SIMPLIFIED HOURLY METHOD TO CALCULATE SUMMER TEMPERATURES IN DWELLINGS

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ABSTRACT

The objective of this study was to develop a method for hourly calculation of the operating temperature in order to evaluate summer comfort in dwellings to help improve building design.

A simplified method was developed on the basis of the simple hourly method of the standard ISO 13790:2008 but with further simplifications. The method is used for calculating room temperatures for all hours of a reference year. It is essential that the simplified method is able to predict the temperature in the room with the highest heat load. The heat load is influenced by the solar load, internal load, ventilation loss, heat loss and the external temperature. The numbers of hours exceeding 26 °C and 27 °C are summarised in order to compare them with the requirements for summer comfort in the Danish Building Regulations.

The simplified method was qualified by comparison with simulation results from an advanced program for thermal simulations of buildings. The results are based on one year simulations of two cases. The cases were based on a low energy dwelling of 196 m². The transmission loss for the building envelope was 3.3 W/m², not including windows and doors. The dwelling was tested in two cases, a case with an ordinary distribution of windows and a “worst” case where the window area facing south and west was increased by more than 60%.
The simplified method used Danish weather data and only needs information on transmission losses, thermal mass, surface contact, internal load, ventilation scheme and solar load.

The developed method can calculate the number of hours above a given temperature limit. The limits are a prerequisite for the development of the simplified method, and a supplementary maximum temperature limit is suggested to ensure robustness. The setting of the ventilation rate is found to be essential for the fulfilment of summer comfort. Thus it is very important to address both opening areas and ventilation rates.

The developed simplified method makes it possible to test whether or not a building design for a dwelling will prevent excess of the summer comfort limits set by the building regulations.

KEYWORDS

Hourly temperature calculation, summer comfort, simplified method

INTRODUCTION

The Danish Building Regulations 2010 (BR10) [1] set new requirements for the thermal comfort in summer. The Building Regulations applies to buildings in low energy class 2015 (LE2015) or in building class 2020 (BC2020). For larger buildings, the documentation must primarily be based on advanced thermal simulations, and it is up to the developer to specify requirements for temperature conditions in summer. For dwellings, the requirements are that 26 ° C must not be exceeded for more than 100 hours a year and 27 ° C must not be exceeded for more than 25 hours a year.
The purpose of this paper is to present a simplified method for calculation of the temperature conditions in dwellings during summer. The simplified method is developed on the basis of

the simple hourly method of the standard ISO 13790:2008 [2], Annex C but with further simplifications.
BR10 contains a requirement that the energy performance framework of buildings must be verified by the program Be10, which is a method of calculating the energy demands of buildings [3]. In Be10, all energy-related data for a building is provided, but since the program calculates monthly average, it cannot be used directly for evaluation of summer comfort. However, the main idea of developing a simplified method is to connect it to the Be10 program, so that the building data provided for the energy calculation can be reused in the simplified method for evaluation of summer comfort.

Primary, the ability to develop a method that can be applied to the dwelling, as a whole, is preliminarily examined. This is a crucial point for developing a simplified method, which may be attributed to the program Be10 [3].
Additionally, it is investigated whether supplementary temperature requirements for dwellings can enhance robustness.

METHODS AND MODELS

The full set of equations for a simple hourly method given in ISO13790: 2008 [2], Annex C, is the basis of this new simplified method. The method was simplified with assumptions about summer conditions in new low energy dwellings in Denmark.

The preconditions for further simplification of the method for determination of summer temperatures in dwellings were:

- All solar heat gains were assumed allocated in the air, i.e. small error when the sun shines directly on the wall or floor, but with internal blinds or other light surfaces the solar heat will actually be allocated in the air.
- It was primarily the internal room surfaces of the structures that interacted with the room air so the heat transfer from the deep mass to the surface was neglected.
- The operating temperature was a combination of air and surface temperatures but not calculated directly as in ISO: 13790:2008 [2].
- Ventilation with outdoor air but the heat recovery can be by-passed in summer.

