection evaluation

Summer heat protection evaluation is a requirement under the German Building Energy Act (GEG), and its implementation is based on the German standard DIN 4108-2:2013-02. This assessment's goals are to ensure thermal comfort and a low cooling demand during the summer. It can be demonstrated using two methods:

- Simplified calculation method
- Dynamic thermal simulation method

Nevertheless, it is well known that there is a discrepancy between planned and reality which can lead to increased energy demand or thermal discomfort. There are several publications dealing with the issues and progress of this regulation. These have pointed out the unrealistic boundary conditions used by the validation methods (Freudenberg and Budny, 2022), which can lead to unreliable results and an underestimation of the real effects of overheating (Hoffmann and Ganji Kheybari, 2021). Among the most common parameters referred in these studies are weather data (Freudenberg and Budny, 2022, Hoffmann and Ganji Kheybari, 2021, Windhausen and Schmidt, 2021, Schünemann, et.al., 2020, Fahrion, et al., 2021), user information such as occupancy patterns (Elsharkawy and Zahiri, 2020), and user control profiles for windows and shading systems (Freudenberg, 2016). For example, a study evaluating modelling approaches for shading systems concludes that the differences found can lead to an underestimation of the actual solar energy input (Hoffmann and Ganji Kheybari, 2021). On the other hand, for the evaluation parameter is stated that by changing some criteria such as overheating hours (OTH) to over-temperature degree hours (OTDH), the standard comes closer to reality because the magnitude of overheating is also evaluated (Freudenberg and Budny, 2022). However, different periods of occupancy have not yet been considered.

Case study

The analysis is divided into three parts. First, a critical room is evaluated according to the methods of DIN4108-2 to assess the differences between the two valid methods. In the second part, the dynamic thermal simulations are adapted using various occupancy profile scenarios, ventilation strategies and weather files to analyse the influence of these parameters. Finally, an alternative evaluation parameter that takes into account the impact of different occupancy times is presented to allow an unbiased comparison of these scenarios.

Figure 1: Model image of MATHE (source: CODE Unique Architekten BDA)

Critical Room

As previously stated, the TU Berlin campus is currently expanding and the Mathematics Building (MA), was chosen as an investigation object. Figure 1 shows that the MA's shape, volume, and façade design allow daylight to enter from all directions, increasing the cooling load.

Offices represent 20% of the floor area in the building, have a similar geometry and were initially designed without mechanical ventilation. This makes them an interesting object of study and allows a sinful comparison of different orientations. The geometry for the analysis is shown in Figure 2.

The room dimensions are 5.1 x 5.1 x 3 m, it has a floor area of 26 m^2, a window area of 13 m^2 and it will host 3 staff members. To comply with the law, transmission heat losses should not be greater than those of the reference building, so for the study the building envelope is based on the non-residential building described in the GEG (Table 1, Annex 2).

- External wall, U-value = 0.28 W/m^{2}K
- Window, U-value = 1.3 W/m^{2}K
- Window, g = 0.6

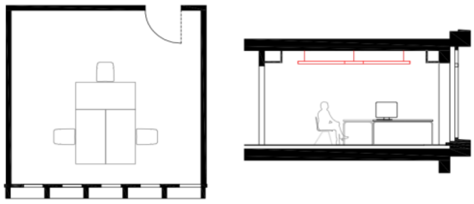

Figure 2: Critical Room

Boundary conditions according to DIN4108-2

Simplified method:

The admissible (Sz) and existing (Sv) solar-gain-characteristic values are calculated according to DIN4108-2, section 8.3.3. For this critical room the admissible solar-gain-characteristic value is: Sz = 0.075.

The following conditions were used:

- Non-residential building
- Climate zone: B (TRY Zone 4)
- Construction type: Medium
- No window inclination
- No passive cooling
- Shading factor: Ext. venetian blinds (0.25)

Dynamic-thermal simulation:

Table 1 summarizes the boundary conditions given in DIN4108-2, section 8.3.4. The building is non-residential and located in climate zone B, so the reference value for the OTDH calculation is 26 °C and the admissible limit is 500 Kh/a. The dynamic simulations were performed using IDAICE which has participated in the SIMQuality test series.

Table 1: Dynamic-thermal simulation boundary conditions as stated in DIN4108-2.

