Energy performance assessment of one DSF active buildings sample in Europe based on clustering analysis.

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ABSTRACT
A sample of existing double-skin façade (DSF) buildings distributed across Europe were analysed by means of data clustering. Studied buildings are located in different European countries and in order to structure the results according to climate conditions, three main regions were proposed. In general, results have shown good energy performance of DSF buildings. Annual energy delivered per square meter useful pavement area were computed for each DSF building and compared. Clusters of DSF office buildings with similar energy behaviour were established. The division of the sample data set into clusters of energy performance had exposed some good practices of DSF technology application. Based on that methodology, two DSF buildings in each region mentioned above were selected as candidates for the search of best energy practices in this building construction technology.

1. INTRODUCTION

In spite of the number of European buildings that are built using double-skin façade (DSF) technology, actual energy performance of DSF buildings is still lacking a more in-depth evaluation. This building-related technology has gained significant acceptance among architects and promoters of high-rise glazed office buildings and, as a consequence, the number of European buildings built using DSF technology is increasing quickly. Nevertheless the actual energy performance of DSF buildings is still lacking a more in-depth evaluation. There is a great variety in DSF typologies and wide variations in energy performance between different DSF buildings. In addition, the technological progress enables the continuous development of alternative façade systems that can prove to be more energy efficient.

Work carried out was focused in ascertain best practices based on actual examples of DSF buildings and assessing the circumstances for which the DSF technology has energetic advantages. Within the Bestfaçade Project “Best Practices for Double Skin Façades” (BESTFACADE) - supported by the European Commission’s IEE Programme – a complete analysis of a sample of completely characterised DSF buildings distributed across Europe were prepared.

BESTFACADE project aim and activities carried out were summarized by Farrou et al. (2007) and Schiefer (2008). Current paper relates to the work performed mainly within work package 3 of BESTFACADE project and deals specifically with the analysis and interpretation of energy performance data. It is structured in the following way: Section 2 presents the studied data; Section 3 discusses the energy performance indicators; Section 4 presents the clustering analysis on the DSF active buildings sample; and conclusions and comments of this study are in section 5.

2. THE STUDIED SAMPLE DATA

Studied buildings are located in different European countries. The target group of buildings directly addressed by BESTFACADE project were DSF buildings in European countries, namely in Austria, Belgium, France, Germany, Portugal, Greece and Sweden. In order to structure the results according to climate conditions, three main regions were proposed (Streicher, 2005): Nordic region represented by Sweden; Moderate region with buildings in Austria and Germany; and the Mediterranean region with Greece and Portugal (using the Köppen-Geiger system of climate classification these regions can be designated by *Dfb*, *Cfb* and *Csa*, respectively (Strahler, 1992)).

The analysis involved 30 DSF buildings. Figure 1 presents the number of buildings from each country.

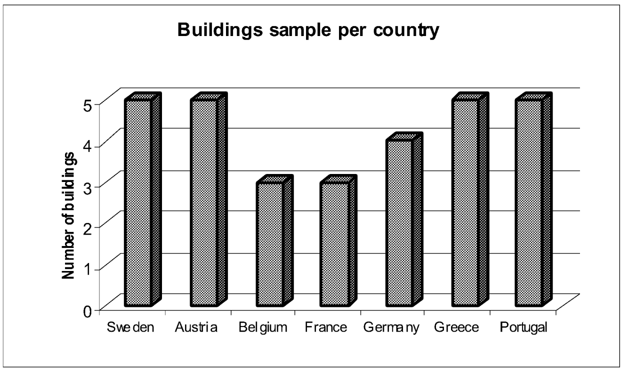

Figure 1: Number of buildings per country.

A combination of data collection tools, which comprises questionnaires, documentation research, interviews and technical visits, was used to gather sufficient data to interpret building's energy performance and critical success factors. Energy data collected for DSF buildings were annual figures for recent years, 2004 and 2005. Data was verified as far as possible by identifying any anomalies outside the expected range of results. Useful energy performance data, merely heating and cooling needs, were gathered in buildings which owners or managers were able to provide a complete set of quantitative data for energy performance analysis. This criterion was not fulfilled in some of the buildings in the sample, and they were excluded from the clustering analysis in a first step.

