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Empirical thermal comfort evaluation of single and double skin façades

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A B S T R A C T

In this paper, the topic of thermal comfort for buildings with double skin façades and single skin façades is demonstrated and discussed. A long-term monitoring was performed in 280 office rooms distributed over 28 buildings in Germany. The survey methods were based on sensor measurements and data simultaneously gathered from questionnaire given to office users. The authors take into consideration the operative temperature, vertical gradient temperature, draught rate, radiation asymmetry, relative humidity and carbon dioxide concentration. The aim is to determine the individual sensory perception of the indoor environment and compare it to the actually measured indoor climate in buildings with double skin façades and single skin façades. In regards to the thermal comfort results, in general, it is shown that double skin façades buildings have slight advantages in relation to single skin façades buildings.

1. Introduction

Double skin façades (DSF) have been used on a larger scale since the nineties for technical and aesthetic reasons in "innovative" office buildings in addition to renovations. Due to the recent pervasive design of transparent building envelopes, various publications have been distributed since then; one example is about the Post Tower, published by Helmut Jahn [1]. These publications contained unenlightened comments, calling these glass buildings "ecological skyscrapers" [2] and "the maximum, nowadays, that can be reached in office and administration buildings" [3]. Remarks like these seem to denote the exemplification of art and other forms of "well equilibrated architecture" [4]. Simultaneously there were several criticisms arguing that so-called solar office buildings were neither energy efficient nor comfortable in relation to buildings with a smaller window to wall ratio. Gertis [5] summarized this discussion with a special focus on DSF already in 1999 and postulated "that instead of a great number of descriptive reports" the need of "measurements under real conditions" exists. This requirement came only after the comprehensive investigations of Müller [6] (four office buildings) and Fisch [7] (one façade). The debate reached a new and highly technically questionable point, when in 2004 the article entitled "Life in the sweatbox" [8] clearly showed that the "big experiment" with glazed office buildings failed without a consolidated and comprehensive basis. The author even admits that he was looking for information on the "wall of silence" and laments the lack of meaningful data about the operation of those buildings. The article was a typical debate about innovative buildings in which numerous "experiences," "opinions" and cited data could be found; exactly what Gertis [5] had previously criticized. At this point, the research project "TwinSkin – double skin façades under test" [9] starts, determining scientifically reliable data from DSF and validating concepts.

2. Research concept

In TwinSkin [9], several DSF office buildings in Germany were analyzed regarding energy efficiency, comfort and functionality. The aim of the project was to analyze the potential for optimization of those office buildings during work operation. The planning and documentation of modern office buildings often end with the building completion, so that little knowledge is available concerning the actual performance of the building and its components in full operation during most of their life cycle. The research project compared the planning objectives with characteristics and operating experiences in DSF, which built the basis for a comprehensive assessment of the functionality of DSF and energy concepts (Fig. 1).

As part of the research project TwinSkin [9], these aspects are analyzed for some selected office buildings. Thus, knowledge is developed to optimize the operation of those buildings. Operational experience acquired from DSF facilities built in the last 10 years may be used as a basis for planning. However, in this paper only the topic of thermal comfort is demonstrated and discussed. Acoustic comfort, functionality and energy efficiency are still to be published.

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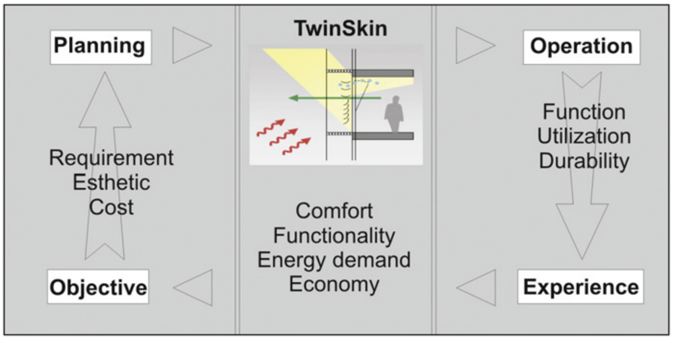

Fig. 1. Concept applied to the entire TwinSkin project.

2.1. Indoor comfort

Considering the energy efficiency, comfort is a key point in the TwinSkin project. Within the category of comfort, the interplay of different factors listed below influences user health and productivity. The user's comfort sensation presents itself as a highly complex process; it depends on a large number of individual factors like thermal comfort, visual comfort, acoustic comfort and finally the hygienic comfort. These investigations are rarely performed under real conditions and there is a great demand for research.

