BESTFAÇADE

Best Practice for Double Skin Façades

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WP 3 Report "Benchmarks and Certification"

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Mário de Matos, Rogério Duarte

ISQ, Portugal (WP3 Leader)

Including contributes from:

Wolfgang Streicher
IWT – Austria

Christian Schiefer
MCE-ANB – Austria

Gilles Flamant, Sabrina Prieus
BBRI – Belgium

Gerard Guarracino
ENTPE – France

Hans Erhorn, Heike Erhorn-Kluttig
Fraunhofer-Institut für Bauphysik - IBP – Germany

Mattheos Santamouris, Ifigenia Farou
NKUA - Greece

Åke Blomsterberg
ULUND / WSP – Sweden

Summary

A methodology for the energy benchmarking of double skin façade buildings is presented and main results of the use of this methodology for a group of buildings located in Europe are given. Best performing double skin façade office buildings are identified and their main characteristics highlighted. Energy benchmarks for double skin façade office buildings and a certification method for façades are also proposed.

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Introduction

Building energy consumption is responsible for a significant part of Europe's primary energy needs and contributes significantly to global greenhouse gas emissions. Promoting energy efficient building-related technologies is therefore an European Union (EU) policy which aims for reduced primary energy needs and which addresses the Kyoto commitments.

One building-related technology that has gained significant acceptance among architects and promoters of high-rise glazed office buildings is the double-skin façade (DSF). The DSF technology, its main characteristics, applications, advantages and disadvantages were discussed thoroughly in Work Packages (WP) 1 and 5 Final Reports (Streicher, 2005; Blomsterberg, 2007).

In spite of the acceptance gained among architects and promoters, and of the number of European buildings that were built using DSF technology, the actual energy performance of DSF buildings is still lacking a more in depth evaluation. The literature database established in WP1 showed that simulation is the main subject addressed when studying DSF buildings; measured energy performance of existing buildings is a less studied subject. As stated in WP2 Final Report (Santamouris *et al*., 2005) the knowledge of actual energy performance of DSF buildings is in most cases small and resides mainly within specialized organizations.

As the data gathered from Bestfaçade project shows, there is a great variety in DSF typologies and wide variations in energy performance between different DSF buildings. It is therefore important to assess the circumstances for which the DSF technology has energy advantages, and based on actual examples highlight the best practices.

Energy benchmarking studies enable the highlighting of the differential performance of different technologies. If applied to DSFs, benchmarking not only identifies the differential in performance of different typologies and the differences between DSF and single skin façade (SSF), but it also helps in the identification of the underlying causes of this difference, and, in this way, promotes a transfer of best practices between architects and all those who are interested in façade design.

The European Commission in the EPBD recognizes the potential of benchmarking in promoting energy efficient and sustainable systems and technologies. Benchmarking, as well as addressing improvements within a certain technology, can also have an important role to play in defining local, regional, national or European incentive policies, towards more efficient and sustainable economy sectors.

This report deals with Energy Benchmarking and Certification in DSF buildings. It builds on the results of the Bestfaçade Project "Best Practices for Double Skin Façades" which spans over 2005 – 2007 and is supported by the European Commission's IEE Programme.

The Report is structured in the following way.

Section 1 presents the generic steps of the benchmarking process.

Section 2 relates these generic benchmarking steps to the different Bestfaçade Project Work Packages. Section 2 also sets up the basis for the benchmarking analysis step – the one to which will be given greater importance in this WP3 report.

Section 3 presents the energy related information that was gathered for DSF buildings in Europe. A preliminary discussion on this information is made by comparing DSF (double skin façade) and SSF (single skin façade) buildings and by performing a cluster analysis with the existing data. As a result of the discussion some insight on the studied buildings enables the selection of DSF *case studies*.

Section 4 presents the characteristics of DSF office buildings with energy needs for heating and for cooling lower than 200 kWh/(m^2 a) – selected DSF case studies. Energy consumption and information gathered from comfort and office manager questionnaires is related and comments on façade typology, ventilation, shading and daylight control are presented.

The insight gained in the previous sections is used in section 5 where energy consumption for DSF office buildings is compared to existing European benchmarks. Energy benchmarks for DSF office buildings located in different climatic regions in Europe are proposed.

In section 6 a framework for the development of a European certification method of façades is proposed.

Finally, section 7 presents the main conclusions of the studies performed within Work Package 3.

1 The Benchmarking Process

Figure 1 shows the benchmark wheel and the generic steps often considered in a benchmarking process: plan, search, observe, analyse, adapt.

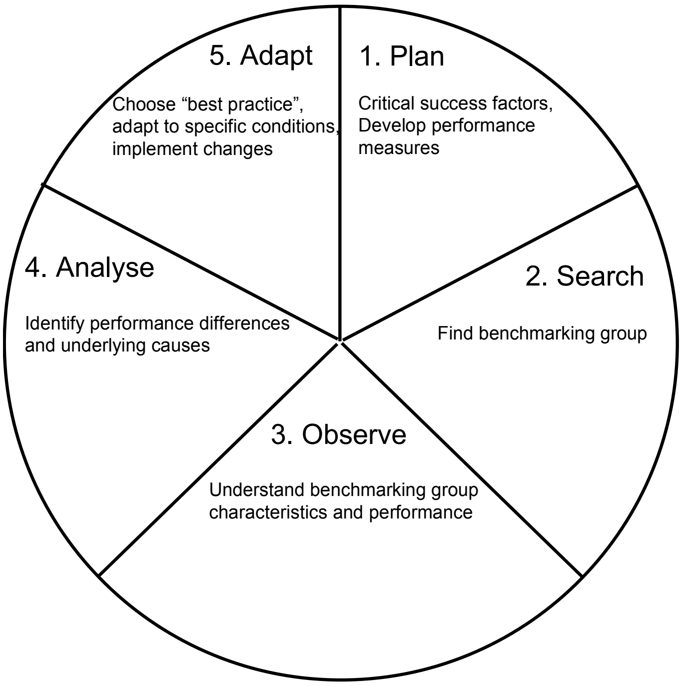


Figure 1 The Benchmark Wheel (Andersen, 1996).

As presented in Figure 1, the first step of benchmarking is **Planning**. It encompasses the following activities:

- Identify the goals of the benchmarking;
- Define what needs to be known;
- Define the most appropriate determinants/indexes of performance;
- Develop the framework and structures necessary to allow measurement and analysis of the relevant performance indicators.

A second step of benchmarking is **Searching**. First of all it is important to recall that benchmarking offers the opportunity to learn from others, but will require confidentiality agreements and a code of conduct to be drawn up between interested parts, covering such issues as;

- Principles of openness and confidentiality;
- Identification of commercially-sensitive data;
- Communication procedures between the benchmark participants;
- Communication procedures between the benchmark participants and the outside world;
- Procedures to avoid leaking of information to the outside world.

This is a subject of great importance since most of the DSF buildings are privately owned profitable office buildings and the recognition of a poor energy performance may impair commercial objectives.

Before one starts to search it is also important to have an idea on the size of the benchmark group. This size is determined by:

- The number and complexity of determinants influencing the performance; a larger group of participants is needed to allow more detailed analysis of the impact and relative importance of a large number of determinants;
- The level of information available on good/excellent performance levels is also related to the provision of a certain minimum number of participants. By involving a larger number of participants, a clearer picture on average and best performance levels can be obtained;

The third step is Observation. The observation step should provide all necessary data to allow a thorough analysis and interpretation of the different aspects of energy performance. This step includes:

- Definition and testing of the data collection system;
- Ensuring common definitions and understanding of the data to be collected;
- Collection of the data for each benchmarking participant;
- Central collection and checking of the data before analysis.

Data collection systems can include questionnaires, interviews and visits as well as more in-depth completion of spreadsheets or databases. In the case of buildings, this can be a huge task due to the great number of parameters that govern the behaviour of a building.

The fourth step is Analysis. The aim of this step is two-fold:

- To quantify and rank/rate the performance of each participant, enabling a meaningful comparison to be made between participants;
- To interpret these results both for individual participants and the group.

There are many methods of data analysis, and each benchmarking exercise can have its own analysis and interpretation method. In simple cases it is possible for a single statistic to define performance. Where the data is complex and a single figure cannot adequately define performance, it may be preferable to produce a set of results which are inter-dependent, and interpret not only the results but also the relationship between them. This is also relevant where there are a large number of factors which contribute to determining performance. In interpreting such complex results it may be necessary to analyse qualitative information as well as numerical data. For large groups, it can be possible to cluster the data according to different determining factors, to analyse or eliminate the impact of this factor.

One of the aims of the Analysis step is to understand which "best practices" contribute to achieving a good performance. It is likely that this analysis will give information on a set of good practices and the conditions in which they work well.

The final step on the benchmarking wheel is to use the results — the best practices — , Adapt and incorporate them in the benchmarking participants and all those interested in DSF technology or design. This step depends strongly on the actual interest of architects and façade designers, and involves:

- using the benchmarking data results and the analysis of the determining factors of performance to identify those practices which can be beneficially transferred;
- planning the necessary changes;
- making the changes; and
- monitoring the impact of those changes.

As the Benchmark Wheel indicates — Figure 1 —, the benchmarking process is most beneficial if the steps are repeated at regular intervals, in order to both monitor the impact of changes, modify practices and procedures to achieve the best results and identify new opportunities either as a result of technology developments or increasing levels of control/knowledge over performance determinants.

2 The Bestfaçade Project Energy Benchmarking

The Bestfaçade Project — Best Practice for Double Skin Façades — commenced in January 2005 and involved interrelated work packages (WP):

WP 1 — State of the art;
WP 2 — Cut-back of non-technological barriers;
WP 3 — Energy related benchmarks and certification method;
WP 4 — Simple calculation method;
WP 5 — Best practice guidelines;
WP 6 — Dissemination;
WP 7 — Common dissemination activities;
WP 8 — Management.

Among the several tasks of the project, one of the central aims was the development of an energy benchmarking methodology and application of this methodology to a set of European DSF buildings. The objective of the benchmarking was:

- Increase the understanding of DSF buildings energy performance;
- Increase the awareness of best practice (energy saving) DSF technologies.

A subsidiary aim of the benchmarking was to give advice on a certification methodology for DSF buildings.

In spite of the focus given to benchmarking in WP 3, with the *analysis* and interpretation step, the benchmarking process was distributed throughout the project in WP1, 3 and 5. The *planning* step is included in the first stages of the project (WP 1) with the identification of the goals, definition of determinants that need to be known and the development of a framework to allow the gathering of necessary data for benchmarking analysis.

The search and observe steps were also included in early stages of the project (WP 1) and consisted of visits to DSF buildings, talks/interviews with architects, façade designers, management, maintenance or commercial persons somehow involved with DSF buildings or DSF technology.

Work Package 3 was based on the work developed in the previous work packages, continued the search and observe stages and dealt with the *analysis* and interpretation of energy performance data, contributing to the understanding of DSF buildings energy performance.

Work Package 5 sums up contributions from the previous work packages to provide guidelines that ease the *adaptation* and integration of the best practices by architects and all those interested or responsible for the development of DSF technology and DSF buildings.

2.1 Determinants of performance

The energy performance determinants/indexes chosen for the energy benchmarking were:
- annual energy delivered per m^2 total floor area;
- annual heating energy delivered per m^2 total floor area;
- annual cooling energy delivered per m^2 total floor area;
- annual ventilation energy delivered per m^2 total floor area.
- annual lighting energy delivered per m^2 total floor area.

These indexes do not assess the behaviour of the building façade; they assess the whole building performance. The reason for choosing these indexes were:
i) the need to address the issue of energy performance of actual existing buildings;
ii) the fact that the assessment should be based on energy bills and/or on data from the buildings monitoring system. Most common building monitoring systems usually don not focus on acquiring information on the façade thermal/energy behaviour, instead, they gather data on the whole building behaviour.

2.1.1 Building size normalization

Normalization of energy performance by building size was considered. Total floor area was the normalizing factor used. This enabled the definition of the performance indexes in the common kWh/(m^2 a) unit[1].

2.1.2 Type of energy delivered and CO_2 emissions normalization

Since energy can be delivered to a building in different ways (e.g., district heating, district cooling, fossil fuel, electricity), normalization to *energy need* – the room demand –, to primary energy and to CO_2 emissions was considered.

Table 1 presents the *standard* conversion factors that were considered when normalizing the building energy consumption data to energy need[2].

Table 1 Normalization to heating and cooling energy need (room demand).

	From kWh/(m² a)		**To kWh/(m² a)**	**Standard conversion**
Heating (All climates)	Fossil fuel	→	Energy need	Multiply by 0.9 [a]
	Electricity	→	Energy need	Multiply by 4 [b]
	District heating	→	Energy need	Multiply by 1 [c]
Cooling (All climates)	Electricity	→	Energy need	Multiply by 3 [d]
	District cooling	→	Energy need	Multiply by 1 [c]

[a] 90% efficiency boiler; [b] COP 4 heat-pump; [c] Standard conversion considers district heating/cooling energy demand equivalent to heating/cooling energy need; [d] COP 3 chiller.

Table 2 presents the *standard* conversion factors that were assumed when normalizing to primary energy (annual tonnes of oil equivalent per square meter) and CO_2 emissions (annual tonnes of CO_2 equivalent per square meter).

[1] Annual kWh per m^2.

[2] Assumed efficiency of secondary HVAC systems: 1.

Table 2 Assumed standard conversion factors to primary energy and CO_2 emissions.

	From kWh/(m^2 a)		To toe/(m^2 a) x 10^{-3}	Standard conversion		To tCO_2e/(m^2 a) x 10^{-3}	Standard conversion
Heating in Nordic and Moderate climates	Fossil fuel	→	Primary energy	Multiply by 0.086 [a]	→	CO_2 emissions	Multiply by 1.2
	Energy need	→	Primary energy	Multiply by 0.096 [b]	→	CO_2 emissions	Multiply by 1.2
Heating in Mediterranean climate	Electricity	→	Primary energy	Multiply by 0.287 [c]	→	CO_2 emissions	Multiply by 1.2
	Energy need	→	Primary energy	Multiply by 0.072 [d]	→	CO_2 emissions	Multiply by 1.2
Cooling in all climates	Electricity	→	Primary energy	Multiply by 0.287	→	CO_2 emissions	Multiply by 1.2
	Energy need	→	Primary energy	Multiply by 0.096 [e]	→	CO_2 emissions	Multiply by 1.2

[a] 1 toe = 11630 kWh; [b] 90% efficiency boiler; [c] Assumed efficiency for electricity production and distribution: 30%; [d] COP 4 heat-pump; [e] COP 3 chiller.

2.1.3 Climate normalization

Initially, climate normalization of the buildings energy performance was considered. Appendix A.1 presents results of climate normalized energy data.

With this normalization a comparison of buildings located in different regions in Europe, subject to different climates was envisioned. However, after considerable effort, this normalization was discarded. It was concluded that low energy buildings are designed for site-specific climate – site specific design – and that trying to assess the energy performance of this type of buildings for an “European average climate”, or even for a “regional average climate”, would produce low quality conclusions.

Comparisons between buildings energy performance remained therefore limited to buildings subject to identical climate conditions, without climate normalization. Three European climatic regions were selected: Nordic, Moderate and Mediterranean. For definitions of these climatic regions see Streicher (2005).

2.2 Framework for data gathering

A data gathering framework based on technical visits, interviews, documentation research and the filling of questionnaires was developed.

Appendix A.2 presents the WP 1 short version, long version and extension to the long version questionnaires for collecting DSF building data and the WP 3 comfort and office manager questionnaires.

2.3 The benchmark group of buildings

The target group directly addressed by this project were DSF buildings in European countries, namely in Austria, Belgium, France, Germany, Greece, Portugal and Sweden.

The analysis initially involved 30 DSF buildings, distributed per country as in Figure 2

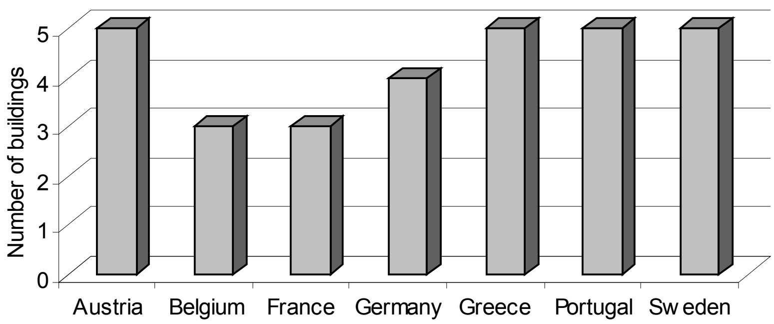


Figure 2 Initial DSF building sample.

For the purpose of energy benchmarking it was also decided to consider data from single skin façade (SSF) office buildings — see section 3.2. With the inclusion of these buildings the sample rose to 58 buildings.

2.4 Data collection and verification

As mentioned in section 2.2 a combination of data collection tools, namely questionnaires, documentation research, interviews and technical visits was used. Annual figures of building energy consumption data, users comfort and mangers opinions were therefore collected.

The energy data came mostly from energy bills, in some cases from monitoring (e.g., Portugal), and because of the difficulty in gathering data it was decided to include also simulations and design values. It was assumed that simulations and design were performed according to the best practices, adapted to climate, building typology and therefore with estimated errors lower than 10%.

Appendix A.3 describes the DSF energy data that was used in the project. Type of energy delivered to the building (e.g., district heating/cooling, fossil fuel, electricity) and method used to determine these data (e.g., energy bills, monitoring, simulation, design) are clearly specified.

Figure 3 presents the number of DSF buildings with known energy performance for each climatic region (Nordic, Moderate, Mediterranean) — the data set used in the WP3 analysis.

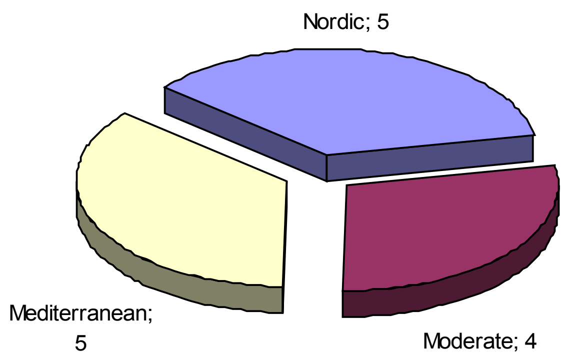


Figure 3 Number of DSF buildings with available energy data for heating and cooling per climatic region.

In spite of the data collection effort and the extension of the collecting period until 2007, of the 30 initial DSF buildings only 45 % — 14 buildings — were able to provide a sufficient set of quantitative data *for energy performance analysis*.

The difficulties in obtaining energy performance data were attributed, mainly, to the building managers fear for loss of confidentiality. Another important reason was the lack of monitoring devices, specially to assess cooling, ventilation and lighting demands.

The majority of the studied buildings were non-public office buildings – see Figure 4. The sample also included a school, an airport terminal and a 1:1 scale test facility.

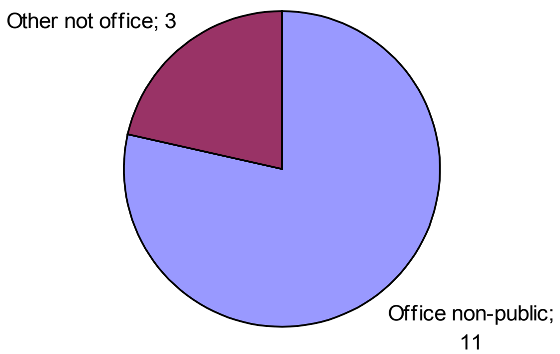


Figure 4 Type of DSF building function.

The following subsections characterize some of the main characteristics of the studied sample (14 DSF buildings). This characterization differs from that of WP1 Report (Streicher, 2005), since the sample is restricted to the buildings with known demand energy or energy need data.

2.4.1 Façade typology

Figure 5 presents the DSF typologies in the studied sample. The nomenclature follows that used in WP1 Report (Streicher, 2005).

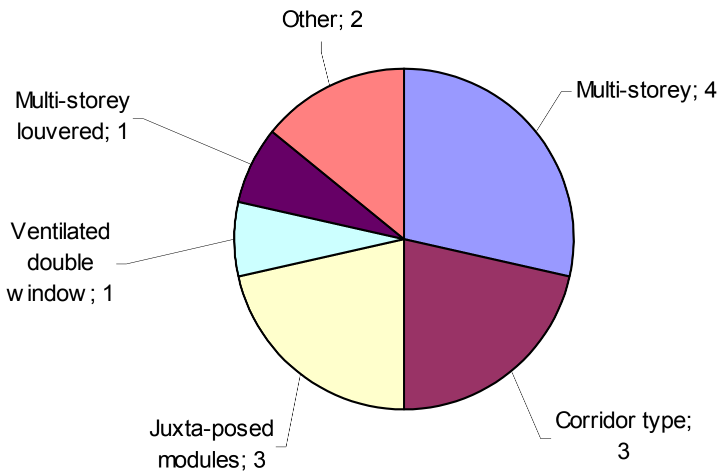


Figure 5 DSF typology.

The most common typology was the multi-storey façade, followed by the corridor type façade and juxtaposed modules.

2.4.2 DSF air cavity ventilation type

Figure 6 presents the number of different types of DSF air cavity ventilation.

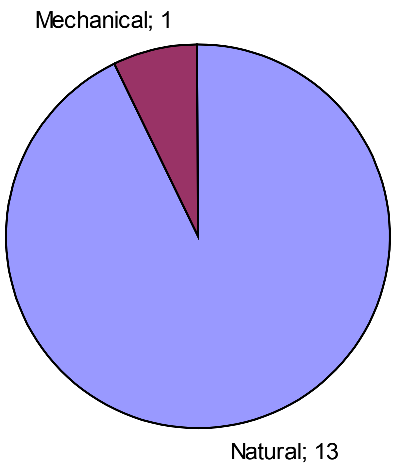


Figure 6 DSF air cavity ventilation type.

Figure 6 shows that in the majority of the buildings the DSF air cavity was naturally ventilated. The building with mechanical ventilation is located in the Mediterranean climatic region.

2.4.3 Room air temperature setpoints

Figure 7 presents for the sample DSF buildings the room air temperature heating and cooling setpoints.

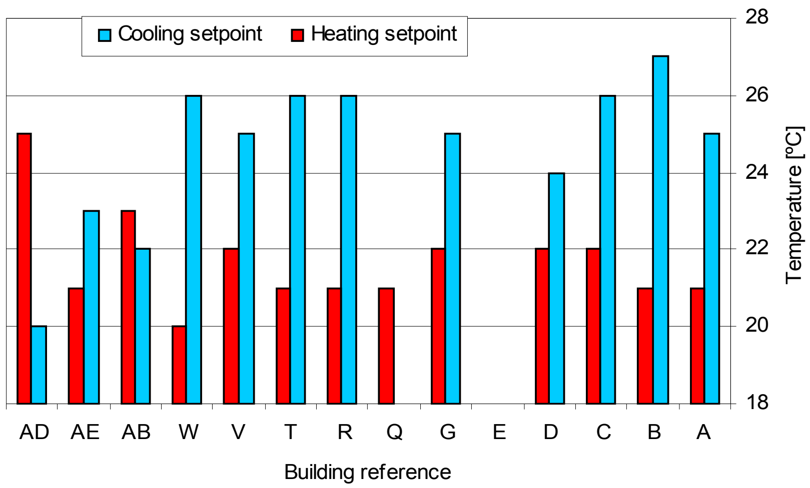


Figure 7 DSF buildings room air temperature setpoints.

Figure 7 shows differences in the setpoints, specially for cooling, where 7ºC differences from 20ºC to 27ºC are observed. The 21ºC heating setpoint is the most used in the studied buildings.

2.4.4 Room heating and cooling system

Figure 8 and Figure 9 present the number of different room heating and cooling systems.

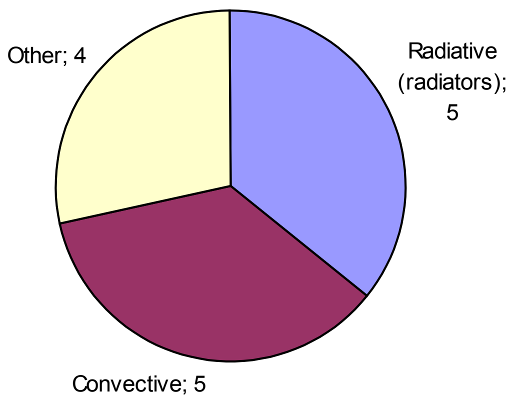


Figure 8 Room heating system.

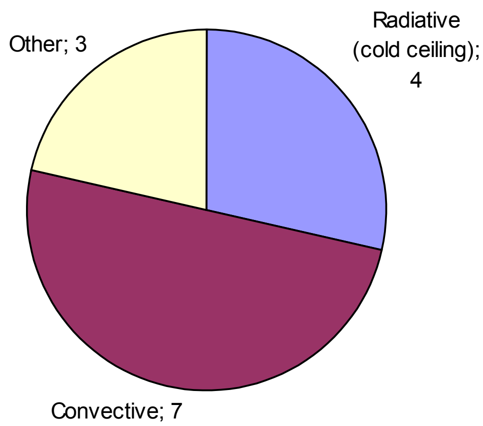


Figure 9 Room cooling system.

Figure 8 shows that radiative and convective room heating systems are equally common in the studied building sample.

For room cooling Figure 9 shows that convective systems are the most common ones.

2.4.5 Type of energy delivered for heating and cooling

Figure 10 and Figure 11 present the number of different types of heating and cooling energy delivered to the buildings.

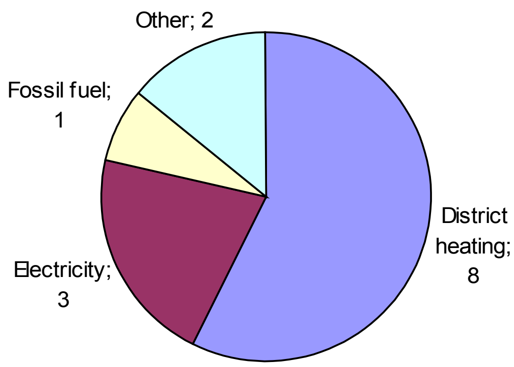


Figure 10 Type of heating energy delivered to the building.

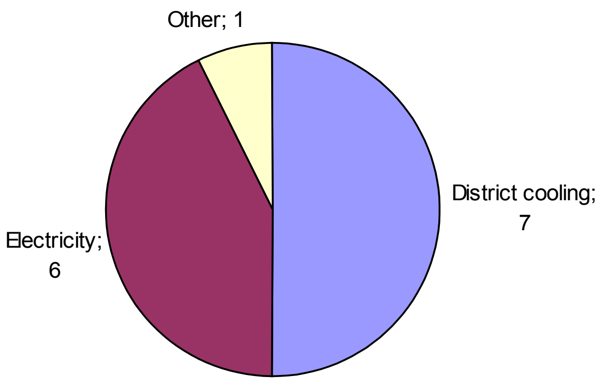


Figure 11 Type of cooling energy delivered to the building.

Figure 10 and Figure 11 show that the majority of the DSF buildings used district heating and cooling to neutralize room energy needs for heating and cooling.

2.4.6 Solar shading devices

Figure 12 presents the number of buildings with solar shading and distinguishes between types of shading devices.

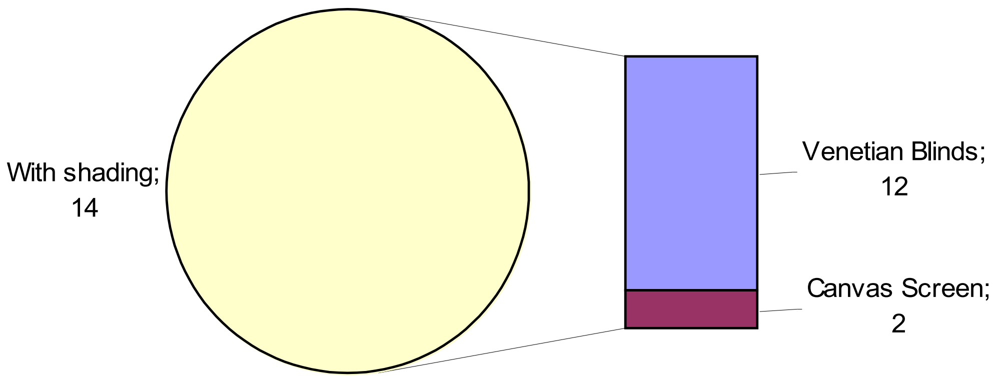


Figure 12 Solar shading devices.

venetian blind canvas screens

All the DSF buildings considered solar shading. Venetian blinds were the most common shading device.

2.4.7 Daylight control

Figure 13 presents the number of buildings with and without daylight control and distinguishes between types of existing daylight control.

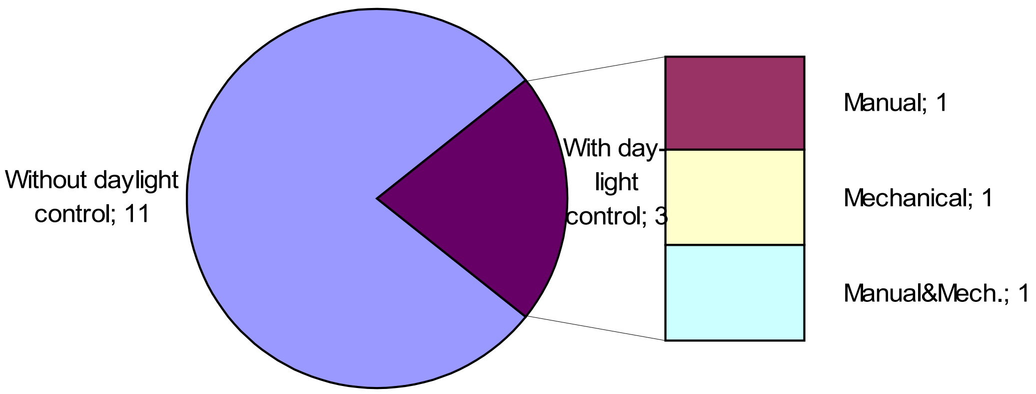


Figure 13 Daylight control.

As Figure 13 shows, few DSF buildings include daylight control technology.

2.5 The data analysis methodology

The analysis of the data considered three different stages. An initial stage consisted in the ranking of the buildings according to the performance indexes defined in section 2.1. This ranking was made for the whole of the DSF sample (14 buildings) and also for a larger sample that included DSF and SSF buildings. At the end of this stage a cluster analysis helped in identifying DSF buildings with similar energy performance trends and elect the best performers for each climatic region.

A second stage analysed the main characteristics of some of the DSF buildings. This stage established "case studies" for each climatic region from which best practices can be drawn.

A final stage consisted of a comparison between the DSF building energy performance and existing European energy benchmarks. This allowed an absolute ranking of the DSF building sample in terms of energy performance. This comparison was used to propose energy performance benchmarks for DSF office buildings.

Since WP3 main task was the analysis of the data gathered on the studied buildings, these three stages are presented below in separate sections.

3 Analysis of Energy Performance Data

Appendix A.3 presents the raw and the energy type normalized data (see section 2.1.2 on energy type normalization) used in the making of the figures presented in this section.

3.1 DSF buildings energy performance

3.1.1 Energy needs for heating and for cooling: Raw data only

Figure 14 presents the energy performance of the sample buildings for which energy needs (measurement[1], simulation, design values) are known (see Table A. 2 and Table A. 3).

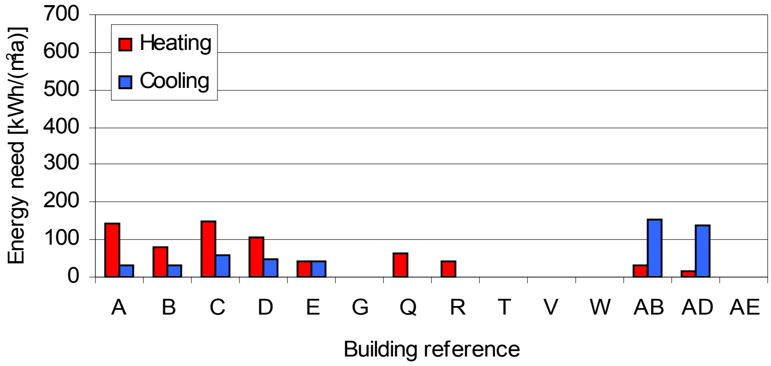


Figure 14 Known heating and cooling energy needs for each DSF (sample) building – Alphabetic order, without energy type normalization.

3.1.2 Energy needs for heating and for cooling: Raw and normalized data

Figure 15 presents separately the energy need for heating and for cooling of the DSF sample buildings. Raw data and delivered energy values normalized to energy needs are presented (see Table A. 5 and Table A. 6).