Assessment of the buildings with double-skin façades based on their energy performance indicators allows the users and the operators of DSF buildings to compare their energy consumption levels and set best future targets, looking for the recognition of potential measures to reduce energy consumptions.

3. ENERGY PERFORMANCE INDICATORS

Herein, energy performance analysis is the study of energy indicators related to one or more variables in order to allow a meaningful comparison between buildings, subject to different (internal and external) environments, management conditions, etc.

Determining the isolated influence of the DSF on the building's energy consumption is an extremely complex task. Whenever the influence of the DSF in the buildings energy balance is significant an alternative approach is to assess the DSF technology indirectly using instead the whole building energy needs.

Buildings energy needs were obtained from energy billing accounting procedures or by computational simulation. For purposes of comparing energy needs it is common to define indicators. A frequently used indicator is annual energy delivered per square meter of useful pavement area, an indicator that normalizes energy consumption by building size. When this indicator is calculated for each building and compared with the rest of the sample, good and poor energy performers are roughly but actively identified. Establishing for each building as energy performance indicators the annual energy delivered per useful area [kWh/m^2a] figures, these indicators, usually called Energy Efficiency Indicators (EEI), were calculated and DSF buildings relative situation compared to define the good and the poor performers of the sample.

Energy performance of buildings is determined by a wide range of factors, some of which are outside the control or influence of DSF technology, therefore data on the background, utilization and managing characteristics for each DSF building was also considered to understand their relative energy performance. Important determinants of building energy performance such as climate, internal gains and the HVAC system used were exhaustively studied (Matos and Duarte, 2007a) and compared with European benchmarks (Matos and Duarte, 2007b) in order to find particular characteristics in the sample and also how they have an effect on energy performance indicators.

4. CLUSTERING ANALYSIS RESULTS

Buildings which are not office buildings were removed from the analysis because their use is different from that of all the other ones.

To further study the energy behaviour of the DSF buildings, values of heating and of cooling energy needs for each DSF building were compared.

Figure 2 presents the energy needs for heating and for cooling for the DSF sample office buildings. Energy type normalization was performed when necessary.

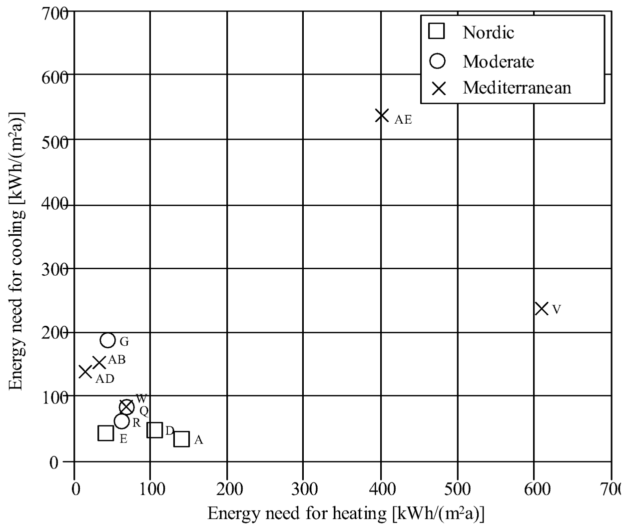

Figure 2: Heating and cooling energy needs for DSF sample office buildings (with energy type normalization when necessary).

As it may be observed in the figure, buildings AE and V can be clearly distinguished from the rest of the sample for having significantly higher heating and cooling energy needs. These are obvious non-candidates to good performing DSF buildings and for this reason were not subjected to further analysis. The remaining sample of 9 DSF office buildings have heating and cooling energy needs lower than 200 kWh/(m^2a).

Clustering analysis of numerical data is used as the basis for many classification algorithms. It identifies natural grouping of objects, 'clusters', and classify them according to existing similarities. Recurrently methods to define energy classes based on a building stock are not suited to classify a group of buildings whenever the sample is small. As explained by Santamouris et al. (2006) a classification using clustering techniques define more robust groups of buildings with common characteristics if compared to equal frequency rating procedures.

A preliminary principal component analysis (PCA) was used to further understand the relative performance of the buildings. PCA is a statistical technique often used to interpret existing mutual relationships within complex sets of data and to explain the characteristics and/or the behaviour of a given set of entities (Sharma, 1996). When running the PCA model with the 9 DSF buildings, Figure 3 is obtained.