2.2. Thermal comfort

Thermal comfort is achieved when the functions of the human body are in balance with the thermal environment, exhibiting the "condition of mind which expresses satisfaction with the thermal environment" [10]. The ideal values and the parameters examined herein are further discussed in detail later in this paper. Thermal comfort is an interaction of indoor temperature values, humidity and the existing air velocity. While several extensive studies have been done, Ole Fanger's studies specifically have a significant influence on the German and European standards. The thermal prediction indexes PMV and PPD, as specified by the norm DIN EN ISO 7730 [10], are an evaluation parameter in Germany to determine the thermal comfort conditions for working and living spaces. These indexes are obtained from a thermal comfort-sensation vote (CV) attained in experiments within a controlled climate chamber [11]. It consists of a mathematical algorithm that combines four

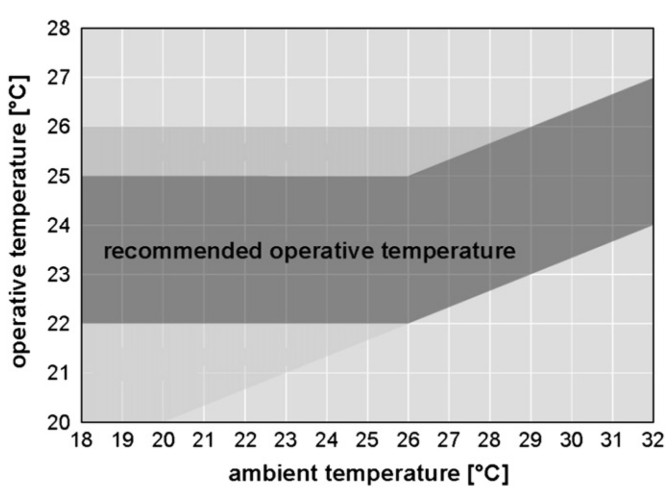

Fig. 2. The recommended operative temperature limits as a function of ambient temperature in accordance with DIN 1946-2 [12].

Fig. 3. The applied mobile unit measuring a user's comfort envelope.

physical parameters: air temperature (t_a), mean radiant temperature (t_r), relative humidity (RH), air velocity (v_a), altogether with two user-related parameters: persons' activities (met) and clothing insulation (clo). The assessment is done on the PMV index as a standard vote defined in climate chambers. The thermal comfort is given on the basis of low activity level; "when the person in their environment feels that air temperature, relative humidity, air movement and thermal radiation are in optimal situation and wishes neither warmer nor colder, neither dry nor humid air" [12]. Evaluation criteria of the thermal conditions were distilled from the extensive DIN 1946-2 [12] in reference to the presented mechanically ventilated office buildings. In those buildings, the office work mainly takes place in a seated position, in the DIN 1946-2 [12] and DIN 33403-2 [13] this activity is predominantly defined as Activity Level 1 with low heat dissipation about 120–130 W/person. In Germany, the investigations indicate that neutral temperature (t_n) tends to coincide with operative temperatures (t_{op}), experiencing an adaptation to indoor climate [14]. This most likely happens due to the high level of user's influence on the thermal conditions of the workplaces [15]. The German norm DIN 1946-2 [12] allows the increasing of internal temperature limits when the ambient temperatures exceed 25 °C and accepts a limit of 10% in the overheating hours (Fig. 2).

For the vertical gradient of air temperature (K) a comfort limit of 2 K temperature difference per meter height is specified as category A in the DIN EN ISO 7730 [10]. The minimum and maximum indoor relative humidity range from 30 to 70% and are defined in the DIN EN 13779 [16]. The relative humidity is defined in the DIN EN 15251 into four categories (A, B, C and D) with ranges between 20 and 70% [17]. The maximum indicated air velocity (v_a) ranges from 0.10 to 0.12 m/s depending on the turbulence degree (t_u) and the standard deviation of the air velocity is specified as category A for winter and summer respectively [10]. Further specifications for indoor thermal comfort are defined in the VDI 2078 [18], DIN 4108 [19] and DIN EN ISO 7730 [10]. Furthermore, there are references to the temperature

Table 1
Categories used during comfort monitoring.

	Description
A	Good comfort, no problems
B	Acceptable comfort, no significant restrictions
C	Comfort slightly reduced, slightly outside of limits
D	Not acceptable

Table 2
PPD limit values proposed by DIN EN ISO 7730 [10].

	Limits	Description
A	PPD < 6%	Good comfort, no problems
B	6% ≤ PPD < 10%	Acceptable comfort, no significant restrictions
C	10% ≤ PPD < 15%	Comfort slightly reduced, slightly outside of limits

ranges in the workplace regulation 2004 [20], the workplace guidelines [21] and the VDI 6011 [22]. In particularly, the permitted indoor air temperatures in Germany have several values that have been issued by adjudicators in recent times. However, to comply with the limits one must consider the planning, the user's behavior, the building operation and the meteorological conditions; these issues have previously provided little clarity [23–27].

