Energy efficiency evaluation of single and double skin façade buildings: a survey in Germany

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Abstract: In the following field study a long-term monitoring was performed in 15 buildings with single skin façade (SSF) and 13 buildings with double skin façade (DSF) distributed among several cities in Germany. The aim was to compare energy efficiency between SSF and DSF buildings under real operation conditions. An evaluation of energy efficiency was carried out mainly by comparing annual consumption values from measurements or utility bills of heating, electricity and resulting primary energy. The results showed that DSF buildings consume on average more heating and electricity than SSF buildings. The energy consumption in the studied DSF buildings is higher than the consumption stated in previous publications. On average, the total primary energy consumption of DSF buildings is 27% higher than SSF buildings.

Keywords: Office buildings, heating, electricity, primary energy.

1 Introduction

Double skin façades have been used on a larger scale since nineties for technical and aesthetic reasons in new office buildings in addition to renovations. The additional cost for construction and maintenance of a second façade is generally reasoned by energy efficiency and indoor comfort improvements. However, these strongly depend on building type, fuel used, weather, window-to-wall ratio, usage pattern, type of heating or cooling system and type of DSF (e.g. ventilation strategy, glass type and cavity geometry). Due to recent pervasive design of transparent building envelopes, several studies have been published; one example is Helmut Jahn's publication about Post Tower [1].

These studies contain unclear comments, calling these glass buildings "ecological skyscrapers" [2], "the top, nowadays, that can be reached in office and administration buildings" [3] and "well balanced architecture" [4]. Simultaneously there were several arguments defending 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 has postulated "that instead of a great number of descriptive reports" there was a need for "measurements under real conditions". Later on further publications also confirmed that little information about DSF behaviour under operation was known [6]. This requirement comes only after the comprehensive investigations of Müller [7] on four office buildings and Rozynski's [8] on one building. The debate reached a new and highly technical questionable point when in 2004 an article entitled "Life in the sweatbox" [9] clearly showed that the "big experiment" with glazed office buildings failed for lack of a consolidated and comprehensive basis. The author even admits that he was looking for information on the "wall of silence" and regrets the lack of meaningful data about 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 claimed.

In an attempt to better understand DSF behaviour and to evaluate thermal performance and energy efficiency in different climates, many studies have been performed applying building energy simulation tools in cold [10-13] as well as warm climate regions [14-17], however only a few works have validated models in experimental DSF or under real operation conditions. Currently, there is no scientific publication comparing energy measured data between SSF and DSF buildings in a large scale.

In general, energy simulation results range from annual energy savings to increased energy for cooling due to summer overheating. The simulation of DSF is a very complex physical phenomenon involving mainly optical, thermodynamic and fluid dynamic processes and no single simulation tool is able to handle all these processes in a desirably efficient way [18].

The use of natural ventilation is one of the main DSF strategies, on the other hand wind-driven ventilation is very difficult to predict with building simulation tools in an accurate way. This was proven by a comprehensive validation encompassing five different simulation tools [19] which showed that neither model was consistent enough to predict the cavity mass flow rate. For this reason, Pasquay [20] reported that an average air change rate should be considered instead of trying to calculate wind-driven ventilation inside the cavity. The new building energy simulation tools coupled with computational fluid dynamics (CFD) show that even when the user has knowledge to correctly create the model, this procedure is very time consuming and may also lead to inaccuracies. This was the starting point of the research project "TwinSkin - double skin façades under test" [21], which evaluated measured data from DSF buildings and validated concepts.

2 Research Concept

In the TwinSkin [21] project several office buildings in Germany were analysed regarding energy efficiency, comfort and functionality. The aim of the project was to analyses the potential for optimization of those office buildings under real operation conditions. The planning and documentation of modern office buildings often ends with building completion, so little knowledge is available concerning the actual performance of the building and its components in full operation during most of its life cycle. The research project compared planning objectives with characteristics and operational experiences in DSF, creating basis for a comprehensive assessment of the functionality of DSF and energy concepts (Figure 1).

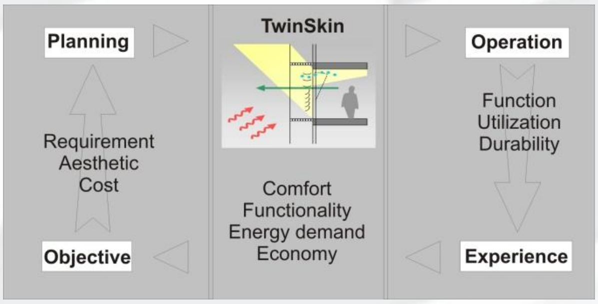

Figure 1: TwinSkin planning concept.