The first principal component in Figure 3 is strongly related to the buildings heating needs and the second to the cooling needs. Buildings in the upper left corner have low heating and high cooling needs. Buildings in the lower right corner have high heating and low cooling needs.

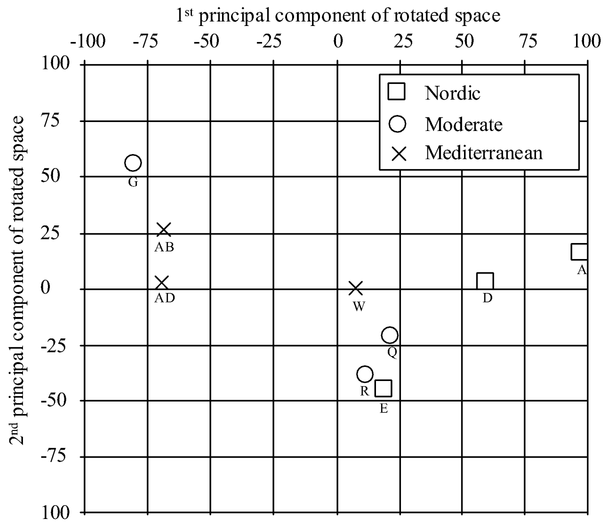

Figure 3: PCA graphical representation of the positions of the buildings on the rotated space.

Figure 3 distinguishes buildings with "expected" behaviour (given their climatic region) from those that have "unexpected" behaviour. Nordic climate buildings should probably occupy the lower right side of the graph, since they should have higher heating and lower cooling energy needs. On the other hand, Mediterranean climate buildings should probably occupy the higher left side of the graph, since they should have lower heating and higher cooling energy needs. Moderate climate buildings should occupy positions intermediate between those of Nordic and Mediterranean climates.

Analysing the Nordic climate buildings, it can be concluded that building E is the best performing, approaching heating need behaviour similar to that of Moderate climate buildings. Building A is the worst performing. Building D has an intermediate performance.

For the Mediterranean climate buildings, it is clearly noticeable that building W exhibits a heating behaviour that is closer to Moderate climate buildings than to the Mediterranean ones. The other two Mediterranean climate buildings, AD and AB, have lower heating needs than building W. Regarding the cooling behaviour, building W is only marginally better than building AD, and slightly better than building AB.

Regarding the Moderate climate buildings, building G can be clearly distinguished from the others. Having very low heating and very high cooling needs, it behaves as if it was located in a Mediterranean climate. For the remaining two buildings, Q and R both have similar heating needs behaviour and R has slightly lower cooling needs. When a cluster analysis using the Mahalanobis distance is performed, Figure 4 is produced.

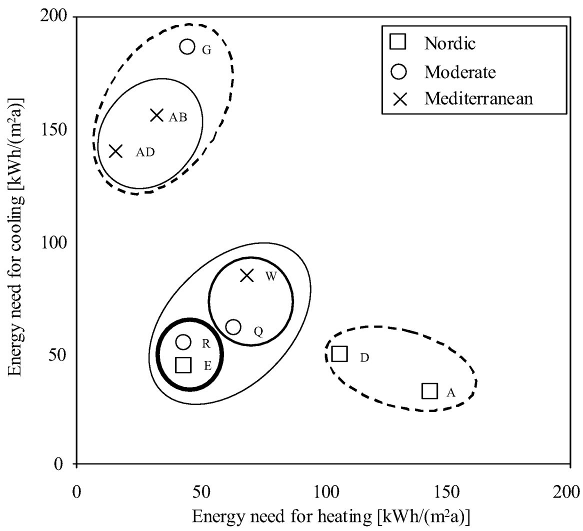

Figure 4: Clusters of DSF office buildings with similar heating and cooling energy needs behaviour.

Figure 4 confirms the analysis of Figure 3 identifying: a "Moderate Cluster", composed of Moderate climate buildings R and Q, to which buildings E and W, respectively, Nordic and Mediterranean, also belong; a "Nordic Cluster", composed of buildings D and A; and a "Mediterranean Cluster", with buildings AD and AB, joined by the Moderate climate building G.

