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Window Ventilation Behavior for Overheating Evaluation: Residents' Survey and Derived Ventilation Profiles

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ABSTRACT

Studies have shown that night-time ventilation can greatly reduce indoor overheating during hot spells. Yet the relevant literature is largely silent on which specific time resolved window ventilation behavior can be applied for investigations with building performance simulations. The aim of this article is to close this gap in knowledge. Specifically, a survey was carried out in two German cities Dresden and Erfurt regarding window ventilation behavior on hot (outside temperature > 30 °C) and average summer days to determine how, when and for how long ventilation is actually implemented in residential buildings. The results show that approximately 80 % of respondents ventilate their living rooms and bedrooms mainly at night and/or in the early morning on both hot and average summer days – although the individual window ventilation behavior may vary significantly. The details provided by the respondents were processed to create characteristic window ventilation profiles in order to reflect the individual user behavior more realistically in future studies, especially for overheating evaluations by building performance simulation.

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1. Introduction

Forecasts confirm that, in particular, the duration and intensity of heatwaves will continue to increase (Intergovernmental Panel on Climate Change (IPCC), 2014). To analyze the thermal comfort of buildings under these climate changes the building performance simulation is a suitable tool (Deutsches Institut für Normung e. V. (DIN), 2013; The Chartered Institution of Building Services Engineers (CIBSE), 2017).

Studies have shown that the natural air exchange due to window ventilation and, above all, night-time cooling via open windows have a significant influence on the heat resilience of buildings and the effectiveness of heat adaptation measures (Rijal et al., 2008; Fabi et al., 2012; Porritt et al., 2013; Ferk et al., 2016; Vellei et al., 2017; Fosas et al., 2018; Ivankovic et al., 2019; Schünemann et al., 2020; Hoffmann and Kheybari, 2021). However, the question arises which time-resolved window ventilation profiles can be taken as representative and realistic in building performance simulations to reflect the individual user behavior and accordingly the reality in an accurate manner.

In general, the influence of the window ventilation on the heat resilience of buildings depends on a variety of boundary conditions. Accordingly, structural conditions (e. g. room volume, window opening area, window orientation), weather conditions, type of room use and occupant behavior can affect the window ventilation. For example, Hall et al. conducted measurements in a model room in a laboratory to determine the air exchange rate depending on the window opening area as well as the reveal depth and arrangement of a bottom-hung window. The results showed that the air exchange is highest without an outside and inside reveal. However, these investigations were designed for winter weather conditions (Hall, 2004). In contrast, Schünemann et al. performed building performance simulations for attic apartments of two multi-residential buildings located in Germany. They concluded that the effect of window ventilation also depends on the building physics of a room (Schünemann et al., 2021). Mavrogianni et al. also performed building performance simulations for residential buildings in London under various boundary conditions (e. g. occupant profiles, building geometry and orientation, insulation level, shading) and found that the effect of window ventilation is associated with the insulation level of a building and window shading (Mavrogianni et al., 2014).

Further studies investigated the influence of external weather conditions on occupants' window ventilation behavior. For example, Fabi et al. showed that the ventilation behavior in apartments is strongly dependent on the outside temperature (linear increase in ventilation intensity as outside air temperatures rise from -10 °C to 25 °C) and wind speed (Fabi et al., 2012). However, this study did not specifically examine the ventilation behavior on summer days (outdoor temperature > 25 °C) or the impact of the ventilation behavior.

Surveys of window ventilation behavior were conducted by Mavrogianni et al. in the United Kingdom. They pointed out that 70 % of residents did not ventilate their apartment at all during the night or at most with only one open window. The main reason given for this was usually security concerns such as the risk of burglary (Mavrogianni et al., 2016). Vellei et al. combined surveys with indoor climate measurements and investigated the thermal comfort in bathrooms, kitchens and living rooms of 46 renovated residential buildings in the United Kingdom. They noted that the degree of overheating was associated with inadequate window ventilation behavior (Vellei et al., 2016).

With regard to window ventilation profiles the German standard DIN 4108-2:2013-02 (Deutsches Institut für Normung e. V. (DIN), 2013) specified boundary conditions for analyzing the summer comfort of buildings using building performance simulation. Thus, from 6 am to 11 pm a constant air exchange rate of 3 h^{-1} can be assumed in residential buildings if the indoor temperature is > 23 °C and the indoor temperature also exceeds the outdoor temperature. During night-time hours, a ventilation rate of 2 h^{-1} can be assumed in residential buildings if the indoor temperature is > 20 °C and at the same time exceeds the outdoor temperature (Deutsches Institut für Normung e. V. (DIN), 2013). According to the standard CIBSE TM 59 (2017), it can be assumed that the windows are open if the indoor temperature exceeds 22 °C and the room is used at the same time. It is also specified that interior doors should be open during the day and closed during sleeping time (The Chartered Institution of Building Services Engineers, 2017).

Of course, these normative approaches are important boundary conditions, but they do not adequately reflect the individual user behavior. Detailed knowledge of the time periods of window opening is needed in order to take better account of individual behavior and induced impacts on heat resilience of apartments. For example, users may be absent for most of the day. Since windows in residential buildings do not usually open and close automatically, residents have to decide when leaving their homes whether to keep the windows open or closed during the day. The question also arises whether the specified air exchange rates in the German standard DIN 4108-2:2013-02 can always be achieved by tilting and shock/cross-ventilation, especially at night when it is also necessary to take account of factors such as burglary protection or outdoor noise. In addition, cross-ventilation may be rejected due to the risk of unpleasant draughts. Furthermore, it is not always possible or desirable to open interior doors for cross-ventilation due to individual requirements for room use.

To get a more precise picture, this work presents the results of a residents' survey carried out in the summer months of the year 2019 to find out how, when and for how long ventilation is actually carried out during hot (outside temperature > 30 °C) and average summer days in residential buildings. Furthermore, characteristic window ventilation profiles will be derived from the survey results in order to more realistically represent individual window ventilation behavior in future studies, especially for investigations with building performance simulations.