Parameter	Value
Simulation Environment	IDA ICE
Building type	Non-Residential
Climate Zone	B - TRY Zone 4 (2010)
Internal heat loads	144 Wh/m^{2}d
Occupancy hours	Mo-Fr; 7:00 - 18:00 hrs.
Ventilation	Basic
Temperature Set point	21°C
Shading Control	North = 150 W/m^2
	South = 200 W/m^2

Orientation and ventilation strategies are used as variables for comparison of both methodologies.

Alternative parameters for the evaluation of the critical room.

Knowing that the boundary conditions in DIN4108-2 are not representative of all critical rooms, the models for dynamic thermal simulations in this case study are adapted using three parameters: occupancy profiles, ventilation rates, and weather data. Their impact is assessed for rooms facing south, where higher solar gains are expected, and rooms facing north.

The different scenarios studied for each parameter are listed in Table 2. And briefly described in this section.

Table 2: Listing of independent parameters and values used in the second evaluation

Orientation	**Occupancy Profiles**	**Ventilation Strategies**	**Weather data**
North	DIN 4108	Basic	TRY 2010, normal year
South	DINV18599 medium	Increased	TRY 2010, extreme summer
	DINV18599 high	Night	TRY 2035, normal year
	Planned	Pulse: 5 min/h	TRY 2035, extreme summer
		Pulse: 10 min/h	

Occupancy profiles:

DIN4108-2 specifies an internal heat load of 144 Wh/m^{2}d for non-residential buildings with an occupation time of 11 h/d during weekdays, resulting in a specific load of around 13 W/m^2. At the same time, DINV18599-10:2018-09 describes non-residential performance profiles, including detailed information on occupancy times and three levels of specific internal heat loads (W/m2): low, medium and high. Using the medium level profiles of DINV18599, 25 out of the 33 zones (with internal heat loads) have specific loads above the 13 W/m2 specified in DIN4108-2. Consequently, the internal heat loads are under-represented in the DIN4108-2 evaluation and overheating may occur for these spaces.

For the analysis, the medium and high profiles for "Group office" (two to six workstations) in DINV18599 were evaluated. Additionally, a simplified profile was created with respect to the given planning information. The critical room is assumed to have the following internal heat loads:

- 3 occupants (1 met) ~ 315 W
- 3 standard personal computers ~375 W
- 7 W/m2 for lighting ~182 W

Table 3, summarize the conditions for each of the occupancy profiles evaluated.

Table 3: Occupancy profiles details.

	Occupancy Profile	**Internal heat loads**		**Occupied hours**	
	Model	(Wh/m^{2}d)	(W/m^2)	(h/d) *	(h/a)
1	DIN4108	144	13.1	11	2860
				07:00-18:00	
2	DINV18599 (M)	73	12.1	6	1560
				10:00-16:00	
3	DINV18599 (H)	132	22	6	1560
				10:00-16:00	
4	Planned	268	33.5	8	2080
				09:00-13:00, 14:00-18:00	

* Mo-Fr

Ventilation Strategies:

DIN4108-2 defines different ventilation strategies that can be used for the evaluation. For the simplified method, basic and night ventilation is considered, whereas for the simulations it is also possible to evaluate increased ventilation during the day. However, the basic ventilation rate is defined only by the room geometry and the influence of occupancy is not considered. Furthermore, only a maximum ventilation rate is defined for the increased and night ventilation strategies, based on specific conditions. These strategies are simple to simulate but difficult to implement and control, particularly in rooms without mechanical ventilation.

On the other hand, the indoor air quality validation based on the Sustainable Building Rating System (BNB) states that continuous ventilation is not feasible due to comfort and energy reasons, and instead introduces pulse ventilation in periods of 5 and 10 minutes every hour during occupancy time. In this study, both approaches are evaluated.

Weather Data:

According to DIN4108-2, Germany is divided into 3 different climate zones and for each, a weather data file from the German Weather Service's (DWD) dataset is given.

- Climate zone A: TRY Zone 2
- Climate zone B: TRY Zone 4
- Climate zone C: TRY Zone 12

Nonetheless, buildings are constructed to operate for long periods of time. For this reason, future conditions must be taken into consideration as well as extreme conditions that can be expected.