2.3. The buildings

This research evaluated 28 buildings distributed among Twin-Skin (DSF) [9] and EVA (single skin façade – SSF) [28] projects. Those buildings, assessed in this field survey are located in several cities in Germany: Berlin (8), Braunschweig (5), Hamburg (3), Hannover (4), Bonn (1), Gelsenkirchen (1), Helmstedt (1), Leverkusen (1), Magdeburg (1), Mannheim (1), Osnabrück (1) and Wolfsburg (1) [15]. The DSF buildings here evaluated are divided into five façade types [29]: box window type, box double skin façade, multi-storey façade and corridor façade.

3. Methodology

Between October 2004 and October 2006, 118 days and 1348 cycles of measurements were performed in 280 rooms distributed among 28 buildings. Concurrently to the measurement information about the room characteristics, the ventilation conditions and the users' individual perceptions concerning the space were collected [30]. The measurements in accordance to DIN 1946-2 [12] and DIN EN ISO 7730 [10] were performed in the summer, winter and in transitional periods for 4 rooms of different solar orientations (E, S, W and N). A five-minute long measurement (with prior 5-min acclimation period) using a mobile unit is performed in those rooms in the morning (before 11:00), noon (11:00–14:00) and afternoon (after 14:00) and conducted exactly where the user is seated at the workplace (Fig. 3). Other workplaces in the same room do not interfere with the measurements; this situation was applied to illustrate the real operating conditions.

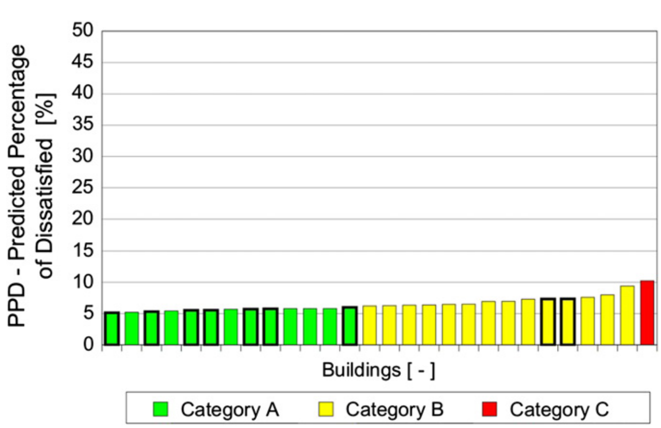

Fig. 4. Ordered representation of PPD index for 28 buildings in Germany during wintertime in accordance with DIN EN ISO 7730 [10] (DSF buildings are outlined in black).

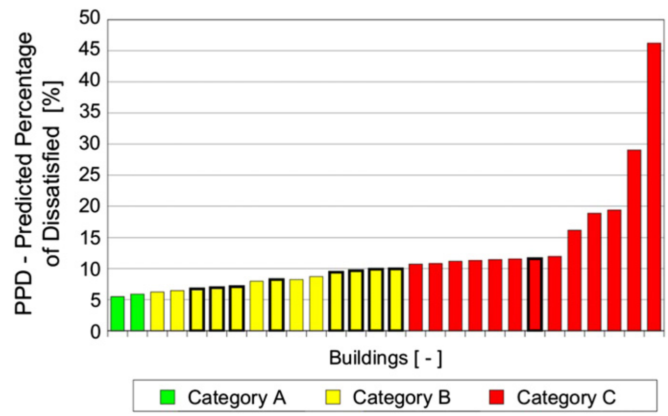

Fig. 5. Ordered representation of PPD index for 28 buildings in Germany during summer time in accordance with DIN EN ISO 7730 [10] (DSF buildings are outlined in black).

While the mobile unit recorded measurements a two pages questionnaire on thermal aspects was given to the user concerning physiological, psychological and physical aspects connected to the surrounding environmental [15]. The questionnaire applied in this study meets the needs of the research and was developed based on standardized models used in other field studies [31–34]. The data obtained from the mobile unit were calculated in according to the norms to assess the PPD (Predicted Percentage of Dissatisfied), PMV (Predicted Mean Vote), Comfort Vote (CV), Operative Temperature (t_{op}), Vertical Gradient of Temperature (K), Draught Rate (DR), Radiation Asymmetry (Δt_{pr}), Relative Humidity (RH) and Carbon dioxide Concentration (CO_2). Thus, the results of TwinSkin buildings (DSF) [9] are compared with the measured results from EVA buildings (SSF) [28]. The assessment is carried out in accordance with DIN EN ISO 7730 [10] sub-divided into three categories (A, B, C and D) as shown in Table 1.

4. Results and discussion

4.1. PPD – predicted percentage of dissatisfied

From physically measured parameters can be defined a percentage of dissatisfied people denominated PPD index. The evaluation is performed according to the reference values from DIN EN ISO 7730 [10] (Table 2).

