E3S Web of Conferences **362**, 03001 (2022) https://doi.org/10.1051/e3sconf/202236203001
BuildSim Nordic 2022

Simplified Thermal Calculating Design Tool for Pre-Designing of Air Flow for Ventilation and Indoor Climate

Jørgen Erik Christensen[1*], Diana Shorsh Osman Faris[2], Ayesha Mah-Noor Jhoja[2], Joan F. Gimeno[3]
[1]Department of Civil Engineering, Kongens Lyngby, Denmark
[2]Arup, Consulting engineering firm, Copenhagen, Denmark
[3]Plan 1 Cobblestone Architects A/S, Valby, Denmark
** Jørgen Erik Christensen: jerik@byg.dtu.dk*

Abstract

Consulting engineering firms use detailed applications to dimension the ventilation air volumes and sizes of overall ventilation systems. The disadvantage is that the programs are very complex and time-consuming to use so a simplified Excel-based program, TCD2 (Thermal Calculation by Design, version 2) has been developed. To document that TCD2 can be used, it has been tested against annual simulations with BSim (Building Simulation) based on several different cases. The results of the comparisons with BSim are promising for the temperature course during working hours and are on the safe side as regards the recommendations of the Danish Building Regulations. Further validations of TCD2 compared to BSim are required to fully recommend TCD2.

Introduction

It is essential to create high-quality buildings with a focus on low energy consumption, summertime thermal comfort and overheating prevention. For this to be possible, it is necessary to meet the requirements of relevant legislation and building regulations and, in addition, the requirements relating to construction design. The involvement of energy aspects during the early stages increases the chances of arriving at an optimal solution.

This paper aims to describe an alternative to the very advanced and detailed applications used for Building Performance Simulation for Thermal Simulation (BPS TS) to dimension the ventilation air volumes and sizes of overall ventilation systems. Researchers have developed these programs and, over the years, added more features and options, making the programs both time-consuming and complex to use. TCD2 has been developed as an Excel-based program (TCD2, 2019) and a fast and free alternative software to reduce the time needed for calculating the ventilation airflow. It is good for preventing overheating and ensuring summertime thermal comfort.

Many large and medium-sized consulting engineering firms have developed programs to estimate the air needed to maintain a pleasant thermal indoor climate. In addition, they have developed programs to calculate the pressure drop in ventilation systems. They use these programs at different stages of the design phase rather than simulation programs like BSim and MagiCAD (Magi Computer Aided Design) (MagiCAD, 2022), which require many calculations. Small companies face a huge challenge due to their limited resources, which prevents them from developing their own programs; instead, they choose to outsource the tasks. TCD2 and TCD Vent (TCD Vent, 2018) are free programs suitable for filling this gap in the market, and since the programs are based on Excel, it is easy for companies to use these programs. Even for large consulting engineering firms, it is of interest as they will be able to quickly estimate the sizing of the ventilation air volumes required for summertime thermal comfort and overheating prevention.

Background

Joan Ferris Gimeno and Jørgen Erik Christensen developed the program TCD2. The background for TCD2 is described in the Method section and in (Christensen et al., 2020). The program is a simplified model for the calculation of heat balance based on the temperatures of the indoor air, the internal surfaces, and the heat capacity of the materials.

TCD2 is an abbreviation for "*Thermal Calculation by Design, version 2*". At the Technical University of Denmark (DTU), TCD2 and TCD Vent (TCD Ventilation) are two sister programs intended to support the teaching of ventilation courses at DTU and provide students with broader practical experience of sizing ventilation systems:

- TCD2 – Dynamic program for the dimensioning of ventilation air exchange for summertime thermal comfort and overheating prevention
- TCD Vent – Design of the overall ventilation system

It is important to note that TCD2 is a simplified program, and users must bear this in mind when evaluating the results. TCD2 should not replace detailed dynamic programs such as BSim, IDA ICE (IDA Indoor Climate and Energy), and IES-VE (Integrated Environmental Solutions – Virtual Environment). TCD2 only calculates the summertime thermal comfort to prevent overheating – not the annual energy consumption.