2. Methodology

To evaluate the window ventilation behavior during summer weather conditions, the methodology of a written survey was used. For this purpose, a total of 400 questionnaires with enclosed envelopes were randomly distributed in letterboxes of multi-residential buildings in two urban districts in Germany. Studies have shown that residents of multi-residential buildings in cities are particularly affected by heat stress due to the urban densification and the associated urban heat island effect (Schünemann et al., 2020b).

The first sample district is located in the city of Dresden (district Dresden-Gorbitz) with precast large-panel housing blocks while the second is located in Erfurt (district Erfurt Oststadt) with buildings from the 19th-century (*Gründerzeit* periode). These types of multi-residential buildings are often not yet adapted to the increasing summer weather conditions (Schünemann et al., 2020). Accordingly, there is a need for action to optimize the summer comfort. In addition, the selected buildings are typical representatives of multi-residential buildings in European cities (Schünemann et al., 2020). The results of the investigations are therefore highly relevant for many urban neighborhoods.

The buildings investigated in the district of Dresden-Gorbitz are both refurbished and non-refurbished precast large-panel housing blocks, usually six storeys high. Here the apartments have a similar floor plan across all storeys. In comparison, the buildings in Erfurt's Oststadt district from the so-called *Gründerzeit* period often have attics converted into living space. These attic apartments differ significantly in floor plan and structural design from the apartments in the underlying three or four storeys. Further details on the building structures, their structural components and window properties can be found elsewhere (Schünemann et al., 2020; Kunze, 2019; Schiela and Schünemann, 2020).

From a total of 400 distributed questionnaires, 83 households had replied by 31 August 2019. The questionnaire itself contained 12 questions, most of which were mainly multiple choice. The two-page questionnaire is shown in Table A 1 (Appendix).

First, the participants were asked to assess the indoor temperatures in the individual rooms of their homes during hot summer days (maximum temperature > 30 °C). The residents were able to evaluate the indoor temperatures during summer weather conditions on a predetermined 5-point scale ("just right" to "hot"). This 5-point scale allowed a detailed gradation of the subjective heat sensation of the residents in the two multi-residential building types and also showed tendencies of the heat sensation in comparison to a 3-point scale (low, medium and high heat stress).

Subsequently, the questionnaire asked about the window ventilation behavior for each room in the apartment, i.e. living room, bedroom, children's room, study and bathroom. Here the respondents could choose between tilt and shock (fully opened) ventilation as well as combinations of these types with cross-ventilation. By means of a timeline, respondents could mark in boxes the specific times when they predominantly used these individual or combined forms of window ventilation. The ventilation behavior was recorded separately for hot summer days (maximum temperature > 30 °C) and average summer days (maximum temperature < 30 °C).

In addition, the survey also considered the obstacles to window ventilation during the day or at night and whether fans were utilized. These questions were also created as multiple choice questions with the specifications of "burglary protection", "driving rain", "outside noise", "insects" and "draught" or "yes" and "no". Additional space was provided for own comments. In the last part of the questionnaire, the participants were asked to provide details about the building, the apartment and the persons making up their household in order to determine any correlation of these factors with window ventilation behavior.

For the data analysis, the residents' responses were first digitized using the spreadsheet program Microsoft Excel. This was followed by a check of the completeness and meaningfulness of the answers. Subsequently, the data were processed into tables and individual questions were linked with filters in order to make statistical statements on window ventilation behavior under certain boundary conditions (e. g. window ventilation behavior depending on the building floor). In order to derive characteristic window ventilation profiles, the specified profiles of each household were evaluated separately and categorized into groups depending on various boundary conditions.

3. Results and Discussion

3.1 Age Structures in the Investigated Districts

A total of 60 people live in the households surveyed in Dresden-Gorbitz and 100 in the households surveyed in Erfurt's Oststadt district. Figure 1 compares the age structure of the 160 residents in the 83 participating apartments in relation to the building floor. Here we distinguish between the ground and intermediate floors (GF+IF) and the top floor (precast large-panel housing blocks) or attic floor (*Gründerzeit* buildings). In this context, intermediate floors are those floors which cannot be classified as a ground floor, a top floor or an attic floor.

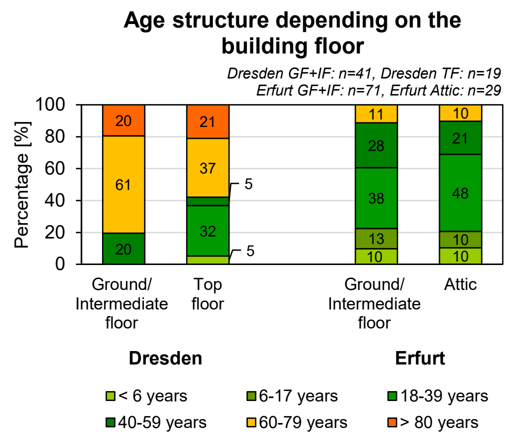

Figure 1 Age structure of the 160 persons living in the 83 surveyed households in Dresden-Gorbitz and Erfurt Oststadt in relation to the building floor

The results show a clear difference between the age structures of the two sample districts. For example, the proportion of residents over 60 years of age is 81 % in Dresden-Gorbitz (ground floor/intermediate floor) and 58 % (top floor) while in Erfurt's Oststadt the ratio is only 11 % for the ground/intermediate floors and 10 % for attic apartments. In the *Gründerzeit* buildings in Erfurt, the majority of residents fall in the age group 18-59 years, i.e. 66 % (ground/intermediate floor) and 69 % (attic).

Age differences between floors are particularly evident in Dresden-Gorbitz. These can generally be attributed to the condition of the buildings. In unrenovated buildings, younger people generally live on the top floors and older residents on the lowest floors. However, a large proportion of residential buildings in the study area have already been upgraded for older people. Newly installed lifts mean that many apartments on the 5th floor are now also barrier free.

3.2 Subjective Heat Stress in Relation to The Floor

Based on the indicated age structures, Figure 2 compares the assessment by local residents of Dresden-Gorbitz and Erfurt's Oststadt of the level of heat stress. Here we see an evaluation for the living room and bedroom on a hot summer day with outside temperatures > 30 °C. The data is broken down by floor in order to determine the subjective heat stress felt by those living on the top floor or attic floor, which are generally much hotter than underlying floors.