[1] Energy type *standard* conversion (section 2.1.2) considers district heating/cooling demand measurements equivalent to energy needs.

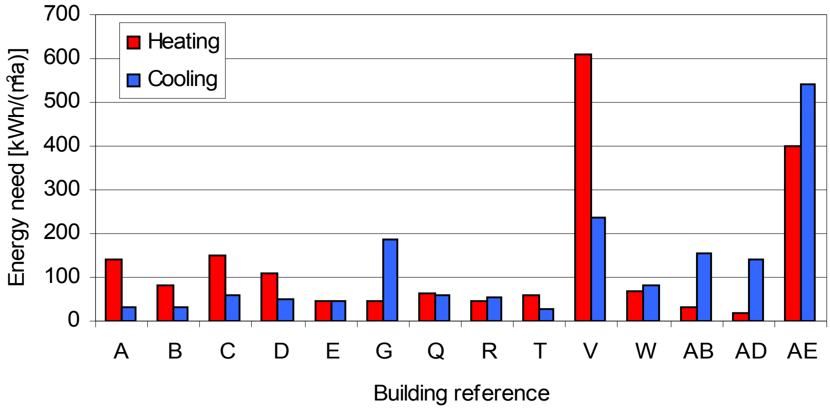


Figure 15 DSF buildings heating and cooling energy need – Alphabetic order, with energy type normalization.

Figure 16 is identical to Figure 15 but with the buildings ordered from low to high energy need values.

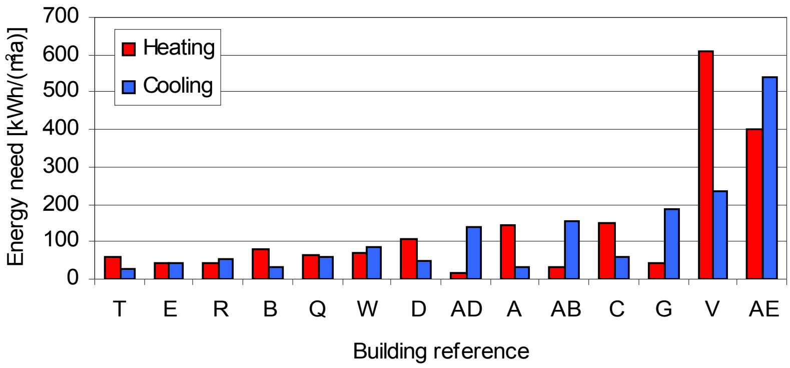


Figure 16 DSF buildings heating and cooling energy need – Ordered from low to high energy need (heating plus cooling) in the building, with energy type normalization.

3.1.3 Delivered energy for heating and for cooling: Raw data only

Figure 17 presents the energy performance of the sample buildings for which delivered energy (measurement[1], simulation, design values) are known (see Table A. 2 and Table A. 3).

[1] Fossil fuel or electricity energy demand measurements only. District heating/cooling demand measurements are presented in section 3.1.1.

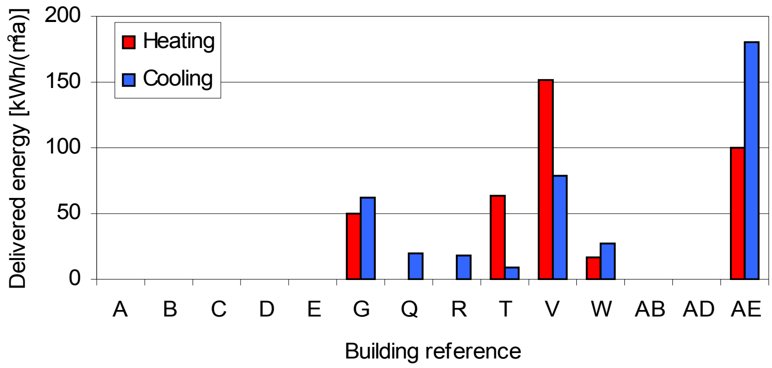


Figure 17 Known heating and cooling delivered energy for each DSF (sample) building – Alphabetic order, without energy type normalization.

3.1.4 Energy need for heating <u>plus</u> cooling: Raw data only

Figure 18 presents the energy performance of the sample buildings for which energy needs (measurement, simulation, design values) are known (see Table A. 2 and Table A. 3).

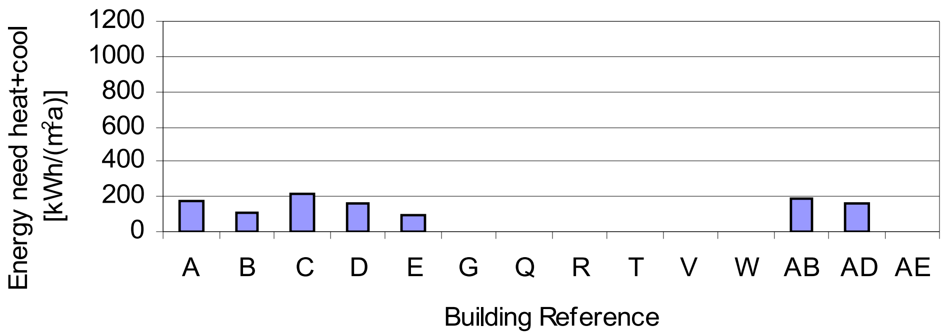


Figure 18 Known heating plus cooling energy needs for each DSF sample building – Alphabetic order, without energy type normalization.

3.1.5 Energy need for heating plus cooling: Raw and normalized data

Figure 19 presents the heating plus cooling energy need for each of the DSF sample buildings. Raw data and delivered energy values normalized to energy needs are presented (see Table A. 7).

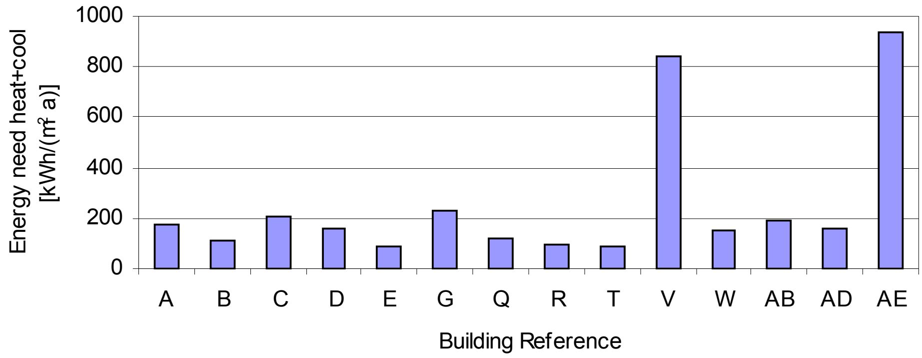


Figure 19 Heating plus cooling energy need per DSF (sample) building – Alphabetic order, with energy type normalization.

Figure 20 is identical to Figure 19 but with the buildings ordered from low to high energy need values.

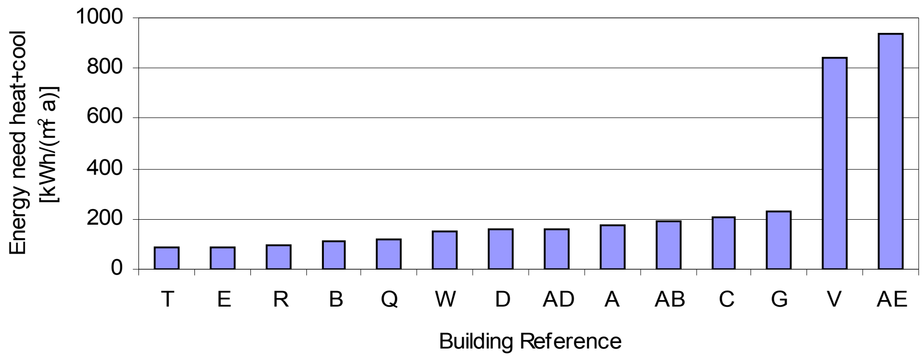


Figure 20 Heating and cooling energy need per DSF sample building – Ordered from low to high energy need in building, with energy type normalization.

3.1.6 Delivered energy for heating plus cooling: Raw data only

Figure 21 presents the energy performance of the sample buildings for which delivered energy (measurement, simulation, design values) are known (see Table A. 7).

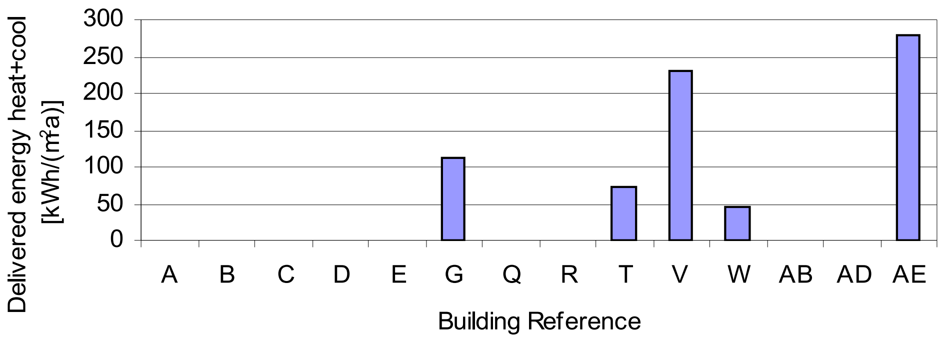


Figure 21 Known heating plus cooling delivered energy for each DSF (sample) building – Alphabetic order, without energy type normalization.

3.1.7 Primary energy for heating plus cooling: Normalized data

Figure 22 presents the energy performance of the sample buildings expressed in primary energy units (see Table A. 7). Section 2.1.2 presents details on normalization coefficients used.

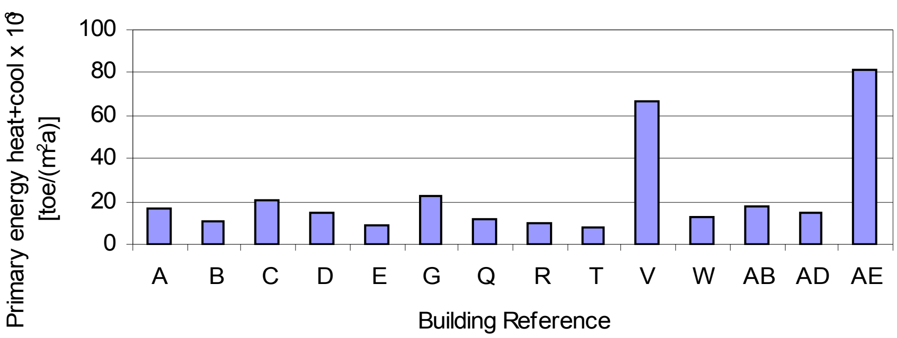


Figure 22 Heating plus cooling primary energy demand for each DSF (sample) building – Alphabetic order, with energy type normalization.

Figure 23 is identical to Figure 22 but with the buildings ordered from low to high primary energy demand values.

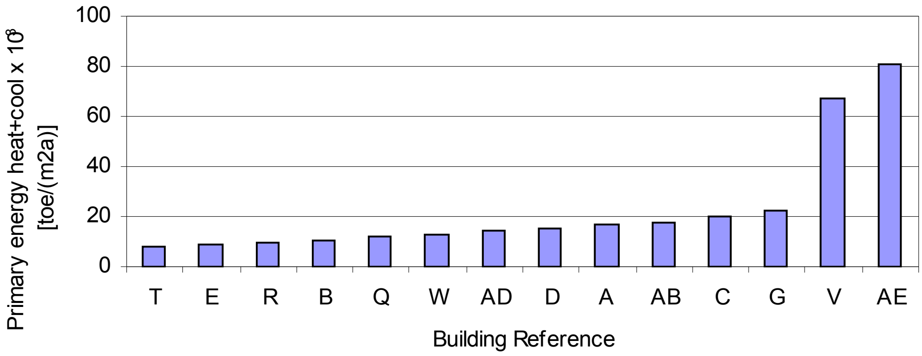


Figure 23 Heating plus cooling primary energy demand for each DSF (sample) building – Ordered from low to high energy need in building, with energy type normalization.

3.1.8 Total electricity consumption: Raw data

Figure 24 presents total electricity consumption (including heating and cooling if applicable) in the DSF sample buildings (see Table A. 4).

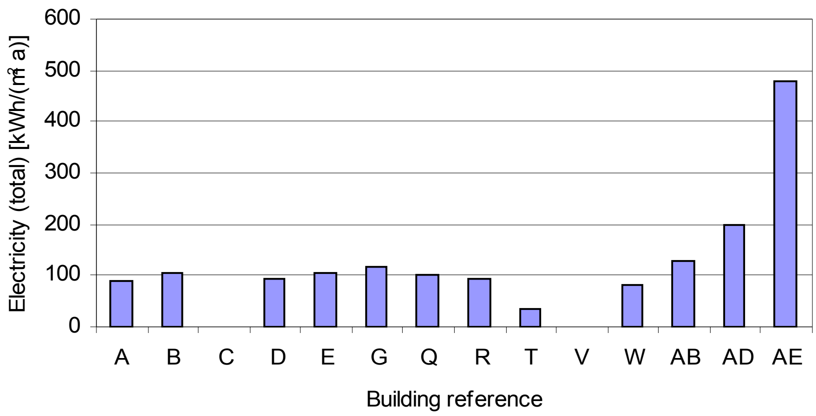


Figure 24 DSF buildings total electricity consumption – Alphabetic order.

3.1.9 Electricity for lighting consumption: Raw data

Figure 25 presents electricity for lighting consumption in the DSF sample buildings (see Table A. 4).

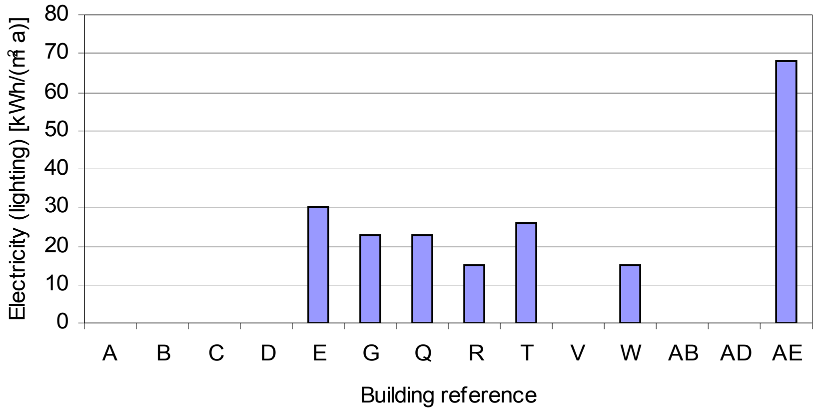


Figure 25 DSF buildings electricity for lighting consumption – Alphabetic order.

3.1.10 Electricity for ventilation consumption: Raw data

Figure 26 presents electricity consumption for mechanical ventilation in the rooms in the DSF sample buildings (see Table A. 4).

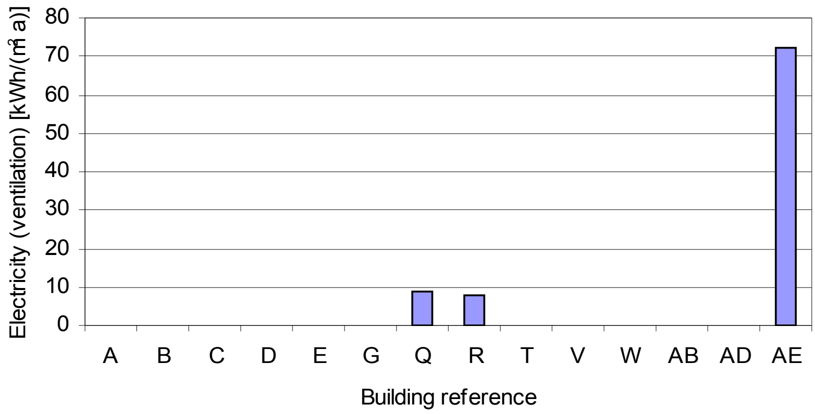


Figure 26 DSF buildings electricity for room mechanical ventilation consumption – Alphabetic order.

3.1.11 Primary energy (total): Normalized data

Figure 27 presents the energy performance of the sample buildings expressed in primary energy units (see Table A. 8). Section 2.1.2 presents details on normalization coefficients used.

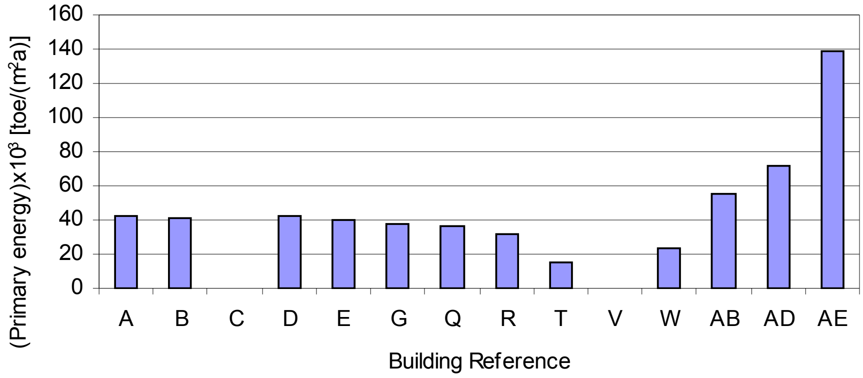


Figure 27 Primary energy (total) for each DSF (sample) building – Alphabetic order, with energy type normalization.

Figure 28 is identical to Figure 27 but with the buildings ordered from low to high (total) primary energy demand values.

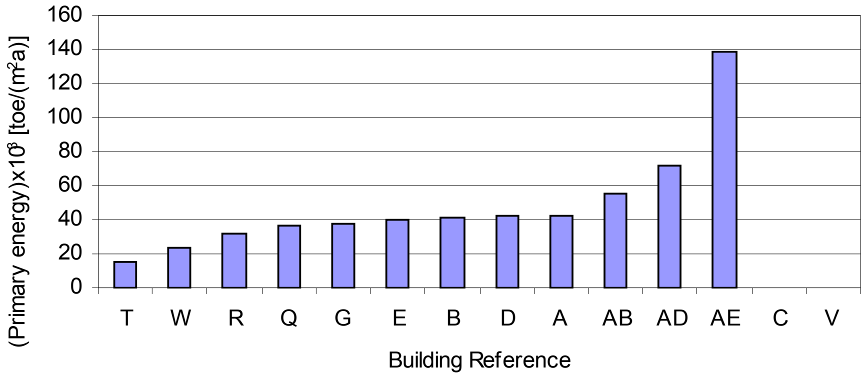


Figure 28 Primary energy (total) for each DSF (sample) building – Ordered from low to high energy demand in building, with energy type normalization.

3.1.12 Estimate of CO_2 emissions: Normalized data

Figure 29 presents estimates of CO_2 emissions of the sample DSF buildings (see Table A. 8). Section 2.1.2 presents details on normalization coefficients used.

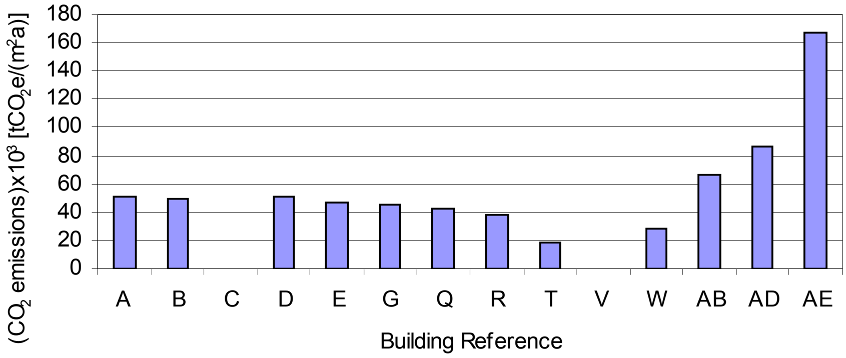


Figure 29 Estimates of CO_2 emissions for each DSF (sample) building – Alphabetic order, with normalization.

Figure 30 is identical to Figure 29 but with the buildings ordered from low to high CO_2 emissions.

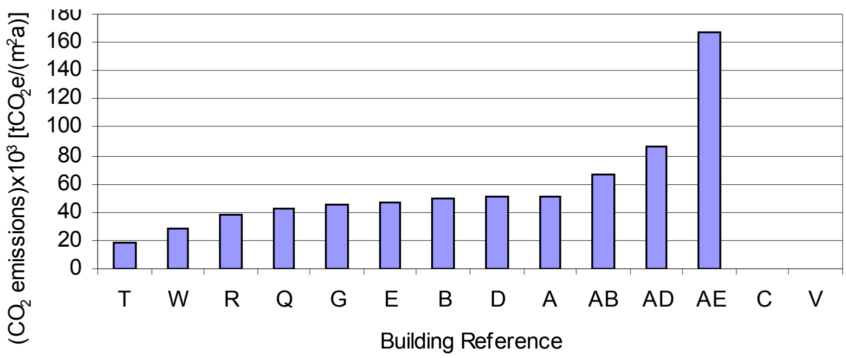


Figure 30 Estimates of CO_2 emissions for each DSF (sample) building – Ordered from low to high CO_2 emissions, with normalization.

3.2 DSF plus SSF buildings energy performance

No energy type normalization was made. Appendix A.3 presents the raw data used in this section (see Table A. 9, Table A. 10 and Table A. 11).

Figure 31 compares values of energy needs for heating and for cooling from DSF and SSF buildings.

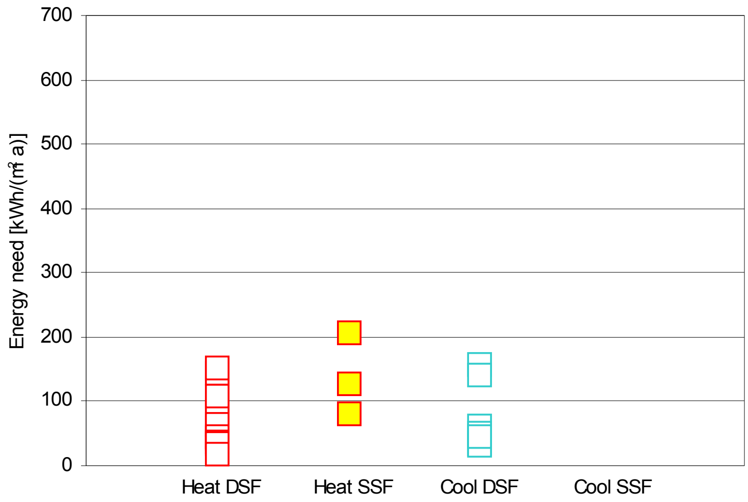


Figure 31 Energy needs for heating and for cooling from DSF and SSF buildings.

From Figure 31 it could be concluded that DSF buildings consume less energy for heating than SSF buildings. However, it should be said that the DSF sample includes two buildings that use district heating located in the Mediterranean region, and that these buildings have comparatively low heating energy needs.

Figure 32 compares values of delivered energy for heating and for cooling from DSF and SSF buildings.

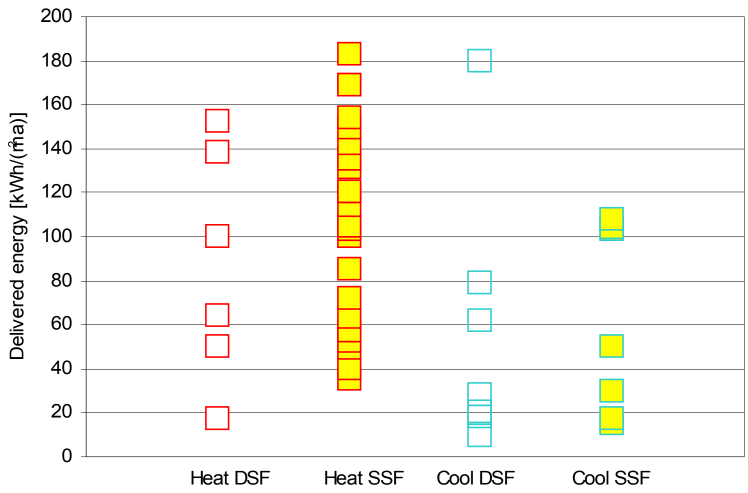


Figure 32 Delivered energy for heating and for cooling from DSF and SSF buildings.

In Figure 32 delivered energy for heating includes heating with fossil fuel and heating with electricity. Figure 32 clearly shows that DSF buildings can perform better *and worse* than SSF buildings.

Figure 33 compares values of total electricity consumption, electricity for ventilation and electricity for lighting from DSF and SSF buildings.

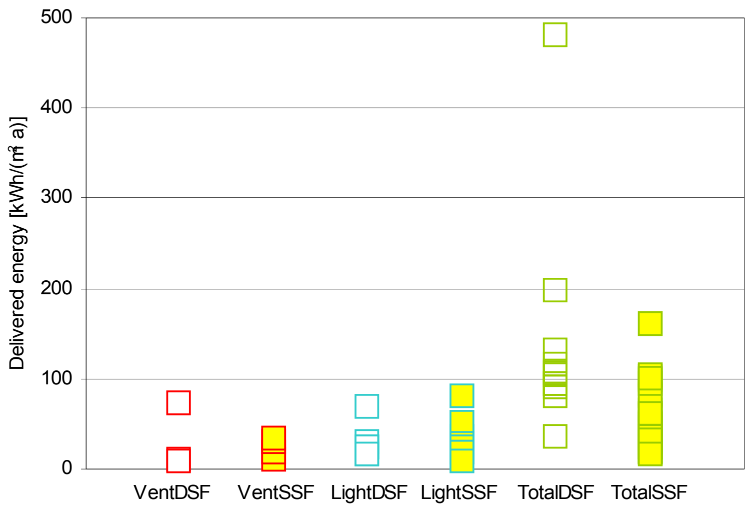


Figure 33 Total electricity consumption, electricity for ventilation and electricity for lighting from DSF and SSF buildings.

From Figure 33 it appears that, on average, DSF buildings consume more (total) electricity than SSF buildings. This could be related to differences in use and HVAC systems present in the buildings that constitute the DSF and SSF samples[1].

From Figure 34 to Figure 39 raw energy data (energy need and demand energy) for DSF and SSF buildings is compared separately, for each climatic region.

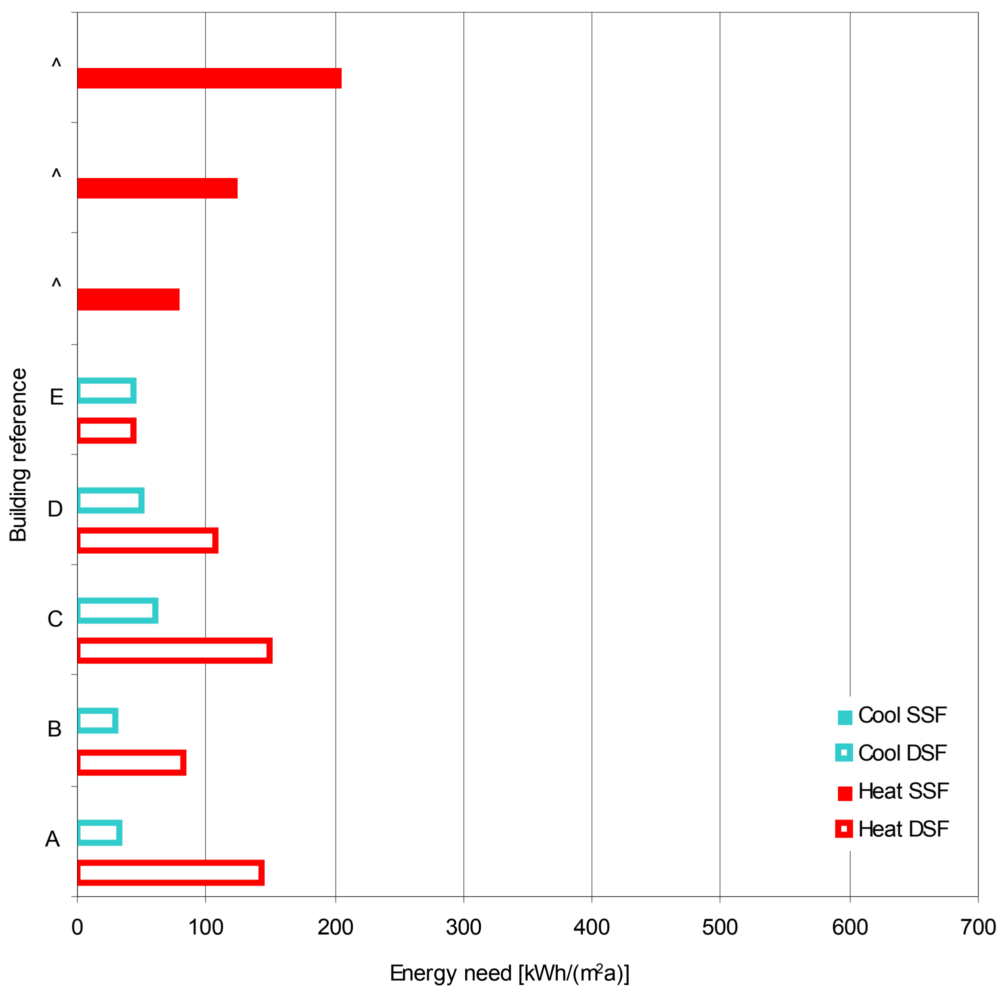


Figure 34 Energy needs for cooling and for heating in DSF and SSF buildings located in the Nordic climate.

[1] For example, some SSF buildings have no colling capacity.

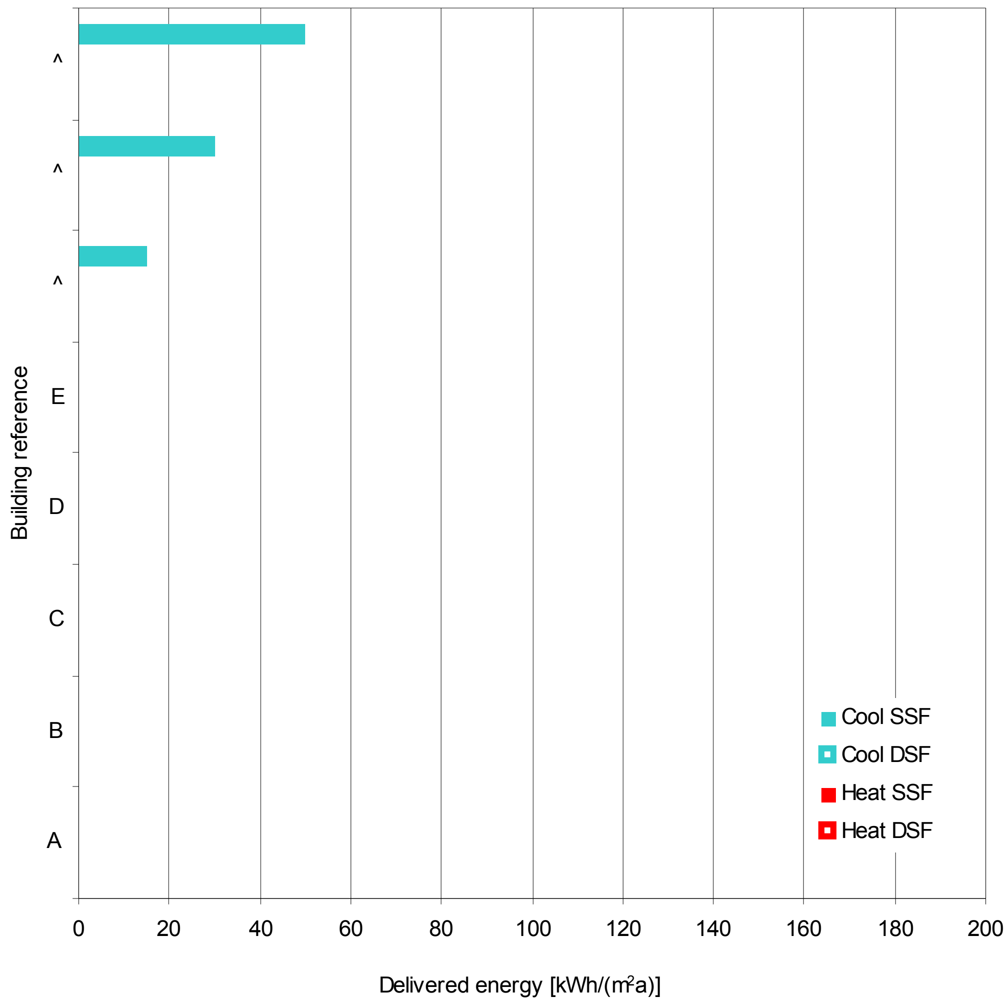


Figure 35 Delivered energy for cooling and for heating in DSF and SSF buildings located in the Nordic climate.