During the early design phase, consulting engineering companies need an estimate of the total pressure loss to dimension the unit and provide an overall price estimate. TCD Vent is suited for this purpose since it is easy and fast to use. TCD Vent makes it possible to calculate throw lengths and prepare ceiling plans, which is not possible in MagiCAD. Ceiling plans include supply and exhaust diffusers, lighting luminaires, and sprinklers. Ceiling plans are often a problem, as several professional groups are involved in reaching an agreement on the location of supply and exhaust diffusers, lighting luminaires, and sprinklers. Furthermore, the architect in charge will have clear views on the aesthetic design of the ceiling, and compromises are therefore needed to arrive at the best or necessary solution. The atmospheric and thermal indoor climate must be pleasant, and adequate ventilation is necessary to achieve this. When determining the size, the most significant value is applied, which in most cases will be the value for dimensioning the thermal indoor climate. Based on these values, it is possible to calculate the size of the overall ventilation system, including ducts, valves, and air handling units.

Methods for Building Simulation Tool

The starting point for the study is the desire to calibrate TCD2 against BSim (BSim, 2022), making it possible to quickly and efficiently estimate the dimensioning ventilation air volume required for summertime thermal comfort and overheating prevention.

For control of thermal indoor climate, there are methods for specification, verification, and control in the (DS 474,1993) code for Indoor Thermal Climate. For buildings other than dwellings, the client's responsibility for the operating temperature includes determining the maximum number of working hours per year with temperatures exceeding 26 °C and 27 °C. If, during working hours, the temperature is above 26 °C for a maximum of 100 hours, and above 27 °C for a maximum of 25 hours, the indoor thermal climate requirements for many types of buildings are met according to (Building Regulations - BR18, 2018) (Building Regulations Guide – BR18, 2018).

A figure of 100 hours above 26 °C during working hours is relatively high. The three summer months in Denmark (June, July, and August) amount to 10 weeks excluding the three-week summer holiday, corresponding to 400 working hours. If, for example, the temperature is above 26 °C for 80% of the working hours in the three summer months (100 h * 80% = 80 h), this will correspond to 20% of the 400 working hours. These are remarkably high temperatures since the staff must be able to concentrate on their work.

In a study (IEA, 1994) of 17 applications of BPS TS, it appears from the conclusion: *"There was a tendency for most programs to predict energy consumption and maximum and minimum temperatures which were lower than measured values"* and *"There was a general tendency to predict temperatures which were too low"*. One of the 17 BPS TS was tsbi3 v2.0, the precursor to BSim, which also predicted lower temperatures than the measured values.

To be safe, consultants in some cases add, for instance, 20% extra ventilation air to be sure since they are responsible for fulfilling the requirements, thus indicating that using a simplified Excel-based calculation program like TCD2 could be an alternative.

Based on the information described, the conclusion for the TCD2 calibration with BSim will be to look at the number of working hours with temperatures above 25 °C, 26 °C, and 27 °C based on a significantly lower number of hours with values above 26 °C and 27 °C.

Building Simulation Tool – BSim

The development of solar data for TCD2 is closely related to BSim (BSim, 2022), which will be described later in this paper. BSim is an advanced application for Building Performance Simulation for Thermal Simulation for analysing buildings and installations. For each time step, the calculations in BSim are performed in a steady-state condition. BSim considers thermal indoor climate such as energy consumption, daylight conditions, natural ventilation, synchronous simulation of moisture, and energy transport in constructions and spaces.

In an earlier investigation of Pre-Designing Ventilation Air Flow in Greenland (Christensen et al., 2020), the results from TCD2 were compared with both BSim and IDA ICE (IDA ICE, 2022). However, comparing different programs in an entirely correct manner is very difficult, and errors occur quickly. How precise the results will be also depends on how closely related the models in the programs are. TCD2 and BSim are more closely related than IDA ICE. The work (Christensen et al., 2020) showed difficulties in getting a good comparison between TCD2 and IDA ICE compared to BSim. Therefore, it has been decided only to use BSim as a reference for the calibration work. In addition, the purpose of the paper is to calibrate TCD2 against BSim to calculate and estimate the ventilation air volume required to meet the summertime thermal comfort requirements and prevent overheating.

