Single Skin Glazed Office Buildings

Energy Use and Indoor Climate Simulations

Harris Poirazis

Division of Energy and Building Design
Department of Architecture and Built Environment
Lund University
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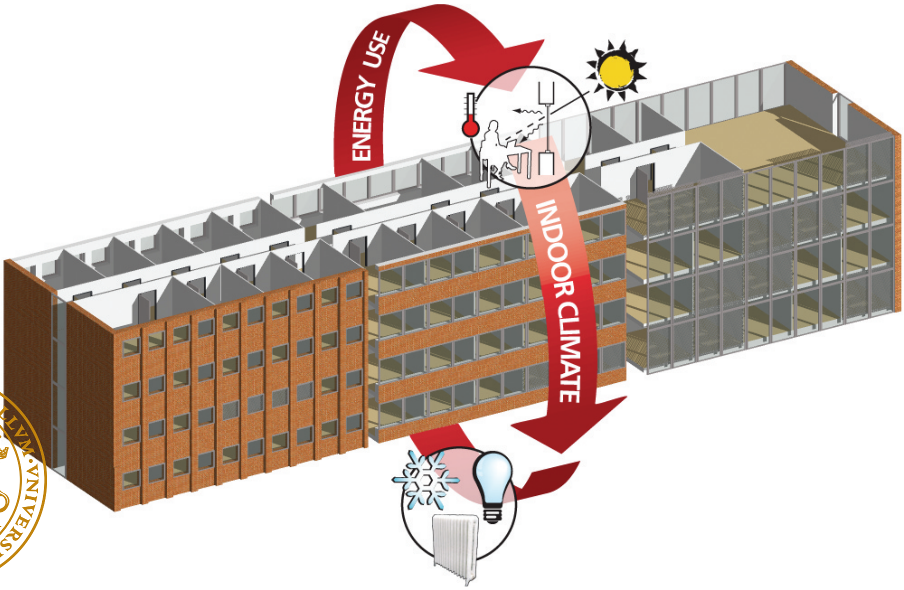

Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 101 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 006 employees and 41 000 students attending 90 degree programmes and 1 000 subject courses offered by 88 departments.

Division of Energy and Building Design

Reducing environmental effects of construction and facility management is a central aim of society. Minimising the energy use is an important aspect of this aim. The recently established division of Energy and Building Design belongs to the department of Construction and Architecture at the Lund Institute of Technology in Sweden. The division has a focus on research in the fields of energy use, passive and active solar design, daylight utilisation and shading of buildings. Effects and requirements of occupants on thermal and visual comfort are an essential part of this work. Energy and Building Design also develops guidelines and methods for the planning process.

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Licentiate Thesis

Key words

Building Performance, Energy Use, Indoor Climate, Indoor Environment, Thermal Comfort, Building Simulations, Single Skin Facades, Glazed Buildings.

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Abstract

Modern office buildings have high energy savings potential and potential for indoor climate improvements. During the nineties many office buildings with glass facades were built, in several cases with double skin glass facades. The advantages of buildings with double skin facades (compared with single skin glazed ones) are considered to be the reduced heating and cooling demand, the increased sound insulation towards the outside and the efficient solar shading. Glazed office buildings are considered to be airy, light and transparent with more access to daylight. However, there is insufficient knowledge concerning the function, energy use and visual environment of glazed office buildings for Scandinavian conditions. Therefore a project was initiated in order to gain knowledge of the possibilities and limitations of glazed office buildings regarding energy use and indoor climate issues. This means further development of calculation methods and analysis tools, improvement of analysis methodology, calculation of LCC, compilation of advice and guidelines for the construction of glazed office buildings and strengthening and improving the competence on resource efficient advanced buildings in Sweden.

The first part of this project involved establishing a reference building with different single skin glazed alternatives, choosing simulation tools and carrying out simulations for the determined alternatives.

As the reference building, an office building representative of the late nineties was chosen. Different possible glazed alternatives were determined for this building. For the simulations the dynamic energy simulation program IDA ICE 3.0 was chosen. It is already obvious that some improvements of the simulation tool are desirable. Further development of simulation tools allows simulation of more precise models. Parametric studies can then be more detailed and additional aspects can be examined.

This report presents the building alternatives studied, the methods and the results of the parametric studies made for office buildings with 30%, 60% and 100% glazed area. Interesting results were obtained through varying the building's orientation, the interior plan type (open

plan and cell type offices), the type of glazing and solar shading devices and the HVAC strategy. The different building models are compared with different indoor environment classifications and a sensitivity analysis is presented regarding the occupants' comfort and the energy used for operating the building.

Highly glazed office buildings risk having a higher energy use for heating and cooling and at times poorer thermal comfort, compared with a building with conventional facade. However, it was shown that energy reduction is clearly possible with improved window types combined with proper shading devices, but the energy use is likely to still be somewhat higher than for the conventional building. Studying indoor climate in a highly glazed building, where the external skin is much more sensitive to the outdoor climatic conditions than a conventional façade, is a complicated task, since many parameters influence its quality. It was shown that an improved indoor environment with low energy use can be obtained if a detailed study for each building design is carried out, involving proper combination of control set points and choice of widow and shading devices, used for certain occupancy and function of the building.

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Lund, May 2005

Harris Poirazis

1 Introduction

This licentiate thesis is an important part of the Glazed Office Building project (see description below). The thesis focuses on analyses of indoor climate and energy use of single skin glazed office buildings, starting with a reference building, in Scandinavia.

1.1 Description of the "Glazed Office Building" project

The energy efficiency and the thermal performance of highly glazed office buildings are often questioned. However, nowadays more and more glazed buildings are built for the following reasons:

- There is a growing tendency on the part of architects to use large proportions of glass that lead to higher transparency.
- Users (who do not take into account the risk of visual and thermal discomfort that can occur due to this construction type) often also like the idea of increased glass area, relating it to better view and more pleasant indoor environment.
- Companies who want to create a distinctive image for themselves (e.g. transparency or openness) often like the idea of being located in a glazed office building.

Therefore the research project "Glazed office buildings – energy use and indoor climate" was initiated and funded.

The aim of the project is to gain knowledge concerning the possibilities and limitations of glazed office buildings exposed to Swedish boundary conditions, with regard to:

- energy use
- indoor environment (thermal and visual comfort, indoor air quality, acoustics, etc)

- environmental performance
- architectural quality and
- life cycle cost

Different office building types will be investigated during the four years of the project and suggestions for energy efficient façade constructions, contributing to making entire office buildings energy efficient, will be made. The performance of highly glazed office buildings will be evaluated, optimised and compared with more traditional buildings. In order to achieve that, both single and double skin façades will be simulated, with regard to energy use and indoor climate.

Additionally, detailed simulations (CFD) of the Double Skin Facade cavity will be carried out, in order to determine air flows and temperatures at different heights of the cavity and for each layer. Detailed knowledge of the system performance will lead to precise predictions of the building performance. Test room measurements will also take place concurrently with the simulations in order to validate the results from the simulations.

Included in the "Glazed Office Buildings" project are

- Further development of calculation methods and analysis tools
- Improvement of analysis methodology
- Calculation of life cycle costs
- Development of advice and guidelines for design/construction of glazed office buildings in a Swedish climate
- Strengthening and development of competence concerning resource efficient advanced buildings in Sweden.

1.2 System approach

A detailed description of the system approach can be found in the "Introductory report for the Glazed Office Building project", (Poirazis, 2004b). Below follows a summary of the mentioned report.

1.2.1 General

Before describing the parameters (and their limitations) that this thesis focuses on, it is useful to describe the main components that constitute the building's performance. In this way it is easier to understand how the energy efficiency and the improved indoor environment interact with each other, thus contributing to the optimisation of the building's overall performance.

The building can be considered as a

- Sub system of the environment that it is located in. During its whole life the building has impacts that are related mainly to environmental and energy use issues.
- Hyper system influencing the comfort and productivity of the occupants.

In order to succeed in a holistic approach during the design stage of an office building, it is important to consider that the parts interact with each other, and influence the systems' performance, as shown in Figure 1.1.

The design team should take into account the design constraints at an early stage of the decision making process, in order to achieve a more overall approach and more accurate predictions. In this way, unpleasant surprises that increase the life cycle cost of the building and/or impair the performance as to energy use and indoor climate can be avoided. These constraints are

- Climate (solar radiation, outdoor temperature, etc)
- Site and obstructions of the building (latitude, local daylight availability, atmospheric conditions, exterior obstructions, ground reflectance, etc)
- Use of the building (operating hours, occupant density, schedule and activity, etc)
- Building and Design Regulations

It is obvious that optimum building design can not be achieved, since the overall goodness can be defined in different ways depending both on the design constraints and on the way that the design team prioritises its goals and needs.

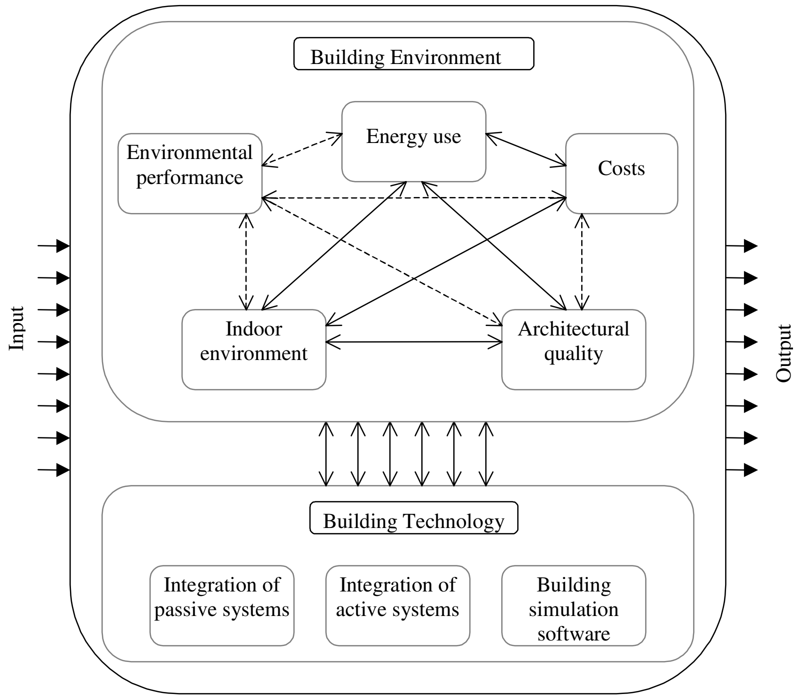


Figure 1.1 *Description of the building system.*

The performance parameters of the building environment interact with each other. Since the energy efficiency with respect to the indoor climate is the main aspect examined in the project “Glazed office buildings” the lines in Figure 1.1 are continuous.

In sustainable building design the integration of solar technologies is a delicate matter. Good performance of passive or active solar systems can not be achieved unless the integration of the solar technologies is considered in the early design stage. The systems’ efficiency is highly connected with the location and use of the building and is directly influenced by the building’s shape and orientation. It has impacts on the life cycle cost, on the environmental profile, and it can be crucial for the quality of the indoor environment (e.g. double skin facades can allow better temperatures in the inner layer of the pane, increasing the uniformity of the thermal environment and thus improving the thermal comfort of the occupants).

1.2.2 Hierarchy of Design Criteria

In the ongoing project “Glazed Office Buildings”, the main objective is to study different types of energy efficient office buildings with acceptable indoor environment, reasonable LCC (investment, operating and maintenance) cost, low environmental impacts and good architectural quality (see subchapter 1.2.6). The figure 1.2 shows the (top to down) hierarchy for the “Glazed Office Building” project. The objectives at the top are quite abstract but they become more specific as one follows the hierarchy down.

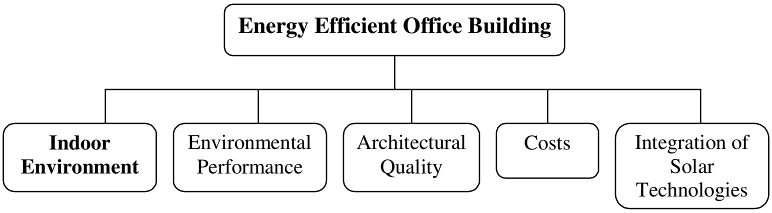


Figure 1.2 Hierarchy of design criteria.

According to Wouters, (2000) the building design is the most important step in achieving an acceptable indoor climate. The restrictions on the energy use of the technical installations constitute an important part of the building performance. Thus, the energy efficiency can be considered an important part of the building design. However, low energy design can not be the only target since other parameters also contribute to the improved overall performance.

Achieving an acceptable indoor environment with respect to energy use is one of the biggest challenges when an office building is designed. The main components that define the indoor environment are shown in Figure 1.3. These parameters have an impact on the occupants’ productivity and furthermore on the total economic value of the building. According to ASHRAE Standard 55 (1981), *“Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment”*.

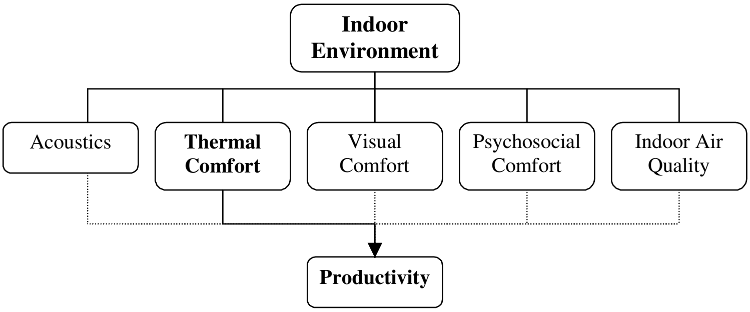


Figure 1.3 *Criteria of indoor environment.*

This thesis deals mostly with thermal comfort parameters while the other parameters are investigated in the main project "Glazed office buildings". The thermal comfort can be divided into primary and secondary factors that influence the quality of the thermal environment, as shown in Figure 1.4.

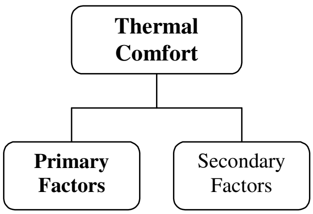


Figure 1.4 *Main aspects of thermal comfort.*

1.2.3 Conditions of thermal comfort

According to Liddament M. (1996), thermal sensation is the most important parameter in the perception of comfort. As he writes, *"Air is the primary transport mechanism for thermal comfort while air speed and turbulence influences the sensation of cooling and draughts. High infiltration or unnecessary air change rates result in the loss of conditioned air and may prevent comfort conditions from being attained"*.

As mentioned above, the factors influencing thermal comfort are divided into primary and secondary ones. The primary factors are shown in Figure 1.5:

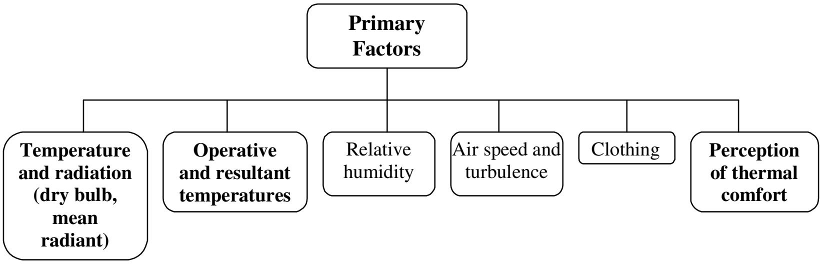


Figure 1.5 Primary factors of thermal comfort.

Temperature and radiation (dry bulb, mean radiant)

The thermal sensation is dominated by the surrounding temperature. However, the standard dry bulb temperature is not always a sufficient indicator for establishing a good indoor thermal environment, since it does not take into account the influence of radiant energy. The mean radiant temperature, however, is a more appropriate thermal comfort indicator since it is a measure of the average radiation exchange between the occupant and the surrounding surfaces.

Operative and resultant temperatures

The operative and mean resultant temperatures empirically combine the dry bulb and the mean radiant temperatures. The operative temperature is the temperature at which a person emits the same heat output as before, but when air temperature (θ_a) = radiant temperature (θ_r) = operative temperature (θ_{op}). The θ_{op} doesn't have the same value for all the parts of the room (when the weighting method is used).

Near cold surfaces θ_{op} drops since the temperatures are low and the angle factors large (the closer the measuring point is to a surface, the larger is the angle factor). The more the occupant moves away from the surface, the more the angle factor decreases and thus the smaller the effect of the cold surface becomes. Since all the surfaces of a room are weighted, the walls can have a larger effect than a cold window (although the wall temperatures can be very close to the mean air temperature). Thus, the operative temperature gives a measure of a room as a whole but it is not a sufficient indicator for showing the impact of a cold surface on occupant's comfort. For this reason, the directed operative temperature is preferred. This is calculated in the same way with the only difference that weighting is done only for the point where the occupant is placed and towards the surface of interest as shown in Figure 1.6. The operative temperature, however, can be used when persons are moving inside the space (i.e. open plan office type).

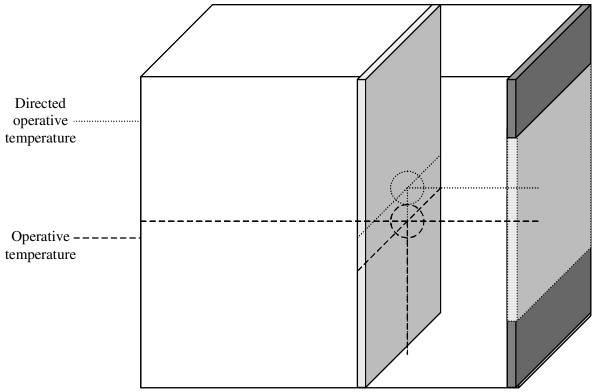


Figure 1.6 Operative and directed operative temperature.

Relative humidity

Relative humidity is the humidity content at a certain temperature compared with the maximum humidity allowed (until condensation starts). Generally, the humidity affects the heat loss by evaporation, which is most important at high temperatures and high metabolism. However, questionnaires have shown that even in the comfort zones the relative humidity has a large impact on the perception of the thermal environment. High relative humidity means that the moisture content of clothing increases which alters their insulating properties. Usually the relative humidity in an office space varies between 30% and 60%.

Air speed and turbulence

The sensation of thermal comfort is influenced by air speed and the scale of turbulence. Often the increased speed can be an advantage in an office space when the temperatures are higher than in the comfort zone. A typical way to increase the air speed is to use circulation fans in the rooms. However, at other times, draughts cause discomfort due to localised cooling.

Clothing

Clothing provides thermal insulation. Thus, it has an important influence on acceptable temperature. The choice of clothing can alter comfort preferences by as much as 2 to 3K. The unit that expresses the clothing insulation is clo; (1 clo = 0.155 m^2KW^{-1}). According to ASRAE Fundamentals (2001), *"because people change their clothing for the seasonal weather, ASHRAE Standard 55 specifies summer and winter comfort zones appropriate for clothing insulation levels of 0.5 and 0.9 clo respectively"*.

Perception of thermal comfort

It is important to clarify that the conditions of thermal comfort are not easy to define, since thermal comfort is a very subjective value. Thus, a thermal environment that is acceptable to some people may be totally unacceptable to others. According to Andresen, (2000), it is not only that people are differently dressed and have different metabolic rates, but their assessment of comfort is also influenced by their psychosocial environment. According to the author, *"no calculation method can predict exactly what will happen in a building under actual operating conditions. Important variables such as occupant density, shading, and equipment heat gain are dependent on factors that are more or less impossible to predict accurately. Sensitivity analyses may help to reveal the robustness of the building, but the amount of effort required is considerable. Despite this, there are standards and so called "objective" methods for assessing thermal comfort quantitatively. The most common ones are ASHRAE standard 55-92 (ASHRAE 1992), ISO Standard 7730 (ISO 1984)"*. In order to describe this factor it is necessary to explain the concepts of **Predicted Mean Vote (PMV) index** and **Predicted Percent Dissatisfied (PPD).** Both the ASHRAE and ISO standards are based on the concepts of **PMV** and **PPD** developed by P.O. Fanger (1970).

- The **PMV** index is a measure of thermal sensation since it expresses the correlation between indoor environment parameters and people's sensation of thermal comfort. It is a function of activity, clothing, air temperature, mean radiant temperature, relative air velocity and humidity. As it is described in ASHRAE fundamentals (2001), *"The PMV index predicts the mean response of a large group of people according to the ASHRAE thermal sensation scale"*. The ASHRAE sensation scale is presented below:

+3 = hot
+2 = warm
+1 = slightly warm
0 = neutral
-1 = slightly cool
-2 = cool
-3 = cold

The values (Y) that refer to the thermal sensation scale depend on the dry bulb temperature and vapour pressure. The *PMV* is defined by the following equation:

$$PMV = [0.303\exp(-0.036M) + 0.028]L$$

Equation 1.1 Predicted Mean Vote index

where according to ASHRAE Fundamentals (2001)

M is the metabolic rate required for the persons' activity + metabolic level required for shivering
L *"is the thermal load on the body, defined as the difference between internal heat production and heat loss to the actual environment for a person hypothetically kept at comfort values of t_{sk} (temperature of skin compartment) and E_{rsw} (evaporation of sweat secreted due to thermoregulatory control mechanisms) at the actual activity level".*

It is a fact that the mathematical expression for *PMV* is quite complex. However available tables and diagrams make it easier to determine the *PMV*.