As part of the research project, all these aspects were analysed for some selected office buildings in order 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 energy efficiency is demonstrated and discussed. Other aspects such as air quality [22], acoustic comfort [23], thermal comfort [24] and a small heating discussion [25] have already been published, as well as the double skin façade handbook for planners [26].

3 Methodology

This paper discusses energy efficiency of DSF and its main objective is to evaluate whether DSF buildings are more energy efficient than SSF buildings. To provide comparability between both façade typologies, SSF buildings are applied in this article as base case with data obtained from EVA project [27]. The EVA project was developed in the same institute, Institute for Building Services and Energy Design (TU-Braunschweig) with a methodology, length of time and goals similar to TwinSkin project, however considering only SSF buildings and conducted by a second research team. For this purpose the DSF buildings of TwinSkin project and the SSF buildings of EVA project were chosen and compared depending on usage type, availability of data, approximate construction age and magnitude. The buildings here presented are office buildings and were evaluated during three years under similar climatic conditions. Buildings without these conditions have been eliminated of the sample and this is the reason why the comparisons have less buildings than the projects evaluated. This procedure may reduce the statistical weight of the comparison, however offers more scientific rigor and reliability about the technical comparability between buildings.

In total, 39 buildings have been evaluated, 14 DSF and 25 SSF, however only 28 are suitable for comparison and can provide reliable measured data. These 28 buildings have been assorted and divided into two categories; natural ventilation/ventilated (NAV) and mechanical ventilation/ventilated (MEV). All DSF buildings are MEV, however the comparison is carried out with SSF buildings presenting NAV and/or MEV and these cases are properly indicated. In the end a comparison having window to wall ratio (WWR) as criteria is also presented and discussed.

Currently, the legal and normative general requirements focus mostly on energy demand of the buildings. Regarding energy consumption, only a few records are available and they are partly difficult to compare. For comparative assessment, energy demand, due to its precision, seems to be, at first sight, more adequate. However, the determined values are not always calculated with same boundary conditions and accuracies (studies on residential buildings give an uncertainty of about 25%, difference between demand and consumption [28]). Nevertheless, energy consumption offers good opportunities for continuous monitoring of existing buildings and identification of energy inefficient buildings. For this reason, the evaluation of energy efficiency is carried out mainly by comparing the annual consumption values for heating, electricity and primary energy. Furthermore, when available, a value is also indicated for the cooling consumption, even in buildings that measure cooling consumption within the electricity consumption value. The energy values here analysed were obtained through measurements, building operators and/or the invoice data received from the utility supplier. The consumption data includes the consumption of the entire building corresponding to the system limits in the research plan (Figure 2). The primary energy of each building has been calculated based on the original primary energy factor and according to the consumed energy.

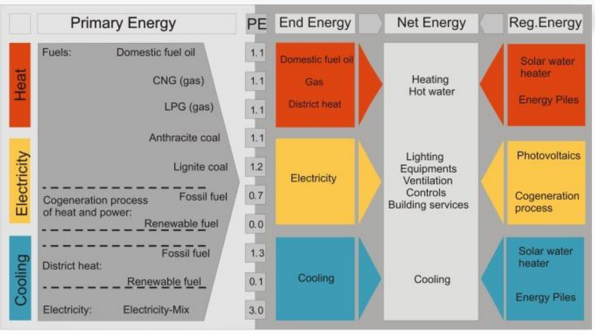

Figure 2: Schema to determine the limits for primary and end energy according to DIN 4701-10 [29].

3.1 The DSF buildings

Concerning energy efficiency, the DSF field survey started by evaluating 14 buildings, yet only 13 buildings had all needed data for comparison and were thus used. All DSF buildings are MEV and are located in several cities in Germany (Figure 3): Berlin (3), Hamburg (3), Hannover (2), Bonn (1), Leverkusen (1), Mannheim (1), Stuttgart (1) and Kronsberg (1). The maximum distance between the cities is around 550 Km with a difference in the annual average temperature of 2°C. In accordance with Poirazis [30], the DSF buildings here evaluated presented four façade types: box window type, box double skin façade, multi-story façade and corridor façade.

Figure 3: Evaluated DSF buildings in Germany.

3.2 The SSF buildings

As previously reported, the energy efficiency of 25 SSF buildings was evaluated, nevertheless only 15 buildings with all needed data for comparison were taken into consideration, of which 10 buildings are NAV and 5 are MEV. These buildings are also located in different cities in Germany (Figure 4): Berlin (4), Wolfsburg (3), Braunschweig (2), Hannover (2), Hamburg (1), Magdeburg (1), Potsdam (1) and Stuttgart (1).