Building Simulation Tool – TCD2

The simulation models. In 1968, Bo Adamson (Adamson, 1968) developed a simplified thermal model for the heat balance in a room. The model was later described by Jørgen Erik Christensen in (Hansen et al., 1988) (Christensen et al., 2020). Being the precursor to BSim, tsbi 2.1 (Johnsen, 1985) formed the basis for the TCD2 model. The indoor air temperature, the internal surface temperature, and the temperature of the accumulating layer make up the simplified thermal model. The heat balance for the three temperatures forms the basis of the temperatures in the next 15-minute time steps.

Internal Heat Loads. Setting up the Internal Heat Loads can be very time-consuming due to all the details needed. TCD2 includes pre-designed values for a single office, shared office, meeting room, classroom, and user design to simplify the work. The general lighting can either be automatic when people are in the room or manually entered by the user, for example, during half of the working hours. (Christensen et al., 2020) and (Christensen, 2017) describe the pre-designed values in TCD2 and the guidelines (Vorre et al., 2017).

Model for solar radiation through glass panes – reference year. The model in TCD2 is built on a design day with a clear sky and lots of solar radiation. William Kristian Krogh Vergo and Jørgen Erik Christensen (Vergo, 2018) developed the method to create the weather data. The data are created on fictitious clear-sky days from the Danish reference year, and these weather data are applied in BSim to create the weather data file for TCD2. The fictitious reference year consists of perfect, cloudless days for the month's two selected dates, the 6th and the 21st. The method is described in detail in (Christensen et al., 2020) for weather data for Nuuk, Greenland; however, a similar model is applied for Denmark. The advantage of this model is a very simplified weather file; however, the disadvantage is that it is time-consuming to create each weather file, and at this stage, only data for Denmark, the Faroe Islands, and Greenland exist.

Solar radiation through a standard double-glazed reference glass pane. The TCD2 weather file is based on a BSim model for windows with a standard doubled-glazed reference pane with two 4 mm layers of glass and an air gap of 12 mm with a U-value of 2.8 W/m^2 K and g-value of 0.76. The weather file in TCD2 is based on the three hourly parameters: direct transmitted solar radiation, diffuse transmitted solar radiation, and ground-reflected transmitted solar radiation. From BSim, one can only provide the total solar radiation into the room and is therefore not able to directly produce three parameters as output. To solve this problem, three simulations with two kinds of weather data have been done.

1. Standard weather data – Output of total transmitted solar radiation (ground reflectance = 0.2)
2. Standard weather data – Output of transmitted solar radiation, excluding ground-reflected radiation (ground reflectance = 0)
3. Diffuse weather data, direct solar radiation = 0 – Output of transmitted diffuse solar radiation, excluding direct and ground reflected radiation (ground reflectance = 0)

After running the three BSim simulations, it is possible to calculate the three components for the TCD2 weather file for the standard reference pane:

- Direct transmitted solar radiation
- Diffuse transmitted solar radiation
- Ground-reflected transmitted solar radiation.

A file is created in BSim with 33 zones based on eight orientations: north, north-east, east, south-east, south, south-west, west, north-west, and four slopes: four slopes 90 º (vertical), 60 º, 30 º, 0 º (horizontal). This model uses the Perez diffuse radiation distribution model.

For the 6th and the 21st days of each month the data are simulated for the 33 combinations resulting in the three values for solar radiation through the standard double-glazed reference pane. Usually, in Denmark, two days are applied for dimensioning:

- 21 June – the longest day of the year
- 6 August – the last summer day

The selected dates for the weather file are the 6th and the 21st days of each month. If the user chooses different dates or directions to the ones in the TCD2 weather file, TCD2 makes a linear interpolation. The four slopes are fixed. All the calculations involved in creating the weather file restrict the user's choice of different slopes and weather data for other locations. The results for other dates or directions are also associated with some uncertainty.

On the other hand, the sun will be lower for south-facing facades and thus provide a greater incidence of sunlight. For this reason, the autumn months may eventually become dimensioning.

The TCD2 weather file contains hourly values, like the data from BSim. In TCD2, the hourly values are translated into half-hour values by dividing the hour into 15-minute intervals. The data emerge by adding and subtracting numbers to and from the different intervals. The result is a smoother curve for the stair function of the solar data; however, the hourly values from TCD2 will not be the same as the TCD2 weather file.