The same dataset proposed in DIN4108-2 (DWD, 2011) was used for this study, but value-added files such as extreme summer conditions and projections for 2035 were evaluated.

Evaluation parameter

The over-temperature degree hours (OTDH) as an indicator helps to understand not only the duration of overheating but also its magnitude (Freudenberg and Budny, 2022). However, this indicator seems to be biased when looking at Table 4. Since each occupancy profile has different annual occupancy hours (OH); the risk of overheating during occupancy can be estimated by expressing OTDH in terms of OH.

Currently, the DIN4108-2 evaluation conditions are equivalent to 0.175 percentage rate of overheating during occupancy hours OTDH/OH, as shown in table 4. The value of this ratio, however, increases for the other profiles with lower OH. This means that there is a greater risk of overheating in these situations, demonstrating the importance of including an informed relationship to occupancy time in order to make a balanced perspective when using different occupancy patterns. As a result, it was thought appropriate to compare the findings of this study using the OTDH/OH ratio. The lower the factor, the better the performance against overheating; however, the allowable limit should be discussed to ensure that the evaluation accurately reflects the desired behavior.

Table 4: Evaluation parameters

Occupancy profile	**OTDH**	**OH**	**OTDH/OH**
Model	**(Kh/a)**	**(h/a)**	**(K)**
DIN4108	500	2860	0.175
DINV18599 (M)	500	1560	0.321
DINV18599 (H)	500	1560	0.321
Planned	500	2080	0.240

Results and Discussion

Evaluation according to DIN4108-2

The results of six different scenarios are summarized in Table 5. The ventilation strategy and orientation used in each scenario are presented, and the results for each method are rated as satisfactory (S) if the requirements are met and unsatisfactory (U) if they are not met. The ODTH is also given in Kh/a for the dynamic thermal simulation results.

The findings show that the simplified method give a satisfactory result for the north-facing room and an unsatisfactory result for the south-facing room, regardless of the selected ventilation strategy. In contrast, if the dynamic simulations are used, the room only meets the validation criteria after evaluating the night ventilation strategy for both orientations.

This confirms that certification is possible for rooms in MA but leads to a contradiction in the results of the methods, especially for north-facing rooms, where the simplified method gave a positive outcome with basic ventilation. This contradiction can be explained by the automatic shading control given as a boundary condition. In the simulations, shading is drawn down at a specific solar radiation of 150 W/m2 for north-facing rooms and 200 W/m2 for south-facing rooms. For the scenarios in Table 5, the shades are never drawn down in the north-facing rooms, but in the south-facing rooms they are drawn down in 38% of the occupancy hours. In the end, the simulation calculates a similar amount of OTDH for both orientations.

Table 5: Results – DIN4108-2

Orientation	**Ventilation strategy**	**Simplified method**	**Dynamic thermal simulation (OTDH in Kh/a)**	
North	Basic	**S**	776	U
	Increased	-	555	U
	Night	**S**	211	**S**
South	Basic	U	765	U
	Increased	-	529	U
	Night	U	200	**S**

In summary, the simplified method is too optimistic, especially for north-facing rooms. To solve this problem, it is recommended to reduce the specific solar radiation threshold at which shading is activated for the north-facing facade or to recalibrate the simplified method.

Evaluation using alternative scenarios

The parameters described previously were combined and evaluated using dynamic thermal simulations; Figure 3 shows the results in a heat map with 4 dimensions: orientation, weather data, occupancy profile and ventilation strategy. The heatmap demonstrate that the use of the OTDH/OH allows a quick comparison of the different occupancy profiles. The scenarios indicated in Table 5 have been outlined in the map.

The best performance (0.07) is given by DIN4108-2 occupancy profile, night ventilation, and normal year weather data. Which is currently valid and could be used for the building certification. On the other hand,