- The Predicted Percentage Dissatisfied (***PPD***) of a large group of people is an indication of the number of persons who will be inclined to complain about the thermal conditions. After estimating the PMV, the predicted percent dissatisfied (*PPD*) with a condition can also be estimated by the following equation:

$$PPD = 100 - 95\exp[-(0.03353PMV^4 + 0.2179PMV^2)]$$

Equation 1.2 Predicted Percentage of Dissatisfied

Those persons not scoring +1, -1 or 0 are deemed to be dissatisfied. From this part, the predicted per cent dissatisfied (PPD) of occupants could be determined.

Accepting that no single environment is judged satisfactory by everybody ((Liddament, 1996) mentions that *"the immediate conclusion of this work was that it was not possible to define a set of thermal conditions that would satisfy everyone. Even when the average of the predicted mean vote was zero, i.e. a neutral thermal environment, 5% of the test occupants were dissatisfied"*), the standards specify a comfort zone based on 90% acceptance or 10% dissatisfied. Thus, the upper limit for operative temperature in summer is 26°C, given 50% relative humidity, sedentary activity, 0.5 clo and a mean air speed of less than 0.15 m/s.

Based on the PMV index, the PPD index can be calculated. The PPD index predicts the percentage of the occupants who will judge their thermal comfort unsatisfactory (corresponding to a vote below –2 or above +2). PPD as a function of PMV is shown in Figure 1.7:

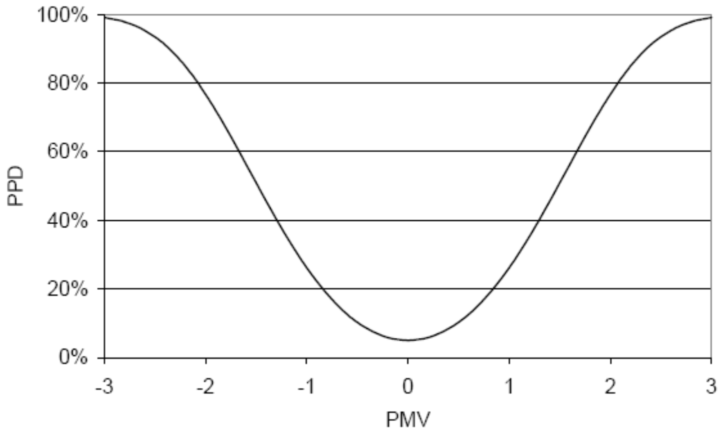


Figure 1.7 PPD as a function of PMV (Pedersen, 2001).

Andresen (2000) claims that *"the PMV model is interpreted as a constant set-point for a given clothing, metabolic rate and air velocity. It does not consider any effects due to adaptation, cultural differences, climate and seasons, age, sex or psychosocial attributes"*. According to the author, *"recent research casts doubt upon the application of steady-state heat exchange equations to what in practice is a variable environment (Clements-Croome, 1997). People are not passive recipients of the environment, but take adaptive measures to secure thermal comfort. They may modify their clothing or activity, modify the lighting or solar heat* *gains, or modify the ventilation rate through opening of doors and windows. This suggests that a more "adaptable" method of comfort judgment is needed".*

The PMV and PPD of building alternatives studied in this thesis will be studied both on a building and individual zone level (Chapter Five).

Other parameters such as state of health, level of physical activity, gender, working environment and individual preferences can also influence the perception of thermal comfort.

Although the secondary factors of thermal comfort, apart from asymmetric thermal radiation (directed operative temperature), are not studied in the present thesis, a brief description follows.

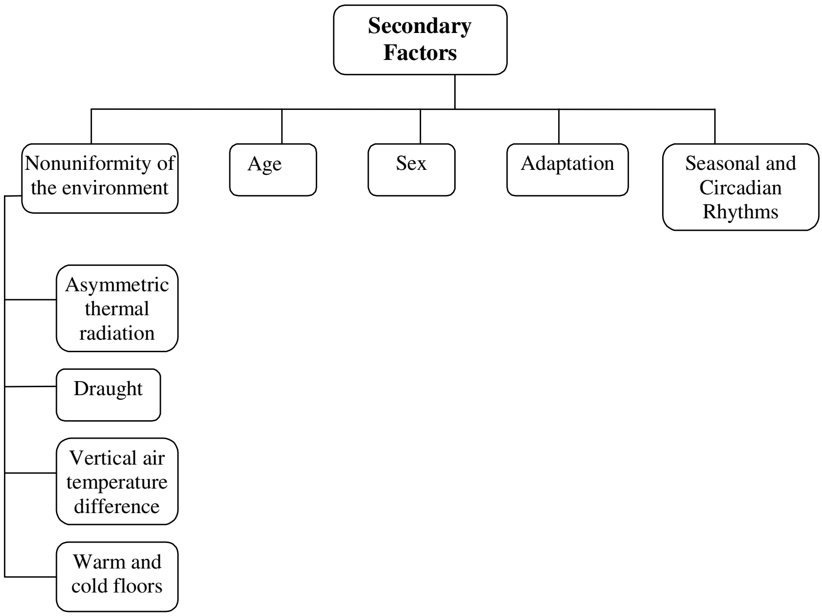


Figure 1.8 Secondary factors of thermal comfort.

As shown in Figure 1.8, the secondary parameters that influence the thermal environment are as follows:

Non-uniformity of the environment

The non-uniform conditions that lead to local discomfort are probably the most important of the above secondary factors. According to ASHRAE Fundamentals (2001), *"a person may feel thermally neutral as a whole but still feel uncomfortable if one or more parts of the body are too warm or too cold".* A number of reasons can lead to a non-uniform environment. Some of these are

- a cold window
- a hot surface
- draught
- a temporal variation of these

- In buildings, **asymmetric or non-uniform thermal radiation** can be caused usually by cold windows, uninsulated walls, or improperly sized heating panels on the wall or ceiling, etc. In office buildings the most common reasons for discomfort due to asymmetric thermal radiation are the large windows (during the heating periods) and improperly sized or installed ceiling heating panels.

- **Draught** is an undesired local cooling of the human body caused by air movement. ASHRAE Fundamentals (2001) describe draught as one of the most annoying factors in offices. Draught makes the occupants demand higher air temperatures in the room or stop the ventilation systems. This can often lead to temperatures above the comfort levels.

- **Vertical air temperature difference:** In most of the offices (or generally spaces in buildings) the air temperature is not completely uniform but increases with height above the floor. When the gradient is sufficiently large, local warm or cold discomfort can occur at the head and/or the feet, although the body as a whole is thermally neutral.

  According to ASHRAE Fundamentals (2001), *due to the direct contact between the feet and the floor, local discomfort of the feet can often be caused by a too-high or too-low floor temperature. Also, the floor temperature has a significant influence on the mean radiant temperature in a room".* Often, when the floor is too cold and the occupants feel cold discomfort in their feet, they usually increase the temperature level in the room. During the heating period, this can be a reason for the increase in energy use. A radiant system, which radiates heat from the floor, can solve this problem. A diagram of how the PPD increases due to the cold/warm ceiling and walls is shown in Figure 1.9:

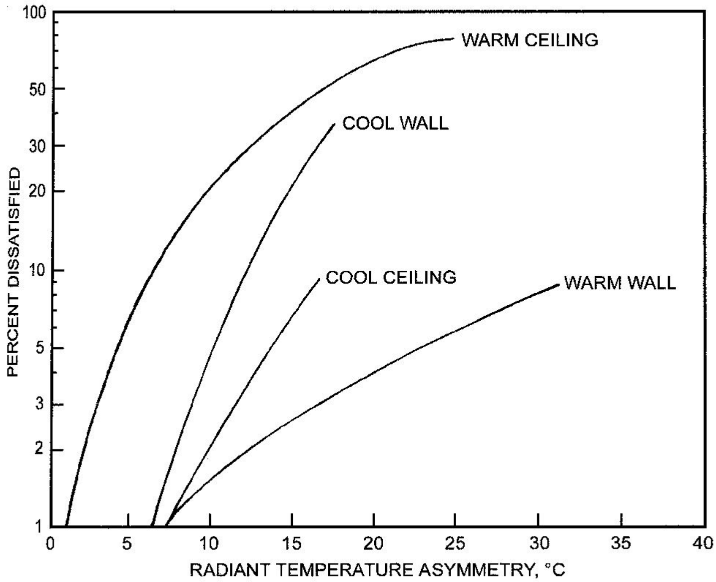


Figure 1.9 *Influence of ceiling and wall temperature on the PPD (ASHRAE, 2001).*

Age

Since the metabolism decreases with age, young and old people do not always have the same preferences when it comes to thermal comfort. Often older people prefer higher ambient temperatures. However, previous research showed that sometimes the thermal environment in an office can satisfy both ages. The need for higher ambient temperature for older people in their homes can be explained by the lower level of activity.

Sex

Both men and women can be satisfied with the same thermal conditions. In ASHRAE Fundamentals (2001) it is mentioned that the temperature of women's skin and evaporative loss are slightly lower than those of men and this balances the lower metabolism of women. The lighter clothing that women usually wear is the main reason for their demand for higher temperatures.

Adaptation

Experiments proved that people can not adapt to preferring warmer or colder climates. According to ASHRAE Fundamentals (2001) *"it is therefore likely that the same comfort conditions can be applied throughout the world. However in determining the preferred ambient temperature from the comfort equations, a clo value that corresponds to the local clothing habits should be used".* Thus, adaptation does not really influence the preference of the occupants regarding the ambient temperature. However, people used to living or working in warm climates can more easily stand higher temperatures while maintaining the same levels of performance than people from colder climates.

Seasonal and Circadian Rhythms

According to ASHRAE Fundamentals (2001) there is no difference between indoor thermal conditions of comfort during the winter and the summer. However, the preference of an occupant for thermal comfort may change during the day since the body has a lower temperature rhythm during the early morning hours and a higher one late in the afternoon.

1.2.4 Thermal Comfort and productivity

Although a lot of attempts have been made to correlate productivity with indoor climate factors, no detailed studies have been made so far that can predict accurately the interaction between these. The occupants' efficiency is a really complicated matter since many different parameters can influence it separately and together at the same time.

Wyon (2000a) describes how discomfort conditions lead to reduced productivity. The author claims that a change from 18°C and dry to 28°C and humid can increase the proportion of dissatisfied from 10 to 90%. Additionally, the thermal effect is greater for clean air than for normally polluted indoor air.

According to the IDA manual, Wyon (2000b), for operative temperature between 20 and 25°C no work is regarded as lost. Above and below these limits experiments show an average loss of 2% in performance per degree.

Hanssen (2000) claims that the ambient temperature can give the most specific correlation between indoor climate parameters and productivity. The author, referring to previous research of Wyon (1987) describes the correlation between air temperature and the number of accidents, productivity of manual work, finger dexterity, number of breaks and mental performance.

The (lower and higher) x-axis (Figure 1.10) shows the activity level and the clothing (summer and winter case) insulation of the occupants. The x-axis in the middle of the diagram can be applied both for active work (1.4 met) during the summer (0.6 clo) and during the winter (1 clo) for sedentary work (1 met). As the author mentions, *"For an office workplace it may be especially appropriate to examine the effect of air temperature on mental performance and manual work".*

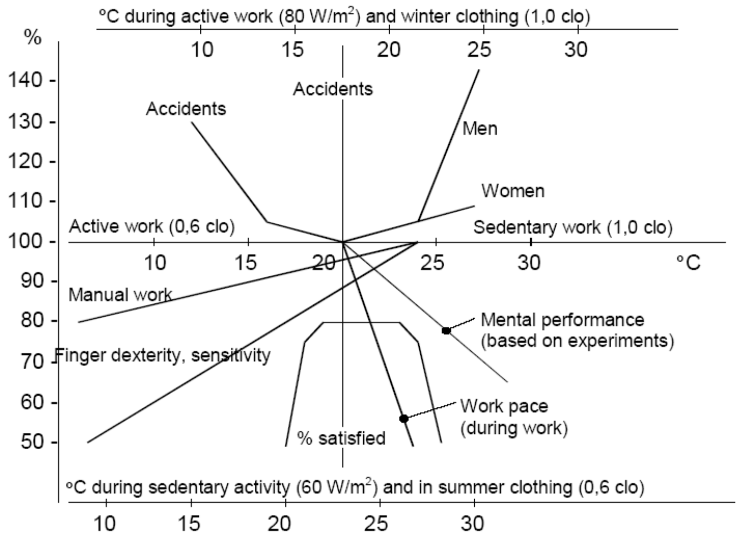


Figure 1.10 Correlation between air temperature and the number of accidents, productivity of manual work, finger dexterity, number of breaks, and mental performance (Wyon, 1986)

It is obvious that it is not always easy to evaluate and improve the thermal conditions in order to increase the comfort and productivity of the occupants. Advanced computer simulation programs often predict

- operative temperatures,
- temperature swings,
- relative humidity and air speeds

in a building with "predictable" occupants. However, the behaviour and adaptability of occupants in reality are far harder to predict. A quite practical approach in order to ensure acceptable indoor thermal environment could be to make sure that the air temperature and the "cold draught" from windows stay within acceptable limits.

1.2.5 Other Indoor Climate parameters that influence the occupants' health and productivity

Indoor Air Quality

According to Nathanson (1995) the quality of the indoor environment depends on the interaction between the site and the

- climate,
- building system,
- potential contaminant sources (e.g. furnishings, moisture sources, work processes and activities, outdoor pollutants, etc) and
- building's occupants

The HVAC system is designed to provide thermal comfort, distribute outdoor air to the occupants, remove odours and contaminants, or dilute them to acceptable levels.

The influence of the indoor environment on the comfort and health of the occupants has been the focus of research for many years. However, according to Hanssen (2000) there is relatively little research examining the total effect of Indoor Air Quality on human wellbeing, employee performance and productivity at work.

As far as this thesis is concerned, CO_2 content given in ppm (with respect to volume) and the relative humidity indicated in %, are calculated.

Visual Comfort

When designing an office building attention should be paid to the visual comfort of the occupants. Although electricity savings through daylight utilisation may not be so impressive (compared for example to those for heating or cooling), correct distribution of light may create a more pleasant indoor environment and thus improve the mood and productivity of the occupants. In Sustainable Building Technical Manual it is mentioned that *"daylighting creates healthier and more stimulating work environments than artificial lighting systems and can increase the productivity up to 15%.*

Daylighting provides also changes in light intensity colour and views that help support worker productivity". Surveys mention that 90% of the occupants prefer to work close to the window, having a view to the outside.

The comfortable visual environment depends on vision, perception and what we want to see in different room configurations and for different activities. The absence of sensation of physiological pain, irritation or distraction is the main aim when the visual properties of an indoor environment are optimized. Christoffersen J. (1995) mentions in his PhD thesis that *"visual perception is an active, information-seeking process, partly conscious and partly unconscious, involving many mechanisms in a cognitive process interpreted by the eye and the brain".*

When designing the shape and position of windows for an office building attention should be paid to the provision of visual comfort for the occupants. The visual function parameters which determine good visibility and pleasant indoor environments are the

- Illuminance, luminance and daylight factor
- Distribution - Uniformity of light across a surface
- Glare
- Direction

1.2.6 Architectural Quality

The Architectural Quality of an office building has great impacts both on the energy use during the occupation stage and the provision of comfort for the occupants. The building's shape and location, the façade's orientation and the integration of passive or active solar systems are some of the parameters that influence the performance of the building in terms of energy use. On the other hand the occupants' perception of indoor environment is closely related to their sociological needs, psychological state, and individual differences. The way that the occupants feel and behave in their working environment influences their comfort and productivity. Thus, it is clear that many parameters have to be examined in the early design stage in order to succeed in an energy efficient design and an attractive working environment.

Impact of architectural design on building performance

When designing a building different parameters have to be considered and combined carefully in order to succeed in an optimal design. The location and orientation of the building, the area of the building's skin in relation to the volume of space enclosed, the type of façade (proportion of glazing, structure, etc) etc are crucial for the building's performance.

On the other hand the building's use (type of occupants' tasks, schedule, etc) defines the indoor performance requirements (thermal and visual comfort, acoustics, etc). Thus, different combinations of design parameters can optimize different performance requirements, affecting energy use, environmental performance and life cycle cost. The integration of solar technologies can often provide improved indoor environment and reduced energy use. However, the key to a successful integration is their consideration at an early design stage.

In highly glazed office buildings, the building's skin is obviously more sensitive to the outdoor environment. High solar gains during the summer may lead to overheating problems during the summer, increasing the energy demand for cooling. Furthermore, the greater the area of building skin in relation to the volume of space enclosed, the more the building is influenced by heat exchanges at the skin. Thus, it is a general rule that a square floor plan is thermally more efficient than a rectangular one because it contains less surface area over which to lose or gain heat. On the other hand, this building form is less efficient in terms of daylighting and passive solar heating and cooling. The shape and orientation of the building have also great impact upon wind driven air infiltration through the envelope.

Perception of indoor environment

In order to understand how the occupant adapts to the working environment, necessary background information is given below. Generally, the occupants' responses to their environment are complex, and according to the "Design Guide for Interiors", (U.S. Army Corps of Engineers, 1997) best understood in terms of three psychological stages of human behaviour: perception, cognition, and spatial behaviour.

Perception of space

The four main parameters that influence people's perception of their working environment are:

- **Privacy:** The plan of an office environment establishes the privacy level at which the office functions.
- **Interaction levels:** The "interaction level" is a mechanism used to achieve a desired level of privacy. The distance between the occupants is categorized as intimate, personal, social, and public.
- **Territoriality:** The need of the occupants (as individuals or groups) to control a space is called territoriality.

- **Crowding:** Crowding occurs when personal space and territoriality mechanisms function ineffectively, resulting in an excess of undesired external social contact.

Influence of architectural design on occupants' behaviour

According to the "Design Guide for Interiors" (U.S. Army Corps of Engineers, 1997) each person responds in a unique way to a specific situation or experience. These responses fall into the following three categories:

- **Sociological determinants** are related to the social needs of the occupants. The factors that concern the sociological responses are group dynamics (the way that the occupants interact with each other) and communication.

- **Psychological determinants:** The psychological needs of the occupants are mostly influenced by the following factors:

  - **Visual privacy** addresses the ability to limit others' view of oneself. In office buildings the occupants do not like the idea of being watched without being aware of who is watching.
  - **Acoustic privacy:** The acoustic privacy of the occupants influences their productivity, level of communication and social interaction..
  - **Aesthetic:** According to the "Design Guide for Interiors", "*aesthetic appreciation is both expressed in and influenced by the environment. To define aesthetic qualities, the designer needs to understand that the concept of beauty differs with time and place, purpose and context*".

- **Physiological determinants** concern the physical needs of the occupants. Factors related to physiological responses are functional efficiency (expresses the degree to which physiological needs are supported in the interior space plan), ergonomic design, life safety and health concerns

1.2.7 Environmental Performance

The impacts of buildings on the environment are diverse. Not only during the construction stage, but also during the occupation and demolition stage, the building interacts with the environment in different ways. For this reason, it is important to consider it both as a part (subsystem) of the surrounding environment and as a hyper-system influencing the comfort and health of the occupants. In this part, importance has been given to analyzing the building as a part of its environment.

As a physical structure, the building is composed of different elements. These elements are extracted, manufactured, assembled, maintained, demolished and finally disposed of. The total environmental impact of the materials used is a sum of the impacts caused in each of the above stages. As "living part" the building has inputs (energy use, services) and outputs (CO_2 emission, wastes, etc).

Phases of the building's life

The environmental performance of the building depends on the following stages:

- **Construction stage**

The environmental performance of a building during the construction stage is the sum of the performance during the manufacturing stage of the materials, the transportation stage and the erection of the building. It is necessary to clarify that the environmental performance depends both on the emissions, waste, etc directly for the production of the materials used and their transportation and the impacts caused by the energy production needed for these procedures.

- **Occupation/maintenance stage**

This is the most important phase concerning the energy use in buildings. According to the PhD thesis of Adalberth (2000) for modern apartment buildings

  - 70-90% of the total energy use (during the life cycle) is during the occupation stage
  - 10-20% is during the construction stage
  - 1-2% is during the demolition stage

- **Refurbishment and demolition stage**

The importance of the refurbishment and demolition stage of an office building is obviously smaller than the ones described above. However, it is worth investigating the environmental friendliness and performance of the materials used during these stages.

Life Cycle Analysis (LCA)

The study of a whole life cycle of a product or a process (in this case a building) from the extraction of raw materials to the disposal or reconstruction is called Life Cycle Analysis (LCA). At this point, it is necessary to mention the advantages and disadvantages of this method and to make clear the importance of its use during the design stage of a building.

The main benefit of the LCA is that it provides information on the environmental performance of different building concepts in a really accessible format. On the other hand, the lack of consistent and peer reviewed international level databases of Life Cycle Inventories of building related products is one of the main problems which limits the use of LCA. However, a LCA can also be limited to the period from construction until deconstruction.