Outdoor temperature. TCD2 performs dimensioning calculations for hot, cloudless summer days. According to (Valbjørn et al., 2000), the maximum daily averages and typical daily variations in the outdoor temperature on clear days are in June 20 ºC±6 ºC, July 21 ºC±6 ºC, and August 20.5 ºC±5.5 ºC. July is a holiday month in Denmark, and many workplaces are closed. Therefore, as described above, 21 June and 6 August are used for dimensioning. As TCD2 is a simplified program, only one dimensioning temperature course of the outdoor temperature of 20 ºC±6 ºC is used, as the difference for August with 20.5 ºC±5.5 ºC is limited. Against this background, the outdoor temperature used in TCD2 is simplified to a cosine function around the daily average air temperature of 20 ºC±6 ºC, Figure 1.

The dates 21 June and 6 August are used in TCD2 for dimensioning. In cases where it is of interest to compare TCD2 calculations with BPS TS with Design Reference Year for Denmark – DRY DK 2013 (Danish Design Reference Year) (DMI, 2013), for hot, cloudless days, the day 21 June in TCD2 can be compared with 1 July in DRY

DK 2013, and 6 August in TCD2 with 6 August in DRY DK 2013, see comparison in Figure 1 and Table 1.

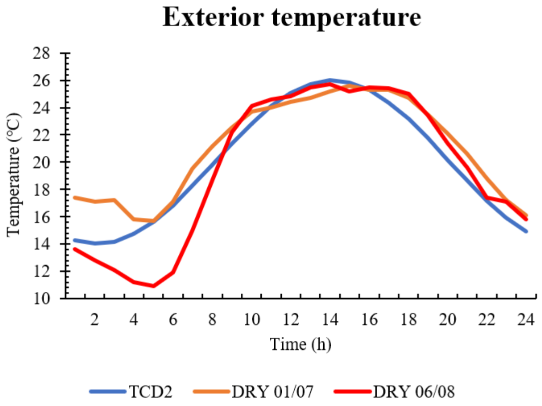

Figure 1: Exterior temperature for TCD2 (20 °C±6 °C) and weather data from DRY DK 2013 for 1 July and 6 August (DMI, 2013).

It can be seen from Figure 1 that the TCD2 exterior temperature matches quite well the actual weather data for a warm, sunny day from DRY DK 2013 for 1 July and 6 August.

Model description

The analysis looks at a shared office with heavy constructions and interior dimensions comprising a width of 10.65 m, depth of 7.2 m and height of 2.6 m, a floor area of 76.7 m^2, and a volume of 199.4 m^3. There are eight people in the office. They have a metabolic rate of 1.2 and emit a dry heat load of approximately 100 W. Each has a computer screen of 25 W and a PC of 30 W. The total internal heat supplement will be 800 W for people, 440 W for PCs / screens, and 192 W for general lighting, (Christensen, 2017) and (Vorre et al., 2017). The staff is in the office from 8 AM to 5 PM on weekdays, leaving for lunch from 12 AM to 1 PM. The load is only half from 7 AM to 8 AM, and 4 PM to 5 PM. It is assumed that the general lighting is on for half the working hours. The staff is off at the weekends.

The reference for the ventilation air is the atmospheric indoor climate (DS_EN 16798-2:2019, 2019-2) for non-residential buildings with a basic ventilation rate for diluting emissions (bio effluents) from people for category II of 7 L/s and for the category low-polluting building of 0.7 L/(s·m^2).

The shared office is located in the centre of the building, with only one exterior facade. The exterior wall has an area of 38.9 m^2, a U-value (Thermal transmittance) of 0.14 W/m^2K, and consists of a heavy construction of concrete and mineral wool insulation. The office meets the minimum requirements of the Building Regulations (Building Regulations – BR18, 2018). The other five surfaces butt up against similar rooms with the same temperature conditions: two sidewalls, a back wall, floor, and ceiling.