The reduced amount of raw data shown in Figure 35 relates to the fact that most of the buildings located in the Nordic climate were district heated and cooled and this energy type is presented in Figure 34 as energy need.

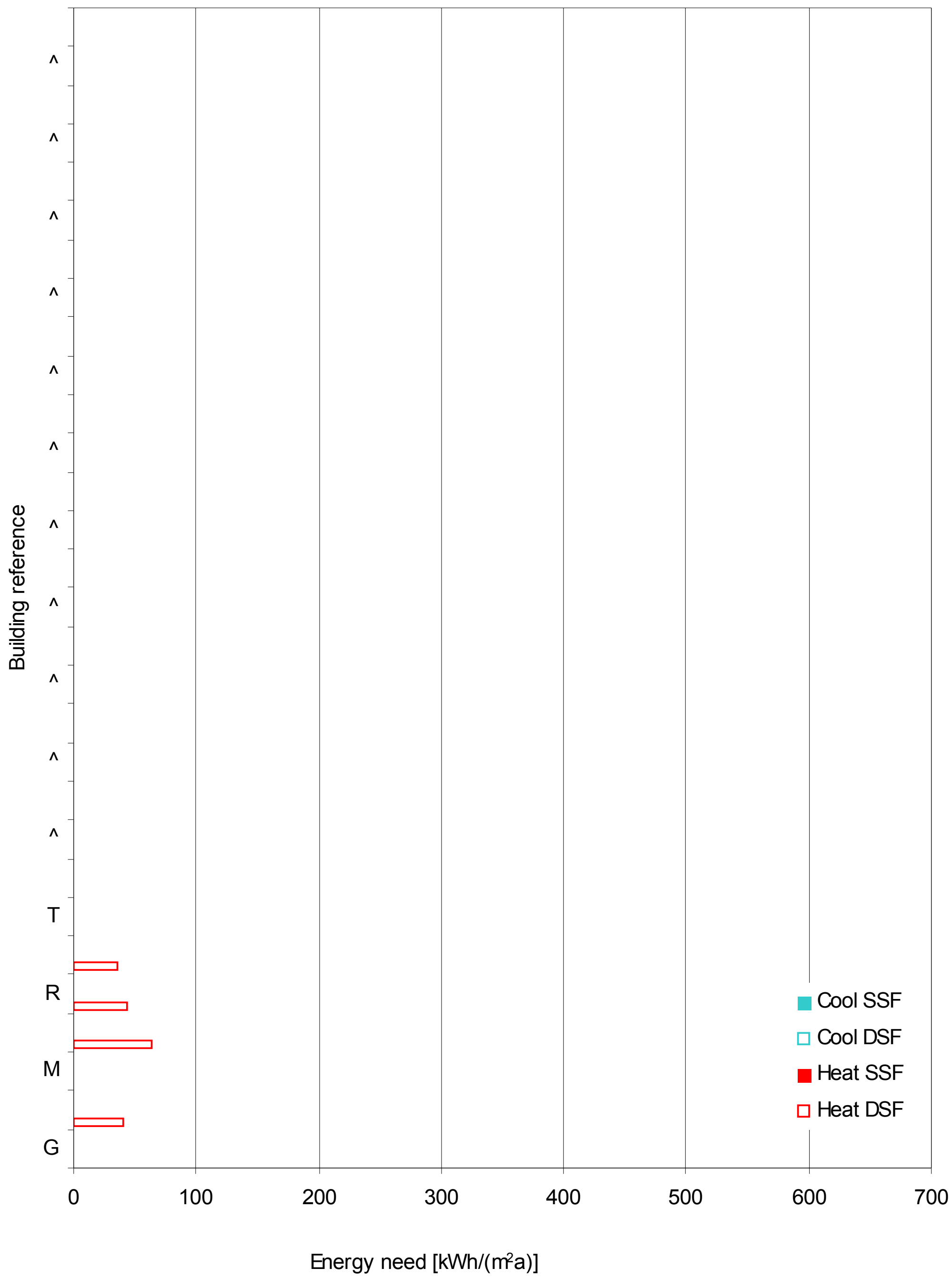


Figure 36 Energy needs for cooling and for heating in DSF and SSF buildings located in the Moderate climate.

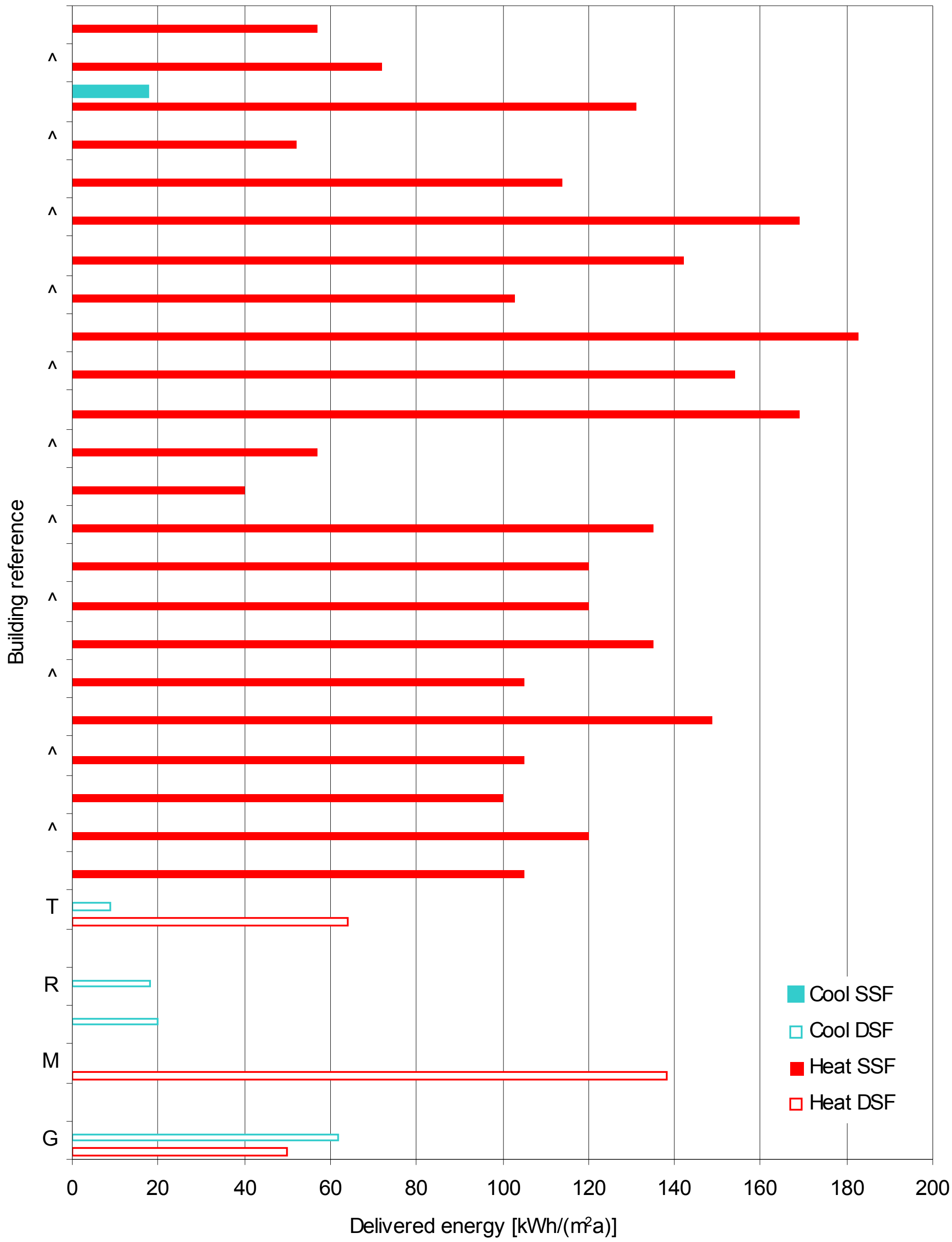


Figure 37 Delivered energy for cooling and for heating in DSF and SSF buildings located in the Moderate climate.

The fact that there are much more SSF buildings with heating than cooling results from the fact that most of the SSF data came from Central European countries where cooling is less common.

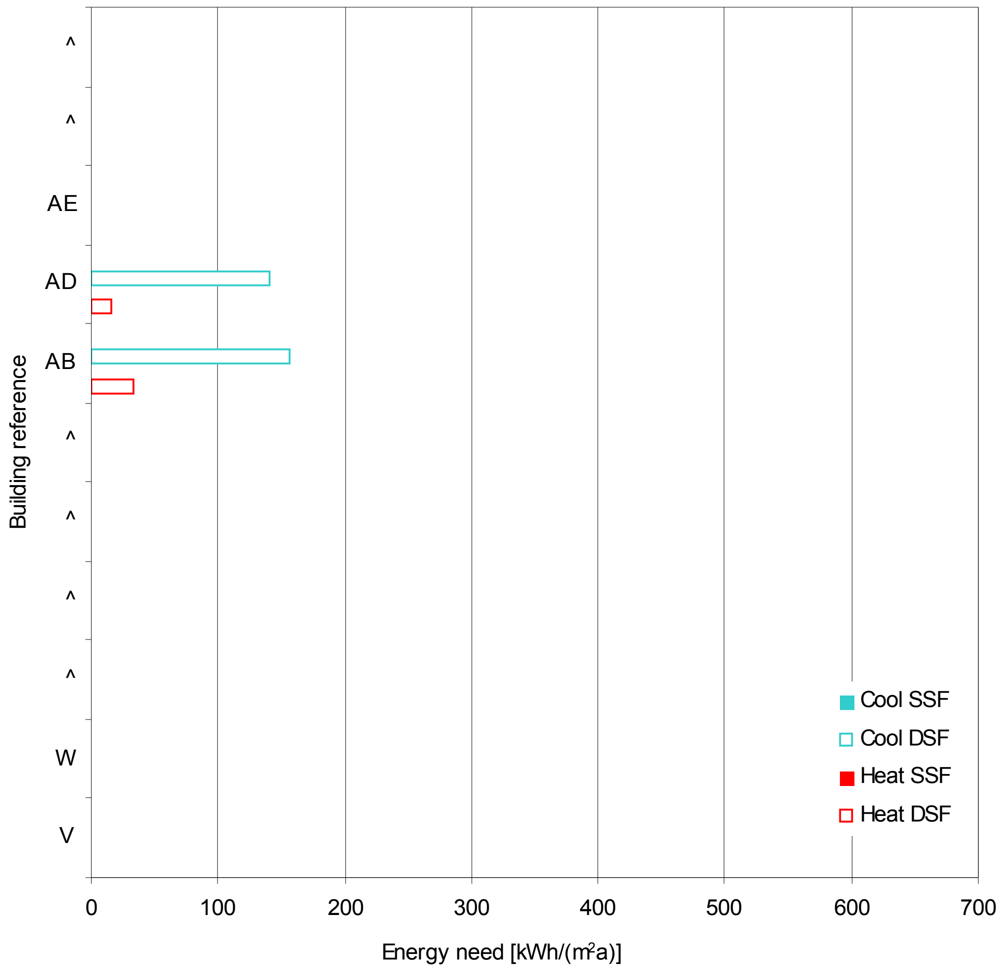


Figure 38 Energy needs for cooling and for heating in DSF and SSF buildings located in the Mediterranean climate.

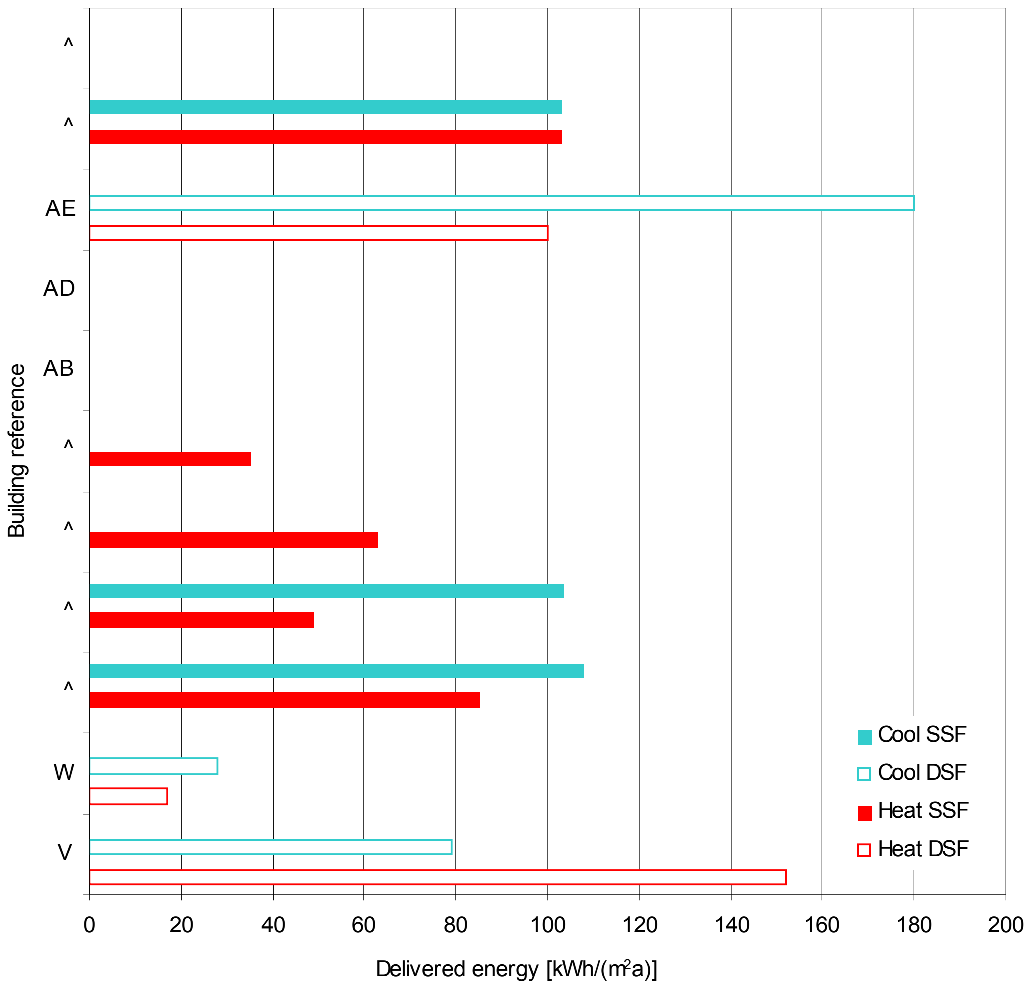


Figure 39 Delivered energy for cooling and for heating in DSF and SSF buildings located in the Mediterranean climate.

When DSF and SSF buildings energy consumptions are compared no clear distinction in the performance of the DSF buildings is noticeable. There are good as well as bad energy performing DSF buildings. This result agrees with the fact that SSF buildings with low glazed areas generally perform better than highly glazed SSF or DSF buildings, and that high glazed DSF buildings can perform better than highly glazed SSF buildings.

3.3 Cluster analysis

To further study the energy behaviour of the DSF buildings, values of heating and of cooling energy needs for each DSF building were compared. No climatic distinction between buildings was made. Buildings B, C and T (non-office buildings) were removed from the analysis because their use is different from that of all the other ones.

Figure 40 presents the energy needs for heating and for cooling for the DSF sample office buildings. Energy type normalization was performed when necessary.

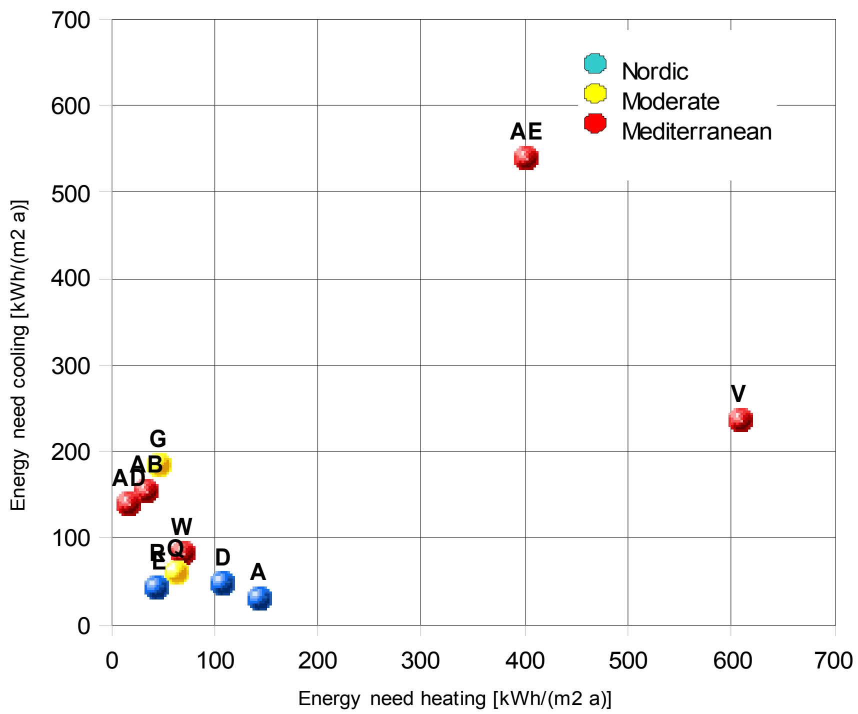


Figure 40 Heating and cooling energy needs for DSF sample office buildings (with energy type normalization when necessary).

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 will not be subject to further analysis. The remaining sample of 9 DSF office buildings have heating and cooling energy needs lower than 200 kWh/(m^2 a).

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 (in this case, buildings). In the present analysis no data reduction benefits were gained, for only two energy performance indexes were used. The reduced statistical significance of the available data also affects the analysis, since comparisons to an average sample data energy performance are made. However, because the PCA analysis enabled further insight into the building energy performance, it is presented.

Running the PCA model with the 9 DSF buildings energy needs for heating and cooling produces Figure 41.

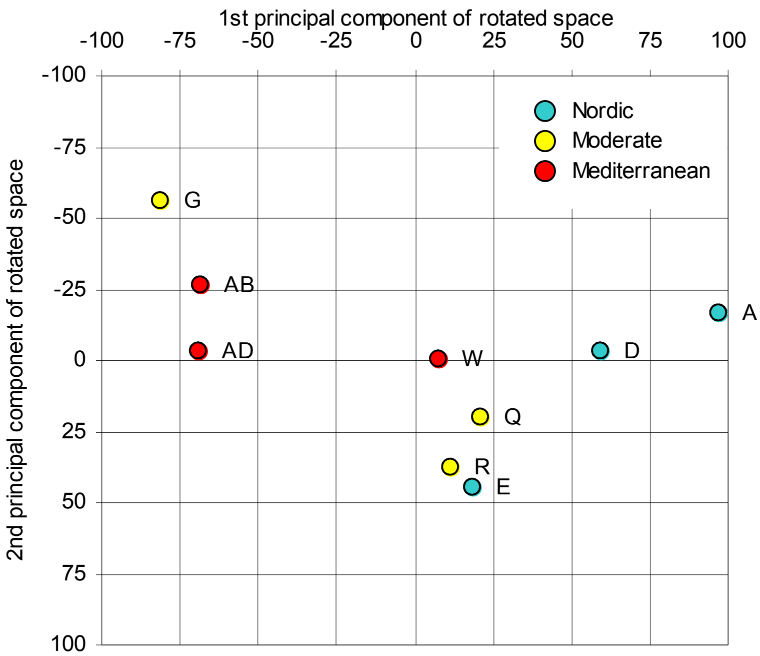


Figure 41 PCA graphical representation of the positions of the buildings on the rotated space.

The first axis (or component) in Figure 41 is strongly related to the buildings heating needs. 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 41 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 a 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, possess 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 42 is produced.

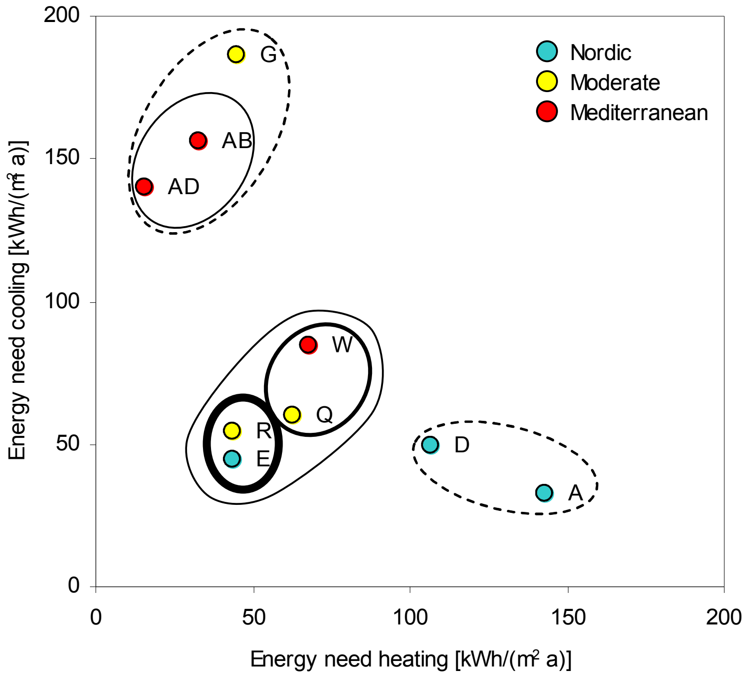


Figure 42 Clusters of DSF office buildings with similar heating and cooling energy needs behaviour (with energy type normalization when necessary).

Figure 42 confirms the analysis of Figure 41 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 are:
- Nordic climate: buildings E and D;
- Moderate climate: buildings R and Q;
- Mediterranean climate: buildings W and AD.

4 Case Studies

4.1 Nordic climate

4.1.1 Building E

Generic characteristics	Year of construction	-2004
	Number of storeys	n.a.
	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
	Setpoints	n.a.
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	City design day
	Data source	Simulation (all cases)
	Annual consumption	44 kWh/(m^2 a) for heating; 44 kWh/(m^2 a) for cooling; 107 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion	Generic	Very good comfort (summer); unaware of DSF concept; HVAC is essential for prestige
	Winter	n.a.
	Autumn	n.a.
	Summer	Very dissatisfied; feeling uncomfortably cold
	Spring	Dissatisfied; would prefer cooler
Remark		Energy performance is based on simulation results. Contradictory users opinion suggests indoor thermal environment problems. These problems should be related to HVAC system and possibly the façade. 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.

4.1.2 Building D

Generic characteristics	Year of construction	2002-2003
	Number of storeys	32
	Gross floor area	22000 m^2
Façade	Type	Corridor; partitioned per storey; two of the three facades are double skin facades, the third (to the north) is a single skin facade. The double skin facades are of the type corridor façade with diagonal ventilation. In the 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 of data gathered	2004
	Data source	Measured (energy bills)
	Annual consumption	107 kWh/(m^2 a) for heating; 49 kWh/(m^2 a) for cooling; 93 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; DSF has lower maintenance costs; window cleaning is the main maintenance issue
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		

4.1.3 Building A

Generic characteristics	Year of construction	-2002
	Number of storeys	n.a.
	Gross floor area	n.a.
Façade	Type	Multi-storey; cavity width 0.80 m; air flows in through grids in the outer skin at bottom level and flows out through grids in the outer skin at top level: outside air inflow and gap air outflow can be controlled by closing the grids above; there are no openable windows
	Area	3200 m^2
	Ventilation	Natural
	Shading	Venetian blinds placed in the gap near the inner skin, slat angle mechanical controlled via solar radiation; no overrule by occupants
	Daylight control	Interior (in the office room) canvas screens enable daylight control. These screens are manually operated
HVAC	Type	Heating with radiators, cooling with cooled ceilings; mechanically ventilated with a system that enables heat recovery; this ventilation system pre-heats
	Setpoints	21ºC winter; 25ºC summer
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	2004
	Data source	Measured (energy bills)
	Annual consumption	143 kWh/(m^2 a) for heating; 32 kWh/(m^2 a) for cooling; 89 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; DSF has higher maintenance costs; window cleaning is the main maintenance issue
User opinion	Generic	Good comfort (summer); aware of DSF concept; HVAC is essential for comfort
	Winter	n.a.
	Autumn	n.a.
	Summer	Satisfied; sometimes feeling uncomfortably cold, but generally felling slightly warm; undesired sunlight reflections
	Spring	Dissatisfied; less comfortable than summer, would prefer warmer
Remark		

4.2 Moderate climate

4.2.1 Building R

Generic characteristics	Year of construction	-2002
	Number of storeys	n.a.
	Gross floor area	20705 m^2
Façade	Type	Corridor; partitioned per storey; natural ventilation through window opening or special openings on both inner and outer 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	HAVC 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 of 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^2 a) for heating+DHW; 18 kWh/(m^2 a) for cooling; 94 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		Energy performance is partly (cooling) based on calculations for an energy audit.

4.2.2 Building Q

Generic characteristics	Year of construction	-2004
	Number of storeys	n.a.
	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, the outer skin has a lower half made of a perforated metal sheet (26% perforation) and a glazed upper half; this solution enables the 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 of 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^2 a) for heating+DHW; 20 kWh/(m^2 a) for cooling; 103 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		Energy performance is partly (cooling) based on calculations for an energy audit.

4.2.3 Building G

Generic characteristics	Year of construction	-2004
	Number of storeys	4 (behind the DSF)
	Gross floor area	227 m^2
Façade	Type	Multi-storey; openable windows; air cavity width: 0.28m
	Area	222 m^2
	Ventilation	Natural
	Shading	Canvas screen in the gap near the inner skin, mechanical controlled with overrule by occupants
	Daylight control	No daylight control
HVAC	Type	n.a.
	Setpoints	22ºC (winter); 25ºC (summer)
Energy use	Supplied energy	n.a.
	Year of data gathered	City design day (all cases)
	Data source	Design (all cases)
	Annual consumption	50 kWh/(m^2 a) for heating; 62 kWh/(m^2 a) for cooling; 115 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; ventilation system is the main maintenance issue
User opinion	Generic	Regular comfort (summer); poor comfort (winter); aware of DSF concept; HVAC is essential for comfort
	Winter	Satisfied; undesired sunlight reflections
	Autumn	Satisfied; as comfortable as in winter
	Summer	Very satisfied; undesired sunlight reflections
	Spring	Satisfied; more comfortable than summer
Remark		Energy performance is based on design results.

4.3 Mediterranean climate

4.3.1 Building W

Generic characteristics	Year of construction	-1998
	Number of storeys	n.a.
	Gross floor area	3050 m^2
Façade	Type	Multi-storey louver (openable outer skin); cavity width: 0.80 m; In the inner skin openable windows can be used for inflow and outflow of room air. the outer skin has permanent openings to the outside; the outer skin is composed of shading devices that control the incoming solar radiation; these vertical panels are mechanically operated to rotate on a central axis. These panels are responsible for reducing daylighting in approximately 70%; Inside the office rooms near the inner skin, manually operated Venetian blinds enable further daylighting control; permanent openings are placed above and below the outer skin panels occupying approximately 1/5 of the panel area; gap ventilation is therefore 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 of data gathered	2000
	Data source	Measured
	Annual consumption	17 kWh/(m^2 a) for heating; 28 kWh/(m^2 a) for cooling; 80 kWh/(m^2 a) total electricity consumption.
Office manager opinion		n.a.
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		

4.3.2 Building AB

Generic characteristics	Year of construction	-1998
	Number of storeys	11
	Gross floor area	8411 m^2
Façade	Type	Corridor; partitioned per storey; cavity gap 0.50 m (approximately)
	Area	2520 m^2
	Ventilation	Mechanical
	Shading	Venetian blinds in the gap near the inner skin, mechanical controlled with overrule by occupants
	Daylight control	No daylight control
HVAC	Type	Convective 4-pipes fan-coil system for heating and cooling
	Setpoints	23ºC (winter); 22ºC (summer)
Energy use	Supplied energy	District heating and cooling
	Year of data gathered	2004
	Data source	Measured (energy bills and monitoring)
	Annual consumption	33 kWh/(m^2 a) for heating; 156 kWh/(m^2 a) for cooling; 130 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; window cleaning is the main maintenance issue; maintenance cost identical to SSF buildings.
User opinion	Generic	Regular comfort; unaware of DSF concept; a more natural alternative to the HVAC system would be preferred
	Winter	Satisfied; undesired sunlight reflections
	Autumn	Satisfied; identical to winter
	Summer	n.a.
	Spring	n.a.
Remark		

4.3.3 Building AD

Generic characteristics	Year of construction	-2003
	Number of storeys	n.a.
	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 of data gathered	2005-2006
	Data source	Measured (energy bills)
	Annual consumption	16 kWh/(m^2 a) for heating; 140 kWh/(m^2 a) for cooling; 197 kWh/(m^2 a) total electricity consumption.
Office manager opinion		Energy conscious building management; maintenance costs identical to SSF; ventilation system is the main maintenance issue
User opinion	Generic	n.a.
	Winter	n.a.
	Autumn	n.a.
	Summer	n.a.
	Spring	n.a.
Remark		Building only partially occupied; problems (due to overheating) with the shading device. Although not a double glazed window - since outside and cavity air communicate - the façade typology is uncommon

4.4 Comments

On typology

An overall analysis of the case studies presented in this section 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, A, 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.

5 Energy Benchmarks

To compare the energy performance of the DSF sample buildings with that of the existing European building stock, energy benchmarks from different European countries were gathered. Table 3 presents the gathered benchmarks (see Appendix A.6 for details).

Table 3 Benchmarks from different European countries: raw data only.

		Heating				Cooling				Electricity		Fossil fuels
		Energy need [kWh/(m² a)]	Delivered energy Electricity [kWh/(m² a)]	Delivered energy Fossil fuel [kWh/(m² a)]	Primary energy [toe/(m² a)x10⁻³]	Energy need [kWh/(m² a)]	Delivered energy Electricity [kWh/(m² a)]	Delivered energy Fossil fuel [kWh/(m² a)]	Primary energy [toe/(m² a)x10⁻³]	Total [kWh/m²a]	Lighting [kWh/m²a]	Total [kWh/m²a]
Sweden		80					15			60	35**	
Germany	1310			120						24		
	1320			105						48		
	Frankfurt_B			131*				17			27	
Belgium	Brussels									149		107
	Walloon									114		102
	Flemish#1									162		317
	Flemish#2									144		189
Portugal					30				35***			
Greece	typical		85				108			208	24	
	good		49				104			164	17	

*Heating includes energy delivered to DHW
**Includes equipments
***From Portuguese energy regulations, considering that most high rise office buildings use almost no energy for heating

Considering the type of energy normalization presented in section 2.1.2, Table 4 presents the values of Table 3 expressed in electricity, fossil fuel and primary energy.

Table 4 Summary of benchmarks from different countries.

		Electricity [kWh/(m² a)]		Fossil fuels [kWh/(m² a)]	Primary energy [toe/(m² a)x10⁻³]
		Total	Lighting	Total	Total
Sweden		60	35*		
Germany	1310	24		120	*17*
	1320	48		105	*23*
	Frankfurt_B		27	131	
Belgium	Brussels	149		107	*52*
	Walloon	114		102	*42*
	Flemish#1	162		317	*74*
	Flemish#2	144		189	*58*
Portugal					35
Greece	typical	208	24		
	good	164	17		

*Includes equipments

Table 5 compares, for each climatic region, raw data for DSF sample buildings — heating and cooling energy needs and delivered energy and electricity — to the most and least demanding benchmarks.

Table 5 DSF buildings energy performance compared to respective climatic region most and least demanding benchmarks. Raw data only.