The simplified method for calculation of temperature conditions in dwellings during summer was carried out in a spreadsheet by using the full set of equations in ISO 13790. To begin the calculation, the initial and boundary conditions should be given. These included initial air and surface temperatures and a minimum air temperature. In addition, some parameters were retrieved directly from Be10 while others had to be specified. The summer ventilation rate was determined based on the effective opening areas for respectively the dwelling and the most critical room. The ventilation loss was calculated by use of the ventilation rate.

The spreadsheet calculated operating temperature as a combination of air temperature and surface temperatures. The heat gain was found by adding solar load and internal load and the heat loss by adding ventilation loss and transmission loss. By subtracting the heat gain from the heat loss the resulting loss/gain was found. By this the heat transfer between the air and surface temperature was calculated and thus new air and surface temperatures were found and the next hours operating temperature could be calculated.

The monthly solar load was retrieved from Be10 and was adjusted to proportionality of the global radiation for each month.

Test cases

The test cases were based on a dwelling design by “Eurodan huse” where the building envelope has been adapted to comply with energy requirements for both LE2015 and BC2020. The requirement for transmission loss for a BC2020 new construction is that it should not exceed 3.7 W/m² and for the test case the transmission loss for the current building was 3.3 W/m².

The total floor area of the dwelling was 196 m² and a floor plan is shown in Figure 1. The living room had large window areas facing both south and west, and it was considered to be at highest risk of having too high summer temperatures. Therefore, the living room was found to be the most critical room and thus served as a reference room. The living room had a floor area of 29 m² and a room volume of 72 m^3. The described dwelling is referred to as Case 0 and is shown in Figure 1.

In this study a "worst case" was constructed by maximising the window areas of the south and west facing facades. This constructed variant is called Case 20 and is shown in Figure 2.

In both cases, the dwelling had balanced ventilation. There was exhaust from; utility room (10 l/s), kitchen (20 l/s) and bathrooms (15 l/s). The ventilation had heat recovery with 85% efficiency, which was bypassed in summer when heat recovery was inappropriate.

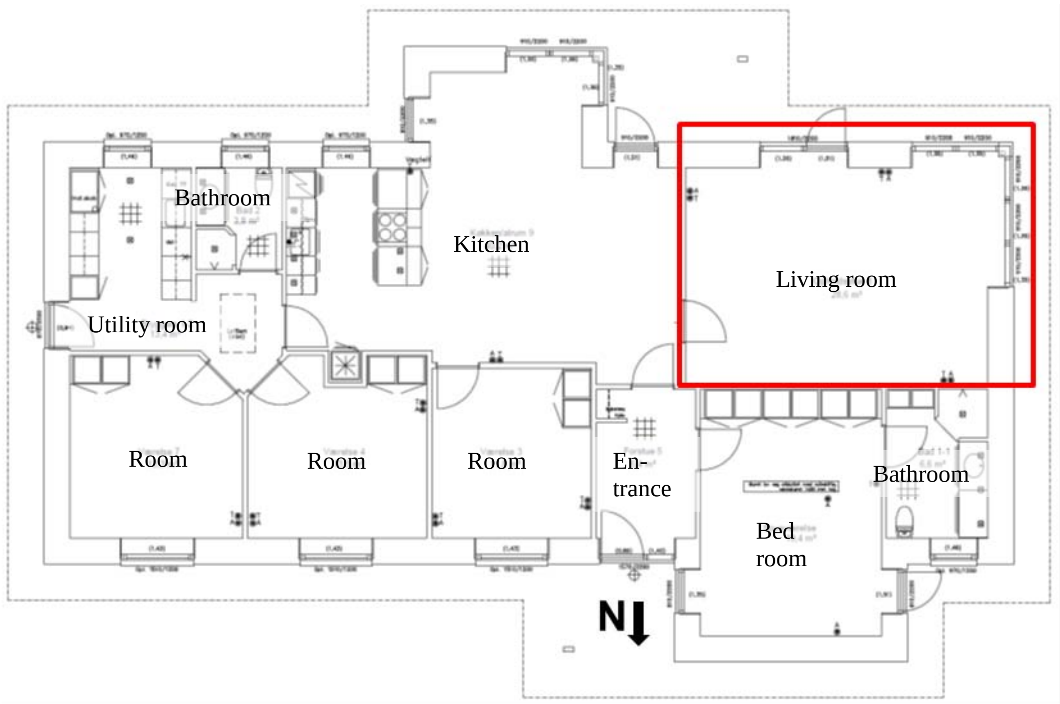

Figure 1. Plan of 196 m² low energy dwelling, corresponding to Case 0. The highlighted area is the living room.