From the previous results, candidates for the search of best practices in DSF buildings were elected, as case studies, from the initial sample of 30 buildings.

- Nordic climate: buildings E and D;
- Moderate climate: buildings R and Q;
- Mediterranean climate: buildings W and AD.

A succinct characterisation of these buildings is presented in the following tables, grouped according to climate region.

Table 1.1: Nordic Climate - Building E

Generic characteristics	Year of construction	-2004
	Gross floor area	30000 m^2
Façade	Type	Ventilated double window
	Area	3032 m^2
	Ventilation	Natural
	Shading	Venetian blinds, mechanical controlled without overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Heating with radiators, cooling with cooled ceilings
Energy use	Supplied energy	District heating and cooling
	Year data gathered	City design day
	Data source	Simulation (all cases)
	Annual consumption	44 kWh/(m^2a) for heating; 44 kWh/(m^2a) for cooling; 107 kWh/(m^2a) total electricity consumption.
Remarks		Energy performance is based on simulation results. Contradictory users' opinion suggests indoor thermal environment problems. The user opinions are from the first year of operation, which means that the HVAC and facade systems were still being adjusted to the actual needs.

Table 1.2: Nordic Climate - Building D

Generic characteristics	Year of construction	2002-2003
	Gross floor area	22000 m^2
Façade	Type	Corridor; partitioned per storey (32 storey); two of the three facades are double skin facades, the third (to the north) is a single skin facade. Double skin facades are of the type corridor façade with diagonal ventilation. In cavity there are gangways on each floor; windows are non-openable; cavity width 0.70 m
	Area	6656 m^2
	Ventilation	Natural
	Shading	Venetian blinds, mechanical controlled without overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Heating with radiators, cooling with active cooling beams; balanced ventilation with heat recovery
	Setpoints	22ºC winter; 24ºC summer
Energy use	Supplied energy	District heating and cooling
	Year data gathered	2004
	Data source	Measured (energy bills)
	Annual consumption	107 kWh/(m^2a) for heating; 49 kWh/(m^2a) for cooling; 93 kWh/(m^2a) total electricity consumption.
Remarks		Office manager opinion's is that building management is conscious with energy consume related subjects

Table 2.1: Moderate Climate - Building R

Generic characteristics	Year of construction	-2002
	Gross floor area	20705 m^2
Façade	Type	Corridor; partitioned per storey; natural ventilation through window opening or special openings on both skins; double and triple glazing in the outer skin; single glazing on the inner skin; air cavity width: 0.55m
	Area	3941 m^2
	Ventilation	Natural
	Shading	Canvas screen in the gap near the inner skin; manual operated
	Daylight control	No daylight control
HVAC	Type	HVAC system that humidifies, pre-heats and pre-cools the air
	Setpoints	21ºC (winter); 26ºC (summer)
Energy use	Supplied energy	District heating and electricity for cooling
	Year data gathered	2003 (winter); City design day (summer and electricity)
	Data source	Measured (winter; energy bills); simulation (summer cooling and total electricity)
	Annual consumption	57 kWh/(m^2a) for heating+DHW; 18 kWh/(m^2a) for cooling; 94 kWh/(m^2a) total electricity consumption.
Remarks		Energy performance is partly (cooling) based on calculations for an energy audit.

Table 2.2: Moderate Climate - Building Q

Generic characteristics	Year of construction	-2004
	Gross floor area	55000 m^2
Façade	Type	Juxtaposed modules; partitioned per storey; except for half of the SE façade, DSF in the perimeter of the building; inner skin windows openable; per storey, outer skin has a lower half made of a perforated metal sheet (26% perforation) and a glazed upper half; this solution enables flow of air between outside and gap
	Area	10512 m^2
	Ventilation	Natural
	Shading	Venetian blinds in the gap near the outer skin, mechanical controlled with overrule by occupants; daylighting sensor inside the gap controlling the slat angle of the Venetian blinds
	Daylight control	Segments, mechanical controlled with overrule by occupants
HVAC	Type	Ventilation via openings in the windows that separate inside air from gap air and a mechanical ventilation system that allows preheating or pre-cooling of inflow air; HVAC system dehumidifies
	Setpoints	21ºC (winter); n.a. (summer)
Energy use	Supplied energy	District heating and electricity for cooling
	Year data gathered	2004 (winter and electricity); City design day (summer)
	Data source	Measured (winter and electricity; energy bills); design (summer cooling)
	Annual consumption	72 kWh/(m^2a) for heating+DHW; 20 kWh/(m^2a) for cooling; 103 kWh/(m^2a) total electricity consumption.
Remarks		Energy performance is partly (cooling) based on calculations for an energy audit.