In winter the individual results for the DSF buildings show from good to an acceptable comfort conditions (Fig. 4). Only two buildings are situated in the PPD category "B", all others are in the zone denominated as good comfort (category A). The former were measured with frequent higher temperatures in winter (DSF buildings are outlined in black).

In summer an increase in the PPD was observed. Fig. 5 shows the placement of the buildings with DSF (DSF buildings are outlined in black) in comparison to other reference buildings of the investigation (SSF). Almost all DSF buildings in this comparison were into

Table 3
PMV limit values proposed by DIN EN ISO 7730 [10].

	Limits	Description
A	$-0.2 < PMV < +0.2$	Good comfort, no problems
B	$-0.5 < PMV \le -0.2$, $+0.2 \le PMV < +0.5$	Acceptable comfort, no significant restrictions
C	$-0.7 < PMV \le -0.5$, $+0.5 \le PMV < +0.7$	Comfort slightly reduced, slightly outside of limits

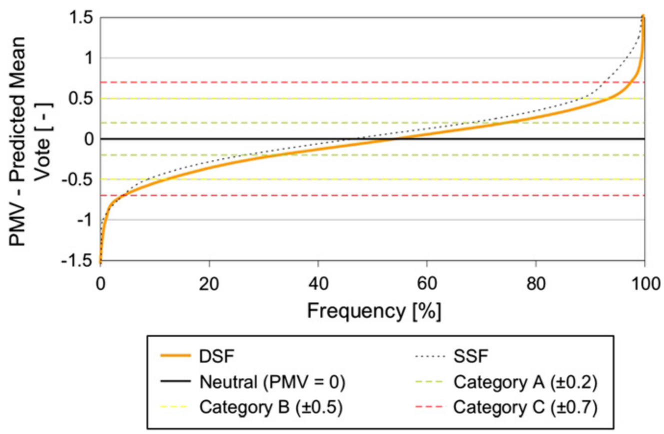

Fig. 6. PMV frequency distribution results for summer and wintertime in accordance with DIN EN ISO 7730 [10] (n: 1345).

category "B", only one building showed limited comfort (category C), caused by lower temperatures (mean value of PPD: 11.6%).

4.2. PMV – predicted mean vote

The causes of the previously mentioned discomfort were verified through the PPD index that represents dissatisfied users due to colder or warmer conditions. The PMV index was used to find a statement about the thermal conditions determined from the measured thermal data. The index is evaluated based on a 7-point rating scale ranging from −3 to +3 indicating with −3 (cold), −2 (cool), −1 (slightly cool), 0 (neutral), +1 (slightly warm), +2 (warm) and +3 (hot), according to Bedford. The valid limits of the PMV index are classified in accordance with DIN EN ISO 7730 [10] (Table 3).

Fig. 6 shows the results of the calculated PMV index for all buildings with assorted frequency distribution for summer and winter measurements. For comparison, a distinction between buildings with DSF (TwinSkin) and SSF (Project EVA) is presented. Considering the statistical sum, SSF are slightly warmer than DSF. Both façade types remain about 40% in the category "A" (SSF: 44% and DSF: 41.3%), other 40% stay in the category "B" (SSF: 37.3% and DSF: 39.9%) and 10% with comfort slightly reduced, category "C" (SSF: 8.1% and DSF: 10.6%). Nearly 10% of the values are outside the above-described comfort conditions. The displacement of the curves in the upper area is somewhat irregular; here SSF buildings are slightly outside the zone of comfort. Buildings with DSF are seldom cooler.

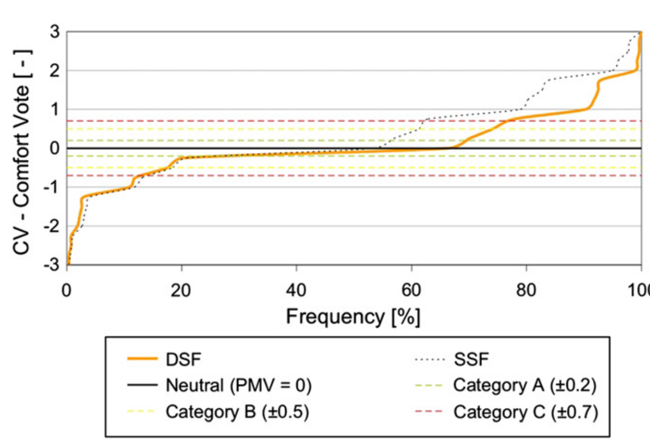

Fig. 7. Comfort vote frequency distribution for summer and wintertime in accordance with DIN EN ISO 7730 [10] (n: 1100).