		Heating						Cooling											
		Energy need [kWh/(m2 a)]			Delivered energy [kWh/(m2a)]			Energy need [kWh/(m2 a)]			Delivered energy [kWh/(m2a)]			Electricity for lighting [kWh/(m2 a)]			Total electricity [kWh/(m2a)]		
		Building	Lowest benchmark	Highest benchmark	Building	Lowest benchmark	Highest benchmark	Building	Lowest benchmark	Highest benchmark	Building	Lowest benchmark	Highest benchmark	Building	Lowest benchmark	Highest benchmark	Building	Lowest benchmark	Highest benchmark
Nordic climate	A	143	80 (Sweden; district heat.)	80 (Sweden; district heat.)				32				15 (Sweden; electricity)	15 (Sweden; electricity)				89	60 (Sweden)	60 (Sweden)
	D	107	80(Sweden; district heat.)	80 (Sweden; district heat.)				49				15 (Sweden; electricity)	15 (Sweden; electricity)				93	60 (Sweden)	60 (Sweden)
	E	44	80 (Sweden; district heat.)	80 (Sweden; district heat.)				44				15 (Sweden; electricity)	15 (Sweden; electricity)	30	35 (Sweden)	35 (Sweden)	107	60 (Sweden)	60 (Sweden)
Moderate climate	G				50	102 (Belgium; fossil fuel)	317 (Belgium; fossil fuel)				62	17 (Germany; electricity)	17 (Germany; electricity)	23	27 (Germany)	27 (Germany)	116	24 (Germany)	162 (Belgium)
	Q	58^a			72^b	102 (Belgium; fossil fuel)	317 (Belgium; fossil fuel)				20	17 (Germany; electricity)	17 (Germany; electricity)	23	27 (Germany)	27 (Germany)	103	24 (Germany)	162 (Belgium)
	R	44^a			57^b	102 (Belgium; fossil fuel)	317 (Belgium; fossil fuel)				18	17 (Germany; electricity)	17 (Germany; electricity)	15	27 (Germany)	27 (Germany)	94	24 (Germany)	162 (Belgium)
Mediterra-nean climate	W				17	49 (Greece; electricity)	85 (Greece; electricity)				28	104 (Greece; electricity)	108 (Greece; electricity)	15	17 (Greece)	24 (Greece)	80	164 (Greece)	208 (Greece)
	AB	33						156									130	164 (Greece)	208 (Greece)
	AD	16						140									197	164 (Greece)	208 (Greece)

a) Values excluding DHW
b) Values including DHW

Green cell is for building performance better than the lowest benchmark.

Yellow cell is for building performance between the lowest and the highest benchmarks.

Red cell is for building performance worse than the highest benchmark.

Based on the values presented in the previous tables, comparing the best performing DSF buildings and the most demanding benchmarks, Table 6 proposes energy benchmarks for DSF office buildings in the three climatic regions used in the project: Nordic, Moderate and Mediterranean.

Table 6 Proposed benchmarks for DSF office buildings.

	Climate		
	Nordic	Moderate	Mediterranean
Heating with fossil fuel [kWh/(m^2 a)]	90	65	
Heating with electricity [kWh/(m^2 a)]			20
Cooling with electricity [kWh/(m^2 a)]	20	45	90
Electricity (except cooling) [kWh/(m^2 a)]	40	40	40
Total delivered (sum of the above)	150	150	150
Total (fossil fuel+electricity) [toe/(m^2 a)]	25x10^{-3}	30x10^{-3}	44x10^{-3}
Total CO_2 emissions [tCO_2e/(m^2 a)]	30x10^{-3}	36x10^{-3}	52x10^{-3}

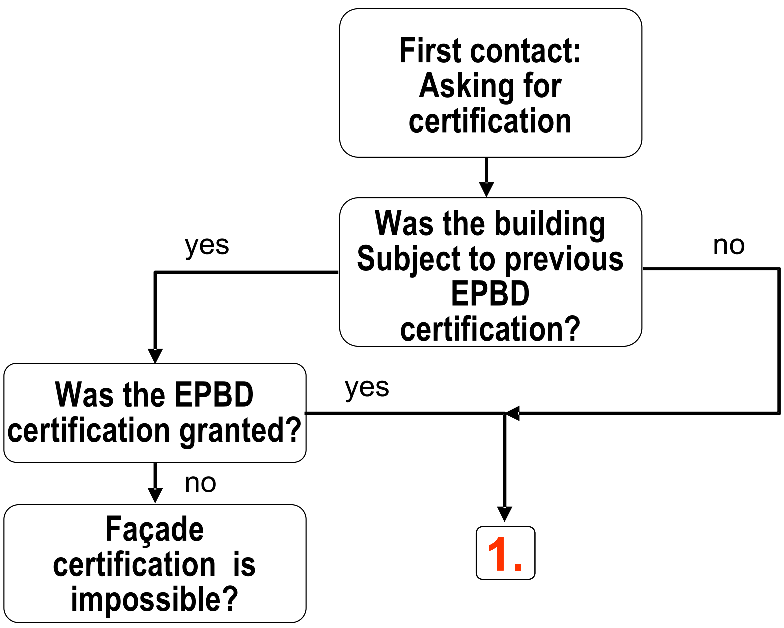
An upper limit of 150 for the total delivered energy (fossil fuel plus total electricity) is proposed. Upper limits for heating, cooling and electricity (except cooling) are also proposed. Since buildings may use heating energy expressed as kWh fossil fuel (mostly in Nordic and Moderate climates that produce heat with boilers[1]) or kWh electricity (mostly in Mediterranean climate where heat-pumps are increasingly used), benchmarks expressed in annual tonnes oil equivalent per square meter are presented. Also presented are benchmarks expressed in units of annual emissions of tonnes CO_2 equivalent per square meter (see section 2.1.2 for conversion coefficients used).

[1] In Nordic countries heating is usually based on district heating produced to a high degree using renewables (biomass).

6 Certification Method for Façades

The energy certification of office buildings — including buildings with double skin façades — is defined by each European Member State based on the EPBD. To certify façades a method similar to the energy certification of buildings already implemented in some European countries is proposed. This method considers the existence of designers and building owners on one side; experts responsible for the rating of the façade on the other side; and finally, at Member-State level, an overall supervision entity. The rating is based on a *Reference Façade Method*, which consists of the comparison of *numerical* energy performance results for the actual building, with the actual façade and HVAC system, and *numerical* energy performance results for the same building but considering a *reference façade and HVAC system*. The reference (or typical) façade and HVAC system is defined at Member State level.

Figure 43 presents the envisioned certification method.



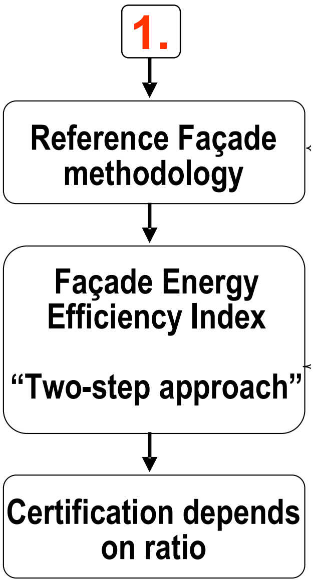


Figure 43 Certification method for façades.

The two-step approach in Figure 43 considers the use of the following two expressions.

$$1^{st}\ \text{Step ratio} = \frac{\text{Building energy need}\big|_{\text{Actual façade}}}{\text{Building energy need}\big|_{\text{Reference façade}}} \quad (1)$$

$$2^{nd}\ \text{Step ratio} = \frac{\text{Building demand energy}\big|_{\text{Actual façade and HVAC system}}}{\text{Building demand energy}\big|_{\text{Reference façade and HVAC system}}} \quad (2)$$

The first step equation (1), based on the (room) energy needs, assesses the energy performance of the actual façade against the reference façade, not taking into account the HVAC system used.

The second step equation (2), based on (system) demand energy, differs from the first step because it takes into account not only the actual façade, but also the actual HVAC system, its efficiency, and compares both these systems to reference ones.

The definition of reference façade, reference HVAC system and numerical simulation tools should be established at Member-State level, taking into account the specifics of building architecture and common construction materials in each country.

7 Conclusions

i) The Bestfaçade Project proposal sought to actively promote the concept of well-performing DSF based on a comprehensive survey of DSF in Europe.

This survey was made, but in regard to building energy performance the survey faced difficulties. Only a small number of buildings were able to provide the necessary data.

This difficulty in gathering energy performance data was a much debated issue. A confidentiality agreement was used and many recent DSF buildings appeared to have centralized building management systems from which energy consumption data could easily be gathered. Two fundamental conclusions regarding this issue were agreed upon:
- Energy data is a sensitive issue in commercially operated buildings and building owners may fear a breach in confidentiality agreement.
- Energy performance data expressed separately as energy for heating, cooling, lighting, ventilation, equipment, total energy is not easily available, as usually only the total energy use for heating and the total use of electricity are monitored. In most cases monitoring and/or simulations are essential to achieve the detail needed for energy benchmarking studies.

ii) The Bestfaçade Project proposal sought the collection of data (including energy data) for 30 buildings. Due to the difficulty discussed above (i) only 14 buildings (from Austria, Greece, Germany, Portugal and Sweden) were able to deliver enough data for energy benchmarking purposes. Further, this data was for buildings in different climate regions (5 buildings in Nordic climate, 4 buildings in Moderate climate and 5 buildings in the Mediterranean climate), not all of them had the same usage (only 11 were non-public office buildings), some data was from monitoring, some from energy bills, some from simulation and some from design and this data (energy delivered to the building) was given in different ways (e.g., electricity delivered, fossil fuel delivered, district heating or cooling delivered).

Given the in so many ways dispersed nature and reduced amount of data, the following conclusions were achieved:

- The set of data was unsuited for statistical treatment and a target energy consumption benchmark defined as the 50th percentile of the DSF buildings sample would therefore be meaningless.
- Energy benchmarking should be based on case study analysis and through the identification of clusters of best performing buildings.

iii) When DSF and SSF buildings energy consumptions are compared no clear distinction in the performance of the DSF buildings is noticeable. There are good as well as bad energy performing DSF buildings. This can be explained by differences in façade construction, but also other factors such as usage and other differences in construction or HVAC systems. This result agrees with the fact that SSF buildings with low glazed areas generally perform better than highly glazed SSF or DSF buildings, and that highly glazed DSF buildings can perform better than highly glazed SSF buildings (see Figure 31, Figure 32 and Figure 33).

iv) When comparing the energy performance of the DSF set of sampled buildings with known European energy benchmarks it is possible to identify buildings that perform better than the most demanding benchmarks (see Table 5).

The following table gathers the main comments on the studied DSF buildings.

Subject	**Comment**
Typology	An overall analysis of the case studies presented in this section 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.
Ventilation	The ventilation of the cavity of the façade seems to be a decisive factor in the success of the design. Different ventilation strategies are possible, from the more conventional outer skin bottom and top slits to the possibility of mechanically rotating (and opening) the outer skin.
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.
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.

v) Based on the analysis performed within WP3, the following energy benchmarks for DSF office buildings are proposed (Table 6 is here reproduced for convenience).

	Climate		
	Nordic	Moderate	Mediterranean
Heating with fossil fuel [kWh/(m^2 a)]	90	65	
Heating with electricity [kWh/(m^2 a)]			20
Cooling with electricity [kWh/(m^2 a)]	20	45	90
Electricity (except cooling) [kWh/(m^2 a)]	40	40	40
Total delivered (sum of the above)	150	150	150
Total (fossil fuel+electricity) [toe/(m^2 a)]	25×10^{-3}	30×10^{-3}	44×10^{-3}
Total CO_2 emissions [tCO_2e/(m^2 a)]	30×10^{-3}	36×10^{-3}	52×10^{-3}

vi) A certification method for façades could contribute to the implementation of best practices in DSF buildings and given the experience gathered in the Bestfaçade Project the reference façade method described in section 6 is the best suited (see Figure 43).

List of Acronyms

DSF, Double Skin Façade

EPBD, Energy Performance of Buildings Directive

EU, European Union

IEE, Intelligent Energy Europe (programme)

n.a., not available

PCA, Principal Component Analysis

SSF, Single Skin Façade

WP, Work Package

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Appendix

A.1 Climate normalization: Preliminary studies

A.1.1 Introduction

The normalization procedure considered was based on the heating and cooling degree day method.

The degree day method considers that climatic conditions can be related to the temperature difference between a base indoor temperature and the outdoor temperature multiplied by the duration of the temperature difference. This can be expressed in the following equations for heating and cooling degree days (the summing is made for non negative values only).

$$HDD = \sum_{t_{start}}^{t_{end}} \left(\theta_{HDD\_base} - \theta_e \right) \tag{A.1}$$

$$CDD = \sum_{t_{start}}^{t_{end}} \left(\theta_e - \theta_{CDD\_base} \right) \tag{A.2}$$

Where,

HDD stands for heating degree days [ºC days]

CDD stands for cooling degree days [ºC days]

θ_{HDD_base} stands for the base heating season space temperature [ºC]

θ_{CDD_base} stands for the base cooling season space temperature [ºC]

θ_e stands for the average outdoor temperature on daily basis [ºC]

t_{start} stands for the starting day of heating or cooling season [day]

t_{end} stands for the end day of heating or cooling season [day]

In general the length of the heating and cooling season and the base space temperatures are defined at a national level and differ from country to country, therefore it was necessary to use a methodology that allowed for a European climate normalization. This methodology considered the establishment of reference conditions for HDD and CDD values in different European cities.

For these cities a computational model (Hurley, 2005) was used to determine average values of normalized heating degree days (HDD^N) and cooling degree days (CDD^N) from 2000 to 2006.

In these calculations a 21ºC base indoor temperature for heating and cooling seasons was considered.

A reference for both the normalized HDD and CDD was defined (based on the HDD^N and CDD^N of the city closer to the average European HDD^N and CDD^N values) and a European climatic normalization factor was defined for each European city as below.

$$f_{HDD}^{City} = \frac{HDD^{N,RefCity}}{HDD^{N,City}} \quad \text{(A.3)}$$

$$f_{CDD}^{City} = \frac{CDD^{N,RefCity}}{CDD^{N,City}} \quad \text{(A.4)}$$

To obtain European city normalization for heating and cooling energy needs the following equations were considered.

$$Q_{Needs,Heating}^{N,City} = Q_{Needs,Heating} \cdot f_{HDD,city} \quad \text{(A.5)}$$

$$Q_{Needs,Cooling}^{N,City} = Q_{Needs,Cooling} \cdot f_{CDD,city} \quad \text{(A.6)}$$

The values of building energy consumption considered in the Bestfaçade project had different origins, and although the basis for building energy consumption data was established for the 2004 year, due to the lack of energy data other years were also considered. Also, some results where obtained considering computational simulation. So a normalization similar to the one presented for the European climate had to be considered to account for specific annual climate variations. This yearly dependent climatic factor was determined for each city from the equations below.

$$f_{HDD,City}^{Year} = \frac{HDD^{N,City}}{HDD^{City,Year}} \qquad (A.7)$$

$$f_{CDD,City}^{Year} = \frac{CDD^{N,City}}{CDD^{City,Year}} \qquad (A.8)$$

Therefore, for a specific year, the climate normalized energy delivered to a space is determined in the following way.

$$Q_{Needs,Heating}^{N,City,Year} = Q_{Needs,Heating} \cdot f_{HDD}^{City} \cdot f_{HDD,City}^{Year} \qquad (A.9)$$

$$Q_{Needs,Cooling}^{N,City,Year} = Q_{Needs,Cooling} \cdot f_{CDD}^{City} \cdot f_{CDD,City}^{Year} \qquad (A.10)$$

A.1.2 Climate normalization: Results

The TAPM programme (Hurley, 2005) was used to determine hourly outdoor air temperatures in different European cities, from the 2000 to the 2006 years. Indoor air comfort temperature was considered constant and equal to 21ºC, regardless of the season.

Table A. 1 resumes some results obtained with the TAPM programme.

Table A. 1 Heating and cooling degree days in European cites and corresponding *f* factors as defined in (A.3) and (A.4) considering regional climate (reg) or European climate (tot) normalization.

		HDDn,city [Kd]	HDDn,ref [Kd]	f cityH - reg	f cityH - tot	CDDn,city [Kd]	CDDn,ref [Kd]	f cityC - reg	f cityC - tot
Conti-nental	Kiev	3099,6		1,44	1,23	391,7		0,52	0,63
	Moscow	6043,0		0,74	0,63	83,4		2,42	2,97
	Warsaw	4209,6	4450,7	1,06	0,91	131,2	202,1	1,54	1,89
Nordic	Copenhagen	4482,2		1,09	0,85	37,4		1,00	6,63
	Helsinki	5503,6		0,88	0,70	15,2		2,45	16,24
	Oslo	3949,1		1,23	0,97	2,8		13,36	88,72
	Stockholm	4466,1		1,09	0,86	33,9		1,10	7,30
	Tallin	5436,9		0,89	0,70	41,4		0,90	5,98
	Vilnius	5346,0	4864,0	0,91	0,72	93,0	37,3	0,40	2,66
Moderate	Amsterdam	3862,1		1,00	0,99	70,2		3,35	3,53
	Berlin	4455,6		0,86	0,86	160,0		1,47	1,55
	Bern	3537,7		1,09	1,08	200,6		1,17	1,23
	Belgrade	3297,0		1,17	1,16	461,9		0,51	0,54
	Brussels	4013,0		0,96	0,95	136,5		1,72	1,81
	Bucharest	3321,5		1,16	1,15	244,3		0,96	1,01
	Budapest	3550,6		1,09	1,08	401,1		0,59	0,62
	London	3852,5		1,00	0,99	72,6		3,24	3,41
	Luxembourg	3615,9		1,07	1,06	254,1		0,93	0,97
	Munchen	4473,0		0,86	0,86	173,9		1,35	1,42
	Paris	3695,3		1,04	1,04	207,1		1,14	1,20
	Prague	4407,7		0,87	0,87	201,1		1,17	1,23
	Salzburg	4559,5		0,85	0,84	179,0		1,32	1,38
	Vienna	4026,1		0,96	0,95	270,5		0,87	0,92
	Zagreb	3136,8	3853,6	1,23	1,22	499,2	235,5	0,47	0,50
Mediterranean	Athens	1569,0		1,67	2,44	635,2		0,75	0,39
	Barcelona	3251,4		0,80	1,18	331,5		1,43	0,75
	Lisboa	2021,6		1,29	1,89	239,8		1,97	1,03
	Madrid	3579,4		0,73	1,07	370,7		1,28	0,67
	Rome	2465,2		1,06	1,55	521,8		0,91	0,47
	Kilkis	3213,4		0,81	1,19	499,8		0,95	0,50
	Salonika	2214,5	2616,4	1,18	1,73	714,6	473,3	0,66	0,35
Total			3827,6				247,6		

Considering the energy need values presented in Table A. 5 to Table A. 7 in Appendix A.3 and European climate normalization, the following figures compare DSF building energy performance with and without climate normalization.

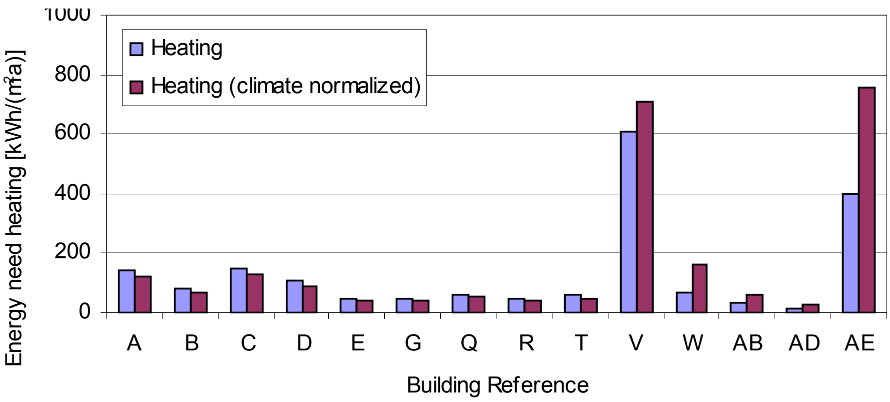


Figure A. 1 Heating energy needs per DSF sample building with and without climate normalization – Alphabetic order.

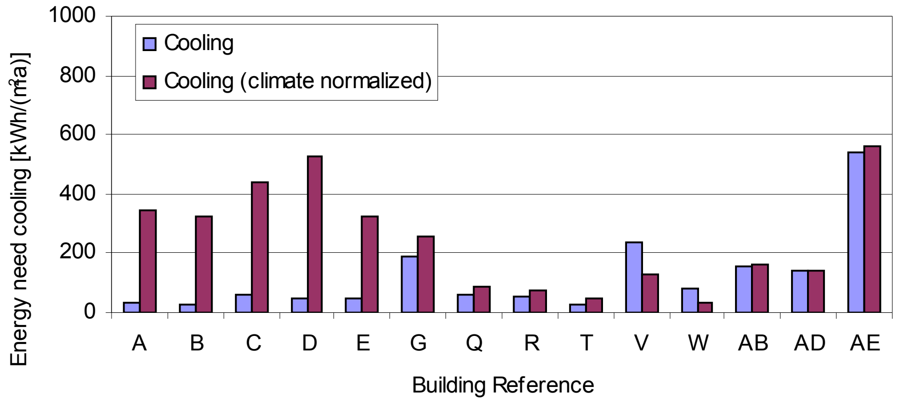


Figure A. 2 Cooling energy needs per DSF sample building with and without climate normalization – Alphabetic order.

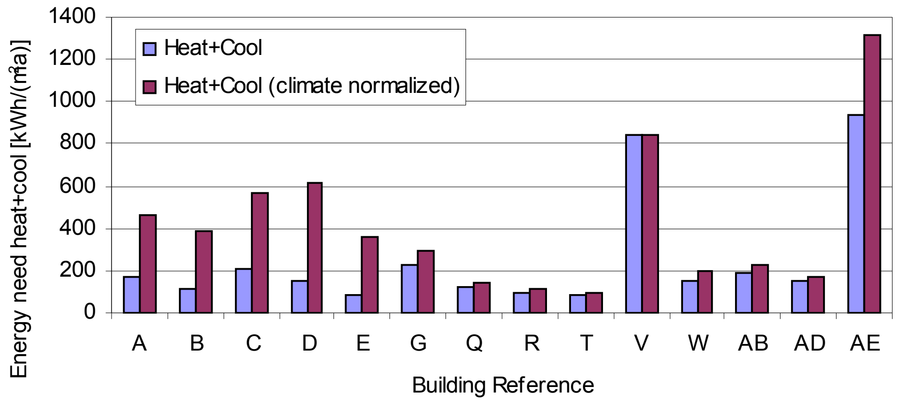


Figure A. 3 Heating plus cooling energy needs per DSF sample building with and without climate normalization – Alphabetic order.

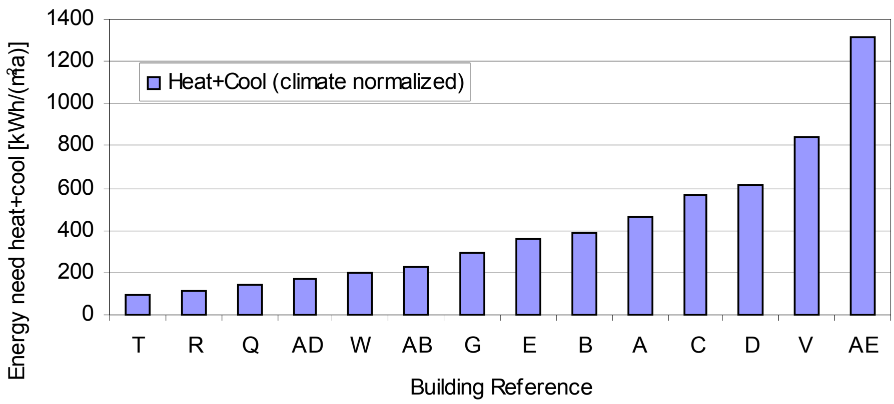


Figure A. 4 Heating plus cooling energy needs per DSF sample building with climate normalization – Ordered from low high delivered energy building.

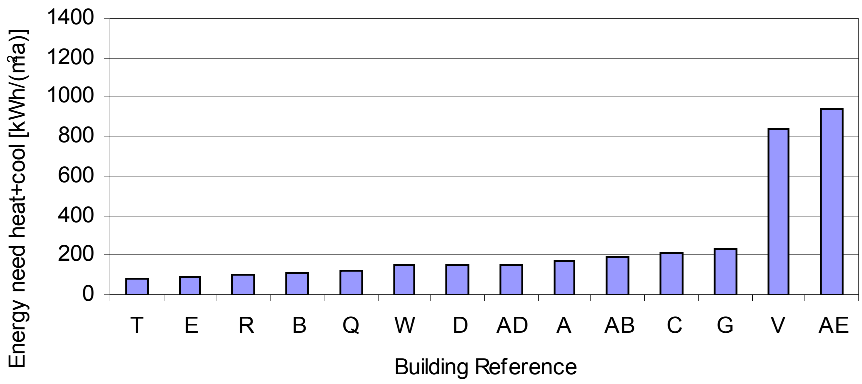


Figure A. 5 Heating plus cooling energy needs per DSF sample building without climate normalization – Ordered from low high delivered energy building.

A.2 Framework for data collection: Questionnaires

A.2.1 Short version questionnaire (façade attributes)

Short Version of Typology (first round)

	person in charge to fill in the form	
1	name	
2	institution	
3	phone	
4	e-mail	
5	date of version:	

		name		orientation		utilization	
6	**short name of facade:**		/		/		info

7 typical photo(s) of the facade: file or comment

information on the building

	address		file or comment
8	country (name in English)		
9	city		
10	postcode		
11	street		
12	house number		

	general			file or comment
13	name (identification) of building			
14	year of completion of building			
15	height of the building above ground level		m	
16	width of the building (diameter)		m	
17	length of the building (diameter)		m	
18	total gross storey area		m²	

	engaged institutions			file or comment
19	owner		name city	
20	erecting company		name city	
21	operating company		name city	
22	architect		name city	
23	energy conception		name city	
24	HVAC		name city	
25	static's		name city	
26	building physics		name city	
27	acoustics		name city	
28	fire protection		name city	
29	aerodynamics		name city	
30	facility manager		name city	
31	other engaged institutions		name city	

room heating system

						file or comment
32	heat supply components	☐ under floor convector ☐ radiator	☐ floor heating ☐ hot air heating	☐ overhead radiation heating ☐ activated concrete core	info	
33	type of used energy	☐ gas/oil ☐ heating network	☐ electricity ☐ solar	☐ biomass ☐ other	info	
34	set temperature room heating			°C	info	
35	are the users able to influence the temperature			please select		
36	space heating consumption			kWh/m²a	info	

room cooling system

						file or comment
37	cooling supply components	☐ under floor convector ☐ no cooling system	☐ floor cooling ☐ cold air cooling	☐ overhead radiation cooling ☐ activated concrete core	info	
38	type of used energy	☐ gas ☐ heating network	☐ electricity ☐ solar	☐ biomass ☐ other	info	
39	cooling category temperature			°C	info	
40	are the users able to influence the temperature			please select		
41	space cooling consumption			kWh/m²a	info	

room ventilation system

				file or comment
42	ventilation is operated by	☐ opening windows into the gap ☐ opening windows to the outside by-passing the gap ☐ mechanical powered air conditioning system		
43	air change rate of mechanical ventilation	during normal trading hours h^{-1} off time normal trading hours h^{-1} in summer nights h^{-1}		
44	the air conditioning system is able to …	☐ humidify ☐ dehumidify ☐ neither nor		
45	are the users able to influence the air change	please select		

local energy tariff

				file or comment
46	natural gas/oil		€ / kWh	
47	electricity at peak time		€ / kWh	
48	electricity outside peak time		€ / kWh	
49	biomass		€ / kWh	
50	heating network		€ / kWh	
51	other …		€ / kWh	

information on the façade

basic geometry of the whole facade

					file or comment
52	width (wf)		m		
53	height facade up to top edge (hf)		m		
54	height bottom building (hb)		m		
55	height of ground level (hg)		m	info	
56	height between floors (fh)		m		
57	number of stories behind the facade		-		
58	width of gap (wg)		m		

ventilation type of facade *(following BBRI, 2005)*			file or comment
59	type of ventilation of the gap (only 1 per facade)	choose item	info

Partitioning of the gap of the facade (only 1 per façade) (*following BBRI, 2005*)

Choose one of the seven following possibilities : info

file or comment

60

☐ 1) Ventilated double window

height of the window		m	width of the window		m	info

☐ 2) Facade partitioned per storey with juxtaposed modules

height of the module		m	width of the module		m	info

☐ 3) Facade partitioned per storey - corridor type

height of the corridor		m	width of the corridor		m	info

☐ 4) 'Shaft-box' facade

height of the box		m	width of the box		m	info

☐ 5) 'Multi-storey' facade

height of the storey		m	width of the storey		m	info

☐ 6) 'Multi-storey louver' facade

height of the storey		m	width of the storey		m	info

☐ 7) Other

please insert a sketch:

please describe:

costs file or comment

61	facade erection costs		€/m²a	
62	cleaning costs		€/m²a	
63	secure attendance costs		€/m²a	

A.2.2 Long version questionnaire (façade and other attributes)

A location

info to structure

address

file or comment

1	country (name in English)	
2	city	
3	postcode	
4	street	
5	house number	

6 please insert a ground plan if available

geographical position

file or comment

7	altitude above sea level		m		
8	latitude		degree		minutes
9	longitude		degree		minutes

climate data (on site measured data preferred)

air temperature

file or comment

10	maximum in the last ten years		°C	approx.
11	minimum in the last ten years		°C	approx.

12 typical average monthly temperatures [°C]

jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	
												graph

average annual temperature: #DIV/0! °C

13 typical hot and bright summer day
[hourly values in °C]

1	2	3	4	5	6	7	8	9	10	11	12	
13	14	15	16	17	18	19	20	21	22	23	24	graph

24 hour average temperature: 0.0 °C

14 typical cold and cloudy winter day
[hourly values in °C]

1	2	3	4	5	6	7	8	9	10	11	12	
13	14	15	16	17	18	19	20	21	22	23	24	graph

24 hour average temperature: 0.0 °C

solar irradiation

file or comment

15 sum of total radiation on the horizontal in an average year | | kWh/m²a | info

16 total radiation on the horizontal on a typical hot and bright summer day
related to climate of question number 12
[hourly values in W/m²]

1	2	3	4	5	6	7	8	9	10	11	12	
13	14	15	16	17	18	19	20	21	22	23	24	graph

17 total radiation on the horizontal on a typical cold and cloudy winter day
related to climate of question number 13
[hourly values in W/m²]

1	2	3	4	5	6	7	8	9	10	11	12	
13	14	15	16	17	18	19	20	21	22	23	24	graph

air moisture

file or comment

18	yearly minimum		%
19	annual average humidity		%

20 relative humidity
on a typical hot and bright summer day
related to climate of question number 12
[hourly values in %]

1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24

graph

21 relative humidity
on a typical cold and cloudy winter day
related to climate of question number 13
[hourly values in %]

1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24

graph

wind

file or comment

22	main wind direction		please choose direction from the list	info
23	maximum wind velocity in 10 meter height (v_{10})		m/sec	info
24	average wind velocity in 10 meter height (v_{10})		m/sec	info
25	maximum wind velocity on the top of the facade		m/sec	info

noise and air quality

file or comment

26	ambient noise level L_{equ} (day / night)		dB (A)

27 surroundings

- ☐ big city
- ☐ main street(s)
- ☐ industrial area
- ☐ small town / village

B information on the building

info to structure

general

file or comment

28	identification of building			
29	year the design process started			
30	year of completion of building			
31	height of the building above ground level		m	info
32	width of the building (diameter)		m	
33	length of the building (diameter)		m	
34	total gross storey area		m²	

engaged institutions

file or comment

35	owner		name city
36	erecting company		name city
37	operating company / building promoter		name city
38	architect		name city
39	energy conception		name city
40	HVAC		name city
41	static's		name city
42	building physics		name city
43	acoustics		name city
44	fire protection		name city
45	aerodynamics		name city
46	facility manager		name city
			name city

info

	utilisation					file or comment
48	utilisation of the considered rooms behind the facade (please check only one item)	☐ residential	☐ office public	☐ office non public		
		☐ selling	☐ services	☐ production		
		☐ industry	☐ hotel	☐ school		
		☐ other ...				

	room heating system				
49	heat supply components	☐ under floor convector	☐ floor heating	☐ overhead radiation heating	info
		☐ radiator	☐ hot air heating	☐ activated concrete core	
50	type of used energy	☐ gas/oil	☐ electricity	☐ biomass	info
		☐ district heating net	☐ solar	☐ other	
51	set point temperature heating			°C	info
52	are the users able to influence the temperature			please select	info
53	space heating demand			kWh/m²a	info

	room cooling system				
54	cooling supply components	☐ under floor convector	☐ floor cooling	☐ overhead radiation cooling	info
		☐ no cooling system	☐ cold air cooling	☐ activated concrete core	
55	type of used energy	☐ gas	☐ electricity	☐ biomass	info
		☐ district heating net	☐ solar	☐ other	
56	set point temperature cooling			°C	info
57	are the users able to influence the temperature			please select	info
58	cooling demand			kWh/m²a	info

	room ventilation system				
59	ventilation is operated by	☐ opening windows into the gap			
		☐ opening windows to the outside by-passing the gap			
		☐ air conditioning system			
60	air change rate of mechanical ventilation	during normal office hours		h^{-1}	info
		off time normal office hours		h^{-1}	
		in summer nights		h^{-1}	
61	the air conditioning system is able to …	☐ humidify	☐ dehumidify	☐ neither nor	info
62	are the users able to influence the air change			please select	info

63	uncomfortable air temperature inside the rooms	no	yes .. in	winter	spring	summer	autumn	no data	info
		further description:							
64	uncomfortable airflow inside the rooms	no	yes .. in	winter	spring	summer	autumn	no data	info
		further description:							
65	radiative asymmetry the rooms	no	yes .. inside	winter	spring	summer	autumn	no data	info
		further description:							
66	glare problems inside the rooms	no	yes .. in	winter	spring	summer	autumn	no data	info
		further description:							
67	acoustic disturbance from outside	no	yes .. in	winter	spring	summer	autumn	no data	info
		further description:							
68	acoustic disturbance from inside (telephony effect)	no	yes .. in	winter	spring	summer	autumn	no data	info
		further description:							
69	too much or too less transparency to outside	no	yes .. in	winter	spring	summer	autumn	no data	info
		further description:							
70	perspiration water formation	no	yes .. in	winter	spring	summer	autumn	no data	info
		further description:							

measured data

71 year of the measured data — info

72 time period — info

summer	winter
one day	one day
one week	one week
other .. from: to:	other .. from: to:

73	position of the measured data	outside	outer shell	facade gap	inner shell	inside	
74	temperature [hourly values °C]	yes / no		yes / no		yes / no	info
75	relative humidity [hourly values %]	yes / no		yes / no		yes / no	info
76	sound level [hourly values dB]	yes / no		yes / no		yes / no	info

77 file name, including the measured data — info

C general information on the facade

info to structure

general

file or comment

78	erected in accordance with the building or for means of renovation ?	choose item	
79	orientation of the facade	choose direction	
80	immediate vicinity	choose item	info
81	U-value (mean of facade)	W/m²K	
82	sound absorption rate (mean of facade)	dB(A)	

shading

83	the facade is shaded by	☐ buildings ☐ topography ☐ plants
84	period of the day with direct solar radiation on the facade on a typical bright summer day	direct radiation from ___ to ___
85	period of the day with direct solar radiation on the facade on a typical sunny winter day	direct radiation from ___ to ___

basic geometry of the whole facade

file or comment

86	width (wf)	m		
87	height facade up to top edge (hf)	m	Area m²	
88	height bottom building (hb)	m		
89	height of ground level (hg)	m		info
90	height between floors	m		
91	number of stories behind the facade	-		
92	width of gap (wg)	m		

ventilation type of façade *(following BBRI, 2005)*

file or comment

93	type of ventilation of the gap (only 1 per facade)	choose item	info

Partitioning of the gap of the façade (only 1 per façade) *(following BBRI, 2005)*

Choose one of the seven following possibilities : info

file or comment

94	☐ 1) Ventilated double window	height of the window	m	width of the window	m	info
95	☐ 2) Facade partitioned per storey with juxtaposed modules	height of the module	m	width of the module	m	info
96	☐ 3) Facade partitioned per storey - corridor type	height of the corridor	m	width of the corridor	m	info
97	☐ 4) 'Shaft-box' facade	height of the box	m	width of the box	m	info
98	☐ 5) 'Multi-storey' facade	height of the storey	m	width of the storey	m	info
99	☐ 6) 'Multi-storey louver' facade	height of the storey	m	width of the storey	m	info

☐ 7) Other

please insert a sketch:

please describe:

100

antiglare device

101 design

- ☐ no shading system
- ☐ canvas screens
- ☐ Venetian blind
- ☐ wings
- ☐ other ...