There are four windows in the office with three different window areas relative to the inside area: 15%, 22%, and 27%. The window which has been investigated has the following data: U_{pane} = 0.8 W/m^2K, U_{frame} = 1.0 W/m^2K, g (total energy transmission value, g-value) = 0.61, LT (Light Transmittance) = 0.65 and frame width of 0.07 m. The windows have exterior solar shading, which is used four hours per day on sunny days. The shading factor coefficient is 0.18 in combination with the window. The thermal bridge around the edge of the window is set to 0.06 W/m·K. The recess value is set to 0 m.

Results

In this paragraph, the focus will be on the calibration of TCD2 against BSim to create a method for getting reliable results using TCD2 for pre-designing airflow for ventilation air volume to meet the summertime thermal comfort requirements. The calibration work includes many different comparisons, and it will only be possible to cover a small part of this work in this paper.

Comparison of solar radiation into the room

The key dates for pre-designing are 21 June and 6 August. On 21 June, the sun is at its highest in the sky, which for south-facing windows results in the sun hitting the pane at the most significant angle of view, resulting in a smaller solar incident at noon. Consequently, 6 August will be dimensioning for south-facing windows. For north, east, and west-facing windows, 21 June will be dimensioning.

As described in the paragraph "Solar radiation through a standard double-glazed reference glass pane," TCD2 uses a time step of 15 minutes for the solar radiation, which gives a minor difference compared to the TCD weather file and BSim results.

In TCD2, it is possible to reduce the solar radiation into the room by the designated "factor for solar radiation". In the following assessment in TCD2, a solar radiation factor of 1 has been used, meaning no reduction. Later in the paper, where TCD2 design days are compared to yearly simulations, the value is set to 0.9 in TCD2. The reason for the reduction is that summer days in the TCD2 weather file are perfect clear-sky days, which is not how the weather is in Denmark in general.

TCD2 weather for TCD2 and BSim

The first comparison is for transmitted solar radiation into the room for TCD2 and BSim for the investigated window (g = 0.4, U = 0.5 W/m^2K) on 21 June and 6 August without solar shading. The results for TCD2 weather data in Figure 2 for 21 June show excellent agreement between TCD2 and BSim for both days and directions. Both programs use TCD2 weather data.

Table 1 shows the percent daily difference in sum for transmitted solar radiation between TCD2 and BSim, with TCD2 as a reference in the left columns. The difference is only approximately 1%, except for north where the difference is 6%. However, the percentage difference in value for north only equates to 18 Wh, which has nearly no influence on the results. These results are expected since the TCD2 solar data are derived from BSim for the same weather data.

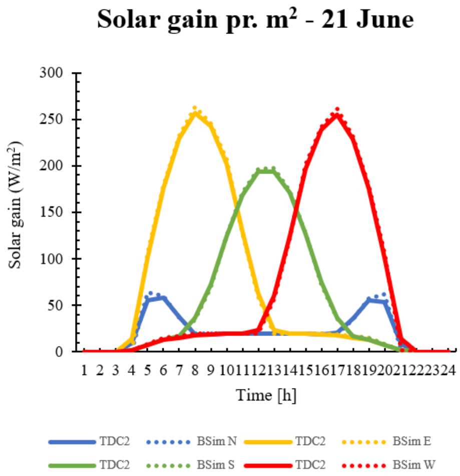

Figure 2: Comparison of TCD2 weather data of transmitted solar radiation through the pane for TCD2 and BSim for 21 June for the south, east, and north.

Table 1: Percent daily difference in sum for transmitted solar radiation between TCD2 and BSim with TCD2 as reference. TCD2 uses only TCD2 Weather data. BSim uses TCD2 Weather data in the left columns and DRY DK 2013 in the right columns.

% Daily diff. in sum for transmitted solar radiation between TCD2 and BSim with TCD2 as reference				
Program	TCD2 Weather Data		DRY DK 2013	
TCD2	21.6	6.8	21.6	6.8
BSim	21.6	6.8	1.7	6.8
Orientation	[%]	[%]	[%]	[%]
North	1.13	6.14	1.34	14.35
East	0.56	0.91	0.85	0.08
South	0.94	0.29	2.50	-0.40
West	0.57	0.91	2.54	-0.29

TCD2 weather for TCD2 and DRY DK 2013 for BSim

The second comparison is like the first one, except BSim uses DRY DK 2013 weather data instead. As described in the paragraph "Outdoor temperature", hot, cloudless days in DRY DK 2013 can be used for 1 July and 6 August to compare with TCD2 for respectively 21 June and 6 August using TCD2 weather data. The results in Table 1 are surprisingly good even though they are based on different programs and weather data. For south and west, the maximum values are up to 2.5% higher for BSim than TCD2, except for north with 14% corresponding to 43 Wh.