Table 4
Summer t_{op} limit values proposed by DIN EN ISO 7730 [10].

	Limits	Description
A	23.5 °C ≤ top ≤ 25.5 °C	Good comfort, no problems
B	23.0 °C ≤ top < 23.5 °C, 25.5 °C < top ≤ 26.0 °C	Acceptable comfort, no significant restrictions
C	22.0 °C ≤ top < 23.0 °C, 26.0 °C < top ≤ 27.0 °C	Comfort slightly reduced, slightly outside of limits

A brief survey was given, as the quantitative measurements were recorded with the mobile unit, to the users present at their workplaces. This was carried out in the summer and winter during the morning, noon and afternoon. The users must vote according to their personal perceptions of thermal conditions. In the users' evaluation there is also a peculiar displacement of the curves in the upper area. The room temperatures within DSF buildings are more likely to have seemingly cooler interior climates (Fig. 7).

The gradations in the frequency line result from a 7-point survey questionnaire, or rather also the possibility between two comfort values to choose. Concerning the perception, 34% of SSF rooms stay in the comfort category "A", however 47% are DSF rooms. At the same time, many evaluations stay outside the comfort zone (very high 50% SSF and 36% DSF). The better result for DSF arises mainly from the warm area (CV > 0.7); this tendency is confirmed by the measurements. During the work-time other aspects influence, or superpose, the comfort evaluation; this relationship, between building operation and comfort evaluation, may be mutually influential [35].

4.3. Operative temperature

According to DIN EN ISO 7730 [10], the indoor operative temperatures (t_{op}) during the summer should reach a maximum of 26 °C and a minimum of 23 °C (Table 4).

In the winter the admissible t_{op} should stay between 20 °C and 24 °C (Table 5).

The t_{op} is displayed in the following frequency distribution (Fig. 8). A simple verification in accordance with DIN EN ISO 7730 [10] shows the maximum recommended temperature in summer (category B) and the minimal recommended temperature in winter (category B). The measured spaces behind DSF presented slightly better conditions. The investigated t_{op} that are frequently over 22 °C are more into category "A", while those rather frequently under 26 °C remain in category "A".

4.4. Vertical gradient of temperature

According to DIN EN ISO 7730 [10] the temperature difference between the temperatures at 0.10 m and 1.10 m above the floor surface should not be greater than 4 K. Table 6 shows the normalized values for the evaluation of vertical gradient of temperature.

The analysis shows good result for more than 90% of the buildings. The difference between SSF and DSF buildings is not significantly evident (Fig. 9).

Table 5
Winter t_{op} limit values proposed by DIN EN ISO 7730 [10].

	Limits	Description
A	21 °C ≤ t_{op} ≤ 23 °C	Good comfort, no problems
B	20 °C ≤ t_{op} < 21 °C, 23 °C < t_{op} ≤ 24 °C	Acceptable comfort, no significant restrictions
C	19 °C ≤ t_{op} < 20 °C, 24 °C < t_{op} ≤ 25 °C	Comfort slightly reduced, slightly outside of limits

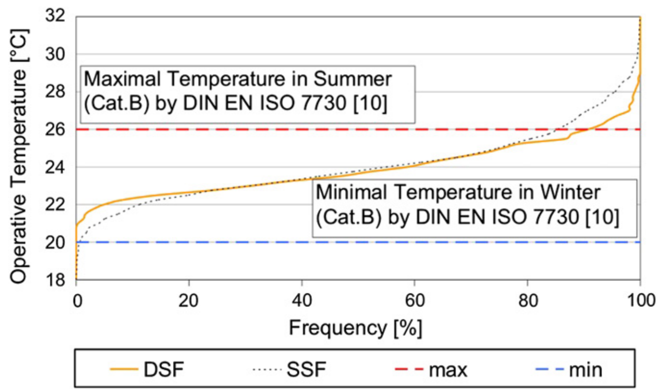

Fig. 8. t_{op} frequency distribution for summer and wintertime in accordance with DIN EN ISO 7730 [10] (n: 1345).

Table 6
Evaluation criteria of comfort as a function of temperature gradient.