102 please mark the position of the device

outside	outer shell		facade gap		inner shell	inside
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7

103 percentage of heat transmission when activated (g value) ______ %

104 reflectance when activated ______ %

105 control system

- ☐ no control system
- ☐ manual driven operated by occupants
- ☐ driven by engine and operated by occupants
- ☐ mechanical controlled with possibility to overrule by occupants
- ☐ mechanical controlled without possibility to overrule by occupants

daylight control systems

106 design

- ☐ no daylight control system
- ☐ prism
- ☐ segments
- ☐ light swords
- ☐ other

107 please mark the position of the shield

outside	outer shell		facade gap		inner shell	inside
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7

108 daylight quotient when activated ______ Tq

109 reflectance when activated ______ %

110 control system

- ☐ no control system
- ☐ manual driven operated by occupants
- ☐ driven by engine and operated by occupants
- ☐ mechanical controlled with possibility to overrule by occupants
- ☐ mechanical controlled without possibility to overrule by occupants

sound absorbers inside the gap

111
- ☐ no sound absorbers installed
- ☐ sound absorbers installed

112 location

please insert a drawing (sketch)
of sound absorber here

113 please describe the material ______

further systems of building automation or fixtures in the facade

114	fire protection system	☐ no fire protection ☐ fire- / smoke detector ☐ sprinkler ☐ other ... description	
115	active solar systems	☐ no ☐ yes ... description	
116	photovoltaic	☐ no ☐ yes ... description	
117	pluvial protection devices	☐ no ☐ yes ... description	
118	radar damping system	☐ no ☐ interference ☐ absorption ☐ yes ... description	
119	other	☐ no ☐ yes ... description	

D construction of the facade

info to structure

Please describe the most important sections (do not forget the shading system)

section 1

120

inside	width		material		file or comment
layer 01		cm			
layer 02		cm			
layer 03		cm			
layer 04		cm			
layer 05		cm			
layer 06		cm			
layer 07		cm			
layer 08		cm		info	
layer 09		cm			
layer 10		cm			
layer 11		cm			
layer 12		cm			
layer 13		cm			
layer 14		cm			
layer 15		cm			
outside					

121	U-value of section 1		W/m²K	info
122	sound absorption rate		db	info
123	g-value without activated shading system		%	info
124	light transmittance Tau L without activated shading system		%	info
125	g-value with activated shading system		%	info
126	light transmittance Tau L with activated shading system		%	info
127	fraction of section 1 on the outside surface area		%	info

section 2

	inside	width		material		file or comment
	layer 01		cm			
	layer 02		cm			
	layer 03		cm			
	layer 04		cm			
	layer 05		cm			
	layer 06		cm			
	layer 07		cm			
128 please insert a drawing (sketch) of section 2 here	layer 08		cm		info	
	layer 09		cm			
	layer 10		cm			
	layer 11		cm			
	layer 12		cm			
	layer 13		cm			
	layer 14		cm			
	layer 15		cm			
	outside					

129	U-value of section 2		W/m²K	info	
130	sound absorption rate		db	info	
131	g-value without activated shading system		%	info	
132	light transmittance Tau L without activated shading system		%	info	
133	g-value with activated shading system		%	info	
134	light transmittance Tau L with activated shading system		%	info	
135	fraction of section 2 on the outside surface area		%	info	

section 3

	inside	width		material		file or comment
	layer 01		cm			
	layer 02		cm			
	layer 03		cm			
	layer 04		cm			
	layer 05		cm			
	layer 06		cm			
	layer 07		cm			
136 please insert a drawing (sketch) of section 3 here	layer 08		cm		info	
	layer 09		cm			
	layer 10		cm			
	layer 11		cm			
	layer 12		cm			
	layer 13		cm			
	layer 14		cm			
	layer 15		cm			
	outside					

137	U-value of section 3		W/m²K	info	
138	sound absorption rate		db	info	
139	g-value without activated shading system		%	info	
140	light transmittance Tau L without activated shading system		%	info	
141	g-value with activated shading system		%	info	
142	light transmittance Tau L with activated shading system		%	info	
143	fraction of section 3 on the outside surface area		%	info	

E routing of air flow in the facade

info to structure

projected main flow direction in the gap

		summer	winter
144	vertical	☐	☐
145	diagonal	☐	☐
146	horizontal	☐	☐
147	none	☐	☐

summer activity

148 rate of air change in the gap day ____ h^{-1} night ____ h^{-1}

149 wind energy inside the gap ____ % of outside wind energy

winter activity

150 rate of air change in the gap day ____ h^{-1} night ____ h^{-1}

151 wind energy inside the gap ____ % of outside wind energy

ventilation openings in outer shell

152 for supply air ☐ yes ☐ no net area ____ cm²/m Facade

153 for exhaust air ☐ yes ☐ no net area ____ cm²/m Facade

154 net area different depending on location within height of facade ☐ yes ☐ no

155 type ☐ windows ☐ shutters ☐ segments ☐ grids ☐ other...

156 closable ☐ yes ☐ no

157 type of control

158 setting points

159 ventilator ☐ no ☐ for supply air ☐ for exhaust air

160 rate of air flow ____ m³/h

161 type of control

162 setting points

163 air filter ☐ yes ☐ no

164 smoke ventilation system ☐ yes ☐ no rate of air flow ____ m³/h

165 leak tightness of ventilation openings data available ☐ yes ☐ no

166 please specify

inner shell opens into the gap

167	for supply air	☐ yes ☐ no net area cm²/m Facade
168	for exhaust air	☐ yes ☐ no net area cm²/m Facade
169	net area different depending on location within height of facade	☐ yes ☐ no
170	type	☐ windows ☐ lamella ☐ other...
171	closable	☐ yes ☐ no
172	type of control	
173	setting points	
174	ventilator	☐ no ☐ for supply air ☐ for exhaust air
175	rate of air flow	m³/h
176	type of control	
177	setting points	
178	air filter	☐ yes ☐ no
179	smoke ventilation system	☐ yes ☐ no rate of air flow m³/h
180	leak tightness of ventilation openings	data available ☐ yes ☐ no
181	please specify	

F maintenance

info to structure

shells

outside	outer shell	facade gap	inner shell	inside
1		2	3	4

182	cleaning of surface 1	☐ by building cradle ☐ by lifting platform ☐ by cleaning robot ☐ from the gap ☐ other.... ☐ no cleansing interval a^{-1} (times per year) — info
183	cleaning of surface 2	☐ from maintenance corridor ☐ from the interior ☐ no cleansing interval a^{-1} (times per year) — info
184	cleaning of surface 3	☐ from maintenance corridor ☐ from the interior ☐ no cleansing interval a^{-1} (times per year) — info
185	cleansing of surface 4	interval a^{-1} (times per year)
186	service-intervals of surface 1	a^{-1} (times per year)
187	service-intervals of surface 2	a^{-1} (times per year)
188	service-intervals of surface 3	a^{-1} (times per year)
189	service-intervals of surface 4	a^{-1} (times per year)

facade fixtures

	type	cleaning-interval	service-interval
190		a^{-1} (times per year)	a^{-1} (times per year)
191		a^{-1} (times per year)	a^{-1} (times per year)
192		a^{-1} (times per year)	a^{-1} (times per year)
193		a^{-1} (times per year)	a^{-1} (times per year)
194		a^{-1} (times per year)	a^{-1} (times per year)
195		a^{-1} (times per year)	a^{-1} (times per year)

G costs

info to structure

erection costs facade

section 1

	inside	width	material		costs €/m²
	layer 01	cm			
	layer 02	cm			
	layer 03	cm			
	layer 04	cm			
	layer 05	cm			
	layer 06	cm			
	layer 07	cm			
196	layer 08	cm		info	
	layer 09	cm			
	layer 10	cm			
	layer 11	cm			
	layer 12	cm			
	layer 13	cm			
	layer 14	cm			
	layer 15	cm			
	outside				- €/m²

197 Summary costs of section 1 | ND | €/m² | info

section 2

please insert a drawing (sketch) of section 2 here

	inside	width	material		costs €/m²
	layer 01	cm			
	layer 02	cm			
	layer 03	cm			
	layer 04	cm			
	layer 05	cm			
	layer 06	cm			
	layer 07	cm			
198	layer 08	cm		info	
	layer 09	cm			
	layer 10	cm			
	layer 11	cm			
	layer 12	cm			
	layer 13	cm			
	layer 14	cm			
	layer 15	cm			
	outside				- €/m²

199 Summary costs of section 1 | | €/m² | info

section 3

please insert a drawing (sketch) of section 3 here

	inside	width	material		costs €/m²
	layer 01	cm			
	layer 02	cm			
	layer 03	cm			
	layer 04	cm			
	layer 05	cm			
	layer 06	cm			
	layer 07	cm			
200	layer 08	cm		info	
	layer 09	cm			
	layer 10	cm			
	layer 11	cm			
	layer 12	cm			
	layer 13	cm			
	layer 14	cm			
	layer 15	cm			
	outside				- €/m²

€/m²

maintenance costs

local energy tariff

201	natural gas/oil		€ / m³
202	electricity at peak time		€ / kWh
203	electricity outside peak time		€ / kWh
204	biomass		€ / kWh
205	heating network		€ / kWh
206	other …		

specific costs

207	heating for the rooms behind the facade		€ /m²a
208	cooling for the rooms behind the facade		€ /m²a
209	ventilation for the rooms behind the facade		€ /m²a
210	lightning for the rooms behind the facade		€ /m²a
211	other …		€ /m²a
212	cleaning costs		€ /m²a
213	attendance costs		€ /m²a

A.2.3 Long version questionnaire (extension December 2005)

	room heating system		
62	space heating demand (calculated)		kWh/m²a
62a	space heating consumption (measured)		kWh/m²a

	room cooling system		
68	space cooling demand (calculated)		kWh/m²a
68a	space cooling consumption (measured)		kWh/m²a

	electricity		
69a	electricity demand HVAC/m² gross storey area		kWh/m²a
70a	space lighting demand/m² gross storey area		kWh/m²a
69	electricity consumption HVAC/m² gross storey area		kWh/m²a
70	space lighting consumption/m² gross storey area		kWh/m²a

76	space ventilation demand		kWh/m²a
76a	space ventilation consumption		kWh/m²a

138	U-value of complete facade section 1		W/m²K
138a	U-value of outer shell of section 1 (if DSF section)		W/m²K
138b	U-value of inner shell of section 1 (if DSF section)		W/m²K
139	sound absorption rate		db
140	g-value of complete facade without activated shading system		%
140a	g-value of outer shell section 1 (if DSF section) without shading		%
140b	g-value of inner shell section 1 (if DSF section) without shading		%
141	light transmittance facade Tau L without activated shading system		%
142	g-value of complete facade with activated shading system		%
143	light transmittance facade Tau L with activated shading system		%

146	U-value of complete facade section 2		W/m²K
146a	U-value of outer shell of section 2 (if DSF section)		W/m²K
146b	U-value of inner shell of section 2 (if DSF section)		W/m²K
147	sound absorption rate		db
148	g-value of complete facade without activated shading system		%
148a	g-value of outer shell section 2 (if DSF section) without shading		%
148b	g-value of inner shell section 2 (if DSF section) without shading		%
149	light transmittance facade Tau L without activated shading system		%
150	g-value of complete facade with activated shading system		%
151	light transmittance facade Tau L with activated shading system		%

154	U-value of complete facade section 3		W/m²K
154a	U-value of outer shell of section 3 (if DSF section)		W/m²K
154b	U-value of inner shell of section 3 (if DSF section)		W/m²K
155	sound absorption rate		db
156	g-value of complete facade without activated shading system		%
156a	g-value of outer shell section 3 (if DSF section) without shading		%
156b	g-value of inner shell section 3 (if DSF section) without shading		%
157	light transmittance facade Tau L without activated shading system		%
158	g-value of complete facade with activated shading system		%
159	light transmittance facade Tau L with activated shading system		%

A.2.4 Comfort questionnaire (summer)

SUMMER QUESTIONNAIRE	Nr
Building:	Date:

The objective of this questionnaire is to characterize the environmental comfort conditions existing in *Double Skin Façade* buildings (DSF buildings) in Europe. We thank you very much for your collaboration in filling it attentively.
All answers are strictly confidential.

DURING SUMMER, IN YOUR WORKPLACE:

1. Choose five of the factors mentioned below that you consider more important for your satisfaction in the working environment during Summer (by order of importance):

a) Noise level
b) Ventilation
c) Outside visibility
d) Temperature
e) Daylight
f) Electric light
g) Decoration/furniture
h) Privacy
i) Location of working space
j) Other (which?)_________________

1st	2nd	3rd	4th	5th

2. Overall, how satisfied are you with the temperature at your workplace during Summer?
(please tick the correct answer)

( ) Very satisfied
( ) Satisfied
( ) Dissatisfied
( ) Very dissatisfied

3. About how often do you feel too hot during Summer in your workplace? *(please tick the correct answer)*

( ) Very often
( ) Often
( ) Sometimes
( ) Rarely

4. And around how often do you feel uncomfortably cold during Summer? *(please tick the correct answer)*

( ) Very often
( ) Often
( ) Sometimes
( ) Rarely

5. How do you generally feel during Summer? *(please tick the correct answer)*

( ) Cold
( ) Cool
( ) Slightly cool
( ) Neither cool nor warm
( ) Slightly warm
( ) Warm
( ) Hot

6. Generally, during Summer, would you prefer to feel cooler, warmer, or are you OK?
(please tick the correct answer)

( ) Much cooler
( ) Cooler
( ) Slightly cooler
( ) I'm OK
( ) Slightly warmer
( ) Warmer
( ) Much warmer

7. In the morning, during Summer, when you arrive at your workplace, would you prefer to feel cooler, warmer, or are you OK? *(please tick the correct answer)*

( ) Much cooler
( ) Cooler
( ) Slightly cooler
( ) I'm OK
( ) Slightly warmer
( ) Warmer
( ) Much warmer

8. How easy is it for you to perform the following actions, in order to feel more comfortable?
(please tick the appropriate answer for each of the cases)

	Easy	Difficult	Impossible
Open/close/adjust windows or air intake from windows			
Adjust shading (binds, curtains)			
Use a fan			
Regulate the air conditioning			
Change to a workplace far from the window			
Have a cold drink			
Take off / Put on clothing			

9. If it is (*or was*) possible, how often do you (*or would you*) perform the following actions, in order to feel more comfortable? *(please tick the appropriate answer for each of the cases)*

	Very often	Often	Sometimes	Rarely
Open/close/adjust windows or air intake from windows				
Adjust shading (binds, curtains)				
Use a fan				
Regulate the air conditioning				
Change to a workplace far from the window				
Have a cold drink				
Take off clothing to feel cooler				
Put on clothing to feel warmer				

10. If you can (*or could*) open windows or adjust air intake from them, when you open/adjust them it is (*or would be*) mostly to: ? *(please tick the correct answer)*

( ) Feel cooler
( ) Let the warmer air in
( ) Ventilate the room
( ) Other (which?)______________

11. If you can (*or could*) open windows or adjust air intake from them but you usually leave them closed/unadjusted it is (*or would be*) mostly because: *(please tick the appropriate answers)*

( ) Hot air comes in
( ) Cold air comes in
( ) You don't need to open them
( ) Because of the air conditioning
( ) They cause drafts
( ) It is too noisy outside
( ) It is too polluted outside
( ) Other (which?)____________

12. If you draw/adjust shading (curtains, blind, etc.) it is (*or would be*) mostly because:
(please tick the appropriate answers)

( ) It is too hot
( ) Because of glare
( ) Undesired reflections of the sunlight (e.g., on computer screen)
( ) For privacy
( ) Other (which?)____________

13. If your office has air conditioning how good is the air conditioning environmental performance?
(please tick the appropriate answers)

( ) It generally works quite well
( ) It shouldn't be so cold
( ) It causes uncomfortable drafts
( ) It makes the air stuffy
( ) It is too noisy
( ) Sometimes it works irregularly, causing temperature discomfort
( ) It should provide more cooling
( ) It causes uncomfortable temperature differences with the outside
( ) It causes an unnatural environment
( ) It makes you sick
( ) Other (which?)____________

14. What do you think about the use of air conditioning in your office? *(please tick the correct answer)*

( ) It is essential for your comfort
( ) It is essential for the prestige of the office
( ) It is better then nothing
( ) You would prefer a more natural alternative
( ) You rather not have it
( ) Other (which?)_______________

15. If you change to a workplace far from the window it is (*or would be*) mostly because:
(please tick the appropriate answers)

( ) It is too hot near the window
( ) Because of glare
( ) Undesired reflections of the sunlight (e.g., on computer screen)
( ) For privacy
( ) Other (which?)____________

16. When you turn on the room or your desk lights it is because: *(please tick the appropriate answers)*

( ) Closing the shading the room gets dark
( ) Natural light is insufficient
( ) It is the usual procedure
( ) Other (which?)________________

17. During Summer, do you regularly feel any of the health symptoms presented below while you are at work? *(please tick the appropriate answers)*

( ) Headaches
( ) Irritated throat
( ) Lack of concentration
( ) Nose irritation
( ) Dry or chapped lips
( ) Chills
( ) Nausea
( ) Lethargy
( ) Dizziness
( ) Skin irritation
( ) Eye irritation
( ) None of these

18. What kind of clothes do you generally wear during Summer in your workplace?
(please tick the appropriate answers)

( ) Open footwear
( ) Shoes
( ) Tights
( ) Stocks
( ) Underwear shirt
( ) Skirt / shorts
( ) Light Summer Trousers
( ) Fabric trousers or jeans/skirt
( ) Summer short sleeve dress
( ) T-shirt
( ) Short sleeve shirt/blouse
( ) Long sleeve shirt/blouse
( ) Blazer
( ) Tailleur
( ) Suit
( ) Jacket
( ) Pull-over
( ) Other (which?)_______________

19. What do you think about the performance of the double skin façade in your office during Summer? *(please tick the correct answer)*

( ) It is essential for your comfort
( ) It is essential for the prestige of the office
( ) You never heard of it
( ) You rather not have it
( ) Other (which?)_______________

20. Where is your workplace located? *(please tick the correct answer)*

( ) Close to the exterior windows (less than 2 meters apart) and *facing* the windows
( ) Close to the exterior windows (less than 2 meters apart) and *sideways* from the windows
( ) Close to the exterior windows (less than 2 meters apart) and *backward* from the windows
( ) Far from the exterior windows (more than 2 meters apart)
( ) Other (which?)___________________

21. What is your general opinion of your workplace in terms of comfort during Summer:

Very Good	Good	Regular	Poor	Very Poor

22. Do you have any suggestions about what could be done to improve the comfort conditions in your workplace during Summer?____
____
____

DURING SPRING, IN YOUR WORKPLACE:

22. Overall, how satisfied are you with the temperature at your workplace during Spring?
(please tick the correct answer)

( ) Very satisfied
( ) Satisfied
( ) Dissatisfied
( ) Very dissatisfied

23. Generally, during Spring, would you prefer to feel cooler, warmer, or are you OK?
(please tick the correct answer)

( ) Much cooler
( ) Cooler
( ) Slightly cooler
( ) I'm OK
( ) Slightly warmer
( ) Warmer
( ) Much warmer

24. Comparing with Summer, are you in Spring more comfortable, less comfortable or equally comfortable? *(please tick the correct answer)*

( ) More comfortable ( ) Less comfortable ( ) Equally comfortable

25. If you are *less comfortable* in Spring choose three reasons mentioned below that you consider more important for your satisfaction in the working environment (by order of importance):

a) Ventilation
b) Temperature
d) Daylight
e) Privacy
h) Other (which?)________________
j) Other (which?)_________________

1st	**2nd**	**3rd**

THANK YOU VERY MUCH

A.2.5 Comfort questionnaire (winter)

WINTER QUESTIONNAIRE Nr ____________________
Building: Date:

The objective of this questionnaire is to characterize the environmental comfort conditions existing in *Double Skin Façade* buildings (DSF buildings) in Europe. We thank you very much for your collaboration in filling it attentively.
All answers are strictly confidential.

DURING WINTER, IN YOUR WORKPLACE:

1. Choose five of the factors mentioned below that you consider more important for your satisfaction in the working environment during Winter (by order of importance):

a) Noise level
b) Ventilation
c) Outside visibility
d) Temperature
e) Daylight
f) Electric light
g) Decoration/furniture
h) Privacy
i) Location of working space
j) Other (which?)_________________

1st	2nd	3rd	4th	5th

2. Overall, how satisfied are you with the temperature at your workplace during Winter?
(please tick the correct answer)

( ) Very satisfied
( ) Satisfied
( ) Dissatisfied
( ) Very dissatisfied

3. About how often do you feel too cold during Winter in your workplace? *(please tick the correct answer)*

( ) Very often
( ) Often
( ) Sometimes
( ) Rarely

4. And around how often do you feel uncomfortably hot during Winter? *(please tick the correct answer)*

( ) Very often
( ) Often
( ) Sometimes
( ) Rarely

5. How do you generally feel during Winter? *(please tick the correct answer)*

( ) Hot
( ) Warm
( ) Slightly warm
( ) Neither warm nor cool
( ) Slightly cool
( ) Cool
( ) Cold

6. Generally, during Winter, would you prefer to feel warmer, cooler, or are you OK?
(please tick the correct answer)

( ) Much warmer
( ) Warmer
( ) Slightly warmer
( ) I'm OK
( ) Slightly cooler
( ) Cooler
( ) Much cooler

7. In the morning, during Winter, when you arrive at your workplace, would you prefer to feel warmer, cooler, or are you OK? *(please tick the correct answer)*

( ) Much warmer
( ) Warmer
( ) Slightly warmer
( ) I'm OK
( ) Slightly cooler
( ) Cooler
( ) Much cooler

8. How easy is it for you to perform the following actions, in order to feel more comfortable?
(please tick the appropriate answer for each of the cases)

	Easy	Difficult	Impossible
Open/close/adjust windows or air intake from windows			
Adjust shading (binds, curtains)			
Use a local heating device			
Regulate the heating system			
Change to a workplace far from the window			
Take off / Put on clothing			

9. If it is (*or was*) possible, how often do you (*or would you*) perform the following actions, in order to feel more comfortable?
(please tick the appropriate answer for each of the cases)

	Very often	Often	Sometimes	Rarely
Open/close/adjust windows or air intake from windows				
Adjust shading (binds, curtains)				
Use a local heating device				
Regulate the heating system				
Change to a workplace far from the window				
Take off clothing to feel cooler				
Put on clothing to feel warmer				

10. If you can (*or could*) open windows or adjust air intake from them, when you open/adjust them it is (*or would be*) mostly to: ? *(please tick the correct answer)*

( ) Feel cooler
( ) Let the warmer air in
( ) Ventilate the room
( ) Other (which?)______________

11. If you can (*or could*) open windows or adjust air intake from them but you usually leave them closed/unadjusted it is (*or would be*) mostly because: *(please tick the appropriate answers)*

( ) Hot air comes in
( ) Cold air comes in
( ) You don't need to open them
( ) Because of the heating system
( ) They cause drafts
( ) It is too noisy outside
( ) It is too polluted outside
( ) Other (which?)____________

12. If you draw/adjust shading (curtains, blind, etc.) it is (*or would be*) mostly because:
(please tick the appropriate answers)

( ) It is too hot
( ) Because of glare
( ) Undesired reflections of the sunlight (e.g., on computer screen)
( ) For privacy
( ) Other (which?)____________

13. If your office has heating system how good is the heating system environmental performance?
(please tick the appropriate answers)

( ) It generally works quite well
( ) It shouldn't be so hot
( ) It causes uncomfortable drafts
( ) It makes the air stuffy
( ) It is too noisy
( ) Sometimes it works irregularly, causing temperature discomfort
( ) It should provide more heating
( ) It causes uncomfortable temperature differences with the outside
( ) It causes an unnatural environment
( ) It makes you sick
( ) Other (which?)____________

14. What do you think about the use of the heating system in your office? *(please tick the correct answer)*

( ) It is essential for your comfort
( ) It is essential for the prestige of the office
( ) It is better then nothing
( ) You would prefer a more natural alternative
( ) You rather not have it
( ) Other (which?)_______________

15. If you change to a workplace far from the window it is (*or would be*) mostly because:
(please tick the correct answer)

( ) It is too cold near the window
( ) It is too hot near the window
( ) Because of glare
( ) Undesired reflections of the sunlight (e.g., on computer screen)
( ) For privacy
( ) Other (which?)____________

16. When you turn on the room or your desk lights it is because: *(please tick the appropriate answers)*

( ) Closing the shading the room gets dark
( ) Natural light is insufficient
( ) It is the usual procedure
( ) Other (which?)________________

17. During Winter do you regularly feel any of the health symptoms presented below while you are at work? *(please tick the appropriate answers)*

( ) Headaches
( ) Irritated throat
( ) Lack of concentration
( ) Nose irritation
( ) Dry or chapped lips
( ) Chills
( ) Nausea
( ) Lethargy
( ) Dizziness
( ) Skin irritation
( ) Eye irritation
( ) None of these

18. What kind of clothes do you generally wear during Winter in your workplace?
(please tick the appropriate answers)

( ) Boots
( ) Shoes
( ) Thick stocks
( ) Stocks
( ) Underwear shirt
( ) Skirt / shorts
( ) Flannel Trousers
( ) Fabric trousers or jeans/skirt
( ) Winter dress, long sleeves
( ) Long sleeve shirt/blouse
( ) Sweater
( ) Thick sweater
( ) Jacket
( ) Suit
( ) Pull-over
( ) Other (which?)_______________
( ) Other (which?)_______________
( ) Other (which?)_______________

19. What do you think about the performance of the double skin façade in your office during Winter? *(please tick the correct answer)*

( ) It is essential for your comfort
( ) It is essential for the prestige of the office
( ) You never heard of it
( ) You rather not have it
( ) Other (which?)_______________

20. Where is your workplace located? *(please tick the correct answer)*

( ) Close to the exterior windows (less than 2 meters apart) and *facing* the windows
( ) Close to the exterior windows (less than 2 meters apart) and *sideways* from the windows
( ) Close to the exterior windows (less than 2 meters apart) and *backward* from the windows
( ) Far from the exterior windows (more than 2 meters apart)
( ) Other (which?)___________________

21. What is your general opinion of your workplace in terms of comfort during Winter:

Very Good	Good	Regular	Poor	Very Poor

22. Do you have any suggestions about what could be done to improve the comfort conditions in your workplace during Winter?____
____
____

DURING AUTUMN, IN YOUR WORKPLACE:

23. Overall, how satisfied are you with the temperature at your workplace during Autumn?
(please tick the correct answer)

( ) Very satisfied
( ) Satisfied
( ) Dissatisfied
( ) Very dissatisfied

24. Generally, during Autumn, would you prefer to feel cooler, warmer, or are you OK?
(please tick the correct answer)

( ) Much cooler
( ) Cooler
( ) Slightly cooler
( ) I'm OK
( ) Slightly warmer
( ) Warmer
( ) Much warmer

25. Comparing with Winter, are you in Autumn more comfortable, less comfortable or equally comfortable? *(please tick the correct answer)*

( ) More comfortable ( ) Less comfortable ( ) Equally comfortable

26. If you are *less comfortable* in Autumn choose three reasons mentioned below that you consider more important for your satisfaction in the working environment (by order of importance):

a) Ventilation
b) Temperature
d) Daylight
e) Privacy
h) Other (which?)________________
j) Other (which?)_________________

1st	2nd	3rd

THANK YOU VERY MUCH

A.2.6 Office Manager questionnaire

QUESTIONNAIRE FOR THE MANAGER OF THE STUDIED SPACES Nr ____________
Building: Date:

1. Main activity carried out in the studied spaces?________________________________

2. Total pavement area of the studied spaces?__________________________________

3. Number of persons working in the studied spaces?____________________________

4. Equipments in the studied spaces?____

5. Which setpoints are generally used during Summer/Winter in the studied spaces.

		Summer	Winter
Working period (which schedule?)_________	T [ºC]		
	R.H [%]		
	Minimum fresh air [m^3/h]		
Non-working period (which schedule?)_________ (weekends?)____________	T [ºC]		
	R.H [%]		
	Minimum fresh air [m^3/h]		

6. Which are the space energy consumptions per energy type?______________________

____

7. Is energy consumption an issue of low, normal or high importance?_________________

8. Which of the following are the main maintenance items:
Window cleaning / Maintenance of ventilation system / Maintenance of shading devices?

____

9. Do you consider operating / maintenance costs of double skin façades higher, lower or equivalent to those of single skin façades?____________________________________

10. Do you consider that the double skin façade provides a satisfactory working environment to the workers throughout the year (in regard to thermal comfort during summer and winter, air quality, natural lightning)?____

____

10. If not, which features should be replacement in order to improve the environment?_________

____

11. Were some façade-related actions already implemented in order to improve the environment?

____

____

12. Do you have any remarks concerning double skin façades (costs, appearance, prestige…)?

____

____

THANK YOU VERY MUCH

A.3 Data checking: Energy need, delivered energy and electricity

A.3.1 Raw data for DSF buildings

Table A. 2 Raw data for heating: DSF buildings.