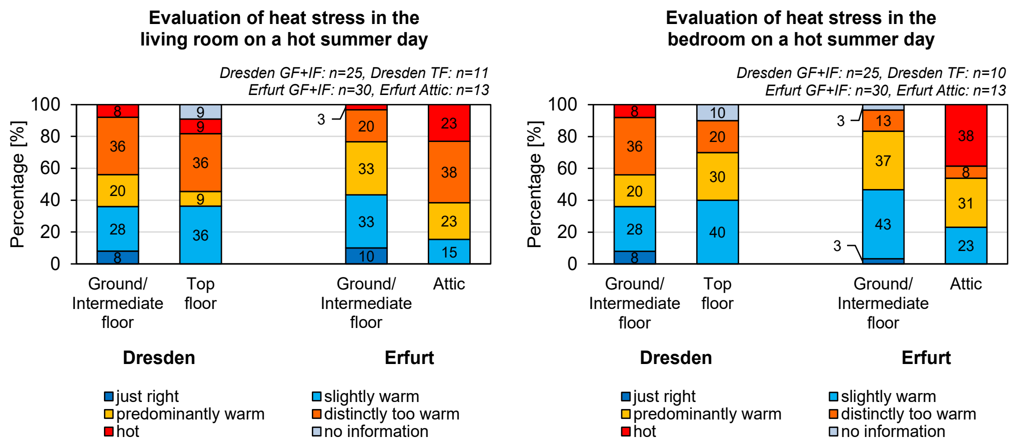

Figure 2 Subjective assessment of heat stress in the living room and bedroom on a hot summer day in relation to the building floor

In general, we see that a similar perception of heat stress is indicated for the living room and the bedroom on each floor of residential buildings in Dresden. Regarding the living room, 64 % (ground/intermediate floor) and 54 % (top floor) of respondents rated the indoor temperature as "predominantly warm" to "hot". Regarding the bedroom, the ratios are 64 % (ground/intermediate floor) and 50 % (top floor). The similar evaluations of heat stress can be attributed to the nearly identical floor plans and interior fittings of the apartments. Furthermore, many buildings in the study area had already been refurbished, in particular, the apartments on the top floors were fitted with ceiling and façade insulation, thereby reducing the possibility of external heat reaching the interior space (Schünemann et al., 2020). In addition, the subjective assessment of the heat stress is particularly dependent on the prevailing weather conditions during the survey as well as the particular situation (floor, ventilation behavior) of each household. The summer of 2019 was one of the warmest ever recorded in Germany, with an average temperature of 19.2 °C and maximum temperatures of over 40 °C (Deutscher Wetterdienst (DWD), 2019). For this reason, the survey findings could help residents cope with the forecasted heatwaves of coming summers.

In Erfurt's *Gründerzeit* residential buildings, we observe a significantly higher perception of heat stress in the attic apartments compared to the top floors in Dresden. Here 84 % of respondents classified the interior temperature in the living room as "predominantly warm" to "hot" while 77 % gave the same evaluation for the bedroom.

The comparison of the results for the ground and intermediate floors of the two multi-residential building types shows that 64 % of the participants in Dresden evaluate the heat stress in the living room and bedroom as "predominantly warm" to "hot". For the buildings in Erfurt, these values are 56 % (living room) and 50 % (bedroom). Accordingly, it can be concluded that the heat stress on the ground and intermediate floors of the *Gründerzeit* buildings is rated lower. The noted disparity in the evaluation of heat stress in the *Gründerzeit* buildings can be attributed to the unique design and structural features of the attic apartments compared to the other residential floors.

In summary, it can be said that there is basically no correlation between the age of the respondents and the subjective assessment of heat stress. Using the methodology of table filtering, it was found that 60 % of residents in Dresden-Gorbitz, who are over 60 years and at the same time live on the ground or intermediate floor, classified the heat stress in their living rooms as "predominantly warm" to "hot". For the attic apartments, this proportion is also approximately 60 %. This shows that a high proportion of older people do not necessarily also evaluate the heat stress in the apartment as high. The decisive factors are rather the location of the apartments in the building and whether it is an attic apartment. Therefore, residents of attics in *Gründerzeit* buildings were particularly likely to indicate a high heat stress.

3.3 Window Ventilation Behavior In The Living Room And Bedroom In Relation To The Floor

The first step in evaluating the window ventilation behavior was to examine the data on window opening in the living room and bedroom. The two types of window ventilation practiced by the surveyed households are here summed for each hour of the 24-hour period in order to reveal those times when the living room and bedroom are most likely to be ventilated. In view of the lack of significant differences between the responses from Dresden and Erfurt, these two datasets are here aggregated and differentiated by floor. In the histograms of Figure 3 and Figure 4, the horizontal axes represent the 24-hour period and the vertical axes the respective proportion of respondents. The indented columns show the proportion of respondents combining a tilted (red) or fully opened window (yellow) with cross-ventilation.