The holistic approach during the design stage of a building involves variables that often interact with each other. Impacts on the surrounding environment, energy needed for the construction and maintenance of the building, use of recycled building components and integration of solar technologies that improve the environmental profile of the building are some of the factors that define the environmental performance of the building.

The main reason for using a LCA is to insert it as part of the decision making process in order to optimize the efficiency of the system. Since a lot of parameters are involved, the complexity increases and the goals should be prioritized from the early design stage in order to make the process more clear.

1.2.8 Costs

In the existing literature three ways of calculating the cost of a building are mentioned.

- **Investment costs:** consideration of the investment cost only
- **Life cycle costs:** Cost for the whole life of a building
- **Total Economic Value:** It goes further than life cycle costing due to the fact that it also includes more “hidden” building related costs or profits such as the productivity of the workers in the building.

According to Fuller and Petersen (1996) energy conservation projects provide excellent examples for the application of LCCA. On the other hand, the Total Economic Value is time restrictive since it often involves very detailed calculations that require detailed input.

For the ongoing "Glazed Office Buildings" project the Life Cycle Cost (LCC) will be calculated for all the alternatives. However, the productivity of the occupants (such as lost working hours) is also calculated in a simple way taking into account thermal comfort criteria. The reason for the decision to calculate the LCC is that calculation of only the investment costs for the suggested alternatives does not provide information on the occupational and maintenance costs, which is crucial when it comes to energy efficient office buildings. The integration of solar technologies with alternative heating, ventilating, and air conditioning (HVAC) systems and strategies can provide a wide variety of models (some of which are considerably more energy efficient than others), interesting to study in a life time prospective.

1.2.9 Interaction between different performance parameters

In this part basic interactions between the performance parameters are described briefly in order to show the complexity of the system.

Indoor Environment

The indoor climate has great impacts on the comfort and thus the productivity of the occupants. Thermal and visual comfort, acoustics, indoor air quality and psychosocial comfort are the most important parameters that constitute the indoor environment.

The building's shape has an important impact on the energy use and also on the thermal environment since the smaller the area of the building skin in relation to the building's volume the less dependent the indoor climate is on the outdoor conditions. Thus, tetragonal shapes can be a lot more efficient in terms of energy use and thermal comfort than rectangular ones.

In highly glazed office buildings the relationship between shape and efficiency can be even more important since the skin is more sensitive to the climatic changes. The boundary conditions of the inner layer of a façade are crucial for the occupants' comfort. Cold surfaces create draughts and lead to a less uniform environment. The integration of double skin facades can provide a more uniform thermal environment since by controlling the cavity temperatures it is possible to avoid cold walls and temperature asymmetries. Although the additional layer (second skin) leads to a reduction of the working area (since the cavity depth can vary usually from 20cm to 2m), the occupants can be placed closer to the façade "earning" the space lost from the construction. Thus in terms of cost, it is important to consider whether Double Facades are efficient or not. It is also important to consider that, in the long run, since the thermoregulatory system can not adapt to the internal thermal conditions, the occupants are more likely to get sick. Thus in terms of life cycle cost it could be interesting to find how "expensive" it is to maintain a good indoor climate by considering not only the investment or occupational cost, but also the productivity of the occupants.

The visual comfort of the occupants (provision of view and daylight) is highly influenced by the occupants' perception of the indoor environment. Depending on the task, proper lighting may influence productivity. The provision of well distributed daylight ensures a healthier and more stimulating working environment than artificial lighting.

The architectural design is crucial for the provision of daylight. Highly glazed buildings are often associated with a more pleasant indoor environment. However, glare problems due to inefficient architectural design can be mentioned. Although in terms of energy and thermal efficiency deep buildings are preferred, narrow buildings are more efficient in terms of provision of daylight. Thus, a rectangular shape is often preferred to a tetragonal one.

It is often doubted whether highly glazed buildings are efficient in terms of energy use and cost or not. Moreover, a large proportion of glass and high transparency do not always lead to a pleasant environment. However, careful and individual design can be a solution to these problems.

Architectural Quality

The architectural quality of an office building can influence energy use, comfort and, thus, the productivity of the occupants. In terms of energy use, the most important parameters to be considered in an early design stage are the building's shape and orientation. It is obvious that the area of the building's skin in relation to the volume of space enclosed is crucial for the indoor thermal conditions and thus for the energy use during the occupation stage. Especially when the façade is highly glazed, the indoor environment is even more sensitive to the changes in the outdoor climatic conditions. High solar gains during the summer may lead to overheating problems and increase energy use for cooling. During the heating periods, the cold exterior skin often causes discomfort problems. Cold draughts, non-uniform indoor thermal environment and vertical air temperature differences can be more intense close to the building's skin. This can limit the size of the occupied zone, e.g. by having to arrange the furniture at some distance from the façade.

Furthermore, architectural parameters have a great impact on the occupants' perception of the indoor environment. Acoustic and visual privacy, aesthetics, functional efficiency and ergonomic design can directly influence the behaviour and the productivity of the occupants. Also life safety and heath concerns are important parameters that should be considered at an early stage. Finally, the space in which each occupant has to work and communicate should be decided after considering the type of task and the background of the occupant. Cell type office buildings can ensure more privacy, while open types can often be related to a more pleasant working environment. In any case, the designer should initially understand really well the sociological, psychological, physiological parameters that influence the occupants' efficiency.

Environmental Performance

The environmental performance of the building is mostly connected with the emissions produced and the energy demand for the production of the materials used (production, maintenance, disposal), although most of the energy is used during the operation of the building. It is important to consider that, in a life cycle perspective, energy use not only during the construction but also during the occupation stage has impacts in the environment. Thus, the environmental performance of a building is connected with the energy use for the production of the building materials, and with the environmental impacts for the production of energy for heating, cooling or lighting the building. It is important to consider that the environmental performance depends both on the size of energy demand and on the way it is produced. Since the energy use is directly connected with the life cycle cost, it is obvious that the integration of solar systems can be environmentally friendly and cost efficient at the same time.

Cost

The life cycle cost is obviously connected with the rest of the performance parameters. Often the "trade off" value of the building performance is expressed in terms of cost. The architectural quality is often mostly connected with the investment cost, and the performance requirements with the occupational phase. However, in a life cycle prospective these two parameters interact with each other. Thus, the optimization of the cost can be achieved only in a life cycle prospective.

1.3 Limitations of the thesis

The present report deals mostly with energy use and indoor thermal environment calculations for office buildings in Nordic climates. More specifically, it deals with the energy use for heating, cooling, lighting, use of equipment, pumps and fans, and the server rooms (including their cooling). In terms of indoor thermal environment importance has been given to the mean air temperatures, the directed operative temperatures and the perception of thermal comfort (PMV and PPD values). Additionally the lost working hours due to high or low mean air temperatures were calculated with a simple model.

Different office building alternatives were simulated for this report. A virtual reference building was created, a building representative of office buildings built during the nineties in Sweden. The façade of this building was changed for different single skin glazed façade alternatives. Some of the building design parameters were assumed to remain the same during the simulations, and some were changed. The parameters that were kept the same are

- The shape of the building
- The roof, ground floor, interior wall and intermediate floor construction
- External obstructions to the building
- HVAC installation types
- Infiltration and exfiltration of the building envelope

Parameters that vary during the simulations are

- Building orientation
- Office plan (cell type and open plan type)
- Internal loads (number of occupants and equipment)
- Occupancy
- Proportion of the glazed façade area (30%, 60% and 100% glazing)
- Glazing and frame type
- Shading devices (type and position)
- Thermal transmittance of the façade elements
- Heat recovery efficiency
- Specific fan power
- Control set points (temperature, lighting)
- HVAC installations

The building elements were chosen based on commercially available products. No optimisation of energy use or indoor climate of the building was carried out at this stage. Advanced technical solutions will be studied later during the “Glazed office buildings” project.

1.4 Definitions and symbols

Building Envelope: The total area of the boundary surfaces of a building through which heat, light, air and moisture are transferred between the internal spaces and the outside environment (Limb, 1992).

Comfort zone: The range of indoor conditions considered acceptable by a certain proportion (e.g. usually more than 80%) of the people working or living in the space (Limb, 1992).

Daylight Factor (*DF*): The ratio of indoor illuminance at a given point to the simultaneous outdoors illuminance on an unobstructed horizontal surface.

Degree Day: The number of degrees of temperature difference on any one day between a given base temperature and the 24 hour mean outside air temperature for the particular location. The average number of degree days for a given period (i.e. during the heating season) is the sum of these degree days divided by the given period (Limb, 1992).

Draught: Excessive air movement in an occupied enclosure causing discomfort (Limb, 1992).

Energy Conservation: The deliberate design of a building or process to reduce its energy use or to increase its energy efficiency (Limb, 1992).

Exhaust Air: The air removed from a space and not reused therein (Limb, 1992).

Glare (discomfort): The sensation of annoyance caused by high or non-uniform distributions of brightness in the field of view.

Glare (disability): Caused when intraocular light scatter occurs within the eye, the contrast in the retinal image is reduced (typically at low light levels), and vision is partly or totally impeded (e.g., when the eye is confronted by headlights from oncoming automobiles).

Heating: The transfer of energy to a space or to the air by the existence of a temperature gradient between the source and the space of air. The process may take different forms, i.e. conduction, convection or radiation. The process is the opposite of cooling (Limb, 1992).

Heat Recovery Efficiency (or Heat Recovery Effectiveness): The proportion of heat recovered from otherwise waste heat passing through a heat recovery system. Normally it is expressed as a percentage (Limb, 1992).

Humidity absolute (d_v): The ratio of the mass of water vapour to the total volume of the sample.

Humidity relative (φ): The ratio of the mole fraction of water vapour in a given moist air sample to the mole fraction in an air sample saturated at the same temperature and pressure.

Indoor Climate (or Indoor Environment): The synthesis of day to day values of physical variables in a building e.g. temperature, humidity, air movement and air quality, etc, which affect the health and/or the comfort of occupants (Limb, 1992).

Illuminance (E): Expresses the amount of luminous flux that arrives at a surface and is measured in lux.

Illuminance and luminance distribution: A measure of the light variation from a point to another point across a plane or a surface.

Luminance: Expresses the light reflected off a surface and is measured in lumens per square meter per steradian or in candelas per square meter (cd/m2). In a way the luminance is directly related to the perceived "brightness" of a surface in a given direction.

Luminous Efficacy: Refers to the ratio of total luminous flux emitted by a lamp to the energy used. It is expressed in lumens per watt (lm/W). According to Adeline Users manual,

$$n = \frac{\text{desired surface illuminance} \times \text{floor area of considered space}}{\text{total power of lighting system}} \quad (\text{lm/W})$$

Mechanical Ventilation: Ventilation by means of one or more fans (Limb, 1992).

Multizone: A building or part of a building that comprises a number of zones or cells (Limb, 1992).

Natural Ventilation: The movement of outdoor air into a space through intentionally provided openings such as windows and doors, or through non powered ventilators or by infiltration (Limb, 1992).

Occupancy: The time, during which people are in a building, usually expressed in hours per day (Limb, 1992).

Occupant Behaviour: The pattern of activity of occupants in a building, including the number of occupants, their distribution, activities and time spent within the building, the way they interact with building facilities, such as ventilation systems, window openings, etc (Limb, 1992).

Outdoor Air: The air taken from the external surroundings and therefore not previously circulated through the system (Limb, 1992).

PMV (Predicted Mean Vote): An index of measure for thermal sensation since it expresses the correlation between indoor environment parameters and people's sensation of thermal comfort. It is a function of activity, clothing, air temperature, mean radiant temperature, relative air velocity and humidity. The scale for PMV varies from -3 (cold) to +3 (warm) (see also subchapter 1.2.3).

PPD (Predicted Percentage Dissatisfied): The PPD of a large group of people is an indication of the number of persons who will be inclined to complain about the thermal conditions. It is measured in percentage (see also subchapter 1.2.3).

Radiation: The transmission of heat through space by propagation of infra red energy; the passage of heat from one object to another without necessarily warming the space in between (Limb, 1992).

Single Zone: A building or a part of a building comprising one zone of uniform pressure (Limb, 1992).

Solar transmittance (T_{sol}): The ratio of the irradiation transmitted through the window system to the irradiation impinging on the window system.

Solar (total) transmittance (or solar factor) (g) The sum of the (primary) solar transmittance (τ) and the ratio of the part of the solar irradiation absorbed by the window system that is transferred to the room to the irradiation impinging on the window system.

Supply Air: Air delivered to a space and for the purpose of ventilation, heating, cooling humidification or dehumidification (Limb, 1992).

Temperature, Ambient: The temperature of the air within a room or zone (Limb, 1992).

Temperature, Dry Bulb: The air temperature indicated by a dry temperature sensing element (such as the bulb of a mercury in glass thermometer) shielded from the effects of radiation (Limb, 1992).

Temperature, Effective (θ_{eff}): The temperature of a still, saturated atmosphere that would produce the same effect as the atmosphere in question.

Temperature, Environmental: The temperature of the air outside a room or zone (Limb, 1992).

Temperature, Operative (θ_{op}): The operative temperature empirically combines the dry bulb and the mean radiant temperatures. The operative temperature is the temperature at which a person emits the same heat output as before, but when air temperature (θ_a) = radiant temperature (θ_r) = operative temperature (θ_{op}). θ_{op} does not have the same value for all the parts of the room (when the weighting method is used).

Temperature, Directed Operative: It is calculated in the same way as the operative temperature, the only difference being that the weighting is done only for the point where the occupant is placed and towards the surface of interest as shown in Figure 1.6, Subsection 1.2.3.

Temperature, Radiant (or Surface) (θ_r): Radiant or surface temperature is the temperature of an exposed surface in the environment. The temperatures of individual surfaces are usually combined into a mean radiant temperature.

Temperature, Resultant: It is similar to the effective temperature but it includes humidity effects.

Temperature, Wet Bulb: The air temperature indicated by a sensing element kept wet (usually by a wick), the indicated temperature thus being related to the rate of evaporation from the wetted bulb. This wet bulb temperature is used by psychrometers to measure relative humidity (Limb, 1992).

Thermal Comfort: A condition of satisfaction expressed by occupants within a building regarding their thermal environment. Since the thermal comfort condition is a subjective feeling of satisfaction, building designers attempt to satisfy as many of the occupants as possible (usually 80% or more) (Limb, 1992).

Thermal Transmittance (U-value, expressed in $Wm^{-2}K^{-1}$): The heat flow transmitted through a unit area of a given structure, divided by the difference between the effective ambient temperature on either side of the structure, under steady conditions (Limb, 1992).

2 State of the art

2.1 General

The office buildings as known today are likely to retain their validity in the foreseeable future. Although there has been, and still is, a dramatic development of the infrastructure for communications (mobile phones, laptops, e-mail etc.), the change in office practice is far less dramatic (Kleibrink, 2002). Nowadays, the exchange of information between and within organizations is very often by e-mail and the activities are increasingly dominated by discussions and flow of information at all levels. High interaction levels may however lead to reduced occupant productivity due to acoustic disturbance. The increase in teamwork and communication, however, can lead to activities and persons disturbing each other, especially if the spatial organisation is not appropriate. The plan of an office environment establishes the privacy (both acoustic and visual) level at which the office functions. Therefore, it is still necessary to provide concentrated individual work in undisturbed surroundings. Modern office work is characterized by quick changes between these two types of activity, so the challenge today is to provide for a combination of individual work and teamwork, while also providing for flexibility for unforeseen developments.

Moreover, in new constructions the conventional envelope of office buildings tends to be replaced by a highly glazed one that can lead to a pleasant visual indoor environment. The recent trend of transparent buildings is often initiated by architects in order to provide more daylight and view to the occupants. Depending on the task of the occupants this can increase their productivity, as mentioned Sustainable Building Technical Manual productivity can increase by up to 15% when daylight is provided instead of artificial lighting. In some cases, however, the occupants can often feel distracted or even annoyed when they can be seen from outside.

2.2 Layout of typical office buildings

There are at least four different concepts of office layout:

- unit or cell-type office
- open-plan and group office
- combination office
- the so-called "business club"

The cell-type office is the most traditional form, where single or double rooms are located along artificially lighted corridors. A single person office is very good for concentrated work, but does not promote informal communication between colleagues. Typical sizes for a single room are: width 1.35 m by depth 4.20 m, width 2.7 m by 4.20 m, width 3 m by depth 3.6 m or width 3 m by depth 5 m. The corridor can be 2 m wide.

The open-plan and group office with hundreds of persons working was designed to encourage communication. Often, many of these offices have after some time been divided by head height cupboards and plants into almost cell-type offices. What some people perceive as a disadvantage is the lack of individual control of indoor climate and lighting. For routine processing work requiring a high degree of informal communication this type of office can be the preferable one.

The combination office, developed in Scandinavia at the end of the seventies, combines the advantages of the cell-type offices and open-plan offices, while avoiding the disadvantages. The workplaces are located in cell-type spaces along the façade and are separated from the indirectly lit internal zones by room high glazed walls. Every workplace has access to discussion areas, direct visual contact with the outside world and the means to control the climate individually. The common space in the middle serves a number of employees and offers common services like meeting areas, copiers, printers, facilities for coffee breaks. The glazed wall provides sound attenuation for the workplaces while allowing visual contact with colleagues. The size of the individual workplaces/rooms is similar to the cell-type ones mentioned above. The common space can be 4.8 m deep.

An office should meet the following four criteria:

- Flexibility: workplaces should be standardized, but should also be adaptable to individual needs.
- Functional efficiency: the working space should meet physiological requirements, ergonomic standards and statutory requirements in order to support optimal working conditions.

- Contact quality: the working spaces should contribute to the transparency of the activities carried out in the office and encourage communication and synergetic effects between employees and departments.
- Corporate culture: the message conveyed by the working spaces should promote the employees' identification with the company and its products and communicate company values internally and externally.

Typical depths for office buildings are

- 12 to 13 metres for a cell-type office
- 13. 5 to 15.5 metres for a combination office

2.3 Energy use in Swedish office buildings

The majority of the office buildings are heated by district heating. Among these buildings, those built between 1961 and 1970 have the highest use of district heating energy, 144 kWh/m^{2}a (see Table 2.1). Most of the heating is space heating, hot service water accounts for 2 – 7% of the heating (Nilson, 1996).

Table 2.1 Use of district heating in Swedish office buildings, as a function of year of completion (SCB, 2001).

Year of completion	**-1940**	**1941-1960**	**1961-1970**	**1971-1980**	**1981-1990**	**1991-**	**Average**
Use of district heating kWh/m^{2}a	137	133	144	112	91	116	122

If cooling is included, then the buildings built between 1961 and 1970 have the highest energy use, 156 kWh/m^{2}a (see Table 2.2).

Table 2.2 Average energy use for space heating, district cooling and electricity for cooling in Swedish office buildings (SCB, 2001).

Year of completion	**-1940**	**1941-1960**	**1961-1970**	**1971-1980**	**1981-1990**	**1991-**	**Average**
Use of district heating kWh/m^{2}a	146	143	156	127	114	127	135

An analysis of energy use for heating and use of electricity in premises showed that the heating energy use has been reduced while the total use of electricity has increased, during the last decades (Energiboken, 1995). The reduction in heating energy use is due to the improved thermal insulation (lower thermal transmittance) and introduction of heat recovery on the exhaust air flow, required by the building regulations. New premises have a lower total use of energy than older ones, but a higher share of use of electricity (see Figure 2.1). In new office buildings i.e. those built after 1980 the use of electricity often accounts for 70% of the use of energy (Nilson, 1996). The current building regulations do not have any real requirement for the use of electricity or the total energy use.

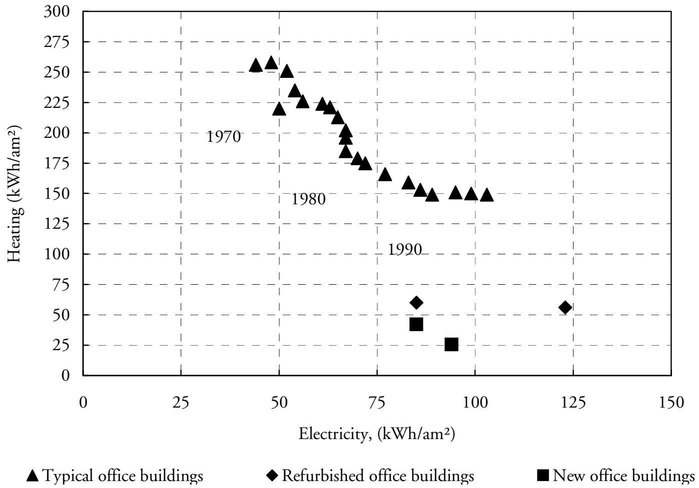


Figure 2.1 *Relation between use of energy for space heating and use of electricity in Swedish office buildings, as a function of year of completion (Energiboken, 1995).*

The reduction in heating demand has in many cases taken place at the expense of an increased use of electricity. Redistribution between these two energy sources has taken place both in new construction and refurbishment. There are several reasons for this, e.g.

- Poor knowledge as to the actual use of electricity in buildings.
- Increased use of office appliances (PCs, printers, servers, copiers, etc)
- The building regulations has focused on heating demand
- No life cycle perspective is applied

There is quite a variation in energy use of office buildings as shown in Table 2.3.