	Heating			
	Energy need [kWh/(m² a)]		Delivered energy [kWh/(m² a)]	
	Simulation or design	Measured (district heating only)	Simulation or design	Measured
A		143		
B		82		
C	150			
D		107		
E	44			
G			50	
Q		58*		
R		44*		
T				64
V				152
W				17
AB		33		
AD		16		
AE				100

*Simulations used to deduce DHW from Heating plus DHW consumption

Table A. 3 Raw data for <u>cooling</u>: DSF buildings.

	Cooling			
	Energy need [kWh/(m² a)]		Delivered energy [kWh/(m² a)]	
	Simulation or design	Measured (district cooling only)	Simulation or design	Measured
A		32		
B		30		
C	60			
D		49		
E	44			
G			62	
Q			20	
R			18	
T				9
V				79
W				28
AB		156		
AD		140		
AE				180

Table A. 4 Raw data for <u>electricity</u> consumption: DSF buildings.

	Electricity [kWh/(m² a)]					
	Ventilation		Lighting		Total	
	Simulation or design	Measured	Simulation or design	Measured	Simulation or design	Measured
A						89
B						105
C						
D						93
E				30	107	
G			23		116	
Q	9		23			103
R	8		15			94
T				26		35
V						
W				15		80
AB						130
AD						197
AE		72		68		480

A.3.2 Raw and energy type normalized data for DSF buildings

Table A. 5 Normalization of type of energy delivered for <u>heating</u>, according to section 2.1.2: DSF buildings (raw data presented in bold; energy type normalized data presented in italic).

	Heating			
	Energy into building	Energy need [kWh/(m^2 a)]	Delivered energy [kWh/(m^2 a)]	(Primary energy) [toe/(m^2 a) x10^{-3}]
A	District heating	**143**	-	*14*
B	District heating	**82**	-	*8*
C	District heating	**150**	-	*14*
D	District heating	**107**	-	*10*
E	District heating	**44**	-	*4*
G	Fossil fuel	*45*	**50**	*4*
Q	District heating	**58**	-	*6*
R	District heating	**44**	-	*4*
T	Fossil fuel	*58*	**64**	*6*
V	Electricity (heat pump)	*608*	**152**	*44*
W	Electricity (heat pump)	*68*	**17**	*5*
AB	District heating	**33**	-	*2*
AD	District heating	**16**	-	*1*
AE	Electricity (heat pump)	*400*	**100**	*29*

Table A. 6 Normalization of type of energy delivered for <u>cooling</u>, according to section 2.1.2: DSF buildings (raw data presented in bold; energy type normalized data presented in italic).

	Cooling			
	Energy into building	Energy need [kWh/(m^2 a)]	Delivered energy [kWh/(m^2 a)]	(Primary energy) [toe/(m^2 a) x10^{-3}]
A	District cooling	**32**	-	*3*
B	District cooling	**30**	-	*3*
C	District cooling	**60**	-	*6*
D	District cooling	**49**	-	*5*
E	District cooling	**44**	-	*4*
G	Electricity (chiller)	*186*	**62**	*18*
Q	Electricity (chiller)+	*60*	**20**	*6*
R	Electricity (chiller)+	*54*	**18**	*5*
T	Electricity (chiller)	*27*	**9**	*3*
V	Electricity (chiller)	*237*	**79**	*23*
W	Electricity (chiller)	*84*	**28**	*8*
AB	District cooling	**156**	-	*15*
AD	District cooling	**140**	-	*13*
AE	Electricity (chiller)	*540*	**180**	*52*

Table A. 7 Energy for heating plus cooling expressed in energy needs, delivered energy and primary energy: DSF buildings (conversion coefficients defined in section 2.1.2).

	Heating + Cooling		
	Energy need [kWh/(m² a)]	Delivered energy [kWh/(m² a)]	(Primary energy) [toe/(m² a) x10⁻³]
A	175	-	17
B	112	-	11
C	210	-	20
D	156	-	15
E	88	-	8
G	231	112	22
Q	118	-	11
R	98	-	9
T	85	73	8
V	845	231	66
W	152	45	13
AB	189	-	17
AD	156	-	15
AE	940	280	80

Table A. 8 CO_2 emissions due to total energy consumption (fossil fuel plus total electricity): DSF buildings (conversion coefficients defined in section 2.1.2).

	Heating	Cooling	Electricity+	Total	
	(Primary energy) [toe/(m² a) x10⁻³]	(Primary energy) [toe/(m² a) x10⁻³]	(Primary energy) [toe/(m² a) x10⁻³]	(Primary energy) [toe/(m² a) x10⁻³]	(CO_2 emissions) [tCO_2e/(m² a)x10⁻³]
A	14	3	26	43	51
B	8	3	30	41	49
C	14	6	-	-	-
D	10	5	27	42	50
E	4	4	31	39	47
G	4	18	16	38	46
Q	6	6	24	35	42
R	4	5	22	31	38
T	6	3	8	16	19
V	44	23	-	-	-
W	5	8	10	23	28
AB	2	15	38	55	66
AD	1	13	57	72	86
AE	29	52	58	139	167

+ Except cooling

A.3.3 Raw data for DSF and SSF buildings

Table A. 9 Raw data for heating: DSF and SSF buildings.

	Heating			
	Energy need [kWh/(m² a)]		Delivered energy [kWh/(m² a)]	
	Simulation, design, national code/bench mark	Measured (district heating only)	Simulation, design, national code/bench mark	Measured
A		143		
B		82		
C	150			
D		107		
E	44			
^	80			
^	125			
^	205			
G			50	
H		40		
M				138
Q		58*		
R		44*		
S	36			
T				64
^			105**	
^			120**	
^			100**	
^			105**	
^			149**	
^			105**	
^			135**	
^			120**	
^			120**	
^			135**	
^				40**
^				57**
^				169**
^				154**
^				183**
^				103**
^				142**
^				169**
^				114**
^				52**
^			131**	
^			72**	
^			57**	
V				152
W				17
^			85	
^			49	
^			63	
^			36	
AB		33		
AD		16		
AE				100
^			103	
^			349***	

*Simulations used to deduce DHW from Heating+DHW consump.
**Includes heating and DHW
***Not used

Table A. 10 Raw data for <u>cooling</u>: DSF and SSF buildings.

	Cooling			
	Energy need [kWh/(m² a)]		Delivered energy [kWh/(m² a)]	
	Simulation, design, national code/bench mark	Measured (district heating only)	Simulation, design, national code/bench mark	Measured
A		32		
B		30		
C	60			
D		49		
E	44			
^			15	
^			30	
^			50	
G			62	
H				
M				
Q			20	
R			18	
S				
T				9
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^				
^			17	
^				
^				
V				79
W				28
^			108	
^			104	
^				
^				
AB		156		
AD		140		
AE				180
^			103	
^				

Table A. 11 Raw data for electricity consumption: DSF and SSF buildings.

	Electricity [kWh/(m^2 a)]					
	Ventilation		Lighting		Total	
	Simulation, design, national code/bench mark	Measured	Simulation, design, national code/bench mark	Measured	Simulation, design, national code/bench mark	Measured
A						89
B						105
C						
D						93
E				30	107	
^	10*		35		60	
^	18*		50		98	
^	30*		80		160	
G			23		116	
H						
M						
Q	9		23			103
R	8		15			94
S						
T				26		35
^					24	
^					24	
^					64	
^					20	
^					34	
^					48	
^					18	
^					24	
^					18	
^					18	
^						48
^						80
^						101
^						50
^						30
^						35
^						83
^						59
^						44
^						36
^	33		27			
^					103	
^					94	
V						
W				15		80
^			24		100	
^			17		61	
^			18		32	
^			8		15	
AB						130
AD						197
AE		72		68		480
^					103	
^						

*Includes fans and pumps

A.4 Analysis of the Office Manager Questionnaires

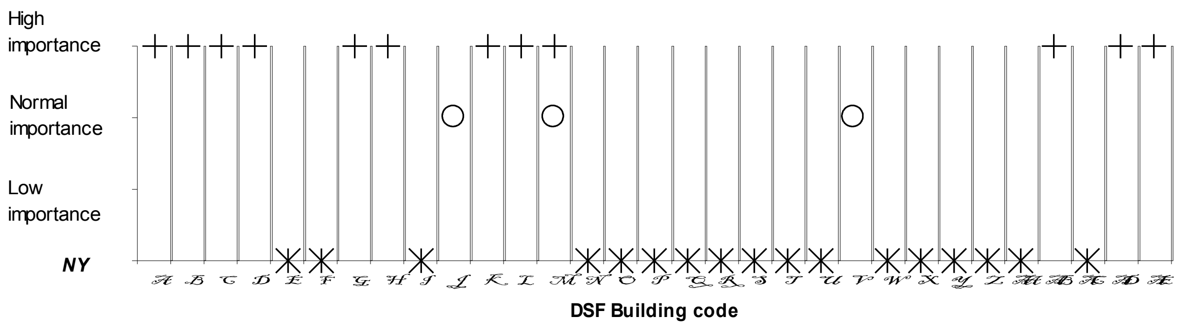


Figure A. 6 How important is the issue of energy consumption?

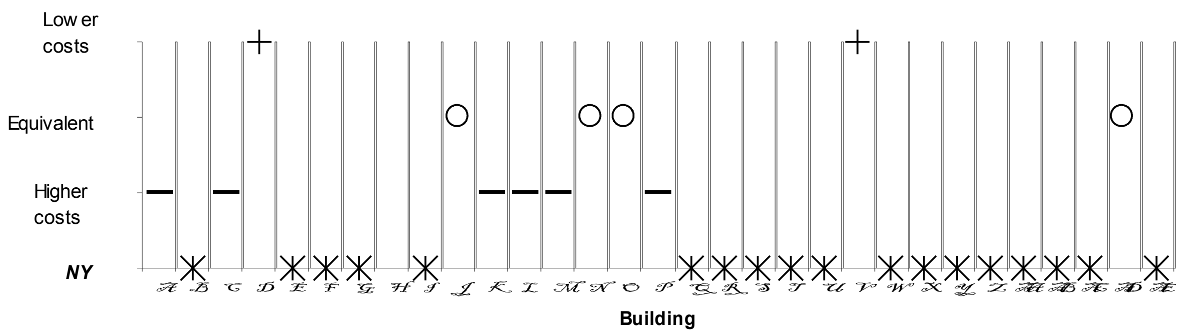


Figure A. 7 Comparing DSF to SSF operational and maintenance costs.

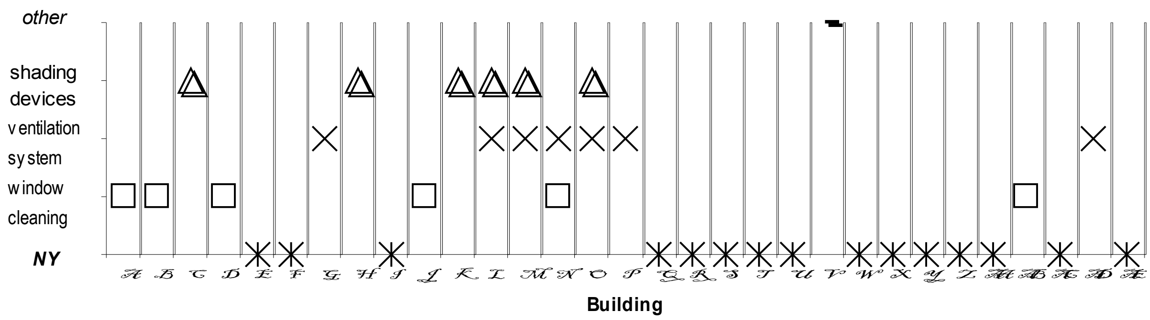


Figure A. 8 DSF buildings main maintenance issues.

A.5 Analysis of the User Comfort Questionnaires

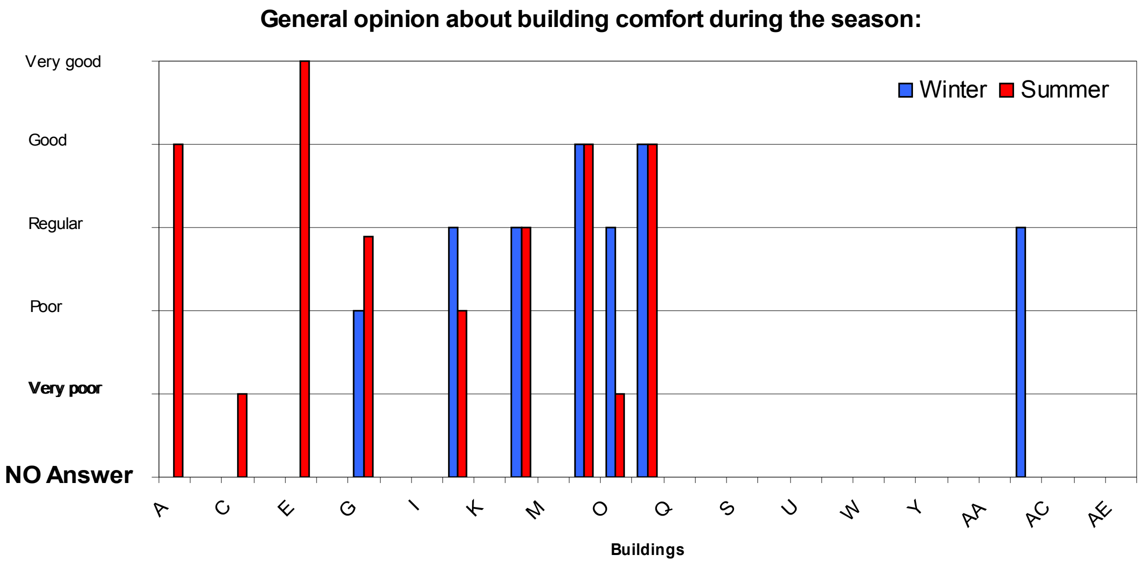


Figure A. 9 General opinion about building comfort during winter and summer.

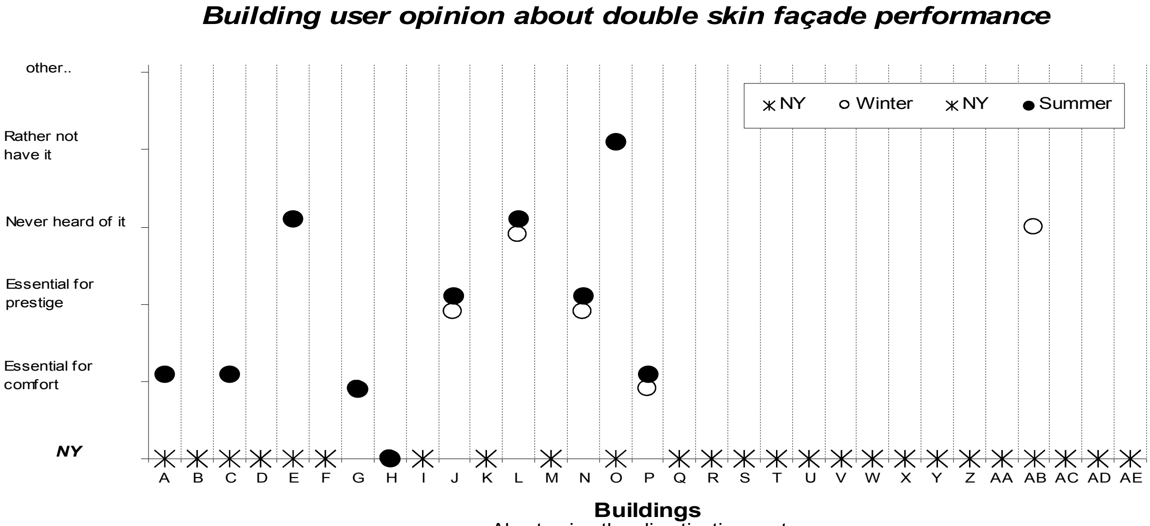


Figure A. 10 Users opinion about DSF performance.

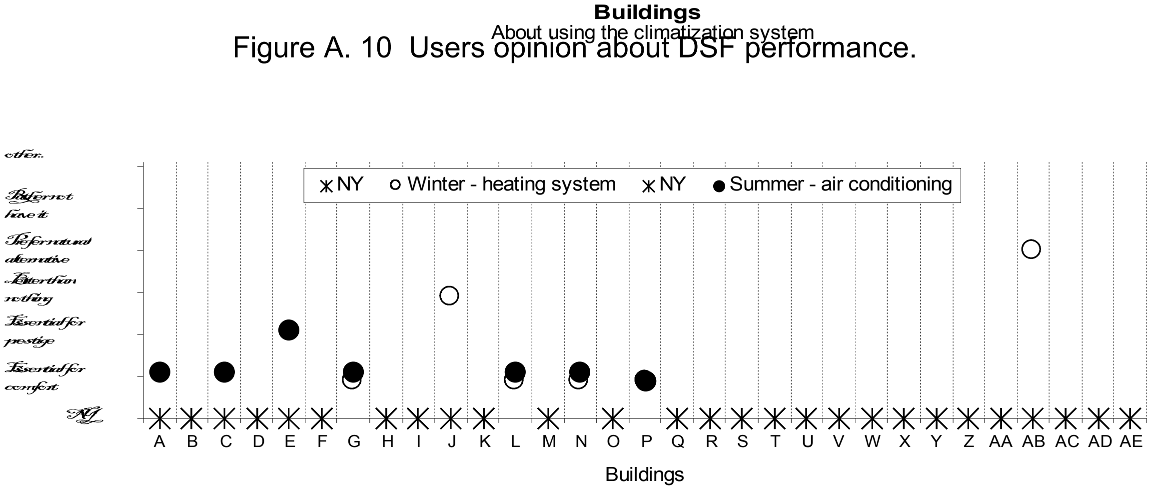


Figure A. 11 About the heating and cooling system.

A.5.1 Winter

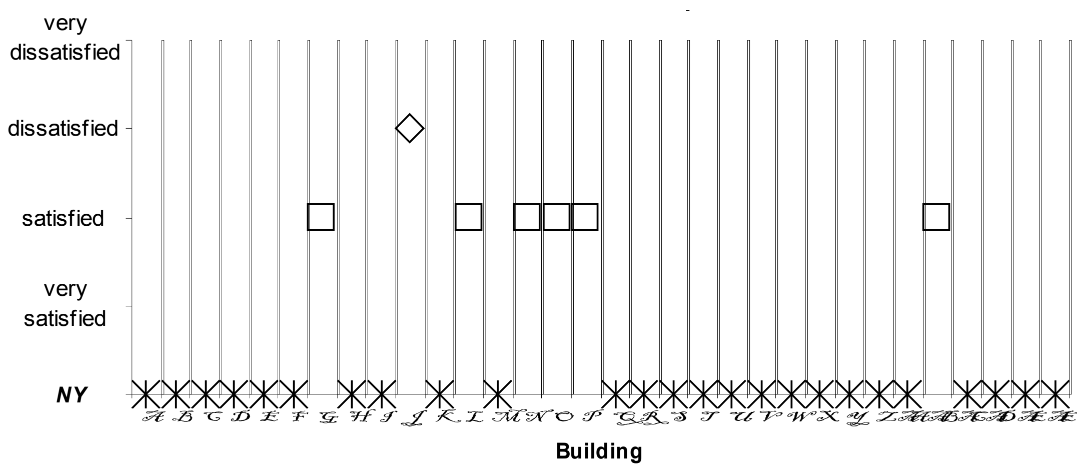


Figure A. 12 Winter: How satisfied with temperature?

Winter: *Feeling too cold*

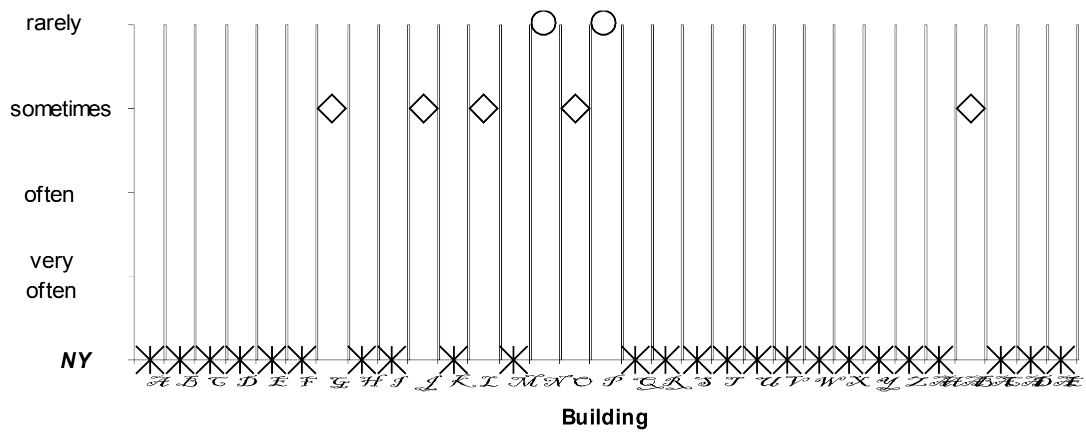


Figure A. 13 Winter: Feeling too cold?

Winter: *Feeling uncomfortably hot*

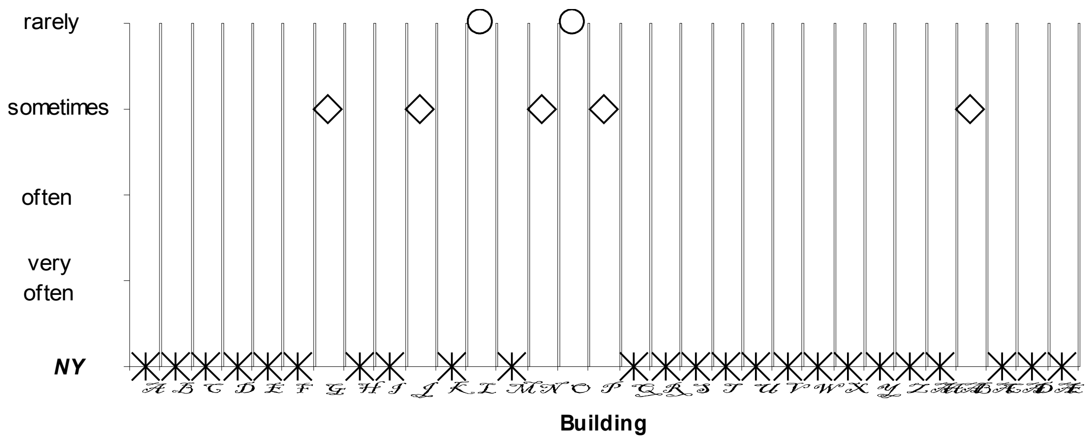


Figure A. 14 Winter: Feeling uncomfortably hot?.

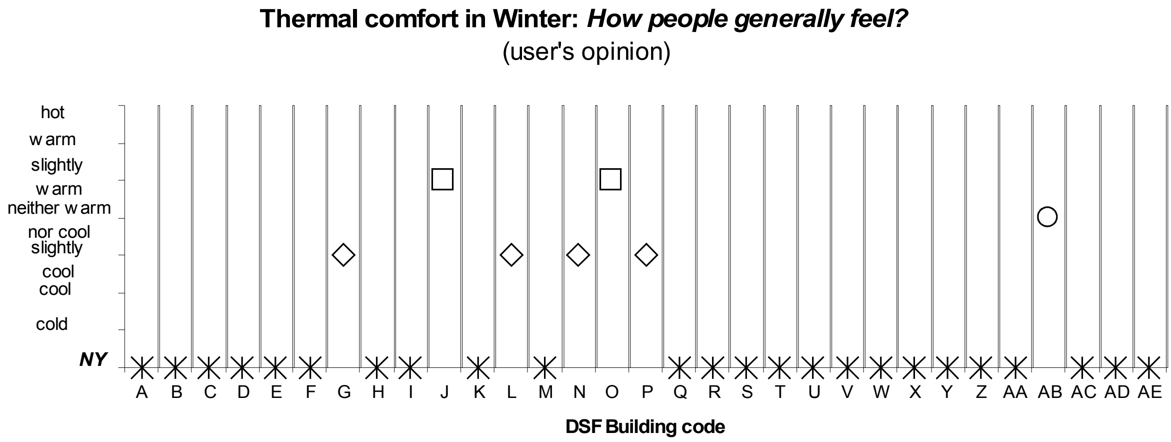


Figure A. 15 Winter thermal comfort: How people generally feel.

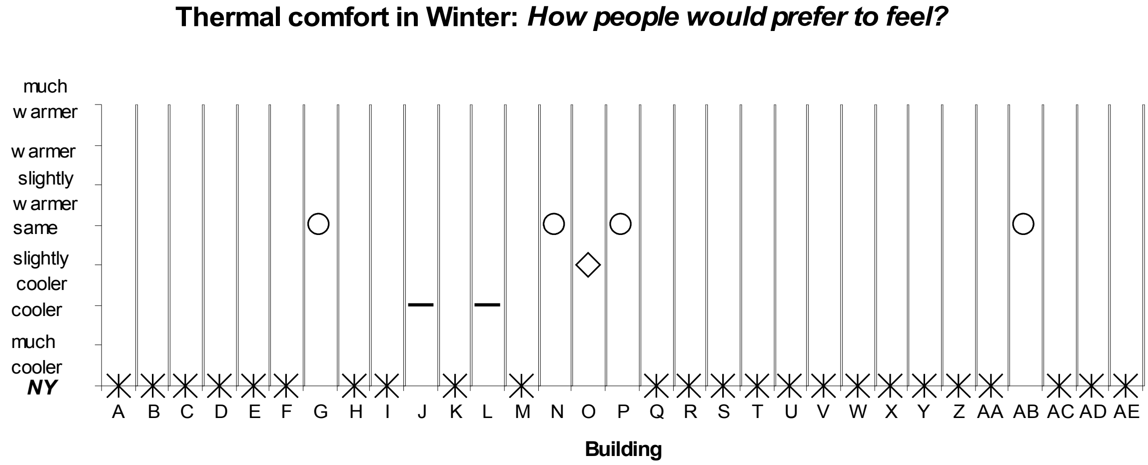


Figure A. 16 Winter thermal comfort: How people would prefer to feel.

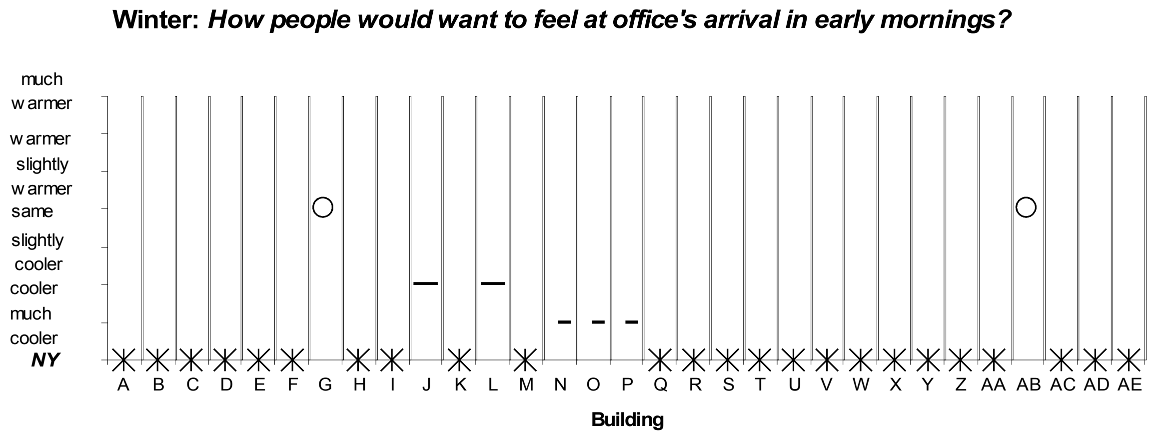


Figure A. 17 Winter: How people would want to feel when arriving early morning.

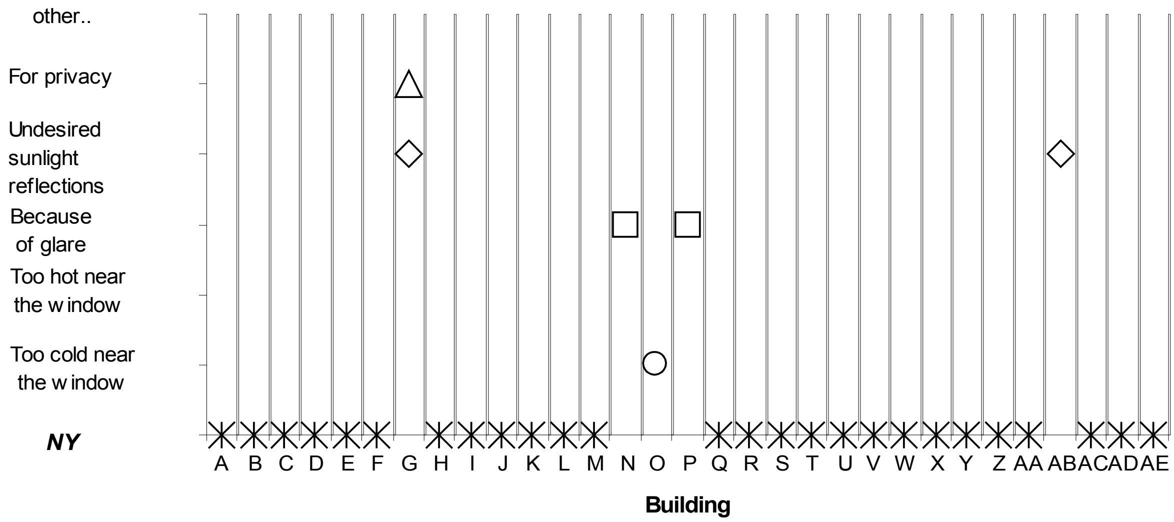


Figure A. 18 Winter: reason for changing to a workplace far from the DSF.

A.5.2 Autumn

Thermal comfort in Autumn: *How people would prefer to feel?*

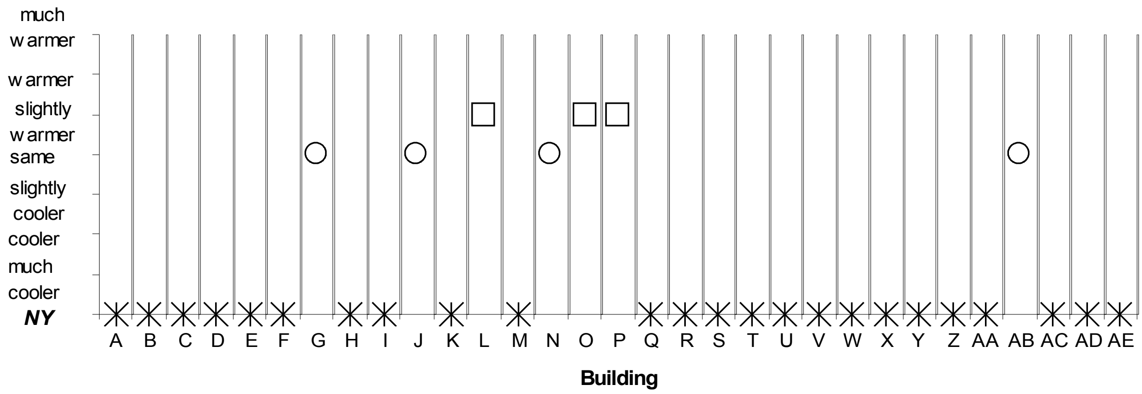


Figure A. 19 Autumn thermal comfort: How people would prefer to feel.

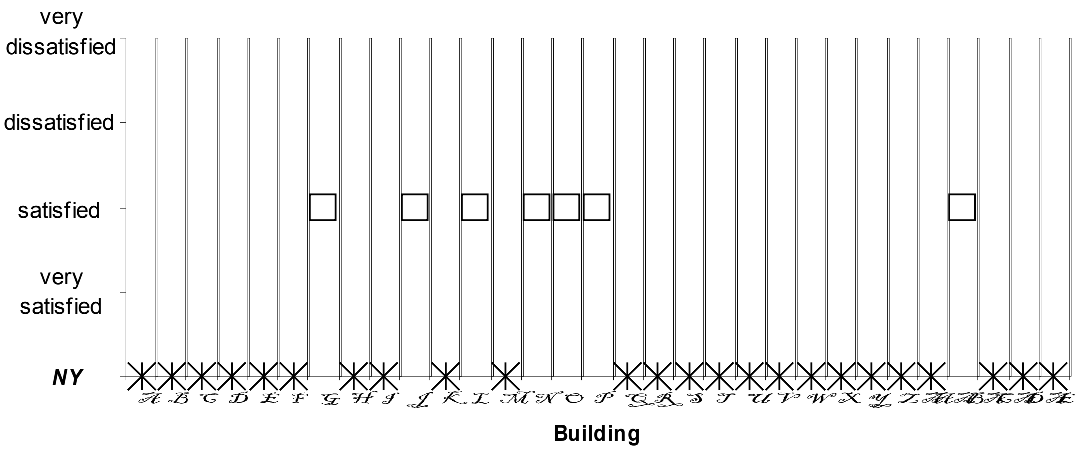


Figure A. 20 Autumn: How satisfied with temperature.