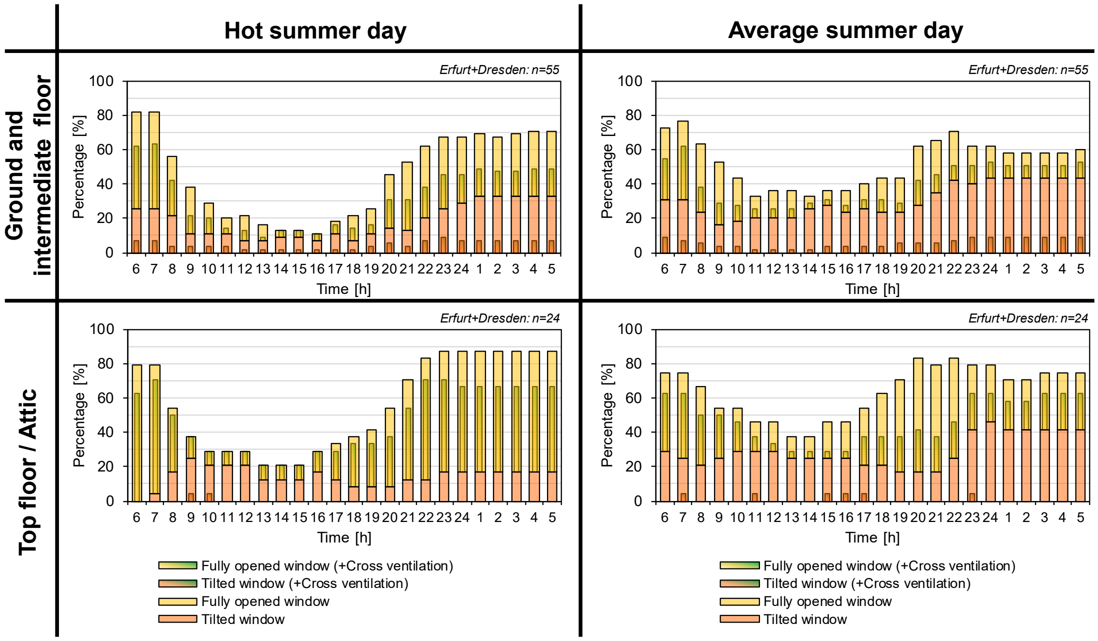

Figure 3 Evaluation of window ventilation behavior in the living room on hot and average summer days for different floors. The indented columns show the proportion of respondents combining a tilted (red) or fully opened window (yellow) with cross-ventilation

The aggregated data for tilt and shock ventilation during hot summer temperatures shows that the majority of respondents keep their windows closed during the day, both on the ground/intermediate floors as well as on the top floors or attic space. Instead, most residents ventilate largely at night or in the early morning hours. It should also be noted that an even larger proportion of respondents living on top floors or in attic spaces will ventilate due to the higher heat loads found there than on the other floors. Specifically, the average proportion of respondents ventilating from around 10 pm to 8 am is approx. 70 % on the ground floor/intermediate floors in contrast to approx. 90 % on the top floor/attic. Furthermore, we also note a steady increase in ventilation from around 4 pm. When ventilation takes place, the window on the top floor or attic is opened completely rather than just tilted. On the ground and intermediate floors, however, the ratio between tilt and shock ventilation is relatively balanced. With regard to window ventilation combined with cross-ventilation, we see that this is much more likely to occur with a fully opened window than a tilted window. This form of combined ventilation also applies to an average summer day and results in the greatest influx of fresh air into the apartment.

Comparing a hot day with an average summer day, it can be seen that in the latter case ventilation increases during the day (primarily tilt ventilation). The proportion of tilt ventilation also increases at night, in particular, this is preferred by respondents in the ground and intermediate floors to fully opened windows. On the top floors or attic spaces, a relatively high rate of shock ventilation occurs between 7 pm and 11 pm.

In principle, the ventilation behavior already described for the living room (Figure 3) also applies to the bedroom (Figure 4): on hot summer days, ventilation is mainly in the early morning hours and at night. During night-time hours from 10 pm to 6 am, however, there is slightly increased likelihood of ventilation on the ground floor and intermediate floors (about 80 %) and lower likelihood of ventilation on the top floor or attic space (about 75 %) than in the living room. Tilt ventilation is hardly used on the top floors or attics. On average summer days, tilt ventilation also increases significantly compared to hot summer days, especially on the top floors or attics.

In summary, while we note some minor variations in window ventilation between the living room and bedroom, no significant disparities can be detected between the two rooms or between the floors. The differences that do occur are, above all, in regard to daytime window ventilation for hot vs. average summer days.

The results on window ventilation behavior during summer weather conditions show that window ventilation is used by approximately 80 % of the respondents in the living room and bedroom to cool the rooms at night. The results of Mavrogianni et al. that 70 % of the residents do not ventilate their apartment at all or only with one open window during the night could thus only be partially confirmed for the building types considered in this study (Mavrogianni et al., 2016).

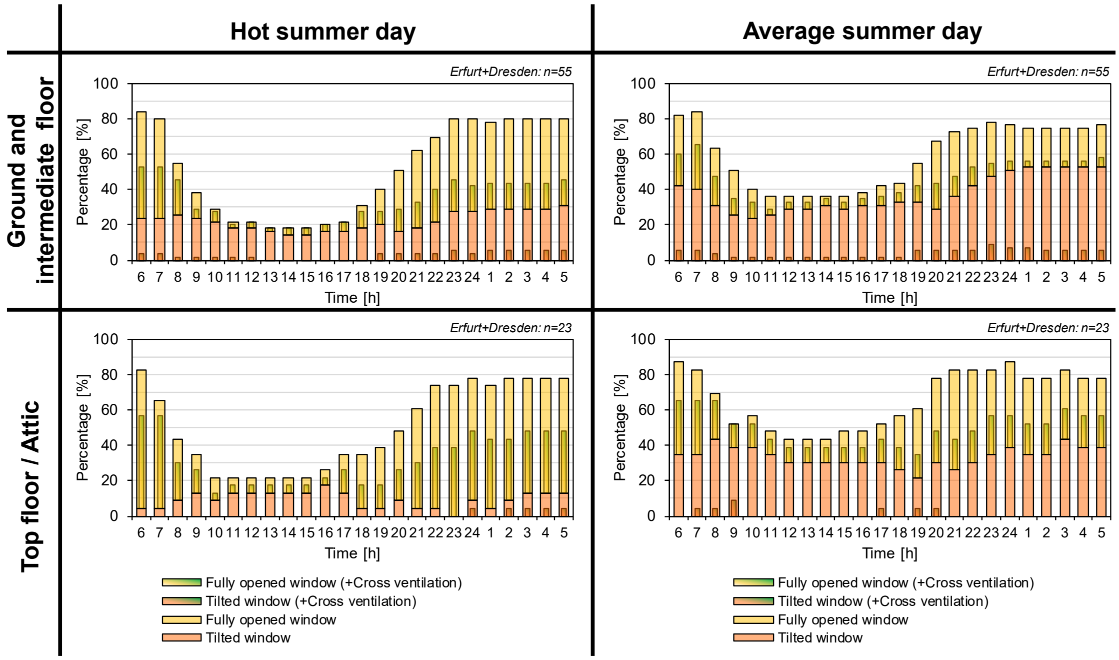

Figure 4 Evaluation of window ventilation behavior in the bedroom on hot and average summer days for different floors. The indented columns show the proportion of respondents combining a tilted (red) or fully opened window (yellow) with cross-ventilation