Table 2.3 Energy use in office buildings (REPAB, 2003).

kWh/m²year (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

There is clearly an energy saving potential, especially with regard to use of electricity for ventilation, cooling, lighting. Targets have to be specified for the use of electricity for fans, pumps, lighting etc and for the cooling demand. The users have to buy energy efficient appliances (e.g. PCs). Important savings can be achieved by adapting the operation of the HVAC system to the actual activity in the building and optimising the operation of the building with regard to ventilation, heating and cooling. The users can contribute by improving their behaviour with regard to the use of lighting, PCs, etc.

2.4 Office buildings in Sweden

Office buildings account for a significant proportion of the floor area in non-industrial buildings in Sweden. The total floor area in office buildings is approximately 30 million m^2 (usable area to let) (SCB 2001). The completed floor area is almost evenly distributed between the different decades, but with less construction during the last decade (see Table 2.4).

Table 2.4 Floor area, millions m^2, as a function of year of completion (SCB, 2001).

Year	-1940	1941-1960	1961-1970	1971-1980	1981-1990	1991-	Sum
Floor area	7.1	4.6	4.9	5.4	5.4	2.8	30.2

Most (65%) of the existing office buildings are rather small, between 200 and 1 000 m^2. Many office buildings are between 1 000 and 5 000 m^2 and some are bigger than 20 000 m^2 (see Table 2.5).

Table 2.5 Number of office buildings within a certain range of floor area, m^2 (SCB, 2001).

Floor area (m^2)	**200-999**	**1 000-4 999**	**5 000-19 999**	**20 000-**	**Sum**
Number of buildings	11 505	4 719	1 415	170	17 809

Most office buildings are equipped with a heating system. However, mechanical cooling systems are also becoming rather common in office buildings. Most of the buildings are equipped with a mechanical ventilation system, usually a system with mechanical supply and exhaust air. The newer ones often have heat recovery on the ventilation.

The energy source for heating office buildings can be oil furnace, district heating, electricity, local district heating, gas or biomass. The most common source is district heating (71%) as shown in Table 2.6.

Table 2.6 Area of office buildings by type of heating (SCB, 2001).

	Oil furnace	**District heating**	**Electric**	**Local district heating**	**Gas**	**Oil + el**	**Biomass**	**Other**	**Sum**
Heated area million, m^2	2.4	23.4	2.0	0.2	0.6	0.4	0	4.1	33.1
Heated area, %	7	71	6	1	2	1	0	12	100

2.5 Glazed office buildings in Sweden

Especially during the nineties, highly glazed office buildings were built in Scandinavia, some of them with single and others with double skin facades. This has been made possible by technical development regarding the construction and physical properties of glass.

During the last years architects have developed an interest in applying the technology of double skin facades in Scandinavia. Buildings with double skin facades built in Sweden are described in several literature sources. A booklet on requirements and methods for double skin facades has been produced by Carlson (2003). A literature review on double skin facades for office buildings has also been written by Poirazis (2004a), describing the main aspects of the system and presenting buildings from Scandinavia, Finland, Germany, United Kingdom, Belgium, etc. Buildings described from Sweden are the Kista Science Tower, The Nokia House Kista, the Arlanda airport, the ABB Bussiness centre and the GlasshusEtt.

Before describing further the aspect of the double skin facades, it is useful to understand why office buildings with fully glazed facades are being built. Architecturally an airy, transparent and light building is created, with more access to daylight than in a more traditional office building (Svensson, 2000). Furthermore, the main argument for constructing double skin glazed facades is that first of all a decision has been made to build a glazed building because of the transparent appearance (Svensson, 2001). The individual arguments, compared with a single skin glazed façade, are noise reduction, natural light, possibility to open windows, protected solar shading, burglary protection, night ventilation, preheated supply air, additional heat during winter, removal of solar energy via the double skin, sustainable construction. This type of building enables ventilation to be adapted to the different seasons and often some kind of hybrid ventilation. It is also claimed that office buildings with double skin facades can result in a reasonable energy use and a reasonable indoor climate.

There is a lack of knowledge in the building trade in Sweden concerning the design of highly glazed buildings and the calculation of energy use, thermal comfort and the influence of different technical solutions on these buildings.

In most of the German projects with highly glazed façades, especially double skin facades, simulations of temperatures, air and energy flows have been carried out before and during the design, with more or less success (FIA, 1998). Often the simulations have deviated from the result in the finished building due to difficulties in defining and accurately determining the boundary conditions. Accurate calculations require experience of the simulation models used, but also detailed knowledge of thermodynamics, fluid dynamics and building physics, and general shrewdness and experience of building services engineering. Increased knowledge and improvement of simulation and calculation methods is needed. Adaptation to Swedish requirements for energy use and indoor climate, as well as adjustment to Swedish climate and Swedish engineering (building and HVAC), are necessary.

The complexity of building and HVAC systems requires a comprehensive view. Energy, comfort and costs must be analysed for Swedish conditions. The low temperatures and solar gains in Sweden can cause thermal discomfort (draughts, a non-uniform indoor climate, etc) due to low temperatures of the inner layer. The low altitudes of the sun during the winter can cause visual discomfort due to glare problems mostly close to the facade. For deep buildings the daylight level can be low in the core of the building, although the façade is fully glazed.

2.6 Double skin facades for office buildings

A literature review report for Double Skin Façades was written by Poirazis (2004a). In this report the concept of the system was described and technical details were given concerning its operation and successful integration in buildings. Examples of buildings are also given.

2.6.1 Definition and concept

The Double Skin Façade is a system consisting of two glass skins placed in such a way that air flows in the intermediate cavity. The ventilation of the cavity may be natural, fan supported or mechanical. Apart from the type of the ventilation inside the cavity, the origin and destination of the air may differ depending mostly on climatic conditions, the use, the location and the occupational hours of the building and the HVAC strategy. The glass skins can be single or double glazing units and the distance between them varies from 20 cm to more than 2 m. Often, for protection and heat extraction reasons during the cooling period, blinds are placed inside the cavity.

The solar properties of the Double Skin Façade do not differ from those of the Single Skin Façade. However, due to the additional skin, a thermal buffer zone is formed which reduces the heat losses and enables passive thermal gain from solar radiation. During the heating period, the preheated air can be introduced inside the building, providing natural ventilation with respect to indoor climate. On the other hand, during the summer overheating problems were mentioned when the façade was poorly ventilated. Different configurations can result in different ways of using the façade, proving the flexibility of the system and its adaptability in different climates and locations.

2.6.2 Classification

The classification of Double Skin Facades differs in the existing literature.

- The most common way to categorize the system is according to the type (geometry) of the cavity.
  - ¤ Multi storey Double Skin Façade: In this case no horizontal or vertical partitioning exists between the two skins. The air cavity ventilation is realized via large openings near the floor and the roof of the building.
  - ¤ Corridor façade: Horizontal partitioning is realized for acoustical, fire security or ventilation reasons.
  - ¤ Box window type: In this case horizontal and vertical partitioning divides the façade into smaller and independent boxes.
  - ¤ Shaft box type: In this case a set of box window elements are placed in the façade. These elements are connected via vertical shafts situated in the façade. These shafts ensure an increased stack effect

Double Skin Facades can also be classified according to the

- Type of ventilation
  - ¤ Natural
  - ¤ Fan supported
  - ¤ Mechanical
- Origin of the airflow
  - ¤ From inside
  - ¤ From outside
- Destination of the airflow
  - ¤ Towards inside
  - ¤ Towards outside
- Airflow direction
  - ¤ To the top
  - ¤ To the bottom (only in case of mechanical ventilation)
- Width of the air cavity
  - ¤ Narrow (10 - 20 cm)
  - ¤ Wide (0.2 – 2 m)
- Partitioning
  - ¤ Horizontal (at the level of each storey)
  - ¤ No horizontal partitioning

2.6.3 Technical Description and building physics of the cavity

Apart from structural characteristics, the literature review report "Double Skin Facades for Office Buildings" (Poirazis, 2004a) focuses on the principles of interior and exterior façade openings and the material type of panes and blinds. These two parameters and the geometry of the façade define the use and the function of the façade.

The most common pane types used for Double Skin Facades are described below.

The internal skin is often a thermal insulating double pane. The panes are usually toughened or unhardened float glass. The gaps between the panes are filled with air, argon or krypton.

The external skin is often a toughened (tempered) single pane. Sometimes it can be a laminated glass instead.

Cases with different panes used are also mentioned. Lee et al. (2002) claim that the most common exterior layer is a heat-strengthened safety glass or laminated safety glass. The second interior façade layer consists of fixed or operable, double or single-pane, casement or hopper windows. Low-emittance coatings on the interior glass façade reduce radiative heat gains to the interior.

Oesterle et al. (2001) suggest that for higher degree of transparency, flint glass can be used as the exterior layer. Since the number of the layers and the thickness of the panes are greater than in single skin construction, it is really important to maintain a "clear" façade. The main disadvantage in this case is the higher construction costs since the flint glass is more expensive than the normal one.

The shading devices used are usually horizontal louvres placed inside the cavity for protection. In the existing literature, there is no extended description concerning the material and the geometry of the shading devices. However, it is mentioned that in large scale projects it is useful to investigate the material and position inside the cavity of panes and shading devices. It is also worth considering proper combination of these two elements in order to succeed in attaining the desired temperatures.

The calculation of the air flow in a naturally ventilated cavity is the key to predicting the temperatures at different heights. Since natural ventilation is one of the main goals of this system, when the air of the cavity is introduced inside the offices it is really important to be certain to maintain an acceptable indoor climate. In the existing literature results for air flow velocities and air temperatures inside the cavity are given based on:

- Simulating the Double Skin Façade system using existing software
- Developing numerical models
  - ¤ Building energy balance (BEB) models
  - ¤ Zonal airflow network (AFN) models
  - ¤ Computational Fluid Dynamics (CFD)models
- Measurements in real buildings
- Measurements in test rooms

2.6.4 Advantages – disadvantages

The advantages and disadvantages mentioned in the existing literature of the Double Skin Façade system are described briefly below:

Advantages

Lower construction cost compared with solutions that can be provided by the use of electrochromic, thermochromic or photochromic panes (the properties of which change according to climatic or environmental conditions).

Acoustic insulation: In the view of some authors sound insulation can be one of the most important reasons to use a Double Skin Façade. Reduced internal noise levels inside an office building can be achieved by reducing both the transmission from room to room (internal noise pollution) and the transmission from outdoor sources i.e. heavy traffic (external noise pollution). The type of the Double Skin Façade and the number of openings can be really critical for sound insulation concerning the internal and the external noise pollution.

Thermal Insulation: During the winter, the external additional skin provides improved insulation by increasing the external heat transfer resistance. The reduced speed of the air flow and the increased temperature of the air inside the cavity lower the heat transfer rate on the surface of the glass, which leads to reduction of heat losses.

During the summer the warm air inside the cavity can be extracted by mechanical, fan supported or natural ventilation. Certain façade types can cause overheating problems. However, a completely openable outer layer can solve the overheating problem during the summer months, but will certainly increase the construction cost.

Night time Ventilation: During the hot summer days, when the external temperature is more than 26°C the interior spaces may easily become overheated. In this case, it may be energy saving to pre-cool the offices during the night using natural ventilation. In this case, the indoor temperatures will be lower during the early morning hours providing thermal comfort and improved air quality for the occupants.

Energy savings and reduced environmental impacts: In principle, Double Skin Façades can save energy when properly designed. Often, when the conventional insulation of the exterior wall is poor, the savings that can be obtained with the additional skin may seem impressive.

Better protection of the shading or lighting devices: Since the shading or lighting devices are placed inside the intermediate cavity of the Double Skin Facades they are protected both from the wind and the rain.

Reduction of the wind pressure effects: The Double Skin Facades around high rise buildings can serve to reduce the effects of wind pressure.

Transparency – Architectural design: In almost all the literature, reference is made to the desire of architects to use bigger proportions of glazing surfaces.

Natural Ventilation: One of the main advantages of the Double Skin Façade systems is that they can allow natural (or fan supported) ventilation. Different types can be applied in different climates, orientations, locations and building types in order to provide fresh air before and during the working hours. The selection of Double Skin Façade type can be crucial for temperatures, air velocity, and the quality of the introduced air inside the building. If designed well, the natural ventilation can lead to reduction in energy use during the occupation stage and improve the comfort of the occupants.

Thermal comfort – temperatures of the internal wall: Since the air inside the Double Skin Façade cavity is warmer (compared with the outdoor air temperature) during the heating period, the interior part of the façade can maintain temperatures that are more close to the thermal comfort levels (compared with single skin facades). On the other hand, during the summer it is really important that the system is well designed so that the temperatures inside the cavity will not increase dramatically.

Fire escape: Claessens and De Hedre mention that the glazed space of a Double Skin Façade may be used as a fire escape. Other authors categorize the different types as described below.

Low U-Value and g-value: Kragh (2000) claims that two advantages of the Double Skin Façades are the low thermal transmission (U-Value) and the low solar heat gain coefficient (g value)

Disadvantages

Higher construction costs compared with a conventional façade.

Fire protection: It is not yet very clear whether the Double Skin Facades can be positive or not, concerning the fire protection of a building. However, some authors mention possible problems caused by the room to room transmission of smoke in case of fire.

Reduction of rentable office space: The width of the intermediate cavity of a Double Skin Façade can vary from 20 cm to several metres. This results in the loss of useful space. Often the width of the cavity influences the properties inside it (i.e. the deeper the cavity, the less heat is transmitted by convection when the cavity is closed) and sometimes the deeper the cavity, the greater the improvement in thermal comfort conditions next to the external walls. Thus, it is quite important to find the optimum depth of the façade, to be narrow enough so as not to loose space, and deep enough so as to be able to use the space close to the façade.

Additional maintenance and operational costs: Comparing the Double Skin and the Single Skin type of façade, one can easily see that the Double Skin type has higher cost regarding construction, cleaning, operating, inspection, servicing, and maintenance.

Overheating problems: If the Double Skin Façade system is not properly designed, the temperature of the air in the cavity may increase, overheating the interior space.

Increased air flow velocity inside the cavity, mostly in multi storey-high types. The possibility of important pressure differences between offices is mentioned in the case of natural ventilation via the cavity.

Increased weight to structure: As expected, the additional skin increases the weight of the construction, which increases the cost.

Daylight: The Double Skin Facades are similar to other types of glazed facades (i.e. single skin façade). However, Oesterle et al. (2001) describe that Double facades reduce the quantity of light entering the rooms as a result of the additional external skin

Acoustic insulation: It is possible that sound transmission problems (room to room or floor to floor) may arise if the façade is not designed properly.

3 Methods

3.1 Building simulations of energy use and indoor climate

The use of simulation tools during the design stage can help the designer improve the overall building performance. The system building – installations can be optimised with regard to indoor climate and energy use. Different alternatives can be studied, compared and optimized in terms of energy use and indoor environment and at a low cost (avoiding full scale experiments), since the performance can be analysed and predicted at an early stage. The simulations can also be used to predict the energy use and indoor climate of an existing building (in the case of a refurbishment project).

In this thesis, simulations have been carried out regarding energy use and indoor climate issues. Parametric studies of buildings with 30%, 60% and 100% window area have been carried out, in order to calculate the energy demand during the occupation stage. Moreover, parameters such as control set point for indoor air temperatures, building orientation, plan type, window type, shading device type and position etc, have been changed in order to study the impact on the building in terms of energy use and thermal comfort. The main purpose of this sensitivity analysis is to study different glazed alternatives and to point out the problems of single skin office buildings. During the next two years of the "Glazed Office Buildings" project solutions and improvements will be suggested regarding reduction in energy use and the provision of acceptable indoor environment by integrating double skin façades.

Initially, a 30% glazed (reference) building was built in the computing tool. The model is a 6 storey high building of rectangular shape. Two plan types (cell and open) were suggested, three control set points and three orientations. The 18 generated alternatives were compared with each other in terms of energy use and quality of thermal environment both on building and zone level. Then, the glazed area of the reference building was increased up to 60% and 7 different window and shading device types were applied for the 3 control set points for both plan types.

The thermal transmittance and solar factor were the parameters changed in these building models. The 42 generated alternatives were compared on a building level. The same number of alternatives was simulated for 100% glazed alternatives and conclusions have been drawn both for building and zone level.

3.2 Brief description of building simulation program used – IDA ICE 3.0

Before choosing a building thermal simulation tool, certain performance criteria were developed. The program was to have the following features:

1. A dynamic building simulation tool
2. User friendly interface
3. Multi-zone capability
4. Simple natural ventilation features
5. Simulation of HVAC systems typical for office buildings
6. Reasonably accurate simulations of different shading devices
7. Possibility of adding new simulation modules developed by the user e.g. a double skin façade module
8. Good support
9. Reasonably well spread among researchers and consultants in Sweden
10. Known outside Sweden

The software candidates were:

- Bsim2000 developed by the Danish Research Institute (SBI)

¤ IDA ICE 3.0 developed by EQUA (Stockholm, Sweden)

DEROB LTH developed by the University of Lund

+ BV2 available from CIT Management AB (Gothenburg, Sweden)

- Bsim2000 has most of the above features (except for 7 and 9)

¤ IDA ICE has all the above features (was therefore chosen for the simulation of the building alternatives)

DEROB has some of the above features (except for 2, 4, 5, 7 and 9)

+ BV2 has some of the above features (except at least 3 and 7)

IDA ICE 3.0 is a computational program for indoor climate studies of individual zones within a building, as well as energy use of an entire building (EQUA, 2002). IDA Indoor Climate and Energy is an extension of the general IDA Simulation Environment. This means that the advanced user can, in principle, simulate any system whatsoever with the aid of the general functionality in the IDA environment.

Most of the time, the system to be simulated consists of a building with one or more zones, a primary system and one or more air handling systems. Surrounding buildings might shade the building. The air inside the building contains both humidity and carbon dioxide. Weather data is supplied by weather data files, or created for a given 24 hour period. Consideration can be given to wind and temperature driven airflow. Predefined building components and other parameter objects can be loaded from a database, which can also be used to store personally defined building components. A simple model of daylight availability at a certain point (occupant's position) of the room is also provided. More information about IDA can be found in the user's guide and in the reference manual (Equa, 2002).

Validation tests have shown the program to give reasonable results and to be applicable to detailed buildings physics and HVAC simulations (Acherman, 2000 and 2003).

3.3 Generation of building alternatives

In this part of the chapter the methodology for the parametric studies of the 30%, 60% and 100% glazed office buildings is summarized. Apart from the description of the generated alternatives, a justification of the selected output follows.