	Limits	Description
A	$\Delta t < 2$ K	Good comfort, no problems
B	2 K $\leq \Delta t < 3$ K	Acceptable comfort, no significant restrictions
C	3 K $\leq \Delta t < 4$ K	Comfort slightly reduced, slightly outside of limits

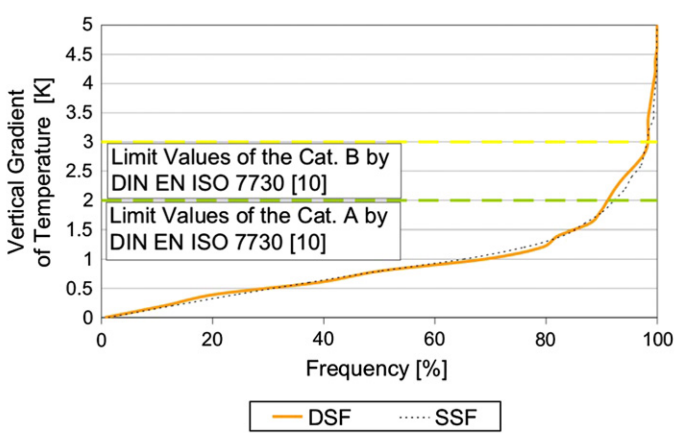

Fig. 9. Frequency distribution of the vertical temperature gradient for summer and wintertime in accordance with DIN EN ISO 7730 [10] (n: 1345).

Table 7
Evaluation of air velocity [m/s] according to DIN EN ISO 7730 [10] depending on the season.

	Summer	Winter	Description
A	$v_a \leq 0.12$	$v_a \leq 0.10$	Good comfort, no problems
B	$0.12 < v_a \leq 0.19$	$0.10 < v_a \leq 0.16$	Acceptable comfort, no significant restrictions
C	$0.19 < v_a \leq 0.24$	$0.16 < v_a \leq 0.21$	Comfort slightly reduced, slightly outside of limits

Table 8
Evaluation of the disturbance by Draught Rate (DR) according to DIN EN ISO 7730 [10].

	Summer	Description
A	DR < 10%	Good comfort, no problems
B	10% ≤ DR < 20%	Acceptable comfort, no significant restrictions
C	20% ≤ DR < 30%	Comfort slightly reduced, slightly outside of limits

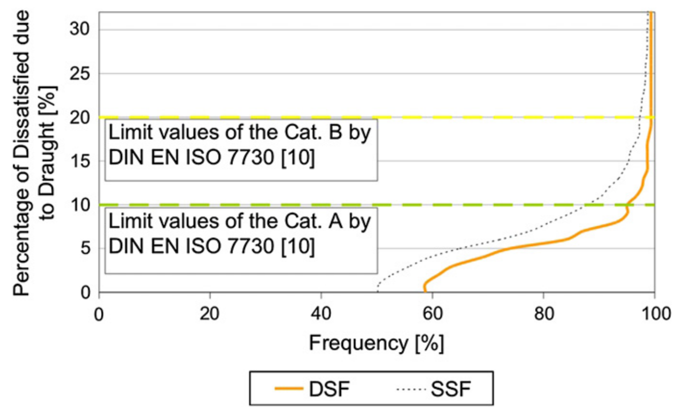

Fig. 10. Percentage of dissatisfied due to draught for summer and wintertime in accordance with DIN EN ISO 7730 [10] (n: 1345).

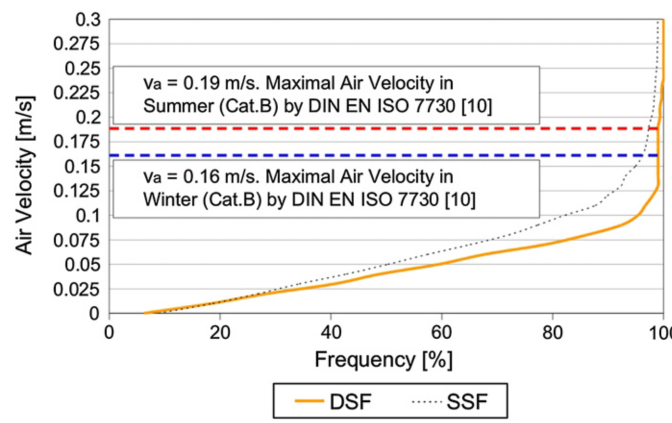

Fig. 11. Comparison of measured air velocity for summer and wintertime in accordance with DIN EN ISO 7730 [10] (n: 1345).

Table 9
Limit values of radiation asymmetry according to DIN EN ISO 7730 [10].

	Warm ceiling	Cold wall	Cold ceiling	Warm wall
A-B	<5 K	<10 K	<14 K	<23 K
C	<7 K	<13 K	<18 K	<35 K

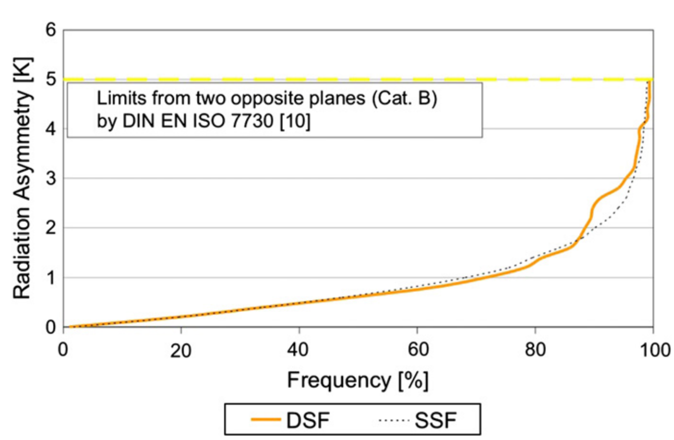

Fig. 12. Individual results of radiation asymmetry for summer and wintertime in accordance with DIN EN ISO 7730 [10] (n: 1345).