Simulation tool

To test the simplified calculation method, a series of calculations was performed with BSim [4], which is an advanced program for building energy simulation. The program simulates operating conditions and the dynamic interaction between building installations and associated automatic control systems. This makes it suitable for indoor climate analysis and calculation of energy consumption in buildings. In analysis, this program is especially suited for parameter studies, for example of sunlight, use of passive solar protection, window sizes and orientation. In this study, BSim version 6, 11, 6, 20 was used.

Operating time
By definition, the operating hours of a dwelling are 24 hours a day. This means that occupants are always expected to be at home to regulate the indoor climate. In this study simulations were made for a time period of one year.

Venting
In BSim, it is possible to have advanced ventilation control settings. Since the simulations concerned a dwelling, the ventilation was expected to follow the operating time, which is always. However, in order to assess the robustness of the solution a simulation was also performed for a case where the dwelling was vacant and thus had limited ventilation.

Ventilation control

1. When the dwelling was always occupied, it was assumed that the window was opened whenever the air temperature exceeded 23 °C.
2. When the dwelling was vacant, the ventilation was restricted to passive venting or basic ventilation.

Sun protection
The robustness was assessed by simulation where the dwelling was vacant and venting therefore limited. As this easily gave high temperatures, it could be assumed that there were internal solar protection in rooms facing south and west, which was always activated. When the dwelling was vacated, it corresponded to the curtains being drawn.

Glass areas
In the simulations, two cases were investigated. The cases are shown in Figures 1 and 2 and have been described previously. Case 0 corresponds to an ordinary dwelling, while Case 20 is a constructed "worst case" variant of the same dwelling and more likely to experience problems of high temperatures in the summer due to enhanced window areas.

Models
A number of BSim models were created as the example shows for Case 20 in Figure 2, or part of it like Case 50. In the model shown in Figure 2, each room was designed as a separate thermal zone, but there were also models where all the rooms were combined into a single thermal zone. The model variants are described separately below.

Common to all models was that four simulations were performed on each model:

1. A simulation where the dwelling is always occupied and without solar protection
2. A simulation where the dwelling is always occupied and with solar protection
3. A simulation where the dwelling is always vacant and without solar protection
4. A simulation where the dwelling is always vacant and with solar protection