3.3.1 Reference building (30% glazed) alternatives

The simulations of the reference building are made for different

- Building interiors
  - ¤ Cell type
  - ¤ Open plan type

- Building orientations
  - ¤ North-south (short façade)
  - ¤ East-west (short façade)
  - ¤ Northwest-southeast (short façade)

- Building's control set points for indoor air temperature:
  - ¤ Strict

- ¤ Normal
- ¤ Poor

The façade construction of the reference building remains the same for all the simulated alternatives discussed in this section. The main focus of the parametric studies of the reference building is a

- cross reference comparison between the 30%, 60% and 100% alternatives
- sensitivity analysis regarding the plan type, orientation and control set points

There are 18 different alternatives with different orientations, set points and plan types as shown in Figure 3.1. A brief parametric study of the energy use has also been carried out for the northwest-southeast cell type building with normal set points generating 9 more alternatives. The parameters changed were:

- Thermal transmittance of the wall
- Thermal transmittance of the windows
- Heat recovery efficiency
- Fan power
- Cooling efficiency

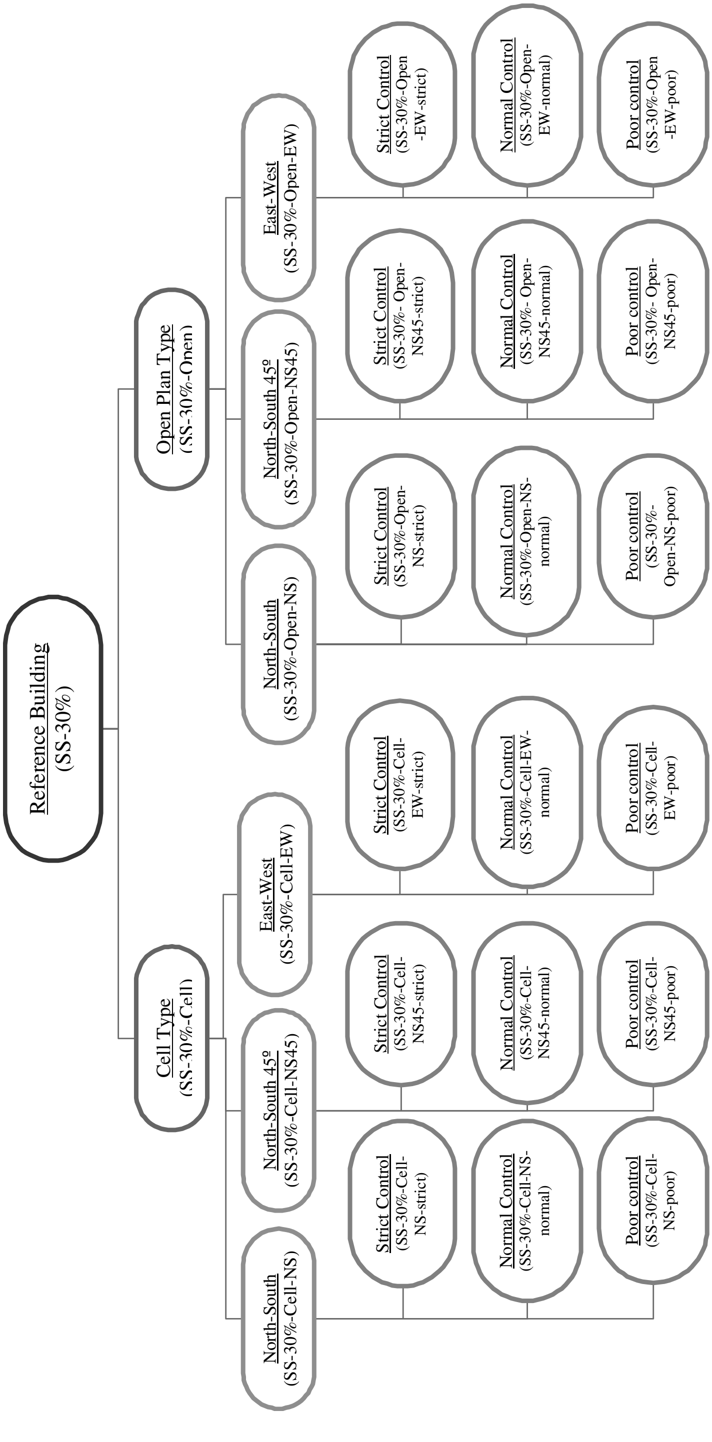
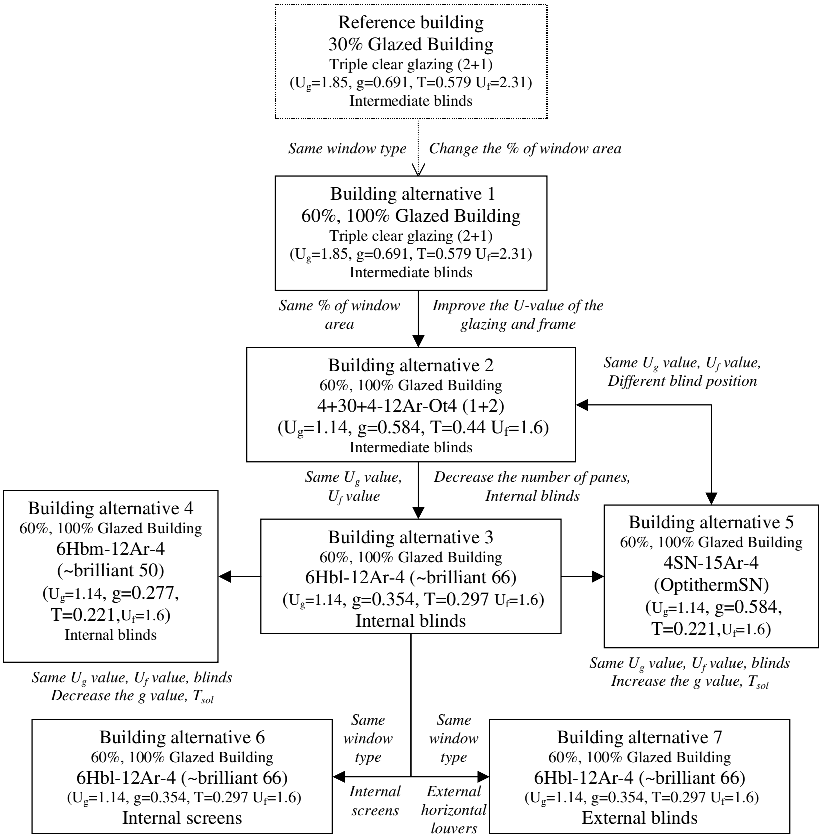


Figure 3.1 *Tree diagram for reference building alternatives.*

3.3.2 60% and 100% glazed alternatives

Seven building alternatives were suggested for the 60% and the 100% glazed alternatives. Below (Figure 3.2) follows a justification of the alternative's selection as the first step of the parametric study's methodology. Commercially available window types in general use were chosen.



4+30+4-12-4: Triple clear
4+30+4-12Ar-Ot4: Triple with low-e and argon
6Hbl-12Ar-4 (brilliant 66): Advanced solar control coating with low-e and argon
6Hbm-12Ar-4 (brilliant 50): Advanced solar control coating with low-e and argon
4SN-15Ar-4 (optitherm SN): Low-e coating and argon

Figure 3.2 Generation of 60% and 100% glazed building alternatives.

The first building alternative works like a “bridge” between the 30% and 60% glazed buildings. The $U_{glazing}$ and U_{frame} values were kept the same, in order to study the impact of larger glazing area on energy use and occupant comfort. The number and type of panes, the type and positioning of shading devices, etc, are the same as for the reference building. The total U value of the window, however, is not the same since the glazing and frame areas are different (A_f= 32% for the long and A_f= 19% for the short façade for the reference building, A_f= 27.7% for the 60% and A_f =14.3% for the 100% glazed building), as described in Chapter 4.

The window type of the second alternative was changed (lower $U_{glazing}$ and U_{frame} values), in order to get a more realistic solution for a glazed building. The frame properties were chosen according to recommendations of Schüco International as shown in Appendix F, and the glazing system 4-30-4-12Ar-Ot4 (2+1) (Optitherm) was chosen from Pilkington’s Glass Catalogue (2004). The type and position of the shading devices remained the same.

The triple glazed unit of the second alternative is replaced by a double glazed unit with the same $U_{glazing}$ (Brilliant 66 according to Pilkington’s Glass Catalogue). The solar factor (g value) of the third alternative is decreased however to 0.354 from 0.584 of the second alternative. The intermediate venetian blinds are replaced by internal ones (the properties of the blinds remain the same) increasing the $g_{effective}$. This window type was chosen as a typical alternative used for a 60% and 100% glazed building.

In the fourth alternative the thermal transmittance of the window remains the same, while the solar factor (g value) decreases even more, by up to 0.277, in order to study its impact on the cooling demand (Brilliant 50 according to Pilkington’s Glass Catalogue). The number of panes, the position and type of shading devices remain the same with the third alternative.

In the fifth alternative the thermal transmittance of the window remains the same, while the solar factor (g value) increases up to 0.584. The window type used in this case is a double glazing unit 4SN-15Ar-4 (OptithermSN according to Pilkington’s Glass Catalogue 2004), with similar properties to the alternative 2. The venetian blinds, however, are placed inside. This case was selected in order to further investigate the influence of g value on the heating and cooling demand. Additionally, since the glazing and frame are the same as in the second alternative, it is possible to investigate the influence of the position of the shading devices on energy use and thermal comfort.

In the sixth alternative internal screens (Hexcel 21136 Satine Blanc 101 according to Parasol) are placed instead of venetian blinds. The window construction is identical with the third alternative, since this is considered to be the one more often used. With this alternative it is possible to investigate the influence of different types of shading device on energy use and indoor environment.

In the last alternative fixed horizontal external louvres replace the internal screens (according to Schüco's recommendations). The window construction is again identical with the third alternative. The louvres' properties are described in Chapter Four.

3.4. Description of the output

3.4.1 Output of the simulation tool IDA

As mentioned above, the output of IDA is used for comparisons at two levels:

- Comparison of the different 30, 60% and 100% glazed building alternatives.
- Comparison of individual zones of the north south and east west oriented 30% and 100% glazed alternatives.

The requested output from IDA simulations concerns mainly the

- Energy use for heating, cooling, equipment, pumps and fans and lighting.
- Indoor Climate (mean air temperatures, directed operative temperatures, indoor air quality and perception of thermal comfort i.e. Fanger's comfort indices).
- Lost working hours (due to the poor thermal environment).

The energy use, the weighted average mean air temperatures, the perception of thermal comfort, the indoor air quality and the lost working hours are examined and compared on a building level. On a zone level the parameters studied are the mean air temperatures, the directed operative temperatures, the predicted mean vote and the predicted percentage of dissatisfied. Since for the cell type more thermal zones were created (depending on its use, number of occupants and equipment, orientation, etc) than in the open plan one, the parametric studies for the second (zone) level were made only for this plan type. The directed operative temperatures were calculated for the cell type (since the occupants are placed in a certain position) while the operative temperatures were calculated for the open plan (since in this building type the occupants are supposed to move about more inside the office space). A more detailed description of the output is given in the Chapter Five.

3.4.2 Output of the "building performance tool"

Due to the large amount of output only the interesting results are presented in this thesis. However, a "building performance tool" is developed concurrently within the "Glazed Office Buildings" project in which all the simulated alternatives are presented in detail (in the tool's database). The main purpose of the tool is to make the results of the overall project more accessible by suggesting already simulated building alternatives. It is not a "decision making tool" since it does not optimize the building performance according to the user's preferences but it can help the user understand the (building) system's sensitivity and improve its performance. The main structure of the tool is described below.

Input

Initially the user will be able to enter the following into an input table

- design constraints
- ranking
- performance specifications

The design constraints include parameters related mostly to the architectural design, the HVAC strategy, the type of materials used and the construction of the façade. If the user chooses one or more design constraints then the number of the possible suggested alternatives will be reduced to the alternatives that fulfil these criteria.

Apart from the design constraints, the user can specify his building performance requirements. These requirements are described in different detail levels and concern mostly the energy efficiency, the indoor climate (thermal and visual comfort, acoustics, etc), the environmental performance and the life cycle costs of the office building. The performance requirements are expressed in scales that will be fully described in the tool's guide.

The third parameter entered by the user is the "importance" (or trade off value) of the performance criteria. After choosing the building performance, a "ranking" table will be filled in at a scale of 0 to 1. In this way, the user will prioritize his/her main goals and will decide the trade off values of his/her requirements. Some of the performance specifications that the user can evaluate and rank are shown below. The detail level can be defined by the user.

Evaluation of the alternatives

In this stage, according to the user's input, the tool evaluates the alternatives that have already been simulated during the "Glazed Office Building" project. The main aim of this tool is not to optimise the system's performance but, instead, to find the building alternatives that are closest to the requirements of the user. The number of building models that will be chosen is defined by the user.

Suggestion of building alternatives

If the model A is the one that corresponds to the user's requirements, then the models 1, 2, 3, etc are the ones simulated during the project and suggested by the tool as the ones closer to the model A. Initially each of the suggested building alternatives (1, 2, 3, etc) will be described briefly or fully (the level of detail will be decided by the user), using the already existing information from the project. The second step is a comparison between model A and the suggested models in order to point out the differences between the requirements of the user and the suggested alternatives. Comments will follow in order to

- Inform the user of the performance requirements, if any, that could not be fulfilled as requested.
- Suggest changes concerning the design constraints, the performance requirements and the ranking, in order to get the suggested models.

Final step

In the final stage, the user will have to choose whether or not to accept one of the suggested alternatives.

- If he/she accepts, since the required and suggested models are close enough, then it is the end of the loop.
- If the user is not satisfied with the suggested output, then he/she will have to go back and repeat the loop according to the suggestions made. The user can repeat the same procedure until satisfied.

The main aims of this tool are to

- Help the user understand the relationship between performance requirements and ranking of the performance criteria.
- Understand the interactions between the parts of the building system. Repeated loops in which only some of the performance requirements are changed will not improve equally the performance of the system. Thus, the user will be able to understand the system's sensitivity, which will lead to an overall approach.
- Help the user find the "trade off value" for each of the performance requirements. It is important to face the dilemma of choosing between two or more parameters that seemed equal for two reasons:
  - ¤ The more the user tries to find an acceptable solution, the more he/she will repeat the same loop and the better he/she will understand the system's sensitivity.
  - ¤ By approaching different parameters that influence the building performance, he/she will come closer to the other members of the design team. The better understanding and the overall approach will lead to better cooperation during the design stage and to an improved building performance.
- Finally, the user can "borrow" information or alternatives from the database enriching his/her knowledge for energy efficient design.

4 Description of the building

The office buildings designed for the "Glazed Office Buildings" project consist of 30% (reference case), 60% and 100% glazing and are located in Göteborg (Sweden) i.e. for the simulations the weather data chosen was recorded in Göteborg in 1977, which is considered to be a representative year. There is no adjacent building shading. All these building alternatives are described in this chapter. The design of the reference building was determined by the project team, with researchers from the Division of Energy and Building Design (LTH), architects and engineers from WSP and Skanska. First, detailed performance specifications (see Appendix A) for indoor climate and energy use were established and then typical constructions were determined for an office building representative of construction from the late nineties. System descriptions and drawings were prepared. The reference building was presented to a reference group and agreed upon.

4.1 Description of the reference building

The description of the reference building concerns the real (designed) building and the simulated model of the building (input inserted in IDA software) made for the energy and indoor climate simulations. In this section a description of both the real and simulated model will be presented.

4.1.1 Geometry of the building

The reference building is a 6 storey high building as shown in Figure 4.1. In terms of geometry and installations, the floors 1, 2, 3, 4, and 5 are completely identical. However, the floors 1-4 are connected (floor, ceiling) with other internal zones of the building while the roof of the 5^{th} floor is connected to the outside and the ground floor is connected to the ground i.e. there is no basement.

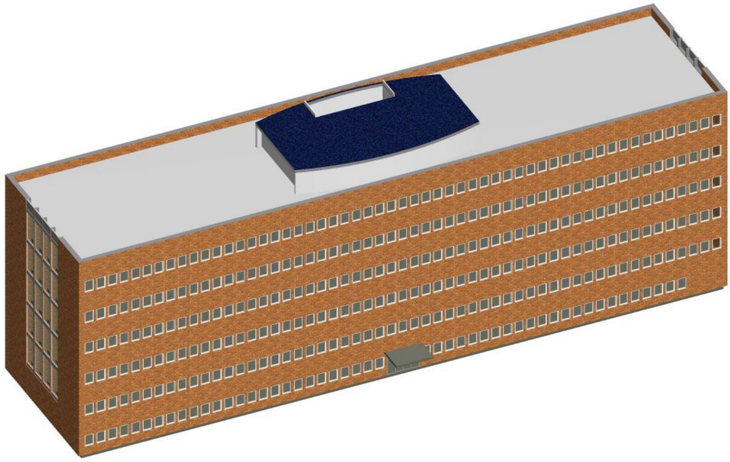


Figure 4.1 View of the Reference Building.

The height of the building is 21 m, the length 66 m and the width 15.4 m. Architectural drawings (floor plans, cross sections, facades) are presented in Appendix B. The room height is 2.7 m and the distance between intermediate floors is 3.5 m. There is a suspended ceiling. The total floor area is 6180 m^2 (BRA usable floor area i.e. floor area inside exterior walls) and 5448 m^2 (LOA non-residential/premises floor area). The total area (on the inside including the window area and the area covered by interior walls and intermediate floors) of each of the long façades is 1386 m^2 and of the short façades 327.6 m^2. Each opaque (wall) area is 957 m^2 and 224 m^2 respectively. The window area (including the frames) in each is 429 m^2 (30.9% of the facade) and 104 m^2 (31.6%) (total window area = 31%). The roof area inside the exterior walls is 1030 m^2.

4.1.2 Office layouts

Two different floor layouts were designed, one with cell-type offices and one with open plan offices. In order to simplify the input model and thus reduce the time of simulation, it is important to create as few thermal zones as possible. On the other hand, the assumptions made should not influence the accuracy of the results or limit the output of the simulations.

For the reference building, 3 floors are assumed, each one with several thermal zones. The zones were chosen to represent different kinds of rooms with different orientations. Adiabatic conditions were assumed for the ceiling of the ground floor, for the ceiling and floor of the 1st floor and for the floor of the 2nd floor. In this way it is assumed that below and above floors 1, 2, 3 and 4 there are identical zones. This is partly correct since below the 1st and above the 4th floor the zones are not exactly the same. However, since the temperatures on all the floors are very similar, the influence of the connections plays a minor role.

Detailed description of the geometry of the zones (including their number of repetition in each floor), the HVAC installations, the occupancy, the equipment, the artificial lighting and the furniture is given in Appendix C.

Cell type office layout

The floor area of the cell type office building as defined in IDA (excluding the fan room) is 6177 m^2. However, the non-residential space is 5448 m^2. In Figure 4.2 the area of each zone type is shown.

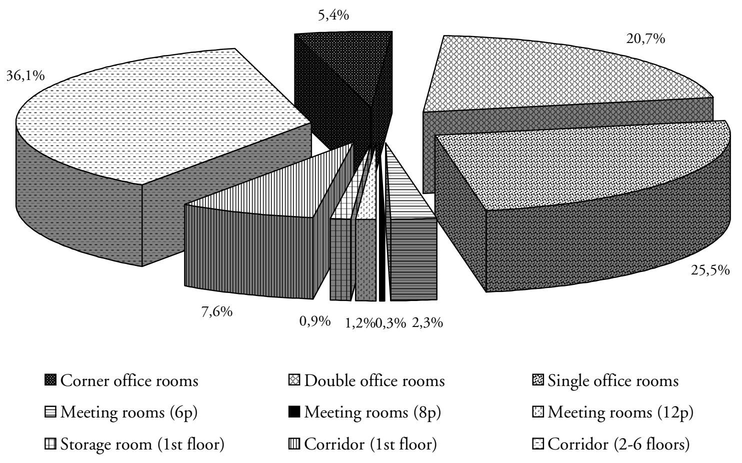


Figure 4.2 Zone areas for cell type office building.

As shown in Figure 4.2, 44% of the building area is corridor, 51% office space and only 4% meeting rooms. Figures 4.3 and 4.4 show the floor plans for the cell type office building (ground floor and 1st-5th floors).

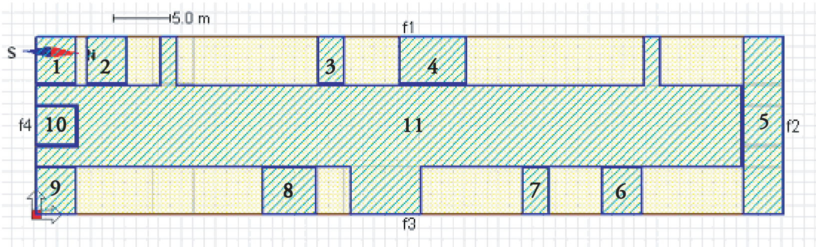


Figure 4.3 Ground floor (cell type): Input for IDA.

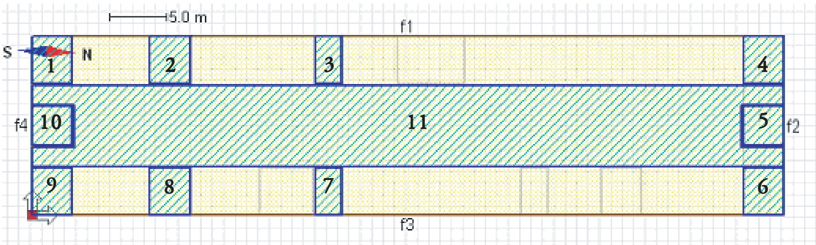


Figure 4.4 First - fifth floors (cell type): Input for IDA.

Open plan office

The floor area of the open plan type is 6177 m^2. Figure 4.5 shows the area of each zone type.

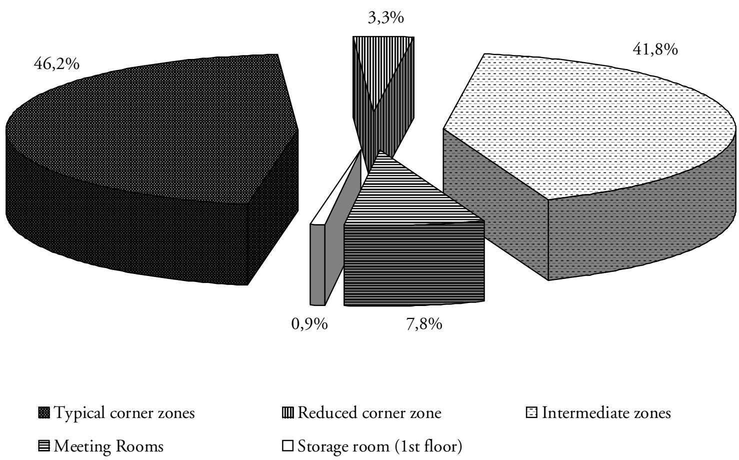


Figure 4.5 Zone area for open plan type.

In the same way, 3 floors are also assumed for the open plan reference building. The first floor has 6 zones. There is airflow exchange between the zones 1, 4, 8 assuming a big opening (always open door) between them. The ground floor is shown in Figure 4.6 and floors 1 to 5 in Figure 4.7.