3.4 Obstacles To Window Ventilation At Night

Night-time ventilation has a major impact on thermal comfort during long periods of hot weather (Schünemann et al., 2021). Accordingly, adequate window ventilation can make a useful contribution to the night-time cooling of rooms. This is especially true in the Central European climate zone where outside temperatures drop significantly at night and tropical nights (minimum temperature > 20 °C) are rare. Night-time ventilation can help to release heat that has accumulated indoors over the course of the day. However, residents have a number of good reasons to keep windows closed at night. Figure 5 shows the findings of the questionnaire on these general obstacles to night-time ventilation.

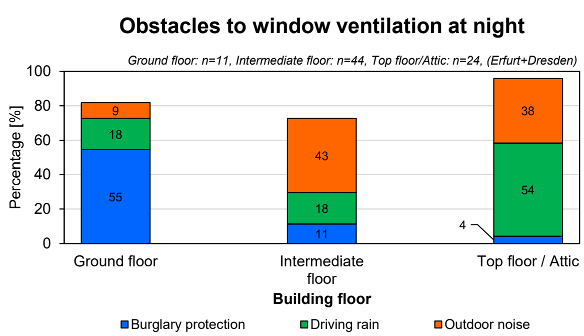

Figure 5 Findings of the 83 surveyed households on general obstacles to night-time ventilation in relation to the building floor

The results show that, depending on the floor type, different reasons are given clear for not opening windows. For example, burglary protection is named by over 50 % of respondents living on the ground floor. The findings of Mavrogianni et al. that burglary protection plays an important role in the implementation of window ventilation could be confirmed with this survey, especially for occupants of ground floors (Mavrogianni et al., 2016). Furthermore, over 50 % of those inhabiting top floors or attics gave driving rain as the main reason. Outdoor noise also plays an important role, especially among those living on intermediate floors (43 %) and on top floors or attics (38 %). Consequently, architects and urban planners must consider special measures to ensure that users are able to exploit night-time window ventilation. This will also benefit climate protection by avoiding the use of air conditioning.

4. Derivation Of Characteristic Ventilation Profiles

The histograms in Figure 3 and Figure 4 give an overview of window ventilation behavior in living rooms and bedrooms over a 24-hour period. However, individual ventilation behavior cannot be deduced from these figures as, for example, it is impossible to determine whether a resident who ventilates in the morning also ventilates in the evening. For this reason, the investigations were extended to examine the questionnaires on a case-by-case basis. Here the only distinction made was between tilted and fully opened windows. For reasons of simplicity, cross-ventilation was neglected and merely recommended as an additional option to achieve a more efficient air exchange. Some individual window ventilation profiles are shown in Figure A 1 and Figure A 2 (see appendix) for the living room and bedroom. A distinction is made between hot and average summer days as well as between the top/attic floor and ground/intermediate floors. The respondents' own assessment of the heat stress on a hot summer day (outside temperature > 30 °C) is shown for the two considered rooms. While the questionnaire results confirm that many respondents ventilate mainly in the morning and at night, a wide range of individual ventilation behavior is also apparent. For example, there are households that ventilate in the morning but not at night. Some respondents also change the applied type of window ventilation over the course of a day. In other households the window is simply left open all day. The ventilation profiles for the living room and bedroom are largely the same.

The subjective assessment of heat stress reveals no or only a weak correlation between perceived heat stress and ventilation behavior. The use of night-time window ventilation to cool down the rooms does not mean that the indoor temperatures are perceived as pleasant. Nor can low window ventilation behavior at night indicate the residents do not suffer from high heat stress. Furthermore, it should be mentioned that the window ventilation behavior can also deviate on certain days from the practices stated here, leading to variations in the perceived heat stress over the course of the summer. In addition to user behavior, the physical structure of the building can also greatly determine whether rooms become overheated (Schünemann et al., 2021).

The histograms in Figure 3 and Figure 4 indicate that there are times during the course of the day when similar forms of ventilation behavior occur in the living room and bedroom or when similar ratios of ventilation behavior arise. In order to derive characteristic ventilation profiles, the authors decided to distinguish between ventilation in the morning (6 am to 8 am), ventilation during the day (8 am to 6 pm), ventilation in the evening (6 pm to 10 pm) and night-time ventilation (10 pm to 6 am). As the window can be either closed, tilted or completely open at any of the indicated time periods, there are a total of 81 (3 window ventilation variants per time period: 3 x 3 x 3 x 3) possible ventilation profiles. In our investigation, we determined (under certain boundary conditions) which variant occurs most frequently in each time period. These boundary conditions are summarized in Figure 6

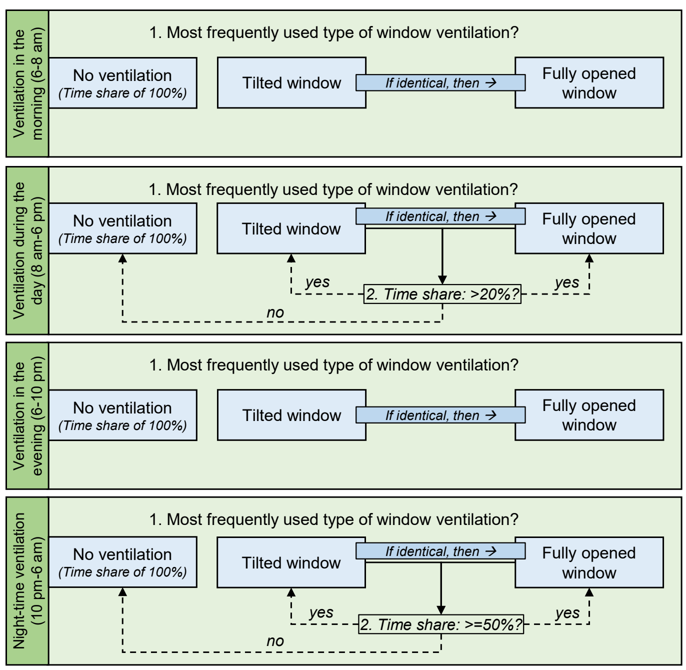

Figure 6 Scheme to derive characteristic window ventilation profiles by setting four selected time periods and boundary conditions for each period