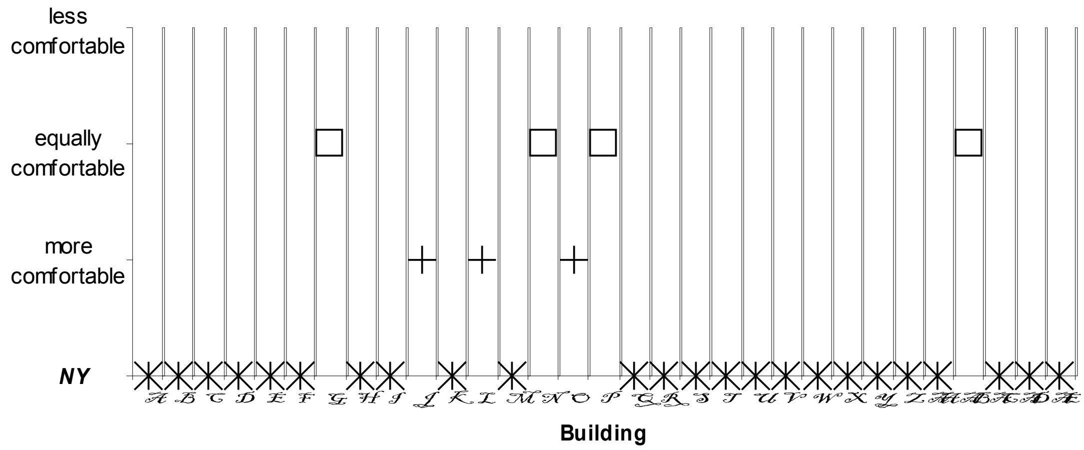


Figure A. 21 Autumn: Comparing with winter.

A.5.3 Summer

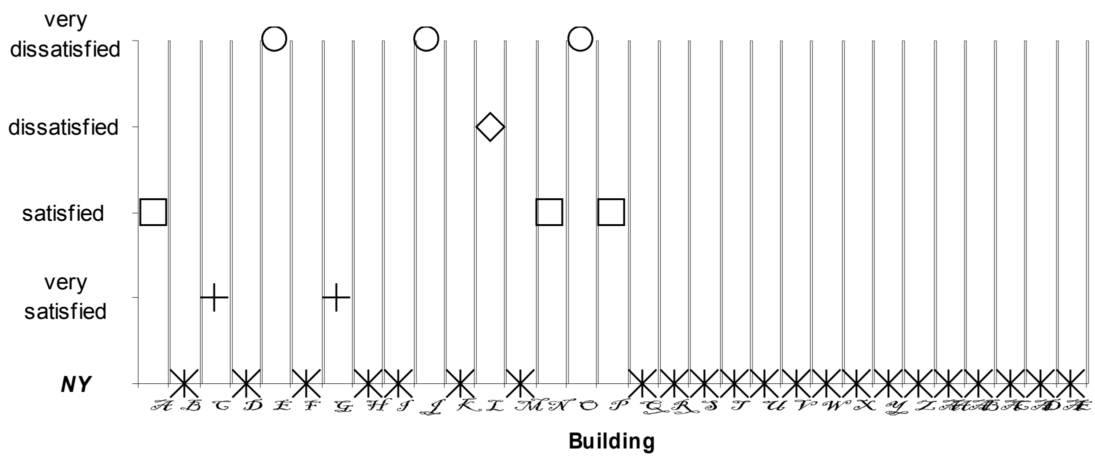


Figure A. 22 Summer: How satisfied with temperature?.

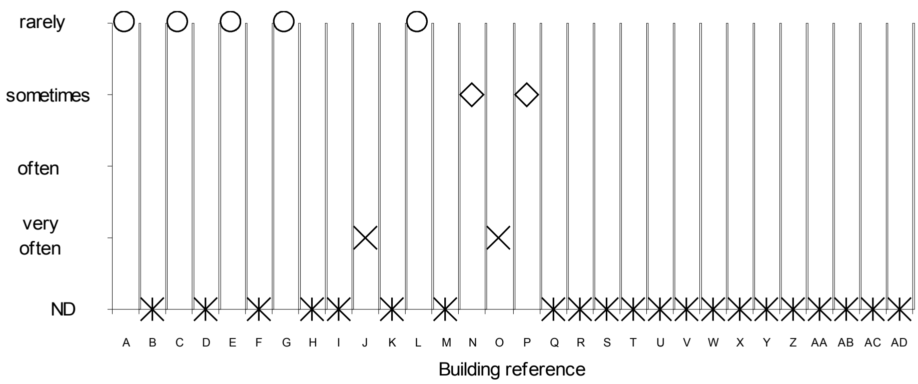


Figure A. 23 Summer: Feeling too hot?.

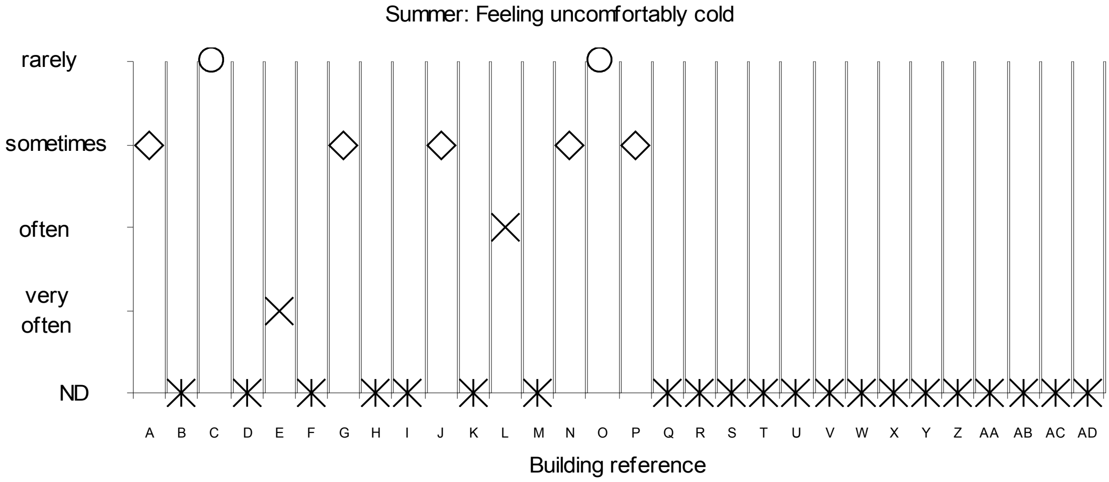


Figure A. 24 Summer: Feeling uncomfortably cold?.

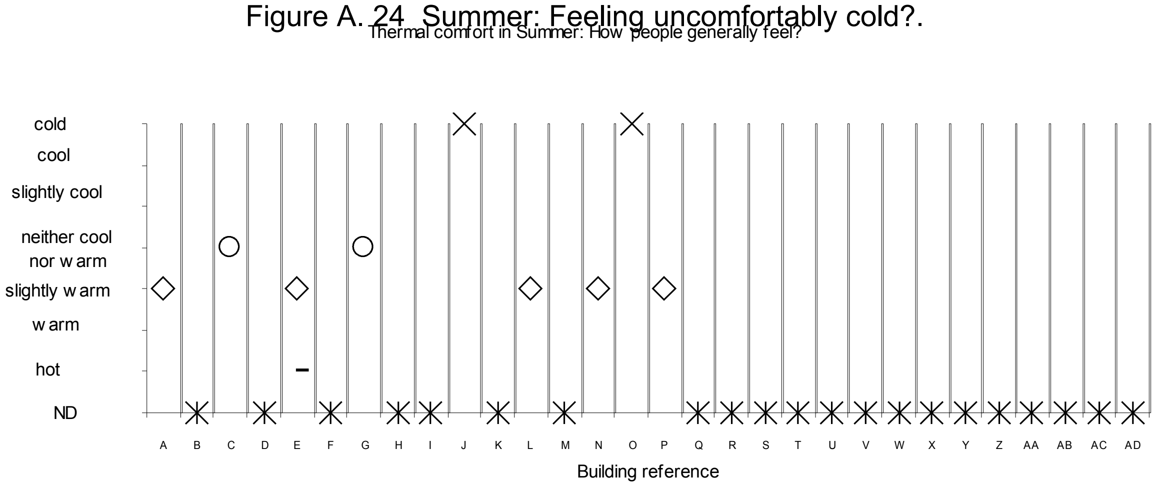


Figure A. 25 Summer thermal comfort: How people generally fell.

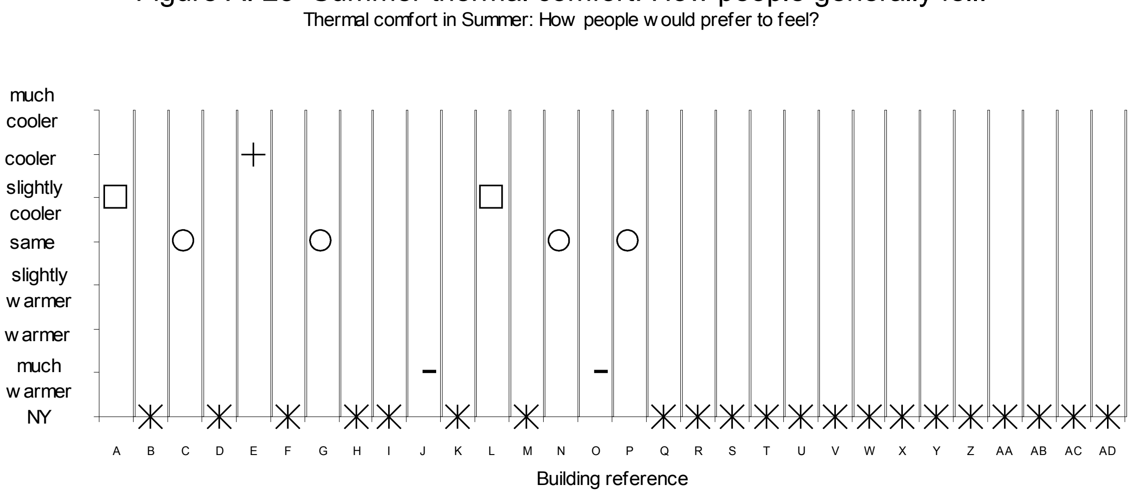


Figure A. 26 Summer thermal comfort: How people would prefer to feel.

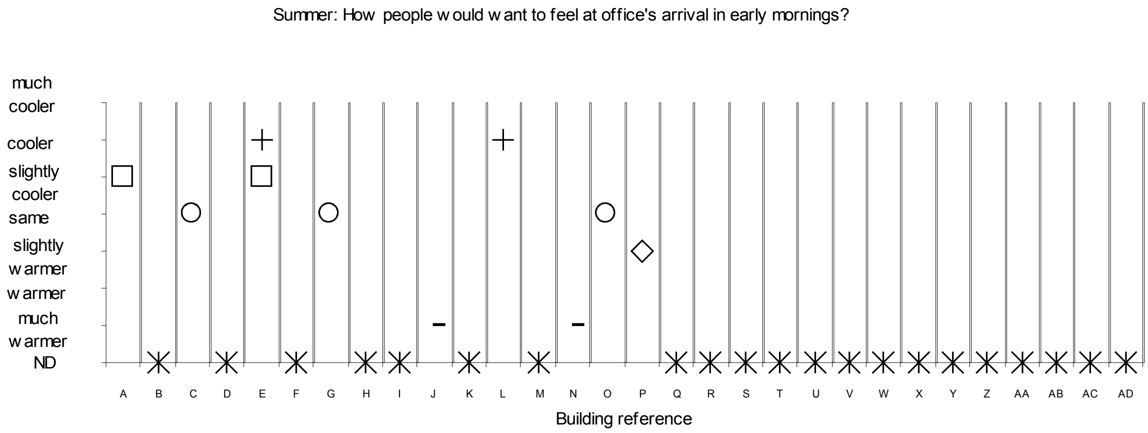


Figure A. 27 Summer: How people would want to feel when arriving in early morning.

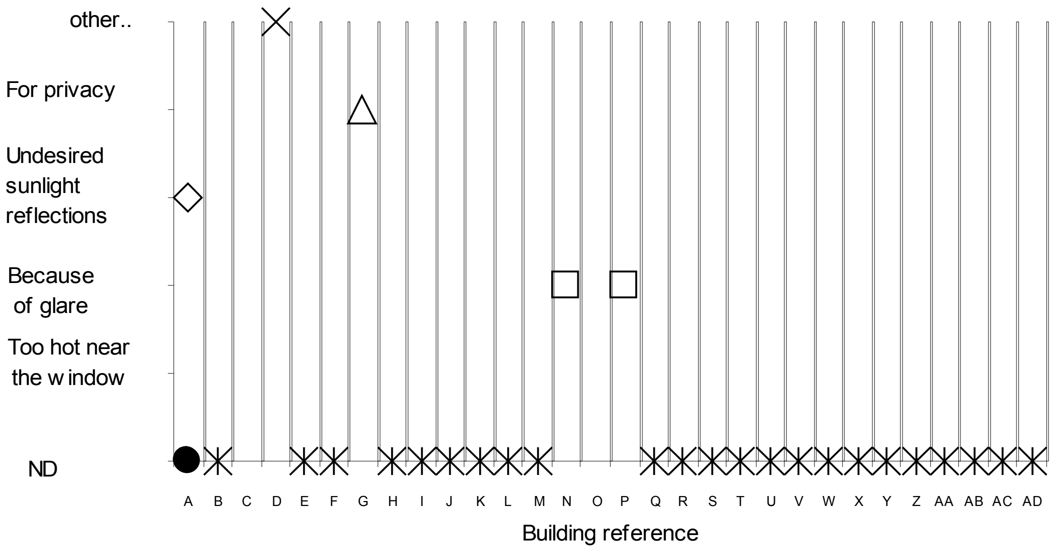


Figure A. 28 Summer: reason for changing to a workplace far from the DSF.

A.5.4 Spring

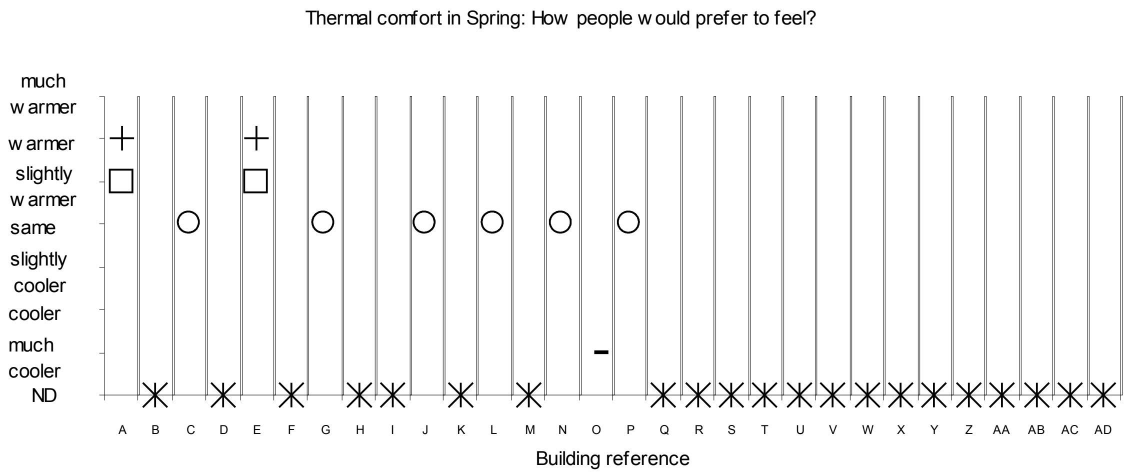


Figure A. 29 Spring thermal comfort: How people would prefer to feel.

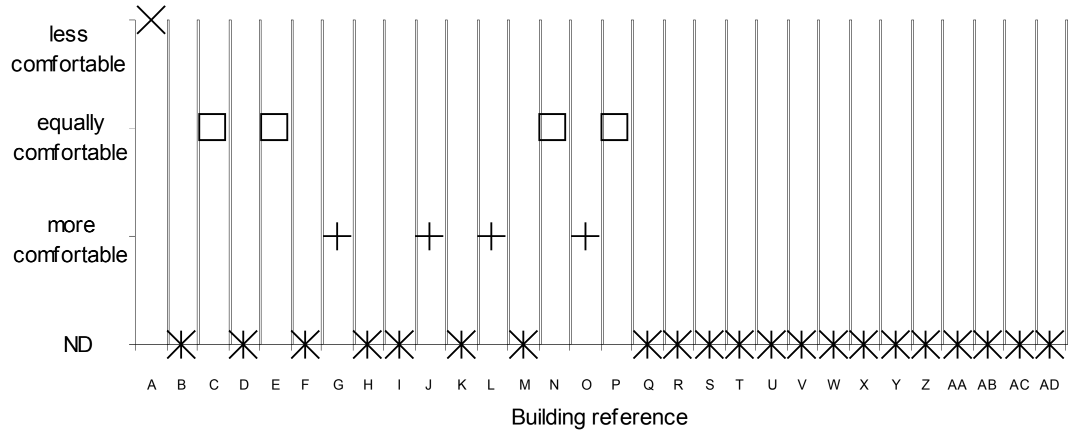


Figure A. 30 Spring: Comparing to summer.

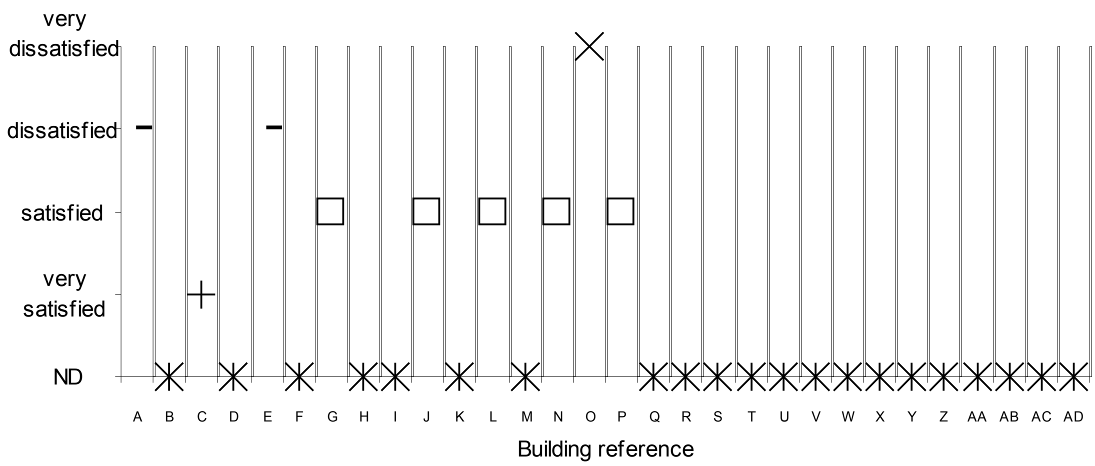


Figure A. 31 Spring: How satisfied with temperature?

A.6 National chapters on building energy consumption and/or benchmarks

A.6.1 Belgium

(by Sabrina Prieus and Gilles Flamant)

Introduction

This section summarizes data about energy consumptions in office buildings in Belgium. The difficulty with buildings with double skin facades is that there are not so many and that most of them are only recently built. Therefore data of energy consumptions are hard to get. In this scope we looked at the energy consumptions of office buildings in general.

Belgium consists of 3 Regions: the Flemish Region, the Brussels Region and the Walloon Region. The 3 Regions each have there own report concerning energy consumption data. The data found in these reports are put into building sectors defined by a code, the NACE code, as defined by the European Union.

The energy data do not present the room demand (energy need for heating and cooling) but well the *delivered energy*; real consumptions of the building per square meter heated surface.

The number of buildings that delivered the data is important to take in account, with respect to the liability of the consumption data.

Type of energy sources used for heating and cooling

In Belgium the traditional heating system for office buildings is using fossil fuels like gas or oil as energy source.

Cooling energy is mainly produced by electrical systems (air-conditioning, absorption cooling, etc.). Many modern office buildings in Belgium have cooling systems. If we consider only high-profile office buildings, even more in case of a high window/wall ratio, or buildings with high internal loads, they are built mostly including an air-conditioning system or another type of cooling system.

Type of available measured energy consumptions

Following the energy consumption nomenclature presented in the WP3 BESTFACADE report, the measured energy consumption available for most buildings are those that are given in the invoices by the energy supplier: the delivered energy. In case of a building being heated based on gas, there is a meter available for the delivered energy consumption of the fossil fuel and at least another one for the electricity. In case of electrical cooling and/or ventilation systems the specific consumption is in most cases contained in the total delivered electricity consumption if not several electrical meters are used.

Obviously this is a problem, since the data that is used for the benchmarking in this report on basis of (delivered) electrical energy might therefore include not only energy consumption for cooling but also for lighting, ventilation, equipment, etc.

On the other hand, the total of fossil fuels will often include delivered heating.

Overview of the energy consumptions of office buildings

In Table A. 12 the consumptions of fuel and electricity per heated surface are classified by Region and the sort of office buildings. Also the number of buildings the data are retrieved from is mentioned. For the Walloon and Brussels Region this is limited to public and private offices. For the Flemish Region there is another subdivision following the NACE code. The data is retrieved from official regional reports [1], [2] and [3]. The buildings are of different sizes, from 2 000 m² to more than 10 000 m².

Table A. 12 Summary of consumptions (delivered energy) for the Walloon region, the Brussels Region and the Flemish Region.

	fuel/surface	electricity/surface
	kWh/m²	kWh/m²
Walloon Region	2002	
Private offices HT (high tension)	102	114
Number of buildings	*30*	*30*
Public offices HT (high tension)	165	56
Number of buildings	*119*	*119*
Brussels Region	2003	
Private offices HT (high tension)	107	149
Number of buildings	*58*	*58*
Public offices HT (high tension)	120	68
Number of buildings	*51*	*51*

Specific average fuel consumptions of public and private offices HT in the Brussels and Walloon Region in function of the degree days

Year	Degree	kWh/m²			
Offices	days	PRIV	PUB	PRIV	PUB
Region	15/15	Walloon		Brussels	
1991	2 102			133	
1995	1 922			119	100
1996	2 383			136	106
1997	1 900	125	178	119	103
1998	1 906	125	181	106	97
1999	1 791	125	172	108	89
2000	1714	112	137	103	86
2001	1 934	120	156	106	114
2002	1 683	102	165	94	131
2003	1 921			107	120

Flemish Region	2003		*2000*	
Financial institutions (NACE code 65-67)	317	162	*222*	*216*
Number of buildings	*14*	*14*	*10*	*10*
Real estate (NACE code 70-74)	189	144	*184*	*154*
Number of buildings	*37*	*37*	*34*	*34*
Public administration, social security (NACE code 75)	203	73	*214*	*76*
Number of buildings	*153*	*153*	*50*	*50*

Private offices: banks, insurance and service companies

Public offices: public administrations and internationals

Another source is the final report of the “Kantoor 2000” [4] project. In total 87 office buildings of different sizes in the Flemish and Brussels Region were looked at with regards to their energy consumption.

Table A. 13 Consumptions (delivered energy) in electricity and fuel for offices (no distinction in the different types)

Net floor surface (total 87 buildings)		Fuel consumption (kWh/m²)	Electricity consumption (kWh/m²)
< 1000 m²	13	128	86
Between 1000 and 5000 m²	23	128	76
Between 5000 and 10000 m²	22	122	117
> 10000 m²	29	95	105

The figures of Table A. 12 and Table A. 13 are slightly different, with regards to a range of energy consumptions. The fuel consumptions of the Brussels Region in Table A. 12 are comparable with the consumptions stated in Table A. 13. The electricity consumption for the private offices in the Brussels Region and Financial institutions in the Flemish Region are higher. The fuel consumptions in the Flemish Region are definitely higher than stated in Table A. 13.

Detailed data on energy consumptions of office buildings

Offices and administrations in the Flemish Region [1]

Total number of buildings in 30/6/2002 in Flanders:

Financial institutions (NACE code 65-67)	5.160
Real estate (NACE code 70-74)	19.140
Public administration, social security (NACE code 75)	3.527

In total 442 questionnaires were sent in 2003 to companies within the sector “offices and administrations”. For the calculations 405 respondents were taken into account. In the next table the number of usable questionnaires is mentioned with every case.

Table A. 14 Consumptions (delivered energy) per NACE code

	2003		*2000*	
Unity	fuel/ surface GJ/m²	electricity/surface GJ/m²	*fuel/ surface GJ/m²*	*electricity/surface GJ/m²*
NACE code 65-67	Financial institutions			
Average	1,14 (317 kWh/m2)	0.58 (162 kWh/m2)	*0,80 (222 kW/m2)*	*0.78 (216 kW/m2)*
Standard dev	1,85	0.20	*0,68*	*0.68*
Min	0,16	0.28	*0,34*	*0.19*
Max	6,78	0.92	*2,58*	*2.56*
Number of buildings	14	14	*10*	*10*
NACE code 70-74	Real estate			
Average	0,68 (189 kWh/m2)	0.52 (144 kWh/m2)	*0,59 (184 kW/m2)*	*0.56 (154 kW/m2)*
Standard dev	0,90	0.56	*0,48*	*0.42*
Min	0,00	0.14	*0,11*	*0.08*
Max	4,18	3.50	*2,33*	*1.89*
Number of buildings	37	37	*34*	*34*
NACE code 75	Government, social security			
Average	0,73 (203 kWh/m2)	0,26 (73 kWh/m2)	*0,77 (214 kW/m2)*	*0.27 (76 kW/m2)*
Standard dev	1,15	0.54	*0,65*	*0.35*
Min	0,00	0,01	*0,01*	*0,00*
Max	10,35	4.74	*3,58*	*1.82*
Number of buildings	153	153	*50*	*50*

Average = average value of the index number

Standard deviation = the deviation calculated on the numbers

Min = the minimum determined value

Max = the maximum determined value
Fuel = fuel consumption
Surface= total (heated) surface
Number of buildings = number of buildings for which the consumption was calculated, dependent on the number of filled in questionnaires

For the sectors with NACE code 65-67 the average values deviates between 2003 and 2000. For the sectors with NACE 70-74 and 75 the results are very similar. There was no climate correction made on the data. With this correction the figures for 2003 would be higher and then the difference between the numbers between 2000 and 2003 would be bigger.

Offices and administrations in the Brussels Region [2]

The private and public offices are studied separately. The first category comprises banks, insurance and service companies. The second comprises public administrations and internationals (no defence).

- Private offices

Buildings from 2 000 to 10 000 m²

For private offices from 2 000 to 10 000 m² and also for offices bigger then 10 000 m² there is no correlation between the specific consumptions and the surface of the offices. However, there exists a correlation between the consumptions and the surfaces. These vary from 42% to 79% for the electricity and from 60% to 85% for the fuel.

Table A. 15 Specific average consumptions of the private offices HT (kWh/m²) in 2003

Buildings > 10 000 m²

33 buildings from 2 000 to 10 000 m² (total surface = 180 777 m²)		
	Electricity	Fuel
Specific average consumption	95 kWh/m²	106 kWh/h

Table A. 16 Specific average consumptions of the private offices HT (kWh/m²) in 2003

Private offices all sizes

23 buildings from 10 200 to 207 627 m² (total surface = 880 975 m²)		
	Electricity	Fuel
Specific average consumption	159 kWh/m²	105 kWh/m²

Table A. 17 Specific average consumptions of the private offices HT (kWh/m²) in 2003

58 buildings from 2 000 to 207 627 m² (total surface = 1 081 752 m²)		
	Electricity	Fuel
Specific average consumption	149 kWh/m²	107 kWh/m²

From 1998, a continue decrease was determined in the specific consumption of electricity of the private offices HT; the year 2003 doesn't follow this continuation.

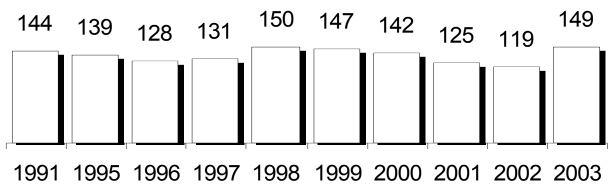


Figure A. 32 Evolution of the specific average consumptions of electricity of the private offices HT (kWh/m²)

This sudden augmentation could be because of the use of climate regulation systems, given that:

Their influence is substantial in private offices :

The year 2003 (and in particular the summer) was very warm (see table below)

Table A. 18 Climate data from 1998 to 2003 and the percentage of buildings with heating and cooling systems

Year	Hours of sun	Cooling18	DJA15	Taverage	Average TMax	% with HVAC sys
1998	1 326	81	1 906	10.5	14.0	n.d.
1999	1 609	136	1 792	11.1	14.7	n.d.
2000	1 392	82	1 714	11.1	14.5	n.d.
2001	1 455	137	1 930	10.7	14.2	42 %
2002	1 480	98	1 684	11.2	14.7	48 %
2003	1 987	208	1 921	11.1	15.1	46 %
Normal average for Belgium	1 555	n.d.	2 088	9.9	13.5	n.d.

Concerning the evolution of the specific average fuel consumptions a strong correlation can be defined with the degree days for private offices HT. Indeed, r² equals 0.78.

Table A. 19 Specific average fuel consumptions of private offices HT in function of the degree days

Year	Degree days 15/15	kWh/m²
1991	2 102	133
1995	1 922	119
1996	2 383	136
1997	1 900	119
1998	1 906	106
1999	1 791	108
2000	1714	103
2001	1 934	106
2002	1 683	94
2003	1 921	107

- Public offices

<u>Public offices 2000 to 10 000 m²</u>

Table A. 20 Specific average consumptions of the public offices HT (kWh/m²) in 2003

22 buildings from 2 100 to 9 245 m² (total surface = 118 155 m²)		
	Electricity	Fuel
Specific average consumption	76 kWh/m²	117 kWh/m²

<u>Public offices > 10 000m²</u>

Table A. 21 Specific average consumptions of the public offices HT (kWh/m²) in 2003

24 buildings from 11 459 to 97 533 m² (total surface = 691 370 m²)		
	Electricity	Fuel
Specific average consumption	67 kWh/m²	120 kWh/m²

<u>Public offices of all sizes</u>

Table A. 22 Specific average consumptions of the public offices HT (kWh/m²) in 2003

51 buildings from 370 to 97 533 m² (total surface = 823 767 m²)		
	Electricity	Fuel
Specific average consumption	68 kWh/m²	120 kWh/m²

Opposed to the private offices in 2003 for electricity we see a reduction in the consumption.

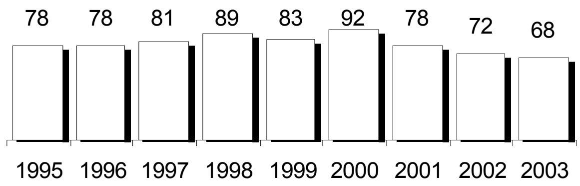


Figure A. 33 Evolution of the specific average consumption of electricity of public offices HT (kWh/m²)

Opposed to the private offices there is no correlation for the public offices between the degree days and the specific fuel consumptions.

Table A. 23 Specific average fuel consumptions of public offices HT in function of the degree days

Year	Degree days 15/15	kWh/m²
1995	1922	100
1996	2 383	106
1997	1 900	103
1998	1 906	97
1999	1 791	89
2000	1 714	86
2001	1 934	114
2002	1 683	131
2003	1 921	120

- Comparison

The private offices have a specific electricity consumption per m² superior to the equivalent in public offices, independent of the size of the building. The effect of informatics and office equipments as well as air conditioning has to be analysed in private companies.

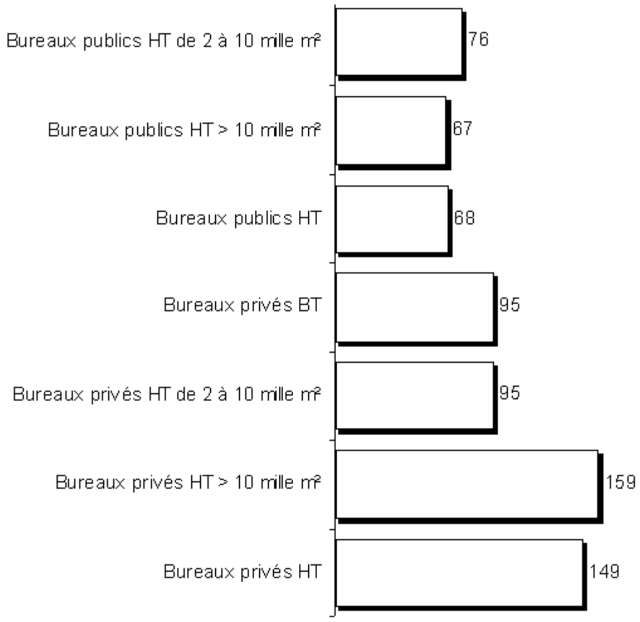


Figure A. 34 Comparison of specific average consumptions of electricity of the offices in 2003 (kWh/m²)

The specific fuel consumptions follow the inverse tendency; there are more important for public offices then for private offices.