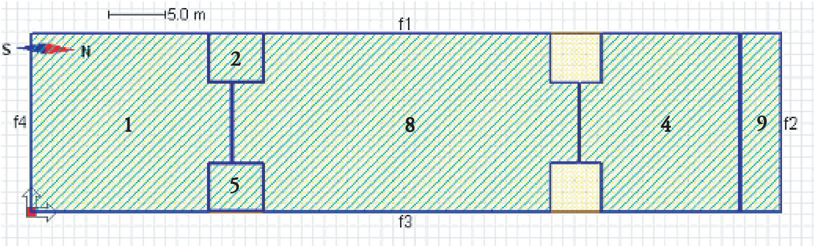


Figure 4.6 Ground floor (open plan type): Input for IDA.

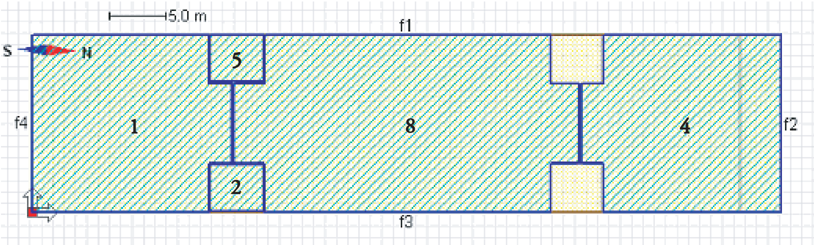


Figure 4.7 First - fifth floors (open plan type): Input for IDA.

4.1.3 Description of building elements

Thermal transmittance of the building materials

Below follows a description of the properties of the building elements used for the reference building (see Table 4.1).

Table 4.1 Description of the building elements used, not taking into account thermal bridges.

Building element	Material type (from inside to outside)	Thickness (m)	Heat conductivity ($Wm^{-1}K^{-1}$)	Density (kgm^{-3})	Specific heat ($Jkg^{-1}K^{-1}$)	U-value ($Wm^{-2}K^{-1}$)
External wall (long façade)	Gypsum board	0.013	0.18	758	840	**0.27**
	Mineral wool	0.1068	0.036	16	754	
	Wood (studs)	0.011	0.14	500	2300	
	Gypsum board	0.009	0.18	758	840	
	Air gap	0.04	0.25	1.2	1006	
	Facing bricks	0.12	0.58	1500	840	
External wall (short façade)	Concrete	0.2	1.7	2300	880	**0.21**
	Mineral wool	0.145	0.036	16	754	
	Air gap	0.04	0.25	1.2	1006	
	Facing bricks	0.12	0.58	1500	840	
Internal wall	Gypsum	0.026	0.22	970	1090	**0.62**
	Air gap	0.032	0.17	1.2	1006	
	Light insulation	0.03	0.036	20	750	
	Air gap	0.032	0.17	1.2	1006	
	Gypsum	0.026	0.22	970	1090	
Linoleum floor	Linoleum	0.0025	0.156	1200	1260	**1.75**
	Concrete	0.3	1.7	2300	880	
	Acoustic tiles	0.012	0.057	720	837	
Ground floor	Linoleum	0.0025	0.156	1200	1260	**0.32**
	Concrete	0.1	1.7	2300	880	
	Expanded plastic	0.1	0.035	1000	1700	
Roof above 6th floor	Acoustic tiles	0.0125	0.057	720	837	**0.16**
	Concrete	0.3	1.7	2300	880	
	Mineral wool	0.2	0.036	16	754	
	Wood	0.02	0.14	500	2300	
	Under felt	0.003	0.13	930	1300	

The thermal transmittance of the materials used was initially calculated by IDA. However, since the thermal losses due to thermal bridges were not included in these calculations, further corrections (calculations) were made as described in Appendix D. A comparison between the theoretical and the practical values calculated by Swedish Building Regulations is shown in Table 4.2. Finally, the practical values, according to the calculation procedure in the Building Regulations, were preferred to be used for the simulation of the reference building. In order to meet the requirements of the Swedish Building Regulations (overall thermal transmittance of the building), modifications were made in the IDA library (increase of insulation for the external walls and roof).

Table 4.2 Theoretical and used thermal transmittance of the materials used

Building element	Theoretical U-value ($Wm^{-2}K^{-1}$)	Used U-value ($Wm^{-2}K^{-1}$)
External wall (long façade)	0.27	0.32
External wall (short façade)	0.22	0.25
Internal walls	0.62	0.62
Roof (above 6th floor)	0.16	0.19
Ground floor	0.32	0.32
Intermediate floors	1.75	1.75

The total U · A value of the building envelope does not meet the requirements of the Swedish Building Regulations, but the energy use for heating meets the requirements of the Building Regulations reference building.

Windows

A description of the geometry and the properties of the windows of the reference building follows.

Windows of the long façade (type A)

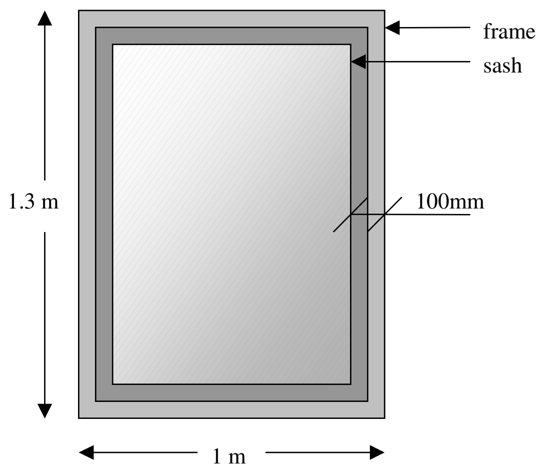


Figure 4.8 Typical window in the long façade.

Table 4.3 Properties of window in the long facade.

Window properties	Size of window	1.3 m^2
	U_{window} typical of 90s	2 W/m^2K
Glazing properties	Description	Triple glazed unit. Outer 4mm clear float, 30mm space, D4-12 inner IGU (Insulated Glazing Unit).
	Size (A_g)	0.88 m^2
	U_g (Calculated with Parasol)	1.85 W/m^2K
Frame properties	Description	Wood covered by aluminium on the outside
	Size (A_g)	0.42 m^2 (32% of the total window area)
	U_f	2.31 W/m^2K
Shading devices*	Description	Intermediate white venetian blinds placed in the 30 mm gap (at 45 degrees)
	$U_{effective}$	1.65 W/m^2K

* Shading devices: it is assumed that the venetian blinds close (100%) when the incident light inside the glass exceeds 100 W/m^2.

Windows in the short façade (type B)

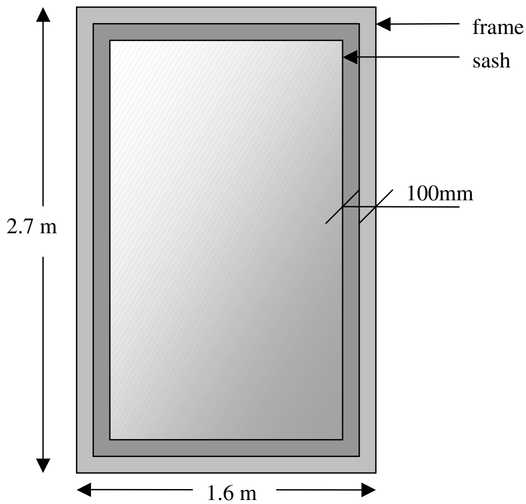


Figure 4.9 Typical window in the short façade.

Table 4.4 Properties of window in the short facade.

Window properties	Size of window	4.32 m^2
	U_{window} typical of 90's	1.94 W/m^2K
Glazing properties	Description	Triple glazed unit. Outer 4mm clear float, 30mm space, D4-12 inner IGU (Insulated Glazing Unit).
	Size (A_g)	3.5 m^2
	U_g (Calculated with Parasol)	1.85 W/m^2K
Frame properties	Description	Wood covered by aluminium on the outside
	Size (A_g)	0.82 m^2 (19% of the total window area)
	U_f	2.31 W/m^2K
Shading devices *	Description	Intermediate white venetian blinds placed in the 30 mm gap (at 45 degrees)
	$U_{effective}$	1.65 W/m^2K

* Shading devices: it is assumed that the venetian blinds close (100%) when the incident light inside the glass exceeds 100 W/m^2.

4.1.4 Special modifications for the simulated model

In order to input the real (virtual) building into IDA some special modifications had to be made.

Office volume

IDA calculates the thermal losses only for the interior of a room (inside part of the internal walls, upper part of the floor to lower part of the ceiling, etc). Thus, in order to include the transmission losses through the external wall above the suspended ceiling and the concrete floor (part b in Figure 4.10), the room height was increased from 2.7 m (real room height) to 3.5 m (Figure 4.11). The same assumption was made for the internal walls. Since the construction of the internal walls is light, in the same way the internal walls were included when defining the office geometry

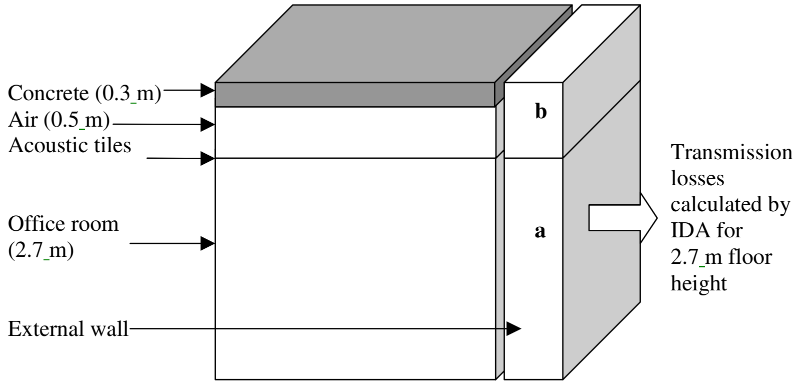


Figure 4.10 Real office model.

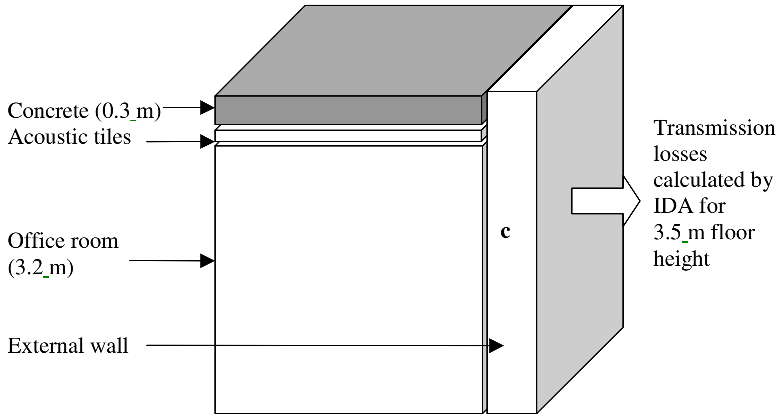


Figure 4.11 Equivalent office model.

Windows

Equivalent windows were also assumed in order to save time for the simulations. For each façade of every thermal zone only one window is assumed. The size of the equivalent window is equal to the sum of the real ones while the proportion of the frame area to the window area remains the same. The equivalent window is placed 0.8 m from the floor and in the middle of each zone.

Internal boundary conditions

On each floor it is assumed that each zone is connected with an identical one. This was achieved since adiabatic conditions were assumed from the computing program. The same assumption was made between the floors. This was achieved by keeping the distance between the zones at a minimum level of 0.5 m.

Infiltration rates

The infiltration rate assumed for the reference building is 0.1 ach (air changes per hour) for the whole building. The easiest way to insert infiltration into IDA is to increase the mechanical supply and exhaust air by 0.1 ach, and reduce the heat recovery efficiency. Since the theoretical value of the efficiency was 60%, and the mechanical air flow (excluding the natural airflow) for the

- Cell type was 3997 l/s and for the
- Open plan type 3307 l/s

and the total airflow (including natural airflow) for the

- Cell type was 4459 l/s and for the
- Open plan type 3521 l/s

the practical value for the heat recovery efficiency is 53.8% and 52.4% respectively.

The practical value was calculated as follows (cell type): if the airflow recovered is to be 2398 l/s (60% of 3997 l/s), then, in order to keep the same recovered air flow when adding infiltration to the model (total airflow 4459 l/s), the efficiency is reduced to 53.8%. More detailed the calculations are described in the Air handling unit subsection 4.1.8.

4.1.5 Control set points for indoor air temperature

Three control set points were chosen for the simulations of the reference building, as shown on Table 4.5. The normal control set point is considered the standard (reference) case, since the lower and upper temperature limit meet the requirements for optimised indoor temperatures according to practice in modern Swedish offices (VVS, 2000). However, the two other control set points can provide useful information concerning variation in energy use as a function of the air temperature and directed operative temperature, the perception of thermal comfort and the occupants' productivity. For the water radiators proportional control and for the cooling beams PI control was assumed.

Another parameter changed with the three control set points is the artificial light provided at the workplace. For the strict control it is assumed that the lights are switched on for the occupants' schedule, regardless of the amount of daylight inside the offices. For the normal and poor control set points, however, set points of 500 lux and 300 lux respectively were assumed at the workplace. The main reason that these set points were assumed is to calculate the savings in electricity for artificial lighting for different control set points, glazing, shading devices and proportion of glass in the building.

Table 4.5 Classification of the indoor environment.

Classification (control set points)	**Minimum Air Temperature winter (°C)**	**Maximum Air Temperature summer (°C)**	**Daylight at workplace (lux)**
Poor	21	26	Setpoints+Schedule 300-5000
Normal	22	24.5	Setpoints+Schedule 500-5000
Strict	22	23	Schedule

4.1.6 Occupancy

Occupant density

Cell type

For the cell type office building the number of occupants is shown in Table 4.6.

Table 4.6 Occupants for cell type.

Zone type	Number of occupants for each zone	Total (theoretical) number of occupants for each zone type	Total (real) number of occupants (during working hours)
Corner offices	1	22	17.6
Double office rooms	2	166	132.8
Single office rooms	1	156	124.8
Meeting rooms (6p)	6	66	24.6
Meeting rooms (8p)	8	8	3.2
Meeting rooms (12p)	12	36	14.4
Storage room	0	0	0
Corridor (1st floor)	0	0	0
Corridor (2nd-6th floor)	0	0	0
Total		454	**319.2**

The total floor area of the building (inside the external walls) for the number of working places (only office rooms) is 18 m^2/occupant. According to the recommendations of the architect involved in the "Glazed office building project" (Christer Blomqvist), it was assumed that the 80% of the occupants are present during office hours. Thus, if the schedule of the occupants for the offices is 8 hours (08:00 -12:00, 13:00 – 17:00) the daily internal loads correspond to the same activity of an actual (real) time of 6.4 hours. The meeting rooms are occupied only 4 hours per day. Thus they are occupied for 40% of the theoretical time. This assumption also includes that visitors will enter the building. The distribution of the occupants in the building is shown in Figure 4.12.

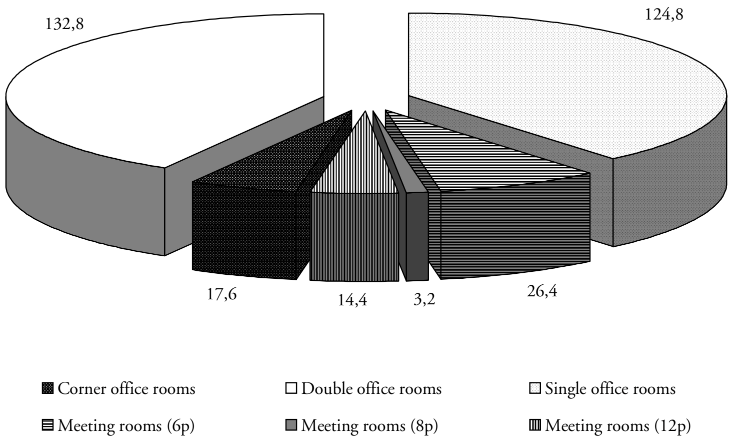


Figure 4.12 Occupants (real) per zone for cell type

The density of the occupants for the cell type office building is shown in Figure 4.13.

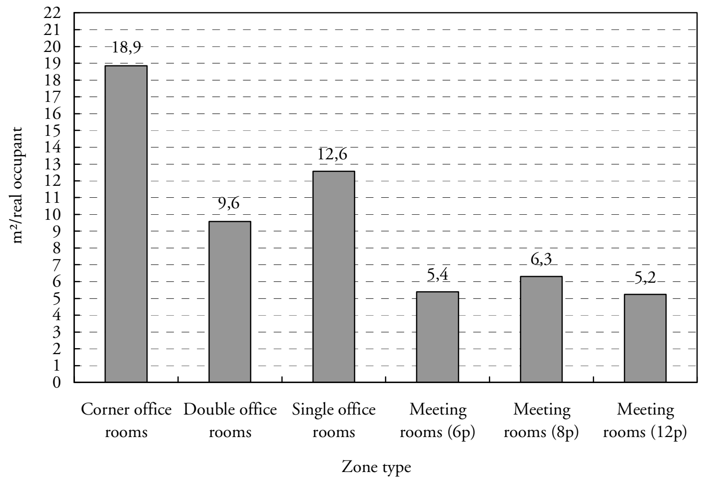


Figure 4.13 Density of each zone for cell type (real number of occupants).

Open plan type

The total floor area of the building (inside the external walls) for the number of working places (only office rooms) is 15.5 m^2/occupant. For the open plan type it is assumed that there is an increase of 20% of the occupants for the offices (cell type) while the density of the meeting rooms remains the same. The number of occupants is shown in Table 4.7.

Table 4.7 Occupants for the open plan.

Zone type	Number of occupants for each zone	Total number of occupants for each zone type	Equivalent number of occupants (during working hours)
Typical corner zones	16	211.2	169
Reduced corner zone	12	14.4	11.5
Intermediate zones	24	172.8	138.2
Meeting rooms	8	192	76.8
Storage rooms	0	0	0
Total		590.4	395.2

The distribution of the occupants in the building is shown in Figure 4.14.

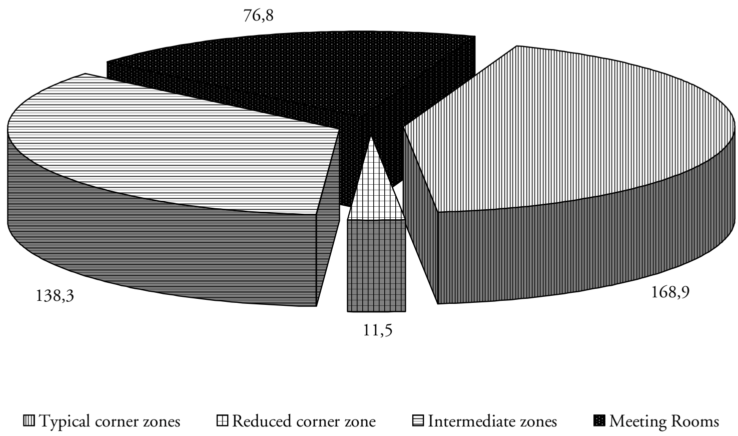


Figure 4.14 Occupants (real) per zone for open plan.

The density of the occupants for the open plan type office building is shown in Figure 4.15.

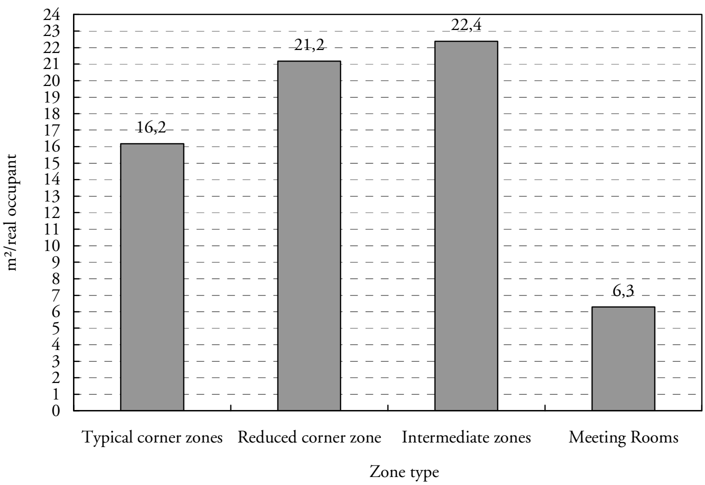


Figure 4.15 Density of each zone for open plan (real number of occupants).

The total real increase of the occupants in the cell type is 15.5% (for the offices the increase is 20%). Since the design and use of the two plan types (cell and open) are not the same (for example the cell type has 2 meeting rooms on floors 1-5 for 6 persons each, while the open plan has for the same floors 4 meeting rooms for 8 persons each). Thus, an equivalent number of occupants (interior of the open plan with density of the cell type) had to be considered in order to calculate the relative increase of the occupants in the open plan.

Occupant load

The occupants' schedule, activity level, clothing and use of the rooms are shown in Table 4.8.

Table 4.8 Occupant load.