The differences are, in general, minor, and this must be seen regarding the annual simulations with BSim, where the factor in TCD2 for the design day is set to 0.9, corresponding to a 10% difference.

Comparison of temperatures in the room for design days and reference year

The intention with TCD2 is to be able to design high-quality buildings with a good indoor thermal climate, using TCD2 as an alternative to advanced applications used for Building Performance Simulation for Thermal Simulation (BPS TS). The approach is to show how TCD2 can be used during the early design phase to dimension the ventilation air volume and size of the overall ventilation system. In situations where time is limited, it will be valuable to still be able to achieve good results using TCD2. To fulfil this goal, it is necessary to test TCD2 against, for instance, BSim. TCD2 must be calibrated to give comparable results to yearly simulations with BSim for the numbers of hours above 25 °C, 26 °C, and hours above 27 °C during working hours.

As described in the paragraph "Methods for Building Simulation Tool", (Building Regulations – BR18, 2018) (Building Regulations Guide – BR18, 2018) claims that the indoor thermal climate requirements for many types of buildings are met if the number of working hours with temperatures above 26 °C is a maximum of 100 hours, and if temperatures are above 27 °C for a maximum of 25 hours. For the TCD2 calibration with BSim, it was concluded that a significantly lower number of hours with values above 26 °C and 27 °C should be used, and the temperature of 25 °C should be included. To ensure an excellent thermal indoor climate, the goal was 100 working hours above 25 °C, 40 working hours above 26 °C, and 10 working hours above 27 °C.

The analysis starts for TCD2 with the two design days: 21 June and 6 August. Using the day with the highest transmitted solar radiation through the windows also gives the highest temperature distribution during the day.

TCD2 uses a design day for repeated hot, sunny periods, which is similar to a very long period. The results are safe compared to the simulation with DRY DK 2013. Based on the investigation of the results, the conclusion is to use the following values for TCD2 for design:

- Factor for solar radiation = 0.9 (reduction 10%)
- Daily mean temperature (DMT) ≤ 26 °C
- Design Hourly Temperature factor (HT) ≤ 7 with cooling
- Design Hourly Temperature factor (HT) ≤ 10 with no cooling
- Goal: 25 °C – 100 hours, 26 °C – 40 hours, 27 °C – 10 hours

The factor for solar radiation is set to 0.9 – meaning that the solar radiation is reduced by 10% to take account of the fact that a full day of clear, sunny skies will not appear in Denmark for a long time. The Design Hourly Temperature factor is obtained during the working hours for the design day by multiplying the number of hours with temperatures above 26 °C by a factor. Table 2 shows the size of the factor depending on the operative temperature. Further investigation is needed of the factor based on a comparison between TCD2 and BSim to get reasonable estimates for the results in TCD2.

Table 2: Example for the Design Hourly Temperature factor – HT. The factor goes up to 28 °C; however, only temperatures up to 27 °C are included in the table.

	Temperature, T °C >=					
	26.00	26.25	26.50	26.75	27.00	HT
Hours	3	2	1	0	0	
Factor	1	0.25	0.5	0.75	1	
H * T	3	0.5	0.5	0	0	4

When the values in TCD2 fulfil the design criteria, the selected ventilation air volumes are transferred to BSim, and the data implemented. Figure 3 shows an example described in the model section of a south-facing shared office with a window area corresponding to 27% of the interior floor area. Figure 3 illustrates the temperature distributions in TCD2 and BSim for 6 August with TCD2 weather data and BSim with DRY DK 2013 weather data. The blue punctured line shows the daily mean temperature (DMT) for TCD2. For TCD weather data, the blue line for TCD2 is below the orange line for BSim from midnight to the end of the working hours. This is quite natural since a solar radiation factor of 0.9 has been used in TCD2. When the blue line for TCD2 with TCD weather data is compared to the red line for BSim with DRY DK 2013 weather data, it can be seen that the red curve for BSim is 1.2-2.1 °C below TCD2. This indicates that the chosen design values for TCD2 are on the safe side. The real test is when the design values are compared to yearly simulations with BSim using DRY DK 2013 weather.