Table 10
Limit values of relative humidity according to DIN EN 15251 [17].

	Limits	Description
A	30% ≤ RH ≤ 50%	Good comfort, no problems
B	25% ≤ RH < 30%, 50% < RH ≤ 60%	Acceptable comfort, no significant restrictions
C	20% ≤ RH < 25%, 60% < RH ≤ 70%	Comfort slightly reduced, slightly outside of limits
D	RH > 70%, RH < 20%	Comfort significantly reduced, significant excess of the limits

4.5. Draught rate

An excessive air movement can cause unwanted draught. The percentage of those who were discontent, due to draught, is very much dependent on the air temperature; therefore different limits exist for summer and winter to assess the air velocity (v_a) according to DIN EN ISO 7730 [10]. Table 7 shows the normalized values for v_a [m/s] depending on the season.

To evaluate a cooling sensation due to draught, the percentage of dissatisfied took into account the parameters of air temperature, mean air velocity and turbulence degree (Table 8); the calculation method used was consistent with DIN EN ISO 7730 [10]. The measured percentages of dissatisfied are shown in Fig. 10. Overall, no significant dissatisfaction due to draught risk could be detected (60% of the DSF rooms show no draught risk). For both façade types, the results remain under 5% dissatisfied (outside category B).

A greater proportion of dissatisfied was found in the SSF buildings. The reason is the higher v_a in those buildings (Fig. 11).

The questionnaires asked the users if they had noted some draught (answer yes/no), afterwards they could evaluate this perception on a 7-point scale questionnaire (from very disturbing to not disturbing at all). In the users' evaluation 35% took a neutral posture on the draught risk, 11% have felt significantly disturbed and 54% were not disturbed. In general the users' questionnaires represent the draught effect slightly different: at least 8% perceived strong draughts, 65% occasionally perceived the draught in different forms and 27% perceived no draught.

4.6. Radiation asymmetry

Radiation asymmetry (Δt_{pr}) between opposite component surfaces is generated by warm or rather cold surfaces and may cause thermal discomfort. The normalized values are shown in Table 9.

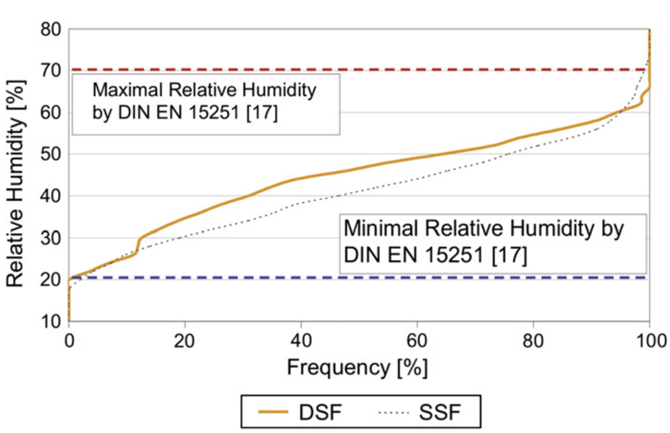

Fig. 13. Evaluation of relative humidity for summer and wintertime in accordance with DIN EN 15251 [17] (*n*: 1345).

Table 11
Limit values of CO_2 concentration.

	Limits	Description
A	CO_2 < 700 ppm	Good air quality, no problems
B	700 ppm ≤ CO_2 < 1000 ppm	Acceptable air quality, no significant restrictions
C	1000 ppm ≤ CO_2 < 1500 ppm	Air quality slightly reduced, slightly outside of limits
D	CO_2 > 1500 ppm	Air quality significantly reduced, significant excess of the limits

Fig. 12 outlines the measured radiation asymmetry of the room surfaces by frequency distribution. The comparison between SSF and DSF buildings shows a good agreement between the office rooms. By higher radiation asymmetry the DSF show a slight increase in the temperature difference, caused by buffer effect. In the evaluation however, remain the rooms within the allowed range. Those results were mostly in the summer, at noon, in buildings with a glazing area greater than 60%. The majority of these buildings also have Concrete Core Activation or rather Cooling Ceiling systems, which also influences the radiation asymmetry.