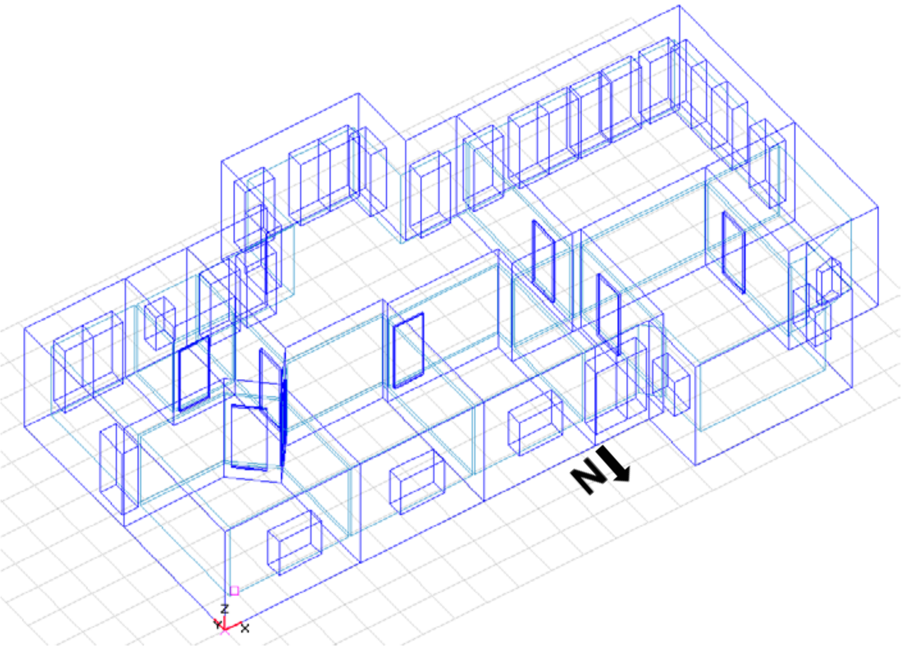

Figure 2. Model of Case 20, a constructed “worst case” variant of Case 0 with substantially increased window area in the South and West façade

Case 0
The geometry of Case 0 is shown in Figure 1. Each room has a separate thermal zone and there is no air mixing between the rooms, which correspond to closed doors between rooms.

Case 0X
In this model the geometry is as in Case 0. Opposite to Case 0 all rooms in the model is associated with the same thermal zone, corresponding to open doors and full air mixing between the rooms.

Case 20
The geometry of Case 20 is shown in Figure 2. The model is similar to Case 0, but with larger window areas to the south and west. Each room has a separate thermal zone and the doors are closed between the rooms.

Case 20X
In this model the geometry is as in Case 20. Opposite to Case 20, all rooms in the model is associated with the same thermal zone, corresponding to open doors between the rooms.

Case 40
This model only contains the living room with adiabatic interior surroundings. The model corresponds to the living room in Case 0 and the room is one single thermal zone.

Case 50
This model only contains the living room with adiabatic interior surroundings. The model corresponds to the living room in Case 20 and the room is one single thermal zone.

Simplified method simulations
By use of the simplified method, calculations were made for Case 0, see Figure 1 and Case 20, see Figure 2. Calculations were performed for every hour throughout the year using the

simplified method and the total number of hours exceeding respectively 26 °C and 27 °C was summarised.

Basically, the simplified method can be used to calculate the temperature condition for every single room in the dwelling. However, if general data for the dwelling is used, as provided in the program Be10 (for energy calculation), the calculation results would correspond to a case with full mixing between zones and open doors between rooms. Thus the results should be comparable with BSim results for cases with just one thermal zone like e.g. Case 0X.
Therefore, to adress the possible high temperatures in the living room, a simulation must be performed where the solar load corresponds to the most critical room, which in this case was the living room. The solar load in the most critical room was the maximum solar load.

The highest ventilation rate for the dwelling was proportional to the sum of the basic ventilation and the effective opening areas. As for the solar load, it was nescessary to evaluate a ventilation rate for the entire dwelling as a whole, and one based on the maximum ventilation for the critical room. The lowest of the two ventilation rates per floor area should be used in the simplified method for calculation of summer comfort. When calculating the ventilation rate, it was allowed to asssume cross ventilation for the most critical room through the door if the rest of the dwelling could be cross ventilated. A limit for a maximum air change rate should be provided or possibly converted into a maximum ventilation rate, e.g. 10 l/s·m².

Additional temperature requirements
In order to ensure the robustness of the dwelling design an additional maximum temperature could be suggested for a vacant dwelling. A supplementary requirement would ensure that pets can stay in vacant dwellings without suffering too high temperatures. A proposal for an additional temperature requirement might be that the temperature in a vacant dwelling should not exceed the maximum outdoor temperature (32.1 °C) for more than a couple of degrees, and thus have a maximum temperature of no more than, e.g. 34 °C.

RESULTS

The results of the simulations are shown in Tables 1 and 2. Table 1 gives the BSim results and Table 2 gives the results of the simplified method.

Temperatures	**Case 0**		**Case 20**		**Case 0X**		**Case 20X**		**Case 40X**		**Case 50X**	
Internal solar protection	+	–	+	–	+	–	+	–	+	–	+	–
Hours above 26 ° C	97	61	247	199	15	6	42	27	119	69	311	191
Hours above 27 ° C	46	23	148	117	3	0	14	6	60	29	205	110
Vacant dwelling												
Max. operating temperature, °C	*33.6*	*33.0*	*41.9*	*38.3*	*31.3*	*30.2*	*34.3*	*32.6*	*49.3*	*43.2*	*55.8*	*48.0*

Table 1. BSim results of simulations.