First, we examined how often each ventilation type occurred in the respective time period and determined the most frequently used type of ventilation. If there was no difference in the frequencies of the tilted or fully-opened window, the latter ventilation type was chosen ("if identical, then" in Figure 6). Subsequently, it was determined whether the most frequently occurring ventilation type was also effectively applied and fulfilled the named boundary conditions. For the definition of the boundary conditions, it was assumed that there must be a certain duration of window opening in the selected time periods in order to achieve an effect with regard to the indoor climate. Accordingly, only those cases of daytime ventilation (8 am to 6 pm) were considered in which the window was kept open more than 20 % of the time, thus enabling warm outdoor air to flow into the room and increase indoor temperatures. This assumption also ensures that fresh air can enter the room during the day, when residents should be at home. At night, ventilation was only deemed to occur if the window was open for at least 50 % of the time, so that the low outdoor air temperatures at night were specifically used to cool down the rooms. At the other times of the day, all households were counted that ventilated for at least one hour. Thus, the effectiveness of some ventilation profiles shown in Figure A 1 and Figure A 2 is over- or underestimated, respectively. However, these assumptions were necessary to limit the range of possible window ventilation profiles and thus to maintain the clarity of the results.

The individual questionnaires were then assigned to one of the 81 possible ventilation profiles and sorted according to frequency. Table 1 shows the identified ventilation profiles independent of the floor.

The window ventilation profiles derived from the survey on window ventilation for summertime outdoor temperatures represent a wide range of individual user behavior. The distinguishing characteristic of the most common ventilation profiles is a lack of ventilation during the day or at night. Combinations of tilt and/or shock ventilation are also employed. The profiles can therefore be used for overheating assessment by building performance simulation to take better into account of individual user behavior.

Table 1 The most common window ventilation profiles for living rooms and bedrooms on hot summer days as determined by the questionnaires

Profile	Ventilation in the morning (6-8 am)	Ventilation during the day (8 am-6 pm)	Ventilation in the evening (6-10 pm)	Night-time ventilation (22 pm-6 am)	Number Living room	Number Bedroom
1	Fully opened window	No ventilation	No ventilation	Fully opened window	13	10
2	Fully opened window	No ventilation	Fully opened window	Fully opened window	11	15
3	Fully opened window	No ventilation	No ventilation	No ventilation	7	11
4	Tilted window	No ventilation	No ventilation	Tilted window	5	1
5	Tilted window	Fully opened window	Fully opened window	Tilted window	4	-
6	Fully opened window	No ventilation	Fully opened window	No ventilation	4	1
7	Fully opened window	Fully opened window	Fully opened window	Fully opened window	3	4

5. Limitations of the Study

It is important to note that the window ventilation profiles were derived from the surveys using simplified assumptions to minimize the number of possible window ventilation profiles. Accordingly, a change in the selected time periods and boundary conditions also changes the ventilation profiles in design and frequency. The results represent case examples for two multi-residential building types of two different districts in Germany. Therefore, the window ventilation behavior may vary in other German regions or countries with or without similar building structures. Due to the fact that only 83 households took part in the survey, the results presented are randomly and have to be checked for transferability. Furthermore, it must also be taken into account that some respondents may have idealized their user behavior and thus the respondents' window ventilation behavior can deviate from the practices stated in the questionnaire and does not necessarily reflect the reality.

6. Conclusion

Previous investigations had shown that window ventilation behavior, especially at night, has a major influence on indoor overheating. However, the question arises which window ventilation profiles are suitable to reflect the individual user behavior and accordingly the reality in a good manner.

To get a more precise picture, a residents' survey was carried out in the summer months of the year 2019 to find out how, when and for how long ventilation is actually carried out during hot (outside temperature > 30 °C) and average summer days in multi-residential buildings. Therefore, two study areas each with different representative building types were chosen located in the German cities of Dresden and Erfurt.

Of a total of 400 distributed questionnaires, 83 households took part in the survey. The questionnaire itself contained 12 questions, which were mainly multiple choice. In addition to room-specific questions regarding window ventilation behavior on hot and average summer days as well as an own assessment of the heat stress on hot summer days, an important part of the survey was to identify some general obstacles to night-time ventilation. These questions were supplemented by information on the building, the apartment and the individuals making up the household.

The following results could be derived from the answers of the questionnaires:

1. No correlation was found between the age of residents and their perception of heat stress. However, the location of the apartment in the building, specifically whether it is an attic apartment or an underlying apartment, plays a significant role.

2. Many respondents ventilate their homes mainly at night and/or early in the morning on hot as well as on average summer days. The majority of respondents keep their windows closed during the day. However, windows are opened more frequently during daytime hours when the summer weather is average rather than when it is hot.

3. The application of night-time window ventilation does not mean that the indoor temperatures in the apartment are perceived as pleasant.