4.7. Relative humidity

According to DIN EN ISO 7730 [10] the humidity has only a minor impact on the thermal sensation. In general, a 10% higher relative humidity can be experienced as warm as 0.3 °C higher operative temperature. However low levels of air humidity may lead to dryness and consequent irritation of eyes as well as respiratory tracts. To categorize the relative humidity, the DIN EN 15251 [17] provides for rooms equipped with humidification and dehumidification normalized values as shown in Table 10.

Concerning the indoor air humidity, rooms within DSF buildings presented slightly better conditions than SSF buildings (Fig. 13). Only 12% of the covered DSF rooms had indoor relative humidity lower than 30% (in the SSF 18% of the rooms), the upper limit according to DIN EN 15251 [17] was never exceeded by DSF rooms.

4.8. Carbon dioxide concentration

Limits for carbon dioxide concentration (CO_2) are not specified in the DIN EN ISO 7730 [10]. Regarding the standard DIN 1946-2 [12], the CO_2 concentration in accordance to Pettenkofer should not be greater than 1500 ppm (parts per million). Limits for a classification were made on the experience derived from IGS field studies [9,28]. Table 11 shows those limits.

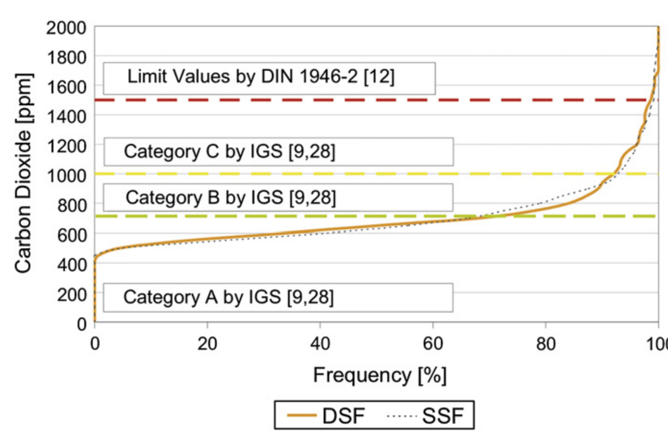

Fig. 14. Evaluation of CO_2 concentrations for summer and wintertime in accordance with DIN 1946-2 [12] and IGS [9,28] (*n*: 1345).

The individual results for CO_2 concentrations are presented in Fig. 14. There are no significant differences between SSF and DSF buildings.

5. Conclusions

The research projects of the IGS discuss German buildings with single skin façades and double skin façades. They were evaluated and compared according to their thermal performance. The following statements about the thermal comfort can be made:

- The PPD index shows that both façade typologies have relatively good thermal behavior in category "A" or "B" during the most part of the year. The DSF buildings offer better thermal comfort in wintertime and despite not having any buildings in the category "A" during the summer, the DSF do not have as many buildings in "C" as SSF. In those cases, the DSF rooms have less thermal amplitude during the summer and offer better ventilation control.
- The PMV index does not show significant differences, however the DSF remain slightly cooler. The CV acquired from the questionnaires also represent that German users in DSF rooms are more likely to have cooler sensations (in warmer conditions).
- The operative temperatures regarding the summer and winter months are more often located in category "A". The DSF rooms present slightly better conditions than SSF rooms.
- The vertical gradient of temperature reveals good results for more than 90% of the investigated buildings; a difference is not significantly evident.
- The draught rate evaluation showed no significant dissatisfaction due to the draught risk; the remaining results were under 5% (category A). The greater proportion of dissatisfied users belongs to SSF buildings due to higher air velocities. The survey questionnaires concerning the perception and the level of disturbance show no significant differences.
- The radiation asymmetry (Δt_{pr}) shows a good agreement. However, along with higher radiation asymmetry, the DSF show a slight increase in the temperature difference; this is a result of the buffer effect.
- The relative humidity recorded within DSF rooms was relatively better than SSF rooms. There are more SSF rooms under 30% air humidity.
- The CO_2 concentration evaluation found no significant differences.

The aim to determine the perceived indoor conditions under real circumstances and compare the individual indoor climate between DSF and SSF buildings was achieved. Regarding the thermal comfort area, the measured results and the questionnaire data given by office users showed, in general, that DSF buildings have slight advantages in relation to SSF buildings. Other studies derived from TwinSkin comparing SSF and DSF buildings concerning the acoustic comfort, functionality and energy performance are still to be published.

In the course of the project it was proven that close cooperation with building operators is a very important point in achieving user comfort. An extensive and long-term field survey like TwinSkin can only be established with dedicated contact persons. Throughout the project, it proved difficult to collect the data amid protracted communication with building operators. For future projects it is suggested that data collection be done in a more independent way, either by itself or by automatic transmission.

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