Yearly simulations with DRY DK 2013

The orientations north (N), south (S), and west (W) have been studied together with three sizes of window (15%, 22%, and 27%), resulting in altogether nine combinations. These cases have been divided into two main cases:

- Cooling
- No cooling

Tables 3 and 4 show the results. In the tables, the parameters are abbreviated as follows: Orientations (O), Window % of the interior area (W), Basic ventilation rate factor (BV), Design Hourly Temperature factor (HT), Air change per hour (ACH), Daily mean operative indoor temperature (DMT). The Basic ventilation rate factor reference, relative to the ventilation air, is based on the atmospheric indoor climate (DS_EN 16798-2:2019, 2019-2), see paragraph “Model description”. The Basic ventilation rate factor is 1 for people at 7 L/s and low-polluting buildings at 0.7 L/(s·m^2).

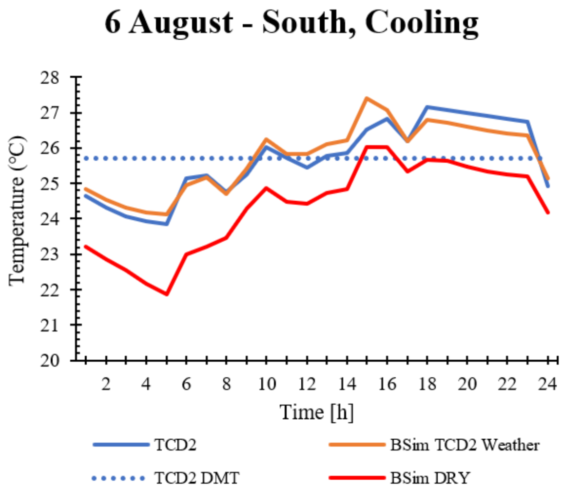

Figure 3: Temperature distributions in TCD2 and BSim for 6 August with TCD2 weather data and BSim with DRY DK 2013 weather data. The punctured line shows the daily mean temperature (DMT) for TCD2

Cooling – with exterior solar shading

In the cooling case, the supply air temperature is set to a minimum of 16 ºC, and the temperature difference between exhaust and supply air is 8 ºC. Table 3 shows the results for the nine simulations without cooling.

Table 3: Results from the cooling case with the nine combinations. The parameters are abbreviated as follows: Orientations (O), Window % of the interior area (W), Basic ventilation rate factor (BV), Design Hourly Temperature factor (HT), Air change (ACH), Daily mean temperature (DMT).

O	**W**	**BV**	**HT**	**ACH**	**DMT**	**Number of working hours above**		
						25°C	26°C	27°C
			Hours limit-BR18				100 h	25 h
			Goal hours TCD2			100 h	40 h	10 h
[°]	[%]	[-]	[h]	[1/h]	[°C]	[h]	[h]	[h]
N	15	1.0	0.0	2.0	24.0	21	0	0
N	22	1.0	0.0	2.0	25.4	79	7	0
N	27	1.1	0.0	2.2	25.0	122	25	0
S	15	1.0	0.0	2.0	25.0	84	6	0
S	22	1.3	2.5	2.6	25.9	119	12	2
S	27	1.5	6.3	3.0	25.7	45	17	10
W	15	1.0	0.0	2.0	24.7	64	2	0
W	22	1.2	3.0	2.4	26.0	59	2	0
W	27	1.2	5.8	2.4	25.8	109	10	0

The design goal: 25 °C / 100 hours, 26 °C / 40 hours, and 27 °C / 10 hours, is met in all nine results. The number of hours above 25 °C is between 21 and 122 hours. The number of hours above 26 °C and 27 °C is between 0 and 25 hours / 10 hours, respectively. The results are way below the limits (Building Regulations Guide – BR18, 2018). The basic ventilation rate factors (BV) are between 1 and 1.5, which are reasonably low values.