BSim results
The results in Table 2 show that Case 0 with internal shading comply with the temperature limits of maximum 100 hours over 26 °C and maximum 25 hours over 27° in the living room. In Case 0X and Case 20X, both with and without shading, the temperature requirements for

thermal comfort were also fulfilled, but these cases did not evaluate the most critical room separately as the entire dwelling was one thermal zone.
For the proposed additional requirement of a maximum temperature of 34 °C when the dwelling is vacant, the results were that Case 0 fulfilled the proposed requirement whereas Case 20 did not. Furthermore, Case 0X with and without solar shading and Case 20X with solar shading were below the proposed minimum temperature.
Case 40X and Case 50X did not fulfil any of the requirements.

Results of the simplified method

Table 2 show results for the calculations with the simplified method. There are results for two different solar loads, one is an average for the dwelling (basic) and one for the most critical room (max). In the case with the basic solar load, a combination with minimum ventilation rate of 0.9 l/s·m² in day and evening hours and 0.6 l/s·m² at night was calculated as described in SBi Guidelines 213 [3], and a similar investigation performed for a doubling of the minimum ventilation rate. The other ventilation rates were based on the effective opening areas of the dwelling and the most critical room, for Case 0 it was respectively 4.3 and 10.6 l/s·m². In the calculations of the ventilation rates it was assumed that all windows could be opened.

Temperatures	**Case 0**						**Case 20**					
Solar load	basic	basic	max	max	max	max	basic	basic	max	max	max	max
Ventilation rate, l/s·m²	0.9	1.8	0.9	1.8	4.3	10.6	0.9	1.8	0.9	1.8	6.1	15.6
Hours above 26 ° C	199	70	908	396	107	41	342	129	1763	798	154	49
Hours above 27 ° C	62	9	611	227	46	20	176	47	1339	531	73	23
Max. operating temperature, °C	*28.1*	*27.3*	*33.8*	*30.8*	*29.1*	*29.1*	*29.5*	*28.0*	*38.4*	*34.1*	*30.0*	*29.6*
With internal solar shading ↓												
Hours above 26 ° C	185	66	825	354	102	37	320	123	1641	744	130	45
Hours above 27 ° C	49	6	547	203	38	17	164	42	1198	483	60	23
Max. operating temperature, °C	*28.0*	*27.3*	*33.4*	*30.5*	*29.0*	*29.0*	*29.3*	*27.9*	*37.6*	*33.5*	*29.9*	*29.6*

Table 2. Results of the simplified method.

The results in Table 2 show that Case 0 both with and without internal shading complied with the temperature limits of maximum 100 hours over 26 °C and maximum 25 hours over 27 °C for the case with basic solar load and a doubling of the minimum ventilation rate and the case with maximum solar load and ventilation rate calculated on basis of the most critical room, living room. For Case 20, the only case to fulfil the requirements, the maximum solar load and ventilation rate was calculated on basis of the most critical room, living room.
According to the results, the influence of internal solar shading was quite small. However, the results differed for the overall image for cases without solar shading by reducing the number of hours above 27 °C.
Case 0 fulfilled the proposed requirement of a maximum temperature of 34 °C, whereas Case 20 did not. However, this was based on the ventilation rates given in Table 2 and not for a vacant dwelling with limited ventilation.

Comparing BSim results and results of the simplified method

For Case 0, the results indicated that it fulfilled the thermal comfort requirements for both the advanced BSim calculation and the simplified calculation method if the ventilation rate was sufficient. For the proposed additional temperature requirement of a maximum temperature of 34 °C, the results were the same that Case 0 fulfilled the requirement for both calculation methods.

For Case 20, the result indicated that it did not fulfil the thermal comfort requirements for the advanced BSim calculation, except in Case 20X. The same result was found for the simplified calculation method except in the case with maximum solar load and ventilation calculated on basis of the most critical room. For the proposed additional temperature requirement of a maximum temperature of 34 °C, the results were similar to the other Case 20 results. The maximum temperature limit for BSim results were exceeded for Case 20 but fulfilled for Case 20X, and for the simplified method the maximum requirement was met for the cases with maximum solar load and ventilation calculated on basis of the entire dwelling and the most critical room.