Schedule	**Schedule for offices:** 08:00 -12:00, 13:00 – 17:00 Typical winter occupant schedule (01/01-31/04, 01/10-31/12): 50% working during the Christmas vacations, otherwise 100% weekends closed. Typical summer occupant schedule (01/5-30/09):50% working during July, 75% working during June and August, otherwise 100%, weekends closed. **Schedule for meeting rooms:** 10:00 -12:00, 13:00 – 15:00 Typical winter occupant schedule (01/01-31/04, 01/10-31/12): 50% working during the Christmas vacations, 100% rest, weekends closed. Typical summer occupant schedule (01/5-30/09):50% working during July, 75% working during June and August, 100% rest, weekends closed.
Activity level	Office Activity1 met = 108 W / occupant (1 met corresponds to 58.2 W / m^2 body surface)Task: sitting, reading
Clothing	For winter conditions: 1 clo For summer conditions: 0.6 clo
Use of rooms	For the offices it is assumed that 80% of the office workers are present during the working hours (since people can work at home or be absent for some other reason).For the meeting rooms it is assumed that they are used 50% of the time and used to 80% of their capacity (total 40% comparing with the offices)

4.1.7 Lights

For the lights of the cell type layout, energy efficient lighting (fluorescent tubes with HF fittings) is assumed, i.e. installed power of 12 W/m^2 for the offices and the meeting rooms and desired illuminance at the desk 500 lux. For the corridors and the rest of the spaces an installed power of 6 W/m^2 and desired illuminance 250 lux was assumed. However, for the open plan the installed power of 12 W/m^2 is assumed for all the working space. The luminous efficacy of the lights is set to 41.7 lm/W.

4.1.8 Air Handling Unit

Ventilation rates

- For the cell type: The air is supplied in the offices and extracted from the corridors. For the offices there is a CAV (constant air volume) control supplying 10 l/s air (normal design value for cell type plan offices) for each person. For the meeting rooms VAV (variable air volume) CO_2 control is assumed.
- For the open plan: In this case the air is supplied and exhausted from the office space (since there is no separation between offices and corridors). The supply air for each person is assumed to be 7 l/s (normal design value for open type plan offices) for the office space (CAV control) and a VAV CO_2 control is assumed for the meeting rooms.

In order to keep the supply and exhaust air flow rates balanced in IDA, it was assumed that the air is supplied in the rooms through the air handling unit and passes to the corridor through transfer air devices (simulated as air leakage paths) to be exhausted. Thus, the amount of the exhaust air (from the corridor) is equal to the mechanical and natural ventilation of the offices. However, since the exact amount of air supplied in the meeting rooms is not known (VAV CO_2 control), in order to keep the balance between the total supply and exhaust air, it was assumed that the amount of air supplied is also exhausted from the meeting rooms.

The infiltration and exfiltration of the whole building was assumed to be 0.1 ach. This rate corresponds to 2.7 m room height. For the meeting rooms (VAV CO_2 control), however, since the mechanical supplied air in the meeting rooms can not be increased manually (assuming that it is natural ventilation) the infiltration of the meeting rooms was added to the infiltration of the offices depending on the size of each office. For the cell type building there is a similar problem with the corridor. Since there is only exhaust air, the infiltration of the corridor was added to the offices.

It is important to consider an assumption that was made for the Air Handling Unit's efficiency. The easiest way to insert infiltration in IDA is to increase the mechanical supply and exhaust air by 0.1 ach/h, and reduce the Heat Recovery Efficiency. However, since the mechanical ventilation of the meeting rooms is not known, it is assumed that the airflow for each one depends on the schedule and the number of occupants.

The theoretical heat recovery efficiency for the AHU is 60%. For the cell type, the efficiency drops to 53.77% due to the natural ventilation. The supply air temperature of the AHU as inserted in IDA is shown in Figure 4.16:

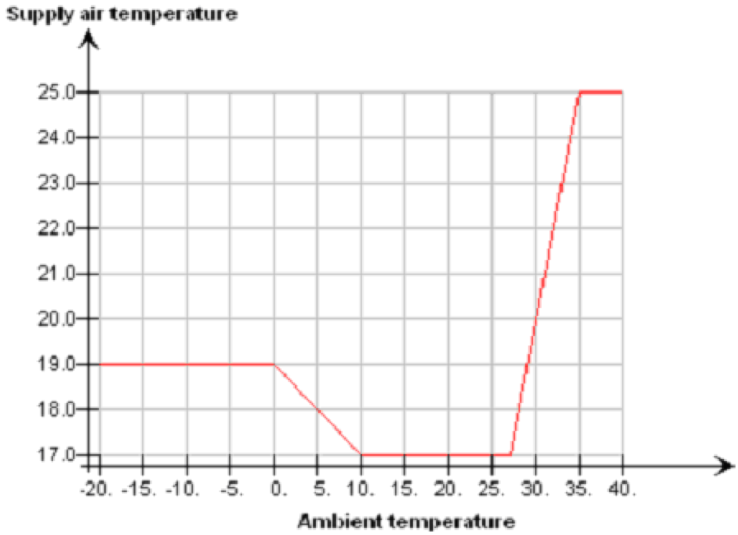


Figure 4.16 Set point for supply air temperature (IDA input).

More detailed description of the ventilation rates of each zone is given in Appendix E.

Equivalent heat recovery efficiency

The infiltration rate decided for the reference building is 0.1 ach for the whole building. As already mentioned, the easiest way to insert infiltration in IDA is to increase the mechanical supply and exhaust air by 0.1 ach, and reduce the heat recovery efficiency. Since the theoretical value of the efficiency was 60%, and the mechanical air flow (excluding the natural airflow) for the

- Cell type was 3997 l/s and for the
- Open plan type 3307 l/s

and the total airflow (including natural airflow) for the

- Cell type was 4459 l/s and for the
- Open plan type 3521 l/s

the practical value of the heat recovery efficiency is 53.8% and 52.4% respectively.

The AHU is on from 5:30 till 22:00 during weekdays (100%) and weekends (50%). However, there is natural ventilation (infiltration and exfiltration) during the rest of the hours. Thus, the off value (natural ventilation during the hours that the AHU is not working) is set to 0.1038 for the cell type according to the following equation:

$$\text{off value} = \frac{\dfrac{\text{natural ventilation}}{\text{total ventilation}}}{\dfrac{100 - \text{heat recovery efficiency}}{100}}$$

Equation 4.1 Off value for the AHU.

Likewise, for the open plan the off value (natural ventilation during the hours that the AHU is not working) is set to 0.1314 (heat recovery efficiency for the off value is 0 since the off value for the heat exchanger is set equal to 0). The on value during the weekends is calculated as follows:

$$\text{on value} = \frac{50\%\ \text{mechanical ventilation} + \text{natural ventilation}}{\text{total ventilation}}$$

Equation 4.2 On value for the AHU.

In Table 4.9 the schedule of the AHU is presented.

Table 4.9 Schedule of AHU unit.

AHU Properties	**Cell type**		**Open plan**	
Air Handling Unit schedule	Week days: 06:00 – 20:00	Weekends: 08:00 – 17:00	Week days: 06:00 – 20:00	Weekends: 08:00 – 17:00
On Value	1	0.552	1	0.5679
Off Value	0.1038		0.1314	

Use of electricity

The use of electricity for ventilation was assumed to be a specific fan power of 2.5 kW/m^{3}s, which is representative of the good buildings of the nineties.

4.1.9 Electrical equipment

In this chapter, a brief description of the electrical equipment used is given. For the cell type office building, the corner offices (1 occupant) are equipped with 1 PC (125 W), 1 printer (30 W) and 1 fax (30 W). The double and single offices are equipped only with PCs (2 and 1 respectively). No electrical equipment is assumed for the meeting rooms. Four copiers (500 W) 4 printers and 2 faxes are placed in each corridor for general use. The annual energy use of equipment for the cell type office building is 22 kWh/m^2. For each floor of the open plan office building it is assumed that there is 1 PC (30 W) per occupant, while the printers (8 units of 30 W and 4 units of 50 W), the faxes (8 units of 30 W) and the copiers (4 units of 500 W) are mainly used by everybody. No equipment was assumed for the meeting rooms. The annual energy use of equipment for the open plan office building is 21 kWh/m^2. The lower annual energy use for the equipment of the open plan alternatives is inconsistent with the higher density, as one would expect that the larger number of occupants would increase the need for equipment use. The open plan type, however, can be crucial since the common use of equipment could decrease this need. Additionally, the meeting rooms (where no equipment was assumed) are more and bigger in the open plan than in the cell type alternatives. The schedule assumed for the use of the equipment is from 08:00-12:00 (80%), from 12:00-13:00 (15%) and from 13:00-17:00 (80%) for a typical workday. During the Christmas vacations and July 50% of the typical use was assumed and during June and August 75%. During the weekends no use of equipment was assumed. Due to equipment in stand-by mode, however, 15% of the load was assumed for the non working hours. The number and schedule of the units were decided after discussions with the architect of the "Glazed office buildings" project (Christer Blomqvist). The energy used by the office equipment is suggested by Wilkins (2000).

For both (cell and open) plan types a server room was assumed with energy use 175 kW/occupant (Jensen, 2003). Thus the energy use is 10 kWh/m^2 for the cell and 13 kWh/m^2 for the open plan type. The cooling of the server room is also included in the energy use calculations.

Energy use of 87.5 kW/occupant was assumed for both plan types. The energy use is 5 kWh/m^2 for the cell and 6 kWh/m^2 for the open plan type. Finally, the energy use for the fans and pumps is calculated by IDA.

4.2 Description of the 60% glazed building

The 60% glazed building is the same as the reference one with the only difference that the glazed area increases from 30% to 60% as shown in Figure 4.17. A detailed description of the façade construction follows.

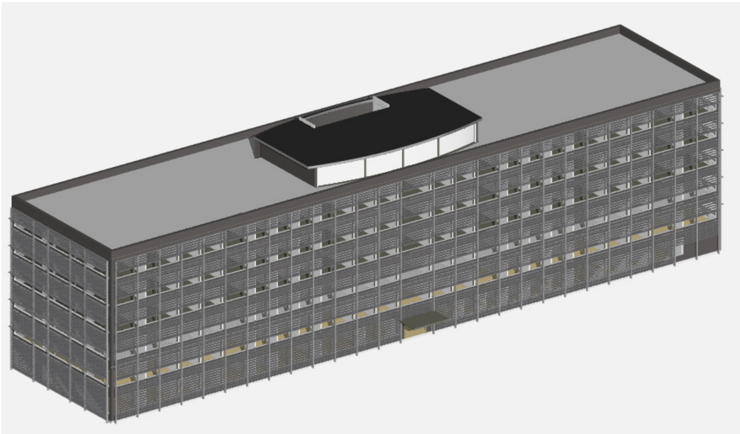


Figure 4.17 60% glazed alternative.

4.2.1 Façade Construction

Façade with internal or intermediate shading devices

A view of the facade of the 60% glazed building (with intermediate or internal shading devices) is shown in Figure 4.18. The total floor height (including the floor construction) is 3.5 m. The distance between the floor and ceiling (excluding the floor) is 3.2 m. The 60% window area refers to a floor height of 3.5 m (exterior façade). The windows can be opened for natural ventilation of the building.

The total window area of a single office is 5.04 m^2 out of 8.4 m^2 wall area (60%). The glass area is 3.6 m^2 (72.5% of the window area) and the frame area 1.4 m^2 (27.5% of the window area).

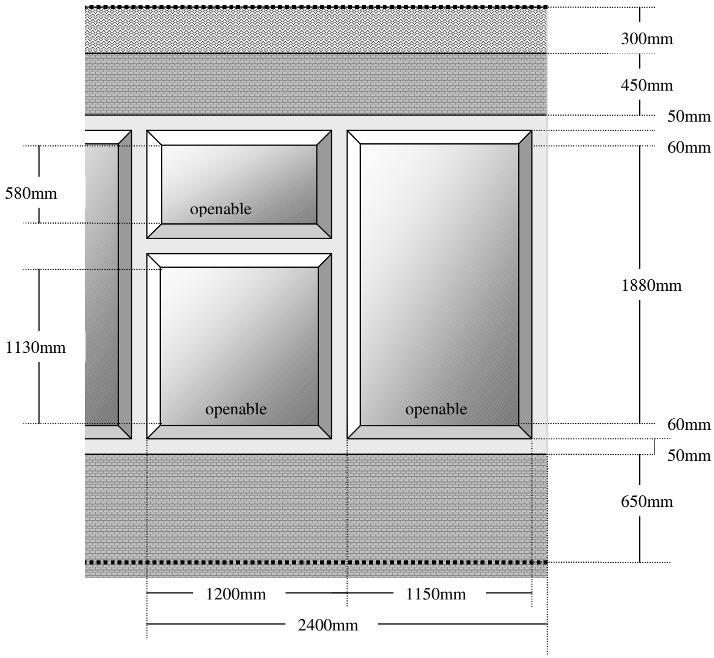


Figure 4.18 *60% glazed façade construction (with intermediate or internal shading devices).*

Façade with external horizontal louvres

The main difference of the facade for the alternative with fixed horizontal louvres is that 2 of the 3 windows are not openable, as shown in Figure 4.19. This results in a higher glass to window area. Additionally, the U_f of the frame for the openable window is 1.8 W/m^{2}K instead of 1.6 W/m^{2}K. The total window area of a single office remains 5.04 m^2 out of 8.4 m^2 wall area (60%). The glass area is 4.3 m^2 (84.7% of the window area) and the frame area 0.7 m^2 (15.3% of the window area). The openable frame is 0.27 m^2 (38.5% of the frame). The dimensions of the fixed external louvres are shown in Appendix F.

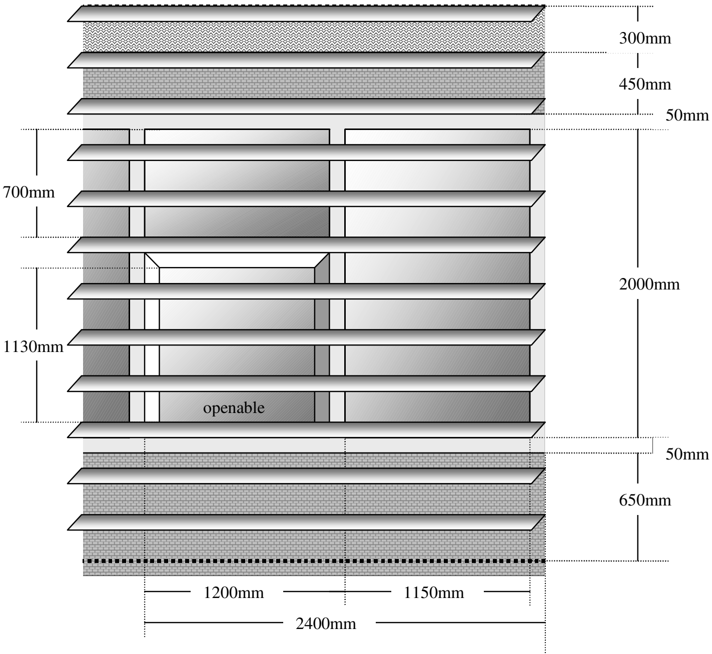


Figure 4.19 60% glazed facade with external fixed horizontal louvres.

4.2.2 Window properties

The window properties for the 60% glazed alternatives are shown in Tables 4.10 and 4.11. The rationale for the choice of alternatives is given in Subsection 3.3.2. For the given $U_{glazing}$ and U_{frame} the U_{window} was calculated according to the following equation:

$$U_{window} = \frac{U_{glazing} \times A_{glazing} + U_{frame} \times A_{frame}}{A_{glazing} + A_{frame}}$$

Equation 4.3 Thermal transmittance of the window.

U_{frame} includes the edge losses. For the 7th alternative there are two frames used in the façade as shown in Figure 4.19. In this case an average U value was calculated using the following equation:

$$U_{average} = \frac{U_{frame1} \times A_{frame1} + U_{frame2} \times A_{frame2}}{A_{frame1} \times A_{frame1}}$$

Equation 4.4 Average thermal transmittance of the frames for the highly glazed alternatives.

The window properties (glazing and frame) for the 60% glazed alternatives are shown in Table 4.10. The frame type of the 7th alternative differs between the windows. Thus for the IDA simulations an overall U value had to be calculated.

Table 4.10 Window properties (glazing& frame).

<table>
<tr><th>Building alternative</th><th>U_{window} (W/m²K)</th><th>$U_{glazing}$ (W/m²K)</th><th colspan="2">U_{frame} (W/m²K)</th><th>$A_{glazing}$ (m²)</th><th colspan="2">A_{frame} (m²)</th></tr>
<tr><td>1</td><td>1.97</td><td>1.85</td><td colspan="2">2.31</td><td>3.6</td><td colspan="2">1.4</td></tr>
<tr><td>2</td><td>1.27</td><td>1.14</td><td colspan="2">1.6</td><td>3.6</td><td colspan="2">1.4</td></tr>
<tr><td>3</td><td>1.27</td><td>1.14</td><td colspan="2">1.6</td><td>3.6</td><td colspan="2">1.4</td></tr>
<tr><td>4</td><td>1.27</td><td>1.14</td><td colspan="2">1.6</td><td>3.6</td><td colspan="2">1.4</td></tr>
<tr><td>5</td><td>1.27</td><td>1.14</td><td colspan="2">1.6</td><td>3.6</td><td colspan="2">1.4</td></tr>
<tr><td>6</td><td>1.27</td><td>1.14</td><td colspan="2">1.6</td><td>3.6</td><td colspan="2">1.4</td></tr>
<tr><td>7</td><td>1.26</td><td>1.14</td><td>1.6</td><td>1.8</td><td>3.82</td><td>0.89</td><td>0.27</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">1.65</td><td></td><td colspan="2">1.16</td></tr>
</table>

Table 4.11 sets out the impact of the shading devices for different glazing alternatives. The “effective” value refers to the cases that the shading devices are used. The default value (set point) of IDA was used for the simulations. This value corresponds to a maximum limit of 100 W/m^2 on the inside of the glass. Above this value the shading devices are used 100%.

The $U_{glazing}$, g, T_{sol} (solar transmittance), $U_{gl.\ effective}$, $g_{gl.effective}$ and $T_{gl,effective}$ (effective solar transmittance) are calculated for perpendicular ray angle “standardized” with the “Parasol” software (Wall and Kvist, 2003).

For the case with external louvres the solar factor and solar transmittance the real g value and T_{sol} over the year are calculated. The reason for this additional calculation is that the horizontal external louvres are fixed (and thus operating all year round). Thus, monthly solar factor values can better approximate the reality compared with the yearly g value that IDA uses for the calculations. Using the mentioned computing program the g_{system} and the T_{system} for every month were calculated as shown in Table 4.12. These monthly values were inserted in IDA (schedule of external shading devices). The $U_{effective}$ of the system with the fixed external louvres is assumed to be the same as the one for the intermediate blinds.

Table 4.11 Impact of shading on glazing alternatives.

Building alternative	$U_{glazing}$ (W/m²K)	g	T_{sol}	$U_{gl.\ effective}$ (W/m²K)	$g_{gl.effective}$	$T_{gl,effective}$
1	1.85	0.691	0.579	1.65	0.301	0.132
2	1.14	0.584	0.44	1.08	0.225	0.104
3	1.14	0.354	0.297	1.07	0.276	0.080
4	1.11	0.227	0.221	1.04	0.218	0.059
5	1.14	0.584	0.44	1.08	0.469	0.117
6	1.14	0.354	0.297	0.92	0.190	0.080
7	1.14	0.354	0.297	1.14	0.2	0.17

Table 4.12 Solar factor and solar transmittance for the fixed external louvres.

Month	g-mean sunshade (%)	g-mean window (%)	g-mean system (%)	T_{mean} sunshade (%)	T_{mean} window (%)	T_{mean} system (%)
1	84.6	34.4	29.1	84.4	29.4	24.8
2	74.4	34.1	25.4	74.0	29.4	21.7
3	58.5	33.9	19.8	57.9	29.2	16.9
4	44.2	33.6	14.9	43.5	29.1	12.7
5	45.2	33.1	15.0	44.7	29.0	13.0
6	49.0	33.0	16.2	48.7	28.9	14.1
7	51.1	32.9	16.8	51.0	28.9	14.7
8	40.5	33.2	13.4	40.2	29.1	11.7
9	48.9	33.4	16.3	48.5	29.1	14.1
10	68.3	33.9	23.1	68.1	29.3	19.9
11	80.5	34.4	27.7	80.2	29.3	23.5
12	87.1	34.5	30.0	86.8	29.4	25.5

A detailed description of the frame construction is given in Appendix F.

4.3 Description of the 100% glazed building

A view of the 100% glazed building shown in Figure 4.20.

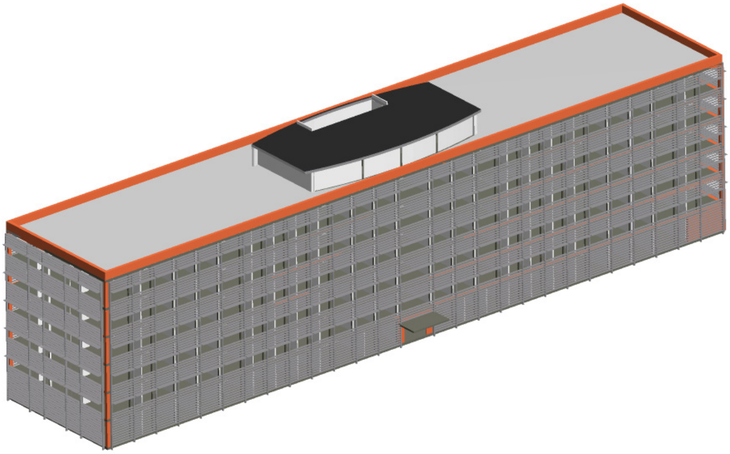


Figure 4.20 100% glazed alternative.