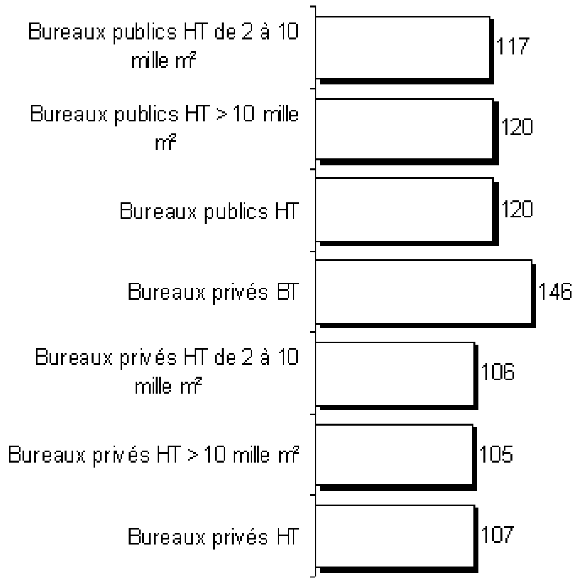


Figure A. 35 Comparison of specific average fuel consumptions of the offices in 2003 (kWh/m²)

<u>Offices in the Walloon Region [3]</u>

The private and public offices are studied separately. The first category comprises banks, insurance and service companies. The second comprises public administrations and internationals (no defence).

- Private offices

Consumptions per m²

Table A. 24 Specific average consumptions of the private offices HT (kWh/m²) in 2002

30 buildings from 80 to 33 000 m² (total surface = 226 227 m²)		
	Electricity	Fuel
Specific average consumption	114 kWh/m² 0.41 GJ/m²	102 kWh/m² 0.37 GJ/m²

Table A. 25 Specific average fuel consumptions of private offices HT in function of the degree days

Year	Degree days 15/15	kWh/m²
1997	1 937	125
1998	1 910	125
1999	1 797	125
2000	1 719	112
2001	1 936	120
2002	1 688	102

- Public offices

Consumptions per m²

Table A. 26 Specific average consumptions of the public offices HT (kWh/m²) in 2002

119 buildings from 170 to 30 000 m² (total surface = 470 619 m²)		
	Electricity	Fuel
Specific average consumption	56 kWh/m² 0.20 GJ/m²	165 kWh/m² 0.59 GJ/m²

Table A. 27 Specific average fuel consumptions of public offices HT in function of the degree days

Year	Degree days 15/15	kWh/m²
1997	1 937	178
1998	1 910	181
1999	1 797	172
2000	1 719	137
2001	1 934	156
2002	1 688	165

- Comparison

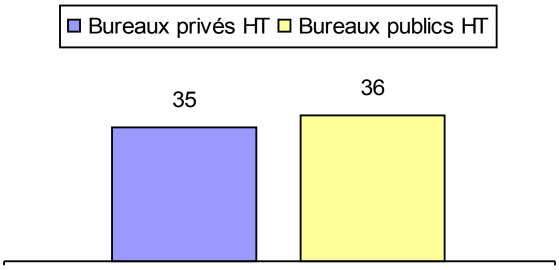


Figure A. 36 Surface of offices in 2002 (m²/employment)

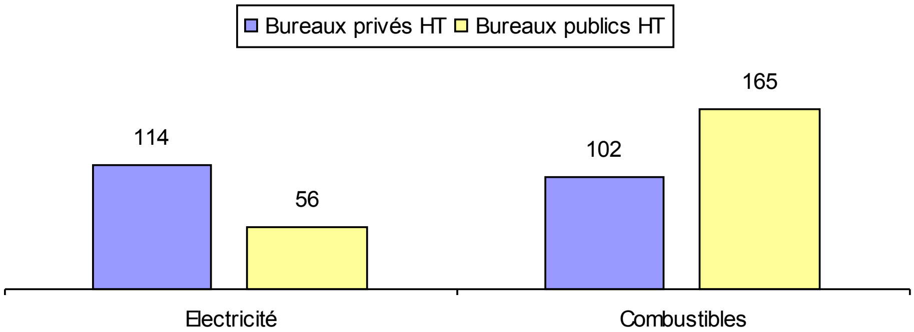


Figure A. 37 Specific average consumptions of offices in 2002 (kWh/m²)

Economic aspects on energy in offices [4]

The “Kantoor 2000” project is specifically directed on office buildings. In total 87 buildings of different sizes were looked at with regards to their energy consumption.

Table A. 28 Consumptions in electricity and fuel for offices (no distinction in the different types)

Net floor surface (total 87 buildings)		Electricity consumption (kWh/m²)	Fuel consumption (kWh/m²)
< 1000 m²	13	86	128
Between 1000 and 5000 m²	23	76	128
Between 5000 and 10000 m²	22	117	122
> 10000 m²	29	105	95

Sources

[1] Bijlage bij de energiebalans Vlaanderen 2003: onafhankelijke methode. Energiekengetallen van de tertiaire sector in Vlaanderen 2003, Juni 2005, K. Aernouts, K. Jespers.

[2] Bilan Energétique de la Région de Bruxelles-Capitale 2003: Consommations spécifiques du secteur tertiaire 2003, Rapport intermédiaire, Mars 2005, pour le compte de l'Institut Bruxellois pour la Gestion de l'Environnement Service Energie. Institut de Conseil et d'Etudes en Developpement Durable asbl.

[3] Bilan Energetique de la Région Wallonne 2002: Consommations spécifiques du Secteur Tertiaire 2002, Mars 2004, pour le compte du Ministère de la Région Wallonne DGTRE, Institut de Conseil et d'Etudes en Développement Durable asbl.

[4] KANTOOR 2000: Studie van Energiegebruik en Binnenklimaat van Kantoren, EINDVERSLAG,1.9.1998 – 31.12.2001, Vlaams Impulsprogramma Energie Technologie, Project 970.389/WTCB, Onderzoek verricht met steun van de Minister van Economie van het Vlaamse Gewest en van diverse bedrijven.

A.6.2 Greece

(by Mattheos Santamouris and Ifigenia Farrou)

Research study has been carried out on 185 offices in Greece. The offices are located in Athens. The sample covers offices of various sizes, with max office area of 20,000 m2, and minimum office area of 40 m2. 49% of the sample has an area less than 1000m2 and 43 % of the sample has an area between 1000 and 5000 m2.

Typical, Best Practice and Passive benchmarks have been defined, Typical as being the median value of sample (50%), Best Practice as being the quartile boundaries (25%) and Passive as being the 5% of the sample. The heating – cooling degree-day method (DDM) is used for weather normalisation of heating while for cooling, the CS index is used.

The buildings have been categorized into air conditioned or non air conditioned.

Table A. 29

Consumption for Heating (kWh/m² a)		
Offices	Air conditioned	Non air conditioned
Typical	85	63
Good practice	49.1	35.5
Passive standard	8.0	16.5

Table A. 30

Electrical Energy Consumption (kWh/m² a)		
Offices	Air conditioned	Non air conditioned
Typical	100	32
Good practice	60.8	15
Passive standard	30.5	3.4

Table A. 31

Energy Consumption for Lighting (kWh/m² a)		
Offices	Air conditioned	Non air conditioned
Typical	24.4	18.4
Good practice	17.1	7.6
Passive standard	5.4	2.5

Table A. 32

Consumption for Cooling (kWh/m² a)	
Offices	Air conditioned
Typical	108.0
Good practice	103.5
Passive standard	1.4

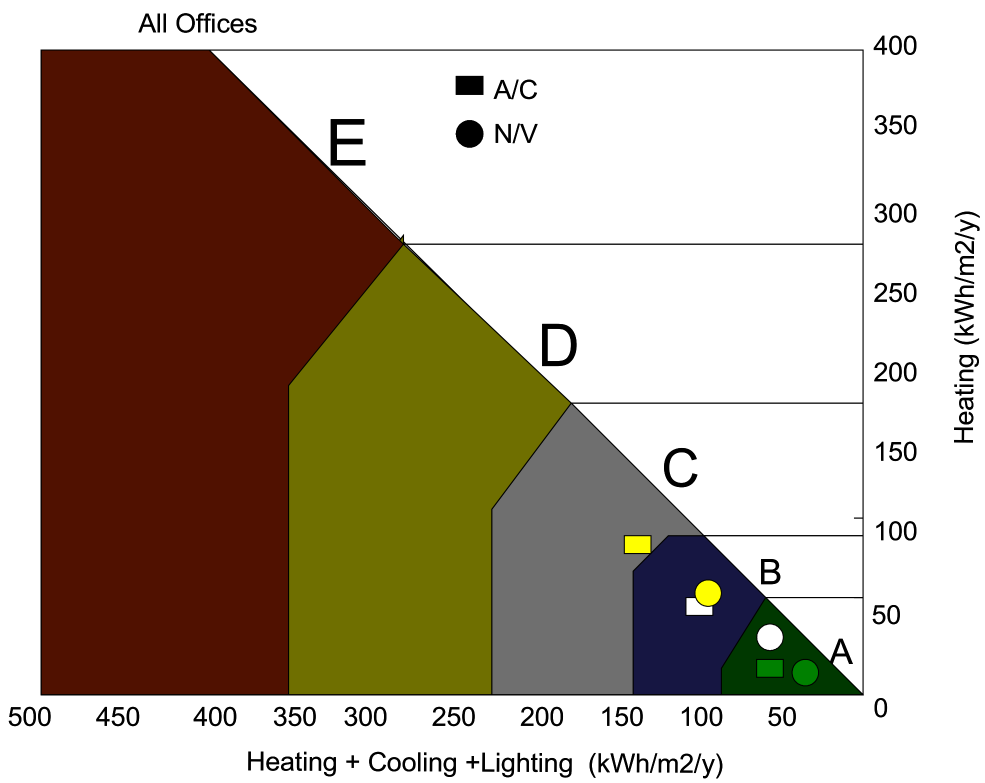


Figure A. 38 Air conditioned and naturally ventilated offices

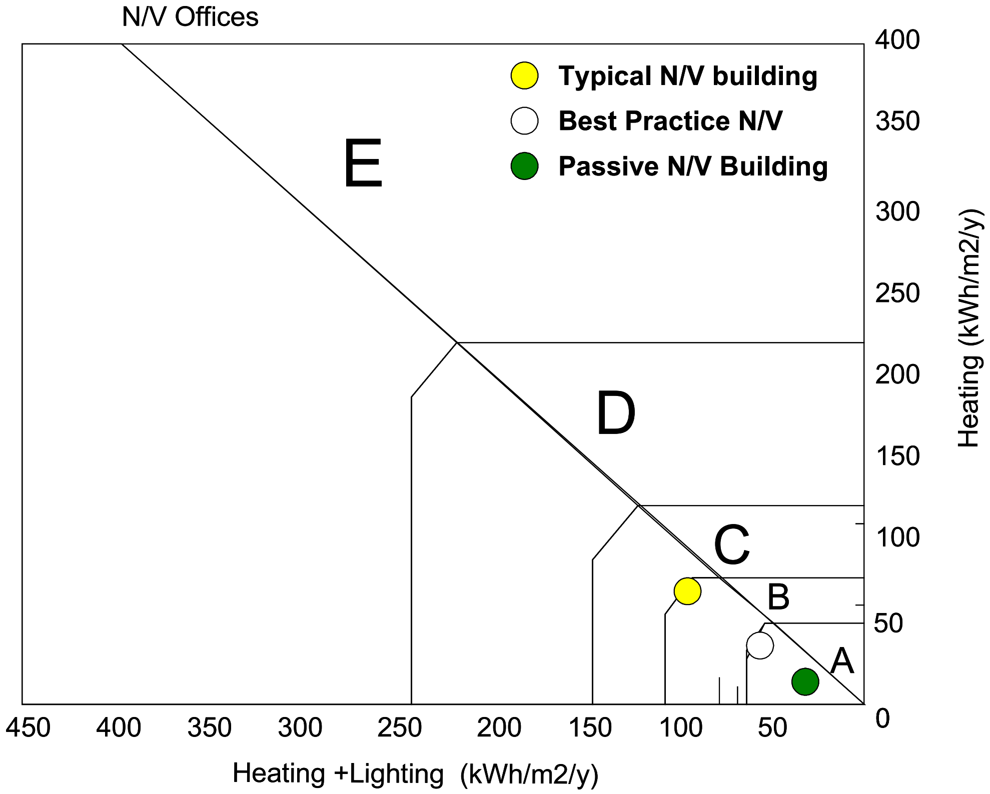


Figure A. 39 Naturally ventilated offices

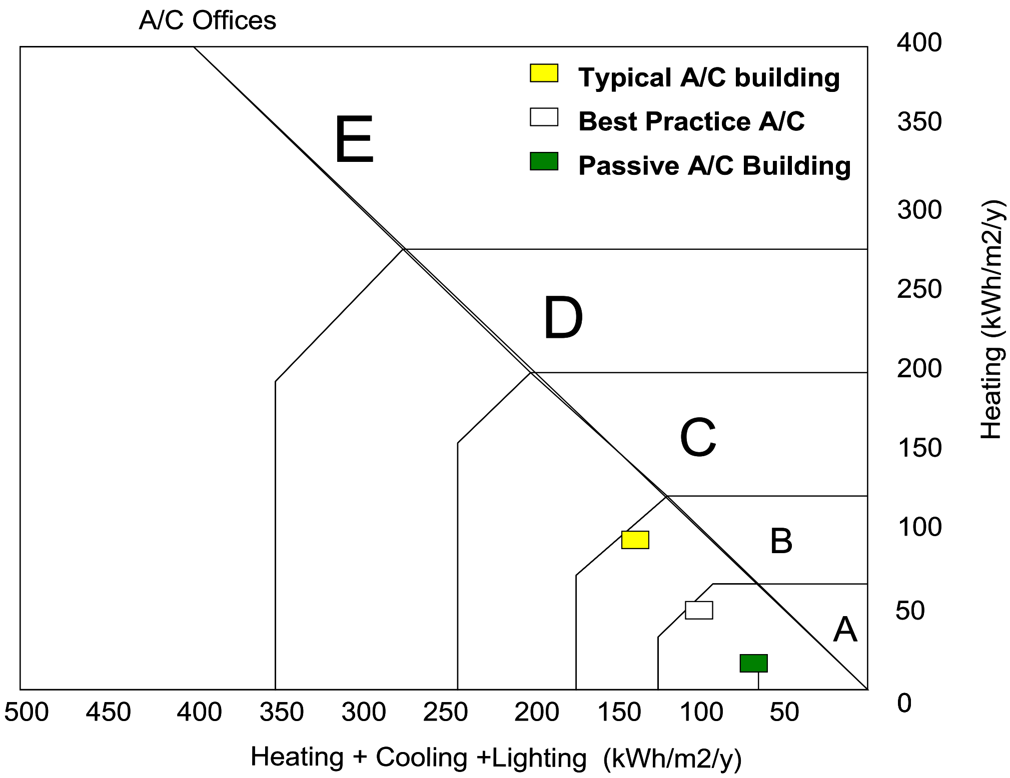
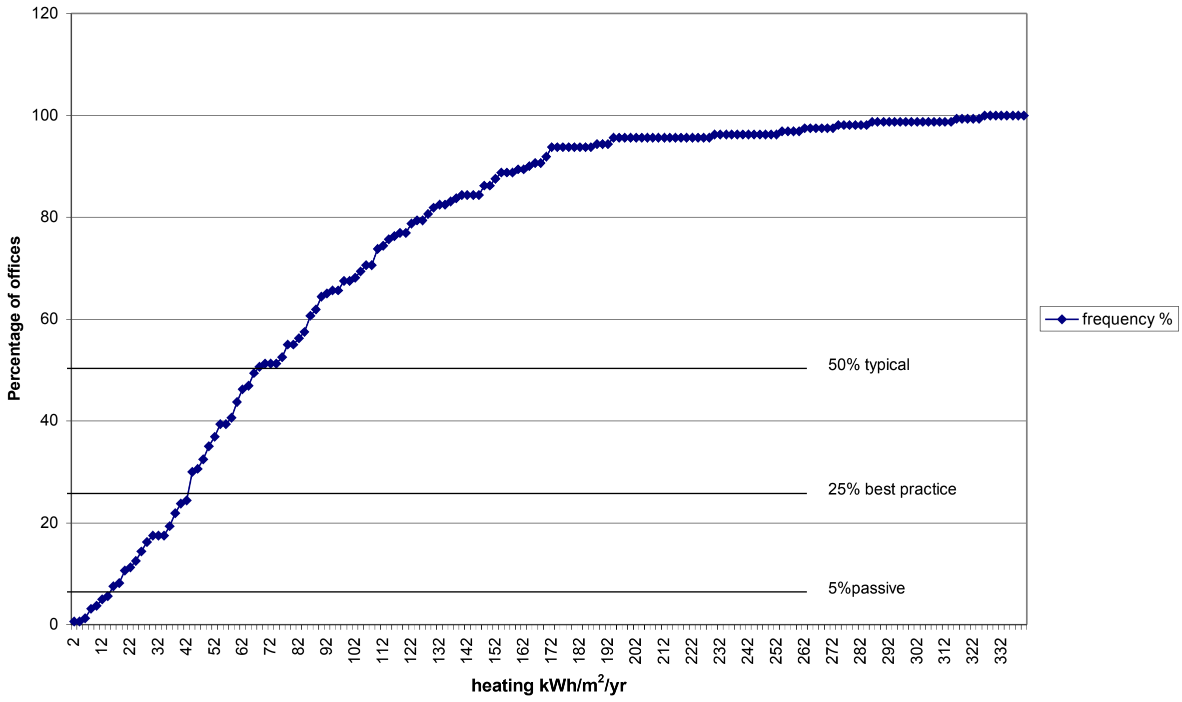
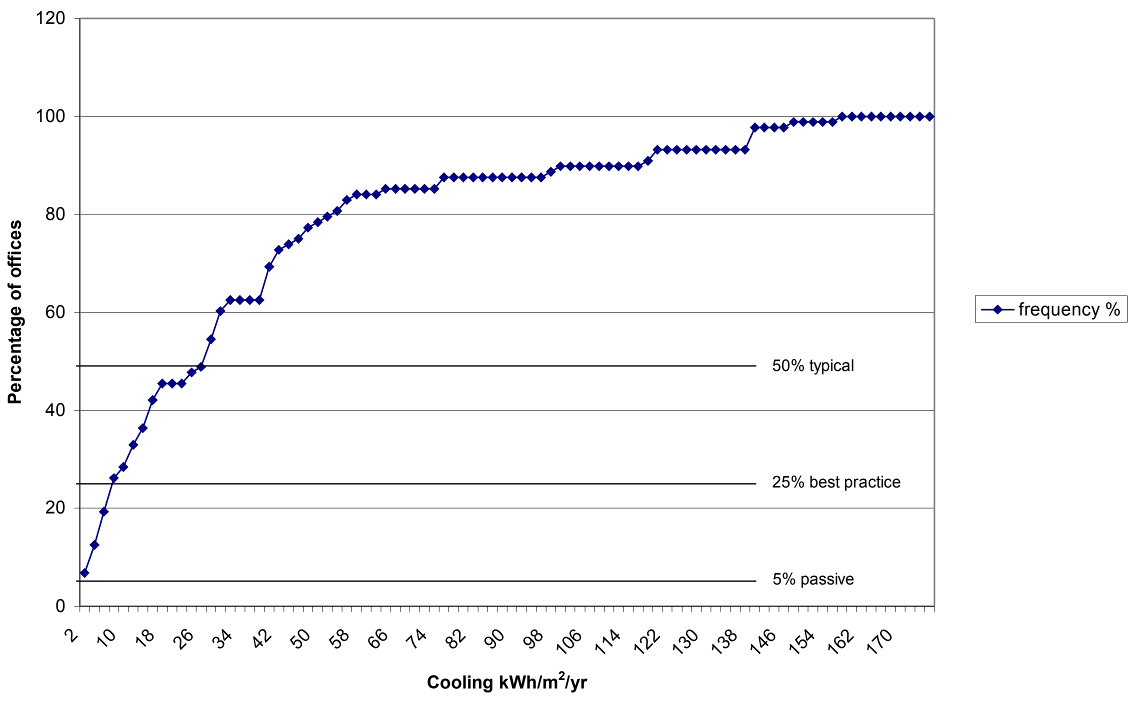


Figure A. 40 Air conditioned offices



Percentage of offices
heating kWh/m2/yr
frequency %
50% typical
25% best practice
5%passive



Percentage of offices
Cooling kWh/m2/yr
frequency %
50% typical
25% best practice
5% passive

A.6.3 Germany

(by Heike Erhorn-Kluttig and Hans Erhorn)

1. Type of energy sources used for heating and cooling

In Germany the traditional heating system is using fossil fuels like gas or oil as energy source. However if it comes to inner-city buildings such as high-profile office buildings which are the main building type for that double skin facades are chosen as façade system district heating is the most applied heating system. Heating by electricity is very seldom and if, heat pumps are used.

Cooling energy is mainly produced by electrical systems (air-conditioning, absorption cooling, etc.) or by district cooling systems. Please note that only a minor part of the buildings in Germany require cooling systems. If we consider only high-profile office buildings, even more in case of a high window/wall ratio, or buildings with high internal loads, they are built mostly including an Air-conditioning system or another type of cooling system.

2. Type of available measured energy consumption

Following the energy consumption nomenclature presented in the WP3 BESTFACADE report, the measured energy consumption available for most buildings are those that are given in the invoices by the energy supplier: the delivered energy. In case of a building being heated based on fossil fuels, there is a meter available for the delivered energy consumption of the fossil fuel and at least another one for the electricity. For buildings heated by the district heating system the supply company monitors the district heating consumption. Electricity is again measured separately. In case of electrical cooling and/or ventilation systems the specific consumption is in most cases contained in the total delivered electricity consumption if not several electrical meters are used. If only one electrical meter is used, the total electricity consumption includes equipment, lighting, auxiliary for heating (and if existing ventilation and cooling) plus of electrically provided cooling energy.

Obviously this is a problem, since the data that is used for the benchmarking in this report on basis of (delivered) electrical energy might therefore include ventilation and/or cooling energy for some buildings and for other buildings only the delivered lighting energy consumption plus the electricity used by the equipment.

On the other hand, the total of fossil fuels will most probably include delivered heating, but for some buildings also delivered cooling energy.

If buildings are heated by heat pumps they will most probably include two different meters, one for the heating energy and one for the other consumers.

It has to be mentioned that nowadays most high profile office buildings include a building energy management system (BEMS or BMS). These systems offer more insights in specific consumptions (depending on different systems, different building parts, etc.).

<u>3. Energy efficiency requirements used and methods on how to proof that the requirements are met</u>

The German implementation of the Energy Performance of Buildings Directive (EPBD) for non-residential buildings, as published in 2007 foresees only one method for new buildings to proof that the required energy efficiency is met: A calculation of the building with the standard DIN V 18599. The planned building and a so-called reference building is assessed with the holistic and detailed method based on a monthly balance and the resulting calculated primary energy consumption of the planned building must not exceed those of the reference building. For the reference building a table in the German energy decree defines reference technologies for the building and the HVAC system that have to be used for the calculation. The results of the calculation cover the following energy detailed consumptions:
- calculated net energy consumption for: heating, cooling, ventilation, lighting and domestic hot water (DHW)
- calculated delivered energy consumption for: heating, cooling, ventilation, lighting and DHW
- calculated primary energy consumption for: heating, cooling, ventilation, lighting and DHW.

The total of these values must not exceed the total calculated primary energy consumption of the reference building.

In case of existing non-residential buildings (with planned major renovations, or to be sold or let) two possible methods are available for issuing the necessary energy performance certificate: The same method as defined for the new buildings or alternatively a method based on the measured energy performance, that means the delivered energy according to invoices by the energy supplier or similar. This data has to be climate normalised and in case that the building is partly empty also recalculated by a factor depending on the used area. There is a guideline provided by the responsible ministry that gives benchmarks for various building types. These benchmarks are presented as delivered heating energy consumption and (delivered) total electrical energy consumption and shall not be exceeded. The benchmarks are derived from a statistical analysis of many buildings of the same building types. In case of (public) office buildings there are three benchmarks available: common public office buildings, public office buildings with low technology grade and public office buildings with high technology grade.

4. Benchmarks provided to the WP3 report

According to the new German EPBD implementation methodology for non-residential buildings there are no benchmarks available for calculated net energy consumptions, neither for calculated delivered energy consumptions. Benchmarks could be derived from calculated primary energy consumptions as the results of the reference building calculation could be used as benchmarks. But these values are building specific, that means they depend on the building geometry, the building use and partly even the applied HVAC system. Therefore benchmarks would result in a “cloud” of data and can only be worked out based longer experience of the method and more performed calculation results.

However the alternative system for existing buildings offer a good possibility to be used as benchmarks. The requirements derived from measured data (delivered energy divided into heating and electricity) are only dependent on the building use.

The German benchmarks provided for this report are as presented in Table A. 33.

Table A. 33 German benchmarks.

Building			Delivered heating+ DHW consumption	(Delivered) electricity consumption	Source
no.	name	type	kWh/m²a	kWh/m²a	
1	1300 Verwaltungsgebäude	administrative buildings	105	24	Bundesministerium für Verkehr-, Bau und Stadtentwicklung: Richtlinie Energiever-brauchskennwerte Nichtwohngebäude" (status 6/9/2006)
2	1310 Verwaltungsgebäude, normale techn. Ausstattung	administrative buildings, standard technical equipment	120	24	
3	1311 Ministerien	ministry buildings	100	64	
4	1312 Ämtergebäude	official buildings	105	20	
5	1314 Arbeitsämter	employment offices	149	34	
6	1320 Verwaltungsgebäude hohe techn. Ausstattung	administrative buildings, high technical equipment	105	48	
7	1330 Gesundheitsämter	health offices	135	18	
8	1340 Polizeidienstgebäude	police offices	120	24	
9	2000 Gebäude für wissenschaftliche Lehre und Forschung	buildings for science and research	120	18	
10	2200 Institutsgebäude für Lehre und Forschung	institutional buildings for science and research	135	18	

Source: Guideline "Richtlinie Energieverbrauchskennwerte Nichtwohngebäude" (draft of guideline for the non-residential buildings of 6/9/2006, also available for residential buildings at the website www.bmvbs.de).

The building types are based on the systematic of the building type catalogue of the Federal States (Bauwerkzuordnungskatalog ARGE BAU). When considering double skin façade buildings within the BESTFACADE project the suitable building types are mostly office buildings. There is no special data for double skin facades. If the aim is to give one value for heating and one value for electricity for office buildings then the no. 1300 (administrative buildings) would be the most neutral one. However the authors advised to use two values, nos. 1310 (office buildings with standard technical equipment) and 1320 (office buildings with high technical equipment) as benchmarks, since double skin facades often are rather expensive highly equipped office buildings.

5. Double skin façade building energy data and single skin façade building energy data provided to the WP3 report

From the 5 German DSF buildings presented in the WP1 report, for one building there was no measured data available. Even more, this building received an energy certificate based on the previous energy decree which was not considering an office user profile but a residential profile. Therefore the calculated data was not forwarded to the BESTFACADE project data base as it can’t be compared with the other buildings.

For the other 3 buildings the available data covers both calculated and measured energy consumptions. In terms of measured energy consumption the available data can only be split into delivered heating energy consumption and delivered electrical energy consumption.

The calculated energy consumption is however available for various energy consumptions: net, delivered and primary for heating, cooling, ventilation, lighting and primary energy. Additionally single skin façade building data was provided on different levels.

The overview on the provided data is presented in the following table.

Building no.	Description of building type	DSF	SSF	Air-conditioned	calculated energy data according to DIN V 18599 [kWh/m²a]																Measured data according to invoices (climate neutralised for average German climate [kWh/m²a]	
					net energy consumption					delivered energy consumption					primary energy consumption						delivered energy consumption for heating and domestic hot water (= fossil fuels)	delivered electrical energy consumption for lighting, equipment + if used: mechanical ventilation, air-conditioning, others)
					heating	cooling	ventilation	lighting	DHW	heating	cooling	ventilation	lighting	DHW	heating	cooling	ventilation	lighting	DHW	total		
D1	DSF office building	X		X	75	15	9	23	11	103	20	9	23	**14**	59	76	27	68	7	237	**72,1**	**103,3**
D2	DSF office building	X		X	34	13	8	15	9	42	18	8	15	**13**	23	67	23	44	7	166	**57,3**	**93,8**
D3	DSF test facility with annual runs	X		X	57,3	23,2		23,2													**64,1**	cooling: **9,1** lighting: **25,5**
D4	office building		X	X																	39,6	47,9
D5	office building		X	X																	56,5	80,2
D6	office building		X	X																	169,3	100,9
D7	office building		X	X																	154,3	50,0
D8	office building		X																		183,1	29,6
D9	office building		X	X																	102,6	35,0
D10	office building		X	X																	142,4	82,6
D11	health office building		X	X																	168,5	59,2
D12	tax office building		X																		114,0	44,0
D13	ministry of finance		X	X																	52,3	36,0

Additionally there exists an average value for an in detail measurements for delivered energy consumptions for a benchmarking pool of 20 office buildings in Frankfurt. Most of the buildings are air-conditioned and they represent a mix between single skin and double skin façade buildings. The average values are:

Measured delivered energy consumption for:

heating + DHW:	131 kWh/m²a
cooling:	17 kWh/m²a
ventilation:	33 kWh/m²a
lighting:	27 kWh/m²a

A.6.4 Sweden

(by Åke Blomsterberg)

1. Type of energy sources used for heating and cooling

In Sweden the traditional heating system for office buildings and blocks of flats in cities is district heating. 70 % of the floor area in office buildings is heated by district heating. Heating by electricity is very seldom used and if, then heat pumps are used. Cooling energy is mainly produced by electrical systems (air-conditioning, absorption cooling, etc.) or by district cooling systems. Many modern office buildings in Sweden have cooling systems. If we consider only high-profile office buildings, even more in case of a high window/wall ratio, or buildings with high internal loads, they are built mostly including an air-conditioning system or another type of cooling system.

2. Type of available measured energy consumption and benchmarks

Following the energy consumption nomenclature presented in the WP3 BESTFACADE report, the measured energy consumption available for most buildings are those that are given in the invoices by the energy supplier: the delivered energy. For buildings heated by the district heating system the supply company monitors the district heating consumption. Electricity is measured separately. If the fuel for the boiler is oil, the delivered energy consumption is documented in the bill, but it is often not exactly a one year consumption. The bill only shows what the owner has ordered. This could have been consumed during more or less than a one-year-period. The one year period has to be recalculated. In case of electrical cooling and/or ventilation systems the specific consumption is in most cases contained in the total delivered electricity consumption if not several electrical meters are used. If only one electrical meter is used, the total electricity consumption includes office equipment, lighting, pumps and fans, electricity for cooling plants/units.

Obviously this is a problem, since the data that is used for the benchmarking in this report is electricity for cooling, while for the Swedish double skin facade buildings in the report the data is district cooling.

3. Benchmarks for the BESTFACADE project

The energy requirement according to the new building code specifies the total energy use excl. electricity for office equipment and lighting i.e. it should be below 100 kWh/m^2year (usable floor area). If this requirement is recalculated to non-residential area, then the requirement is approximately 110 kWh/m^2year. The energy use for heating and cooling is not specified separately. However an example fulfilling this limit could be “low” in the table below, 105 kWh/m^2year vs. 110 kWh/m^2year, which means “normal” and “high” will not meet the new building code.

Table A. 34 Energy use in office buildings – benchmarks based on statistics for the office building stock in Sweden (REPAB 2003). Only “low” fulfils the new Swedish building code.

Energy use, kWh/(m2 a) (non-residential area)	District heating	Electricity (fans, pumps etc.)	Electricity (lighting, PC etc.)	Electricity cooling	Total electricity	Total energy use
low	80	10	35	15	60	140
normal	125	18	50	30	98	223
high	205	30	80	50	160	365

References

REPAB, 2003. Årskostnader Kontor 2003 (Yearly costs Office buildings). REPAB AB, Möndahl.