DISCUSSION

Summer comfort

In BR10 contains requirements for thermal comfort in summer, which apply to buildings in low-energy class 2015 (LE2015) or in building class 2020 (BC2020). Specifically for dwellings, the requirements stipulate that 26 °C must not be exceeded for more than 100 hours a year and 27 °C not for more than 25 hours a year. Two calculation methods were tested on two dwelling cases. Both methods gave results that show that Case 0 complies with the summer comfort temperature requirements. Therefore, it is concluded that Case 0 is an example of a dwelling, which meets the requirements for thermal comfort in summer. Opposite, the results for Case 20 showed that the summer comfort requirements cannot be met. This matches our expectations, since Case 20 is a constructed “worst case” variant of Case 0 with substantially increased window area in the south and west façades.

In general there is agreement between the results of the two simulation methods, the advanced BSim program and the developed simplified method. The results for the influence of internal solar shading are quite small. The effect is that the number of hours above 27 °C is lowered for cases with internal solar shading. This is important, as this temperature limit seems to be the most restrictive requirement for summer comfort.

Supplementary temperature requirements

Occupants have different user behaviours, but in all cases it must be assumed that dwellings will be vacant for longer or shorter periods. This differs from the assumption in these calculations. Therefore, an additional requirement of a maximum temperature, which must be observed when the dwelling is vacant, will help to ensure that pets and flowers do not suffer from extremely high temperatures. The proposed requirement is a maximum temperature of 34 °C, and the results from both calculation methods show that Case 0 complies with the requirement, while Case 20 do not. Thus, an additional requirement of a maximum temperature when the dwelling is vacant will support the other summer comfort requirements for the thermal indoor climate.

Caution with calculated temperatures

As in every other calculation program, both Be10 and BSim give results that are highly dependent on the calculation parameters. Therefore, it should be emphasised that the results in terms of number of hours above 26 °C and 27 °C do not correspond to the number of hours that can be measured in an occupied dwelling. One assumption in the calculation is that dwellings are always occupied and thus that occupants can provide extra ventilation to prevent too high temperatures. However, the requirements for evaluation of summer comfort can help to prevent the construction of dwellings that are vulnerable to solar gain and have limited window openings that are unable to provide sufficient ventilation.

Future work
The simplified method for hourly calculation of the operating temperature in order to evaluate summer comfort in dwellings needs to be tested on other dwelling designs. This should also include block of flats and terraced houses.

CONCLUSION

A simplified method has been developed for hourly based calculation of temperatures in dwellings. The simplified method enables evaluation of the summer comfort in dwellings. The calculation method applies to dwellings that are by definition always occupied and can thus be vented. The highest temperatures will be experienced in the most critical room. Therefore, the calculation is performed on basis of the solar load for that room.

The method ensures that there is adequate ventilation by windows that can be opened in both the most critical room and in the whole dwelling. The simplified method can be implemented in the program Be10, so that program as an additional result can provide the summarised number of hours above respectively, 26 °C and 27 °C, which can be used to evaluate summer comfort.

The calculation method was tested on two dwellings, Case 0 and Case 20. The result was that Case 0 meets the thermal summer comfort requirements, while Case 20 does not. This result was expected, as Case 20 is a constructed “worst case” variant of Case 0 with substantially increased window area in the south and west facade.

Along with the development of the method, a proposal is made for a supplemental maximum temperature requirement for a vacant dwelling. Also in this case the results show that Case 0 can comply with the requirement, while Case 20 cannot. The proposed maximum temperature in a vacant dwelling is 34 °C.

The simplified method summarises the number of hours above 26 °C and 27 °C, but that does not necessarily mean that this number of hours will correspond to the number of hours with high summer temperatures in a real dwelling. The number of hours with high summer temperatures will largely be driven by user behaviour. However, it is expected that the simplified method can help to ensure that there is sufficient opportunities for ventilation of the dwelling and suitable solar protection.

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