Table 3.1: Mediterranean Climate - Building W

Generic characteristics	Year of construction	-1998
	Gross floor area	3050 m^2
Façade	Type	Multi-storey louver (open able outer skin); cavity width: 0.80 m; In the inner skin open able windows can be used for inflow and outflow of room air. Outer skin has permanent openings to the outside and is composed of shading devices that control incoming solar radiation; these vertical panels are mechanically operated to rotate on a central axis, being responsible for reducing daylighting in approximately 70%; Inside the office rooms near inner skin, manually operated Venetian blinds enable further daylighting control; permanent openings are placed above and below outer skin panels; gap ventilation is abundant.
	Area	410 m^2
	Ventilation	Natural
	Shading	Venetian blinds, mechanical controlled without overrule by occupants
	Daylight control	Yes (n.a.), mechanical controlled without overrule by occupants
HVAC	Type	Convective system for heating and cooling
	Setpoints	20ºC (winter); 26ºC (summer)
Energy use	Supplied energy	Electricity for heating and cooling
	Year data gathered	2000
	Data source	Measured
	Annual consumption	17 kWh/(m^2a) for heating; 28 kWh/(m^2a) for cooling; 80 kWh/(m^2a) total electricity consumption.
Remarks		Totally open able outer skin

Table 3.2: Mediterranean Climate - Building AD

Generic characteristics	Year of construction	-2003
	Gross floor area	8158 m^2
Façade	Type	Shaft-box – "*façade pareclosée respirante*" with only a few centimetres air cavity width where the pressure balance between the air gap and the outside is maintained.
	Area	4153 m^2
	Ventilation	Natural
	Shading	Venetian blinds in the air cavity, mechanical controlled with overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Convective system for heating and cooling
	Setpoints	25ºC (winter); 20ºC (summer)
Energy use	Supplied energy	District heating and cooling
	Year data gathered	2005-2006
	Data source	Measured (energy bills)
	Annual consumption	16 kWh/(m^2a) for heating; 140 kWh/(m^2a) for cooling; 197 kWh/(m^2a) total electricity consumption.
Remarks		Building only partially occupied; problems (due to overheating) with the shading device.

5. CONCLUSIONS

For purposes of comparing energy needs, obtained by computational simulation calculations, energy billing accounting procedures or with monitoring dealings, annual energy delivered per useful pavement area normalizes energy related consumptions by building size. These indicators were determined for each DSF building and compared in the sample by making use of clustering analysis.

Results have shown good energy performance of some of the DSF buildings present in the sample.

The analysis carried out has clearly shown that an energy rating technique such as clustering analysis is convenient to be applied to better understand the characteristics of the buildings sample and thus organize possible energy improvements and suggest good practices. Work accomplished has assessed energy performance indicators to define groups of buildings with similar energy behavior and also look for establishing a group of case studies with good energy performance.

Evaluating individually each main technical attribute of the double-skin façade present is likely to conclude that:

On typology - An overall analysis of the case studies presented leads to the conclusion that the corridor façade typology (partitioned per storey) is present in all European climates and can have good energy performance. The corridor façade in the Mediterranean climate was mechanically ventilated.

On ventilation - The ventilation of the cavity of the façade seems to be a decisive factor in the success of the design. As cases D, R, Q and W show, several strategies are possible, from the more conventional outer skin bottom and top slits to the possibility of mechanically rotating (and opening) the outer skin.

On shading - In all case studies solar shading devices were used. The most common device is Venetian blinds located in the gap near the inner skin. In some cases solar shading is mechanically operated and controlled using a light sensor.

On daylight control - Separate daylight control is seldom used (however, the above mentioned light sensors for shading control can also be used for daylight control, and this is not unusual). When separate daylight control is used, it usually consists of manually operated canvas screens located inside the inner skin.

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