OTDH/OH		ORIENTATION							
		NORTH				SOUTH			
		WEATHER							
Occupancy profile	VENTILATION	Normal Year (2011)	Extreme Summer (2011)	Normal Year (2035)	Extreme Summer (2035)	Normal Year (2011)	Extreme Summer (2011)	Normal Year (2035)	Extreme Summer (2035)
DIN4108	Basic	0.27	0.28	0.31	0.32	0.27	0.32	0.32	0.34
	Increased	0.19	0.20	0.25	0.27	0.18	0.23	0.26	0.27
	Night	0.07	0.15	0.14	0.16	0.07	0.16	0.14	0.16
	Pulse 5	0.24	0.26	0.29	0.31	0.24	0.29	0.30	0.32
	Pulse 10	0.15	0.18	0.23	0.23	0.13	0.20	0.22	0.22
DINV18599 (M)	Basic	0.30	0.32	0.33	0.34	0.29	0.35	0.34	0.36
	Increased	0.22	0.23	0.28	0.29	0.22	0.27	0.29	0.30
	Night	0.11	0.17	0.18	0.19	0.10	0.19	0.19	0.19
	Pulse 5	0.26	0.29	0.31	0.33	0.27	0.32	0.32	0.34
	Pulse 10	0.18	0.20	0.25	0.25	0.17	0.23	0.25	0.24
DINV18599 (H)	Basic	0.34	0.38	0.37	0.36	0.34	0.40	0.39	0.39
	Increased	0.25	0.27	0.30	0.32	0.25	0.30	0.31	0.33
	Night	0.16	0.18	0.23	0.24	0.15	0.21	0.23	0.22
	Pulse 5	0.29	0.33	0.33	0.34	0.29	0.35	0.35	0.36
	Pulse 10	0.21	0.23	0.27	0.28	0.20	0.26	0.28	0.28
Planned	Basic	0.40	0.45	0.43	0.44	0.45	0.47	0.47	0.48
	Increased	0.30	0.33	0.34	0.35	0.29	0.35	0.36	0.37
	Night	0.21	0.23	0.27	0.29	0.21	0.26	0.27	0.29
	Pulse 5	0.35	0.40	0.40	0.39	0.37	0.42	0.43	0.43
	Pulse 10	0.25	0.29	0.31	0.33	0.26	0.31	0.32	0.33

Figure 3: Heat map, Scenarios evaluated in the Study Case

the worst performance (> 0.40) is given by the planned model of internal heat loads and basic ventilation. The individual influence of each parameter studied is discussed below.

Orientation:

The left part of the results in Figure 3 is for north-facing rooms, while the right part represents south-facing rooms. The heat map confirms that the orientation has no influence on the evaluation outcome. The reason for this, as explained above, is the boundary conditions of the automatic shading system specified in DIN4108-2. It is recommended to provide different control strategies and user profiles, especially for rooms without automatic shading, so that designers can consider different possible solutions to reduce the risk of overheating.

Weather data:

The influence of weather data is shown as columns. As expected, the heat map shows that the overheating risk is higher in extreme summers than in a normal year. Moreover, the risk is expected to be even higher in the future. With an average OTDH/OH difference of +0.06 between normal year 2010 and extreme summer 2035.

These results support the idea of using weather projections and extreme conditions to ensure that spaces do not overheat during building operations. Moreover, there are several representative concentration pathways (RCP 2.6-8.5) that predict global temperature rise till 2100. Accordingly, this study will be extended towards simulation with weather data for 2020-2100 according to the RCPs to analyze possible changes in the overheating risk. This could lead to more resilience of the evaluation methods towards climatic changes in the future.

Occupancy profiles:

The four profiles studied are represented in horizontal blocks. Overall, the results show that the profile used in DIN4108-2 is the most optimistic, followed by DINV18599 (M). Furthermore, the highest risk of overheating is for the profile created with the planning documents which can be interpreted as the worst case for the critical room in this study.

As a suggestion, for the evaluation of summer heat protection it is proposed to use the profiles given in DINV18599, thus customizing the critical room. Or as an alternative, design more detailed occupancy profiles that represent the real or expected operation of the studied room. Taking into account that the internal heat loads must be specified not only in specific daily terms (Wh/m^2d) but in combination of specific load (W/m^2) and occupancy hours (h/d), preferably in schedules.

Ventilation:

Finally, on the ventilation strategies studied. The results are presented as rows in Figure 3 and show, as expected, that OTDH/OH values improve with increased and night ventilation. The ability to reproduce this behaviour is the main problem identified in the analysis. Therefore, alternative methods of pulse ventilation were evaluated. Overall, increased ventilation mirrors the results of 5-min/h pulse ventilation, with a mean difference of 0.03 OTDH/OH. This means that pulse ventilation can be used to simulate increased ventilation strategy. However, this does not mean that it is an expected user profile. It is suggested that different user-window operating profiles be created, possibly with control variables that users find uncomfortable, such as indoor and outdoor temperature and CO_2 concentration levels, so that the analysis can be combined with indoor air quality analysis, especially in rooms without mechanical ventilation.