No cooling – with exterior solar shading

In the no-cooling case, keeping the operative temperatures below 26 °C is a challenge since the outside temperature goes up to 26 °C. Table 4 shows the results for the nine simulations without cooling. In general, the design goals are met in all nine results.

Usually, the number of hours with temperatures above 25 °C is between 82 and 107 hours. The number of hours above 26 °C is between 4 and 38 hours. For 27 °C, the similar results are between 0 and 9 hours. Again, the results are way below the limits (Building Regulations Guide – BR18, 2018). The basic ventilation rate factors (BV) are between 1.6 and 5. For the highest value, 5, this corresponds approximately to an air change of ten times per hour, which might cause draught risk and discomfort.

Table 4: Results from the no-cooling case with the nine combinations. The parameters are abbreviated as follows: Orientations (O), Window % of the interior area (W), Basic ventilation rate factor (BV), Design Hourly Temperature factor (HT), Air change (ACH), Daily mean temperature (DMT)

O	**W**	**BV**	**HT**	**ACH**	**DMT**	**Number of working hours above**		
						25°C	26°C	27°C
			Hours limit-BR18				100 h	25 h
			Goal hours TCD2			100 h	40 h	10 h
[°]	[%]	[-]	[h]	[1/h]	[°C]	[h]	[h]	[h]
N	15	1.6	9.3	3.2	26.0	92	4	0
N	22	2.4	5.8	4.8	25.5	84	18	0
N	27	2.4	6.7	4.7	25.7	107	27	0
S	15	2.5	7.8	5.0	25.6	103	33	0
S	22	3.7	9.5	7.3	25.7	102	38	8
S	27	5.0	8.5	9.9	25.6	87	26	9
W	15	2.0	9.3	3.7	25.8	82	17	0
W	22	3.1	5.8	6.1	25.3	84	25	0
W	27	3.5	8.3	6.9	25.5	89	29	4

Discussion

The intention is to document that TCD2 is a useful alternative to BPS TS applications. The results from the comparison with BSim have shown that the goal has been achieved, with good results on the safe side and far below the recommendations in (Building Regulations Guide – BR18, 2018).

The author's goals are met regarding the targets of 40 hours with temperatures above 26 °C and 10 hours above 27 °C.

Despite the promising results, it would be appropriate to further investigate whether it will be possible to introduce an additional factor for the Design Hourly Temperature factor (HT) based on a temperature above 25 °C. This requires further study, which cannot be covered in this paper.

Choice of a temperature course in TCD2 for a simplified cosine function around the air's daily average temperature of 20 ºC±6 ºC fits well with a warm, sunny day from DRY DK 2013 for 1 July and 6 August. This additionally matches the desire to choose 21 June and 6 August as the dimensioning days.

In TCD2, a 0.9 reduction factor for solar radiation has been used. When comparing the results for the temperature distributions for 6 August in TCD2 and BSim with DRY DK 2013 weather data, the BSim curve is up to two degrees below the TCD curve, and this is an indication that the design value for the reduction factor for solar radiation of 0.9 is on the safe side.

Further studies are needed of different types of cases, looking at different thermal mass values, types of panes, internal heat loads, and external solar loads in order to fully recommend the use of TCD2. In addition, the use of the room is essential, as it makes a huge difference whether it is used as an office, for meetings, etc.

Conclusion

The purpose of this paper was to investigate whether it is possible to develop alternatives to the more advanced BPS TS applications such as BSim, IDA ICE, and IES-VE that can be used in the initial design phase or renovation of buildings. The simplified Excel-based program TCD2 has been studied to determine the dimensioning ventilation air volume and the summertime thermal comfort. TCD2 cannot be used to calculate the annual energy consumption.

The temperature distribution in TCD2 has been tested against BSim annually based on several different cases to assess whether the results are reliable. The results of the comparisons with BSim have shown that the target for the calculations has been achieved, as the numbers of working hours with temperatures above the set limits of 25 °C, 26 °C, and 27 °C are in line with the desired targets and far below the recommendations from the Building Regulations Guide, which has been one of our goals.

However, a more extensive validation process is needed to cover a broader range of room types, including thermal mass values, pane types, and internal/external heat loads. In addition, it may be necessary to introduce an additional factor for the Design Hourly Temperature factor (HT) based on a temperature above 25 °C.

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