4. On hot and average summer days, the ventilation behavior in the living room and bedroom differs only slightly.

To achieve the objective of characteristic window ventilation profiles, the next step was to evaluate the individual ventilation behavior of each household. For this purpose, boundary conditions were defined for four selected periods over 24 hours and the generated ventilation profiles classified by frequency. This resulted in the identification of seven ventilation profiles, which can be basically differentiated by a lack of window ventilation during the day or at night. The profiles represent a wide range of user behavior and can thus be used in a targeted manner for overheating assessment by building performance simulation to realistically represent window ventilation behavior. Different ventilation profiles and thus ventilation scenarios can thus be examined for a building. For example, it is possible to select a ventilation profile for rooms on the ground floor that only takes into account ventilation in the morning and/or evening, if night ventilation is not possible due to burglary protection. It is also possible to investigate whether ventilation in the evening and/or morning is sufficient to reduce the heat stress in the building or whether measures to support the air exchange by means of a ventilation system are necessary. For the top floors or attics that are particularly affected by heat stress, it can also be investigated whether night-time ventilation is sufficient to achieve a comfortable indoor climate during summer weather conditions or whether further measures (e. g. window shading) are required.

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Appendix

Table A1 The two-page questionnaire used to survey window ventilation behavior during hot summer weather

1. How do you evaluate the indoor temperatures in the individual rooms of your apartment during persistently hot outdoor temperatures in the summer?

	just right	slightly warm	predominantly warm	distinctly too warm	hot
Living room	☐	☐	☐	☐	☐
Bedroom	☐	☐	☐	☐	☐
Children's room / study	☐	☐	☐	☐	☐

2. How often and for how long do you usually use the following window ventilation options in your apartment during **persistently hot summer outdoor temperatures** (daytime maximum > 30 °C)? Please mark the periods in the boxes.

Window ventilation / Time	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
Living room																								
Tilted window																								
Fully opened window																								
Cross ventilation																								
Bedroom																								
Tilted window																								
Fully opened window																								
Cross ventilation																								
Children´s room																								
Tilted window																								
Fully opened window																								
Cross ventilation																								
Study																								
Tilted window																								
Fully opened window																								
Cross ventilation																								
Bathroom																								
Tilted window																								
Fully opened window																								
Cross ventilation																								

3. How often and for how long do you usually use the following window ventilation options in your apartment during **average summer outdoor temperatures**? Please mark the periods in the boxes.

Window ventilation / Time	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	1	2	3	4	5
Living room																								
Tilted window																								
Fully opened window																								
Cross ventilation																								

Bedroom																								
Tilted window																								
Fully opened window																								
Cross ventilation																								
Children´s room																								
Tilted window																								
Fully opened window																								
Cross ventilation																								
Study																								
Tilted window																								
Fully opened window																								
Cross ventilation																								
Bathroom																								
Tilted window																								
Fully opened window																								
Cross ventilation																								

4. Please give reasons why you generally do not use the following window ventilation options during the day or at night? (multiple answers possible)										
	Burglary protection		Driving rain		Outdoor noise		Insects		Draught if several windows are opened in the apartment	
	day	night	day	night	day	night	day	night	day	night
Tilted window	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Fully opened window	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cross ventilation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Miscellaneous and comments:										

5. Do you use fans or similar in your apartment to increase thermal comfort on hot summer days?	
☐ Yes	☐ No

6. How many floors does your building have in total?						
1	2	3	4	5	6	7 or more
☐	☐	☐	☐	☐	☐	☐
7. What floor do you live on? Please also indicate whether it is an attic apartment.						
1	2	3	4	5	6	7 or higher
☐	☐	☐	☐	☐	☐	☐
Attic?			☐ Yes		☐ No	

8. How big is your apartment?				
☐ less than 40 m²	☐ 40-60 m²	☐ 61-80 m²	☐ 81-105 m²	☐ more than 105 m²

9. How many people in the following age groups live in your household?						
	under 6 years	6 - 17 years	18 - 39 years	40 - 59 years	60 - 79 years	over 80 years
Number	_ pers.	__ pers.	__ pers.	__ pers.	__ pers.	__ pers.