Conclusion

This study confirms that the methods used to validate the summer thermal insulation according to DIN4108-2 have limitations and contradictions, especially in north-facing rooms. This is one of the reasons for discrepancy between reality and planning. Furthermore, it is pointed out that in order to reduce the discrepancy between the models evaluated with dynamic thermal simulations and reality, it is necessary to add relevant parameters representing the operating conditions of the critical room and to use a meaningful and unbiased parameter for the evaluation, such as the overheating risk (OTDH/OH).

The parameters analysed here help to bring the simulation model closer to the planned operating conditions. The assessment must take into account the operating time of the building and adapt to the weather data for this time span. Furthermore, it is shown that the occupancy profile plays a crucial role in the evaluation and must be complemented by information on the expected behaviour of the occupants, e.g. occupancy times and their interaction with windows and shading systems.

Acknowledgment

This research is a part of the project EnEff:HCBC HochschulCampus Berlin-Charlottenburg: 1. Umsetzungsphase, funded by the German Federal Ministry for Economic Affairs and Climate Action, reference number 03ET1632A

References

Bewertungssystem Nachhaltiges Bauen (BNB).(2015) Soziokulturelle Qualität, Behaglichkeit und Nutzerzufriedenheit. Kriterium: 3.1.1 Innenraumlufthygiene

Deutscher Wetterdienst (DWD). “Testreferenzjahre (TRY).” Wetter Und Klima - Deutscher Wetterdienst - TRY - Testreferenzjahre (TRY),

DIN 4108-2:2013-02. Thermal protection and energy economy in buildings – Part 2: Minimum requirements to thermal insulation

DIN V 18599-10:2018-09. Energy efficiency of buildings – Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting – Part 10: Boundary conditions of use, climatic data

Elsharkawy, H.; Zahiri, S. (2020). The significance of occupancy profiles in Determining Post Retrofit Indoor Thermal Comfort, overheating risk and Building Energy Performance. Building and Environment, 172, 106676.

Fahrion, M. S., Nickl, C., Bangalore, D., Lakatos, M., Brombacher, M. (2021). Sommerlicher Wärmeschutz durch die Begrünung von Außenanlagen und Gebäuden. Bauphysik, 43(5), 291–302.

Freudenberg, P. (2016). Entwicklung und kalibrierung einer planungsmethode für nichtwohngebäude mit besonderen Raumklimatischen Anforderungen. Stuttgart Fraunhofer Irb Verlag

Freudenberg, P.; Budny, O. (2022). Grenzen der Verfahren zur Bewertung des Sommerlichen wärmeschutzes nach din 4108-2:2013. Bauphysik, 44(1), 29–39.

Gesetz zur Einsparung von Energie und zur Nutzung erneuerbarer Energien zur Wärme- und Kälteerzeugung in Gebäuden (Gebäudeenergiegesetz - GEG) (2020)

Hoffmann, S., Ganji Kheybari, A. (2021). Untersuchungen zum sommerlichen Wärmeschutz – Teil 3: Modellierung Komplexer Geometrien und Unterschiedlicher Material-eigenschaften von Verschattungssystemen. Bauphysik, 43(3), 159–173.

Inderfurth, Alexander, Karasu, Arda, Nytsch-Geussen, Christoph, Steffan, Claus. (2017). Architectural-Geometrical Simplification for Multi-Zone Building Models for Urban Refurbishment Projects, Building Simulation Conference, San Francisco

Schünemann, C.; Ziemann, A.; Goldberg, V.; Ortlepp, R. (2020): Urban climate impact on indoor overheating-a model chain approach from urban climate to thermal building simulation. In: Gyula Zilahy (Ed.): Sustainability in Transforming Societies.

SimQuality "Tools".(2022) https://simquality.org/

Windhausen, S., & Schmidt, P. (2021). Klimadaten als Wesentlicher Bestandteil zur Beurteilung des sommerlichen wärmeschutzes. Bauphysik, 43(3), 154–158.