Figure 4: Evaluated SSF buildings in Germany.

4 Results and Discussion

In the results four energy indicators are evaluated; initially the breakdown into heating (end energy), electricity (end energy) and cooling (end energy), and finally the primary energy. The energy values are shown in kWh/m².a and refer to net building area and consumption only. The following diagrams use identification codes instead of the building names to prevent a direct association of a single building / company with high consumption. In the diagrams, buildings with DSF are named with the code D and the SSF buildings with code S, the numbers after the letters are randomly given. The number of buildings in the comparisons may vary according to availability of comparable and reliable data for that energy indicator.

4.1 Heating

In the heating comparison only MEV buildings are evaluated, 5 SSF and 13 DSF. At this point it should be noted that energy for the air conditioner heater or for hot water preparation may be included in the heating values. The heating consumption of SSF buildings varies from 43 kWh/m²a to 127 kWh/m²a with an average of 94 kWh/m²a, while for DSF buildings the consumption ranges from 32 kWh/m²a to 181 kWh/m²a with an average of 110 kWh/m²a, 16 kWh/m²a more than SSF buildings (Figure 5). On average, all buildings have higher air temperatures in the cavity in comparison to the ambient temperature [21] and despite the buffer effect of the DSF, no heating savings could be observed. Apparently, the variables with prevailing influence are the user and the operation mode of the building and not so much the building elements. The higher air temperatures in the cavity are not sufficient to reduce transmission losses and in most cases the heated air from the cavity is not integrated into the air handling unit.

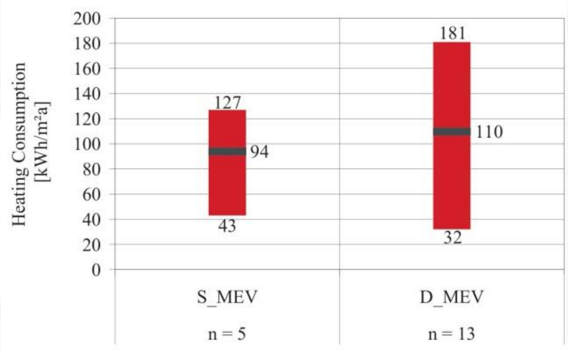

Figure 5: Comparison of annual heating consumption between SSF and DSF buildings with mechanical ventilation.

4.2 Electricity

Figure 6 shows electricity consumption for the entire building, which includes electricity consumption for building services, equipment, lighting and cooling (when generated by electricity) in the working and living areas. For this electricity comparison only MEV buildings are evaluated.

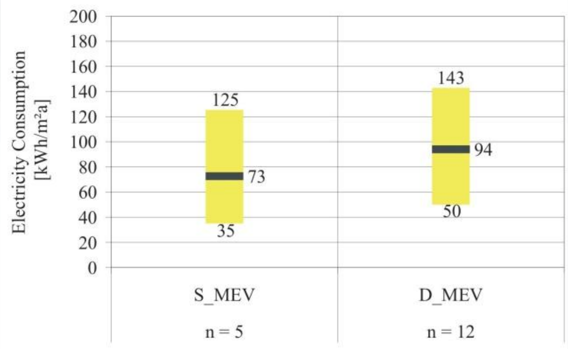

Figure 6: Comparison of annual electricity consumption between SSF and DSF buildings with mechanical ventilation.

The electricity consumption of SSF buildings ranges from 35 kWh/m²a to 125 kWh/m²a while the DSF buildings varies from 50 kWh/m²a to 143 kWh/m²a. On average, the DSF buildings reveal an electricity consumption of 94 kWh/m²a, 21 kWh/m²a more than the SSF buildings. It was not possible to measure separate electricity consumption for lighting and cooling in all buildings, however a few buildings with available data showed greater electricity consumption for lighting due to the addition of the second façade, probably impacting the cooling demand by increasing the internal gains. Electricity appears to be the greatest disadvantage of DSF buildings and this difference concerning electricity strongly impacts the primary energy.

4.3 Cooling

Likewise other measurements, existing kWh meters and sensors were used to validate the cooling needs. Most buildings do not count cooling or the points of measurement are different. On the basis of this differently measured data, a comparison of several hypotheses had to be considered. Depending on the available data, the cooling was measured through the following: electricity used for the cooling machine and the cooling amount behind the cooling machine or behind the district cooling delivery (the metres measured cooling amounts). Free cooling systems via Energy piles (heat pump) and hybrid chillers are mostly indeterminable and not recognizable in the energy consumption of the buildings.