10. What kind of apartment do you live in?			
☐ Rented apartment	☐ Freehold apartment	☐ Own house	☐ other

11. Please indicate the date on which you completed this questionnaire:	___2019___.

12. Do you have further notes or comments on the topic?

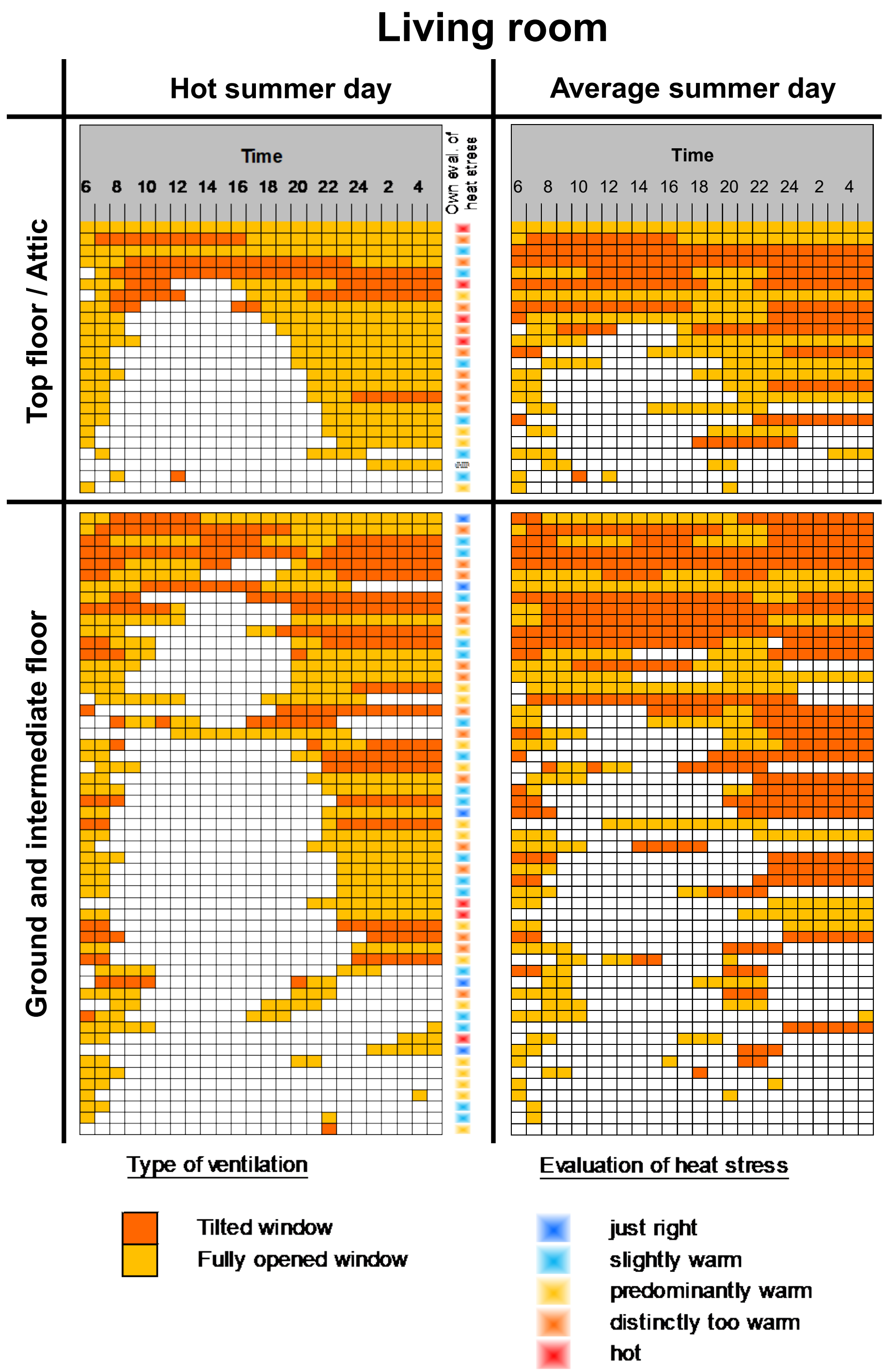

Figure A 1 Ventilation profiles for the living rooms on hot and average summer days depending on the floor. Each row represents the individual window ventilation behavior of a surveyed household. For hot summer days with an outside temperature > 30 °C, the individual assessment of the heat stress in the living room is also shown

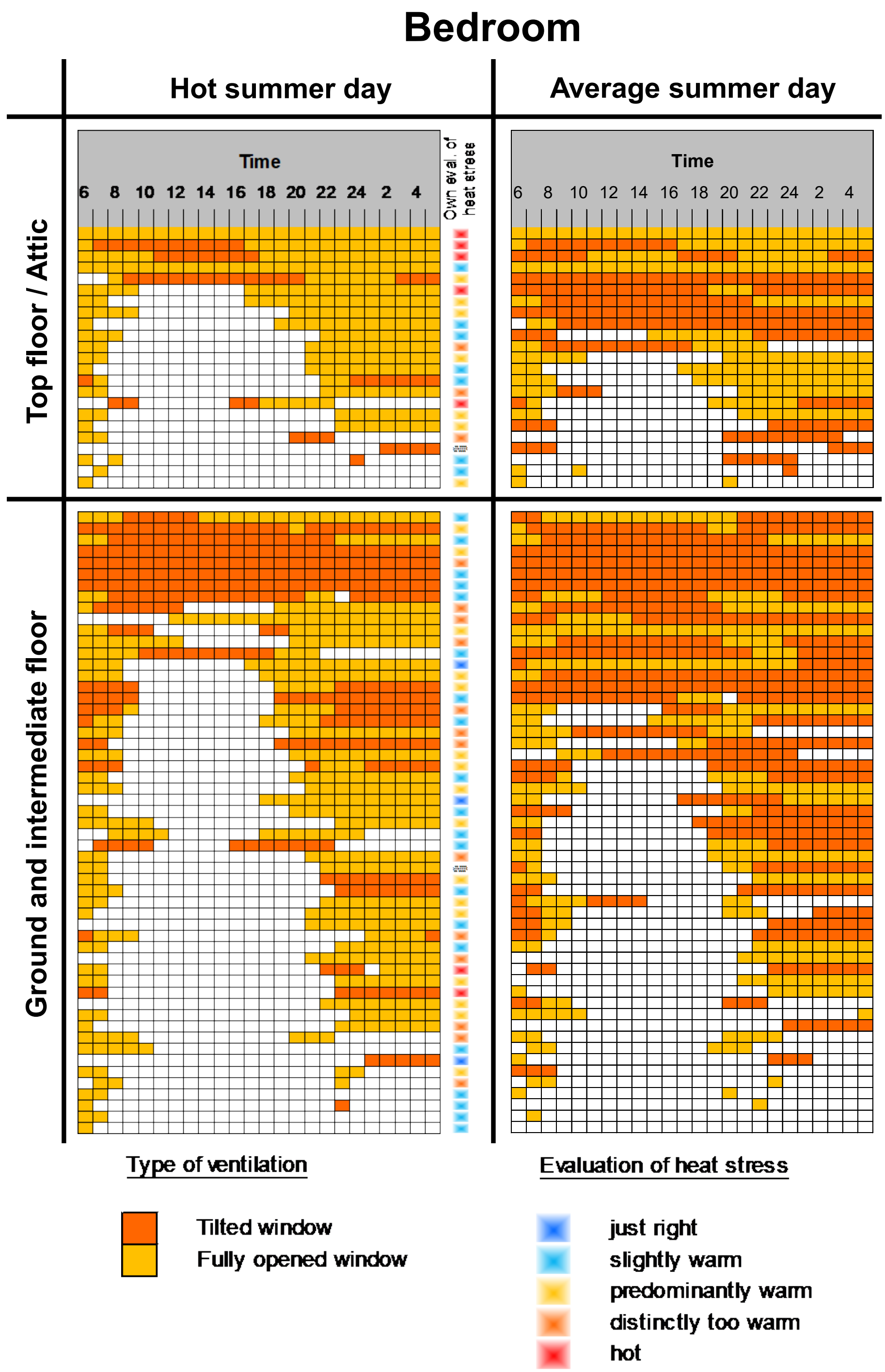

Figure A2 Ventilation profiles for the bedrooms on hot and average summer days depending on the floor. Each row represents the individual window ventilation behavior of a surveyed household. For hot summer days with an outside temperature > 30 °C, the individual assessment of the heat stress in the bedroom is also shown