Among all DSF buildings three buildings showed all needed data for comparison. Three additional buildings were considered. However, their cooling demand was evaluated by analysing the electricity consumption of the central cooling station. This lead to a number of hypotheses and conjectures and therefore, the values are not presented and only real measured data is further discussed. The measured data ranges from 3.5 kWh/m²a to 12 kWh/m²a in the reliable cases. These values fall below the reference values of current publications such as [31]. Here cooling electricity consumption for a standardized new building is given as 15 kWh/m²a and for an optimized project as 10 kWh/m²a. Taking into consideration only these three buildings, no significant additional cooling consumption for DSF buildings could be determined. In further investigations or research projects a separate monitoring of the cooling should be conducted for more precise results.

4.4 Primary energy

At this point, the primary energy consumption of 27 SSF and DSF office buildings is shown in Figure 7. The primary energy has been calculated according to the primary energy factors of the DIN 4701-10 [29] and corresponds to the overall energy consumption of the building. In this diagram, 10 SSF buildings with NAV and 5 SSF buildings with MEV are compared with 12 DSF buildings equipped with MEV.

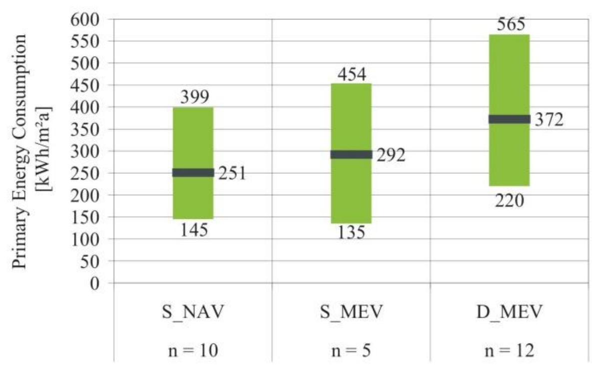

Figure 7: Comparison of total primary energy consumption between all SSF and DSF buildings (NAV+MEV).

The primary energy consumption of all SSF buildings ranges from 135 kWh/m²a to 454 kWh/m²a with an average of 265 kWh/m²a. The SSF buildings with MEV consume on average 292 kWh/m²a, 41 kWh/m²a more than NAV buildings. The primary energy consumption of DSF buildings varies from 220 kWh/m²a to 565 kWh/m²a with an average of 372 kWh/m²a. By comparing MEV buildings only, DSF buildings consume on average 80 kWh/m²a more than SSF buildings. Taking into consideration the whole sample of 27 buildings, the consumption curve of DSF buildings not only starts above the SSF curve but also ends above it, representing a tendency of higher primary energy consumption for DSF buildings.

4.5 WWR versus energy consumption

Finally, a comparison between SSF and DSF buildings in regards to the WWR criteria should be presented. The WWR values found in the sample of buildings vary from 31% WWR up to 90% WWR and were divided into three ranges (31-50%, 51-70% and 71-90%). The WWR for DSF represents the primary façade (inner façade). This evaluation encompasses all NAV and MEV buildings, 28 buildings for heating and 27 buildings for electricity. Most of the buildings are concentrated in the middle range of 51-70% WWR, regarding the other two ranges, more SSF buildings fit in the first range (31-50%) and more DSF buildings fit in the third range (71-90%). This reflects the tendency of DSF buildings to be highly glazed.

Figure 8 shows the average heating, electricity and resulting primary energy consumption for SSF and DSF buildings, divided into three WWR ranges. Analysing the SSF buildings, the higher the WWR the higher is the energy consumption, though this tendency is more aptly proven for heating than for electricity (due to the SSF electricity value within the 71-90% WWR). This probably occurs due to the energy balance between lighting and cooling, however it is strongly dependent on the type of glazing [14].

The same tendency is not identified for DSF buildings, where a breakpoint in the middle range is observed and the consumption curves for heating and electricity present opposite behaviour. Analysing electricity and heating in all WWR ranges, it is noted that the DSF buildings have constant higher energy consumption, the only exception being heating within the 71-90% WWR. It seems that for higher WWR the SSF is more affected by heating whereas the DSF is more affected by electricity. However taking into consideration the total primary energy, the only and small advantage of DSF about heating within the 71-90% WWR disappears due to primary energy conversion factors.

The primary energy consumption presented in Figure 8 is calculated through the original primary energy factors of each building. However, even when calculated from end energy with one equal factor to make all buildings better comparable, the results do not differ. For primary energy, DSF buildings present higher energy consumption in all WWR with considerable and consistent differences compared to SSF.

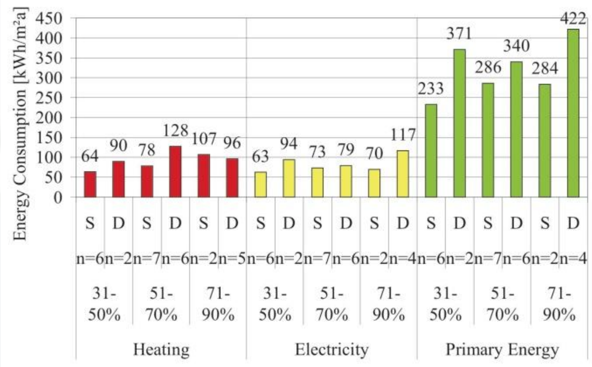

Figure 8: Average heating, electricity and primary energy consumption for all SSF and DSF buildings (NAV+MEV) distributed according to three ranges of WWR.

5 Conclusions

Within the scope of this study and the database concerning the energy efficiency comparison between SSF and DSF buildings, conclusions can be drawn as follows.

By comparing just MEV buildings, the DSF buildings consume on average 17% more heating and 28% more electricity. Unfortunately, for most buildings the electricity consumption encompasses i.a. cooling and lighting, thus it was not possible to establish a detailed breakdown analysis.

Concerning cooling, only three buildings presented reliable data. The results show no significant additional cooling consumption for DSF buildings in relation to SSF buildings. Nevertheless, in this topic, due to the small size of the sample a pattern cannot be determined.

Regarding the primary energy consumption, SSF buildings with MEV consume 16% more energy than NAV buildings. By comparing MEV buildings only, DSF buildings consume on average 27% more energy than SSF buildings.

The higher the WWR for SSF buildings the higher is the heating consumption. In DSF buildings, a breakpoint in the middle range is noted and the consumption curves for heating and electricity have opposite behaviour. It seems that for higher WWR the SSF are more affected by heating while the DSF are more affected by electricity. Considering the primary energy, DSF buildings show higher energy consumption in all WWR with considerable and consistent differences compared to SSF.

In general and according to the experience acquired during this field survey it can be assumed that:

The analysbehavioured DSF buildings usually consume more energy than that previously stated in publications or than the calculated demand during the planning process. This outcome is more aptly proven for heating than for other forms of energy which were not measured or recorded in all buildings in the same way.

Energy savings due to the DSF buffering effect were not verified. One building that showed this was the Deutsche Messe Hannover. Despite the demonstration of a comparatively strong thermal buffer effect (through measured air temperature in the cavity), no reduction in the heating consumption was registered. Similarly and according to collected data, no significant additional cooling consumption could be observed. However, a relationship between the façade and the thermally induced energy consumption could not be determined. The causes are varied and extend from early design phases to different usage conditions.

Concerning the electricity for lighting, it was noted that DSF buildings have a slightly higher consumption than SSF buildings; this is a result of the second layer of glass and the shading devices inside the cavity. Nevertheless, it must be taken into consideration that DSF buildings represent a more highly equipped type of building.

Despite the difficulties encountered in some buildings in generating a consistent breakdown, the samples present accurate and reliable data for the total energy consumption. As a result, the primary energy consumption confirms that the evaluated DSF buildings in Germany consume more energy than the SSF buildings, opening an opportunity for debate under a holistic perspective.

In comparison to SSF buildings, the evaluated DSF buildings cost more money, on average consume more energy and the extra material for the additional façade and equipment have a bigger impact on natural resources and the environment. As a final conclusion and under a holistic perspective, the attempt to erect more energy-efficient buildings by applying DSF instead of SSF does not seem to be a feasible option.

In terms of encountered problems and the experience acquired during the course of this project, it was proven that close cooperation with building operators is a key issue in obtaining reliable data. An extensive and long-term field survey like this research can only be established with dedicated contact persons. Throughout the research 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 manual measurement or by automatic transmission.

The comparison between SSF and DSF through measured data is a very difficult task since it should be carried out with a large and very uniform sample of buildings. However, especially in DSF buildings, the highly equipped façades associated to extremely optimized HVAC systems and the uniqueness of the projects, make the comparability of buildings a great challenge. Another difficulty faced was managing the buildings' operators and owners concerns regarding the security and confidentiality of the collected data. Additionally, the high costs of installing a large number of individual kWh meters for the breakdown analyses are rarely absorbed by building operators. Parallel to the reduced number of DSF buildings available for research, it should be taken into consideration some unpredictable problems that occur during the long-term survey, like renovations and long periods of empty floors due to the tenants' exchanges.

The results stated in this paper concern SSF and DSF buildings in Germany only. As the results have a direct relation to the local climate, type of user and operation, the statements should not be taken as a guideline for other countries.

Acknowledgements

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