The U-values and g-values for the windows are the same as for the 60% alternatives. The façade construction of the 100% glazed building with internal or intermediate shading devices is shown in Figure 4.21.

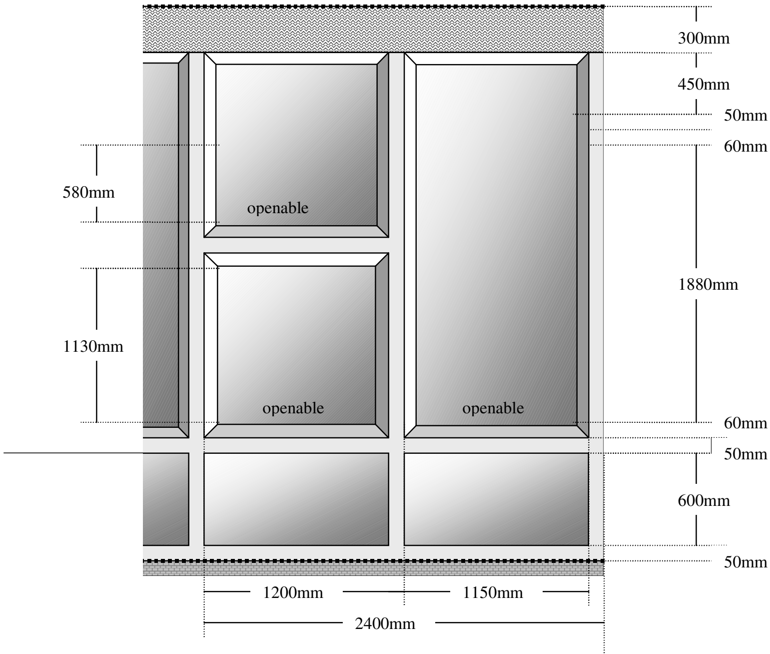


Figure 4.21 *100% glazed façade construction (with intermediate or internal shading devices).*

The façade construction of the 100% glazed building with fixed external horizontal louvres is shown in Figure 4.22.

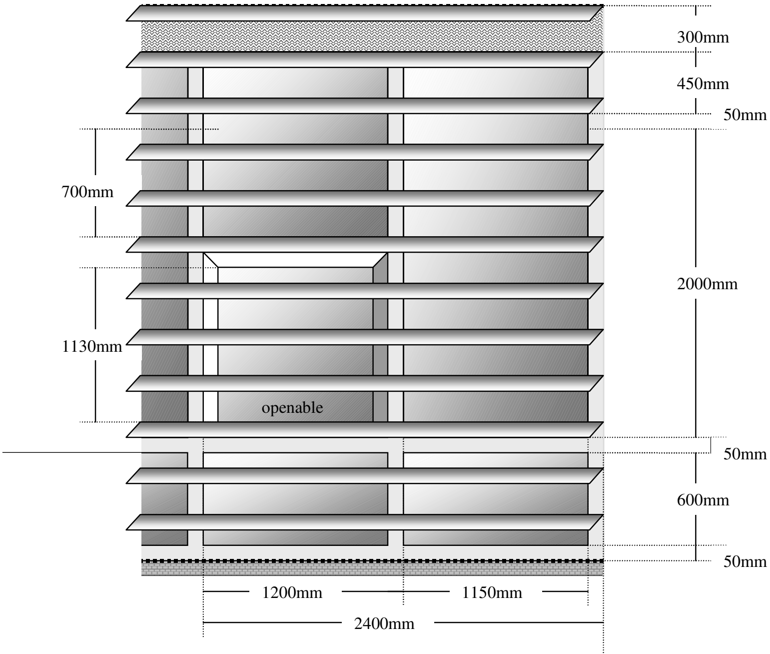


Figure 4.22 100% glazed facade with external fixed horizontal louvres.

5 Results from the simulations

In this part the results of the simulations are presented and briefly discussed. The main focus of the parametric studies is a cross comparison between the glazed alternatives.

5.1 Description of the output

5.1.1 General

For the glazed buildings, the results are analysed at two levels:

- Comparison of the difference between reference, 60% and 100% glazed building alternatives at a building level concerning energy use and indoor climate issues
- Comparison of indoor climate for individual zones of the north south and east west oriented 30% and 100% glazed alternatives.

The requested output from IDA simulations concerns mainly the

- Energy use for
  - ¤ Space heating
  - ¤ Cooling
  - ¤ Ventilation
  - ¤ Pumps, fans, etc
  - ¤ Lighting

- Indoor Climate
  - ¤ Air temperatures
  - ¤ Directed operative temperatures
  - ¤ Indoor air Quality
  - ¤ Perception of thermal comfort (Fanger's comfort indices)

- Productivity (lost working hours)

The energy use, the weighted average monthly air temperatures, the perception of thermal comfort, the indoor air quality and the lost working hours are examined and compared on a building level. On a zone level the parameters studied are the mean air temperatures, the directed operative temperatures, the predicted mean vote and the predicted percentage of dissatisfied. Since for the cell type more thermal zones were created (due to its use, number of occupants and equipment, orientation, etc) than in the open plan one, the parametric studies for the second (zone) level were made only for this plan type. The directed operative temperatures were calculated for the cell type (since the occupants are placed in a certain position) while the operative temperatures were calculated for the open plan (since in this building type the occupants interact more and therefore they tend to move about more inside the office space).

5.1.2 Parametric Studies on building level

The comparison on a building level of the 30%, 60% and 100% glazed buildings can be complicated due to the large amount of simulated alternatives and the different performance criteria involved (energy use, thermal comfort, etc). For the reference building three orientations, three set point intervals (for heating/cooling) and two plan types were considered (18 alternatives), while for the 60% and 100% glazed buildings only the plan type and the set points vary for the 7 alternatives (42 alternatives generated for the 60% and 42 alternatives for the 100% glazed building). The chosen orientation was northwest-southeast (short façade), called NS 45.

In order to study the impact of each orientation, plan type, set point or façade element on the building performance, one parameter at a time is changed and the rest remain the same. For example, if the impact of the control set points (strict, normal or poor) on the energy use is examined, then all the alternatives with the same interior plans and orientations will be compared with each other.

The performance parameters examined on a building level are the

- **Energy use** for
  - Heating
  - Cooling
  - Ventilation
  - Pumps, fans, etc
  - Lighting

- **Weighted (average mean monthly) air temperatures for the working area:** In each zone of the building the mean air temperature is calculated by IDA (for every hour). These results are used to calculate the average monthly mean air temperature for each zone. The weighted average mean air temperature is the sum of the mean air temperatures of each zone multiplied by the size and number of zones divided by the total floor area (excluding the corridors) as shown in equation 5.1.

$$T_{mean} = \frac{\sum \left(T_{mean,zone} \times A_{zone} \times N_{zones} \right)}{A_{total}}$$

Equation 5.1 Weighted Average Mean Air Temperature

where

$T_{mean,zone}$ is the monthly average zone temperature
A_{zone} is the zone area
N_{zones} is the number of the zones
A_{total} is the total floor area

The limitation of the weighted average mean monthly air temperatures is that no information is given as to the variation over time or space.

For the cell type office building, only the zones 1-10 were included in the calculations (offices and meeting rooms). The corridor (zone 11) was excluded since the impact on the occupants' comfort is limited. However, for the open plan type the whole area was considered for the calculations since all this area is used as working space. All the calculations (excluding those for energy and productivity) are made for a middle floor (in IDA described as B).

- **Number of hours between certain (weighted) average mean air temperatures for working space:** This output gives information similar to the weighted average mean air temperatures for the working area. However, this is more a quantitive indicator compared with the previous output since the previous one only gives monthly averages and does not provide any information concerning the variation of the indoor temperatures during the year.

- **Weighted average PMV**: As already described in Subsection 1.2.3, the Predicted Mean Vote is a qualitative indicator of the perception of thermal comfort. Likewise, the weighted average PMV is a monthly average PMV value of each occupant multiplied by the number of occupants in each zone and the number of the identical zones, divided by the total number of occupants. This factor can basically show whether or not the controls are proper for a certain occupancy, since it provides information for all the year.

- **Number of working hours for certain average PPD:** As already described in Subsection 1.2.3, the Predicted Percentage of Dissatisfied is more a quantitive indicator of the perception of thermal comfort. In a similar way **weighted average PPD** is the sum of the PPD of each occupant multiplied by the number of occupants in each zone and the number of the identical zones, divided by the total number of occupants.

  This output is more a quantitive indicator for the perception of thermal environment in the working space. Although it does not show whether the occupant feels warm or cold, it provides the necessary information to classify an indoor thermal environment, both on a zone and on a building level.

- **Productivity:** This parameter connects the perception of the indoor environment with the work efficiency of the occupants and possibly with the total economic value. Too high or too low air temperatures in a room result in production losses from the occupants. In ICE 3.0 a model for this according to Wyon, (2000) has been included. For mean air temperatures between 20 and 25°C no work is regarded as lost. Above and below these limits experiments show an average loss of 2% in performance per degree.

- **Indoor Air Quality:** The CO_2 content given in ppm (with respect to volume), and the relative humidity indicated in %, are shown. Since the indoor air quality does not change with the orientation or the controls, only basic models will be presented.

5.1.3 Parametric Studies on zone level

The parametric studies on a zone level concern only the cell type 30% and 100% glazed building. The large number of zones created for the simulation of the alternatives provides sufficient information regarding the following indicators mostly studied for this case:

- Number of hours between certain mean air temperatures for each zone
- Directed Operative temperatures for different zones
- Comparison between Directed Operative and Mean Air temperatures

- PMV and PPD
- Indoor Air Quality

5.2 Energy use

5.2.1 Energy use for the building alternatives

The energy use for space heating, cooling, lighting, pumps, fans and server rooms for the 30%, 60% and 100% glazed alternatives is presented in the Tables below.

Reference building alternatives

As stated above, 18 building alternatives were generated with 30% glazed area (2 plan types, 3 orientations and 3 control set points). The energy use for each simulated alternative is shown in Table 5.1.

Table 5.1 Energy use for the reference building alternatives.

	Energy use for heating (kWh/am^2)	Energy use for cooling (kWh/am^2)	Energy use for lighting (kWh/am^2)	Energy use for equipment (kWh/am^2)	Energy use for pumps, fans (kWh/am^2)	Energy use for server rooms (kWh/am^2)	Energy use for cooling server rooms (kWh/am^2)	Total (kWh/am^2)
SS-30%-Cell-NS-strict	56	21	14.7	22	8	10	5	**137**
SS-30%-Cell-NS-normal	52	11	14.4	22	8	10	5	**123**
SS-30%-Cell-NS-poor	47	7	14.2	22	8	10	5	**114**
SS-30%-Cell-NS45-strict	56	20	14.7	22	8	10	5	**136**
SS-30%-Cell-NS45-normal	52	11	14.4	22	8	10	5	**123**
SS-30%-Cell-NS45-poor	47	7	14.2	22	8	10	5	**114**
SS-30%-Cell-EW-strict	56	19	14.7	22	8	10	5	**136**
SS-30%-Cell-EW-normal	52	10	14.4	22	8	10	5	**122**
SS-30%-Cell-EW-poor	47	7	14.2	22	8	10	5	**113**
SS-30%-Open-NS-strict	50	29	19	21	6	13	6	**144**
SS-30%-Open-NS-normal	45	18	19	21	6	13	6	**127**
SS-30%-Open-NS-poor	38	11	19	21	6	13	6	**114**
SS-30%-Open-NS45-strict	50	29	19	21	6	13	6	**144**
SS-30%-Open-NS45-normal	45	17	19	21	6	13	6	**127**
SS-30%-Open-NS45-poor	38	10	19	21	6	13	6	**113**
SS-30%-Open-EW-strict	51	28	19	21	6	13	6	**143**
SS-30%-Open-EW-normal	45	16	19	21	6	13	6	**126**
SS-30%-Open-EW-poor	38	9	19	21	6	13	6	**112**

Where (a) is annual energy use

A brief parametric study of the reference building alternatives has been carried out for the northwest-southeast cell type building with normal set points generating 9 more alternatives. The parameters changed are set out in Table 5.2.

Table 5.2 Energy use for the reference building alternatives (parametric studies).

	Energy use for heating (kWh/am²)	Energy use for cooling (kWh/am²)	Energy use for lighting (kWh/am²)	Energy use for equipment (kWh/am²)	Energy use for pumps, fans (kWh/am²)	Energy use for server rooms (kWh/am²)	Energy use for cooling server rooms (kWh/am²)	Total (kWh/am²)
SS-30%-Cell-NS45-normal (Uwall 2.0)	47	12	14.4	22	8	10	5	**119**
SS-30%-Open-NS45-normal (Uwall 2.0)	41	19	19	21	6	13	6	**124**
SS-30%-Cell-NS45-normal (Uwall 4.0)	56	10	14.4	22	8	10	5	**126**
SS-30%-Open-NS45-normal (Uwall 4.0)	48	16	19	21	6	13	6	**129**
SS-30%-Cell-NS45-normal (Uwindow 1.5)	45	11	14.5	22	8	10	5	**116**
SS-30%-Open-NS45-normal (Uwindow 1.5)	38	18	19	21	6	13	6	**122**
SS-30%-Cell-NS45-normal (Uwindow 2.6)	61	9	14.5	22	8	10	5	**130**
SS-30%-Open-NS45-normal (Uwindow 2.6)	53	15	19	21	6	13	6	**132**
SS-30%-Cell-NS45-normal (hr50)	58	11	14.4	22	8	10	5	**128**
SS-30%-Open-NS45-normal (hr50)	49	17	19	21	6	13	6	**131**
SS-30%-Cell-NS45-normal (hr80)	42	11	14.4	22	8	10	5	**113**
SS-30%-Open-NS45-normal (hr80)	37	17	19	21	6	13	6	**119**

Where (a) is annual energy use

In the 1[st] alternative the thermal transmittance of the external walls (average) was reduced to 0.2 W/m^{2}K, while in the 2nd it was increased to 0.4 W/m^{2}K. In the 3[rd] alternative, the thermal transmittance of the widows was reduced to 1.5 W/m^{2}K, while in the 4[th] it was increased to 2.6 W/m^{2}K. The heat recovery of the 5[th] alternative was decreased to 50% and for the 6[th] one increased to 80%. In the 7[th] alternative the supply fan power was reduced from 2.8 kW/m^{3}s to 2 kW/m^{3}s while for the 8[th] one it was increased to 5 kW/m^{3}s.

60% glazed alternatives

In total, 42 alternatives were generated for the 60% glazed office building (7 windows and shading device types, 2 plan types and 3 control set points). The energy use for the 60% glazed alternatives is shown in Tables 5.3 and 5.4.

Table 5.3 Energy use for the 60% glazed alternatives (cell plan type).

	Energy use for heating (kWh/am^2)	Energy use for cooling (kWh/am^2)	Energy use for lighting (kWh/am^2)	Energy use for equipment (kWh/am^2)	Energy use for pumps, fans (kWh/am^2)	Energy use for server rooms (kWh/am^2)	Energy use for cooling server rooms (kWh/am^2)	Total (kWh/am^2)
SS-60%-Cell-NS45-strict (1)	76	31	14.7	22	8	10	5	**167**
SS-60%-Cell-NS45-strict (2)	54	36	14.7	22	8	10	5	**150**
SS-60%-Cell-NS45-strict (3)	58	28	14.7	22	8	10	5	**146**
SS-60%-Cell-NS45-strict (4)	59	22	14.7	22	8	10	5	**142**
SS-60%-Cell-NS45-strict (5)	53	48	14.7	22	8	10	5	**161**
SS-60%-Cell-NS45-strict (6)	58	27	14.7	22	8	10	5	**145**
SS-60%-Cell-NS45-strict (7)	62	14	14.7	22	8	10	5	**137**
SS-60%-Cell-NS45-normal (1)	72	20	13.4	22	8	10	5	**151**
SS-60%-Cell-NS45-normal (2)	50	24	13.8	22	8	10	5	**133**
SS-60%-Cell-NS45-normal (3)	54	18	14.2	22	8	10	5	**131**
SS-60%-Cell-NS45-normal (4)	55	13	14.4	22	8	10	5	**129**
SS-60%-Cell-NS45-normal (5)	48	36	13.8	22	8	10	5	**143**
SS-60%-Cell-NS45-normal (6)	54	16	14.2	22	8	10	5	**130**
SS-60%-Cell-NS45-normal (7)	59	7	14.4	22	8	10	5	**126**
SS-60%-Cell-NS45-poor (1)	66	14	13.2	22	8	10	5	**138**
SS-60%-Cell-NS45-poor (2)	44	17	13.7	22	8	10	5	**120**
SS-60%-Cell-NS45-poor (3)	48	12	14.1	22	8	10	5	**120**
SS-60%-Cell-NS45-poor (4)	50	9	14.3	22	8	10	5	**118**
SS-60%-Cell-NS45-poor (5)	43	28	13.6	22	8	10	5	**130**
SS-60%-Cell-NS45-poor (6)	48	12	14.2	22	8	10	5	**119**
SS-60%-Cell-NS45-poor (7)	53	5	14.4	22	8	10	5	**118**

Where (a) is annual energy use

Table 5.4 Energy use for the 60% glazed alternatives (open plan type).

	Energy use for heating (kWh/am^2)	Energy use for cooling (kWh/am^2)	Energy use for lighting (kWh/am^2)	Energy use for equipment (kWh/am^2)	Energy use for pumps, fans (kWh/am^2)	Energy use for server rooms (kWh/am^2)	Energy use for cooling server rooms (kWh/am^2)	Total (kWh/am^2)
SS-60%-Open-NS45-strict (1)	70	38	19	21	6	13	6	**172**
SS-60%-Open-NS45-strict (2)	49	44	19	21	6	13	6	**157**
SS-60%-Open-NS45-strict (3)	52	34	19	21	6	13	6	**151**
SS-60%-Open-NS45-strict (4)	53	29	19	21	6	13	6	**147**
SS-60%-Open-NS45-strict (5)	47	54	19	21	6	13	6	**166**
SS-60%-Open-NS45-strict (6)	52	33	19	21	6	13	6	**150**
SS-60%-Open-NS45-strict (7)	56	21	19	21	6	13	6	**142**
SS-60%-Open-NS45-normal (1)	65	26	19	21	6	13	6	**156**
SS-60%-Open-NS45-normal (2)	43	31	19	21	6	13	6	**139**
SS-60%-Open-NS45-normal (3)	46	22	19	21	6	13	6	**133**
SS-60%-Open-NS45-normal (4)	48	17	19	21	6	13	6	**130**
SS-60%-Open-NS45-normal (5)	42	41	19	21	6	13	6	**148**
SS-60%-Open-NS45-normal (6)	47	21	19	21	6	13	6	**132**
SS-60%-Open-NS45-normal (7)	50	10	19	21	6	13	6	**125**
SS-60%-Open-NS45-poor (1)	57	18	19	21	6	13	6	**139**
SS-60%-Open-NS45-poor (2)	36	22	19	21	6	13	6	**123**
SS-60%-Open-NS45-poor (3)	39	17	19	21	6	13	6	**120**
SS-60%-Open-NS45-poor (4)	41	10	19	21	6	13	6	**116**
SS-60%-Open-NS45-poor (5)	35	31	19	21	6	13	6	**131**
SS-60%-Open-NS45-poor (6)	39	15	19	21	6	13	6	**119**
SS-60%-Open-NS45-poor (7)	43	6	19	21	6	13	6	**113**

Where (a) is annual energy use

100% glazed alternatives

The same number of alternatives as for the 60% buildings was generated for the 100% glazed office buildings. The energy use for these alternatives is shown in Tables 5.5 and 5.6.

Table 5.5 Energy use for the 100% glazed alternatives (cell plan type).

	Energy use for heating (kWh/am^2)	Energy use for cooling (kWh/am^2)	Energy use for lighting (kWh/am^2)	Energy use for equipment (kWh/am^2)	Energy use for pumps, fans (kWh/am^2)	Energy use for server rooms (kWh/am^2)	Energy use for cooling server rooms (kWh/am^2)	Total (kWh/am^2)
SS-100%-Cell-NS45-strict (1)	95	43	14.7	22	8	10	5	**198**
SS-100%-Cell-NS45-strict (2)	63	50	14.7	22	8	10	5	**173**
SS-100%-Cell-NS45-strict (3)	69	37	14.7	22	8	10	5	**166**
SS-100%-Cell-NS-strict (3)	69	38	14.7	22	8	10	5	**168**
SS-100%-Cell-EW-strict (3)	69	34	14.7	22	8	10	5	**164**
SS-100%-Cell-NS45-strict (4)	71	29	14.7	22	8	10	5	**160**
SS-100%-Cell-NS45-strict (5)	62	67	14.7	22	8	10	5	**189**
SS-100%-Cell-NS45-strict (6)	69	35	14.7	22	8	10	5	**164**
SS-100%-Cell-NS45-strict (7)	75	16	14.7	22	8	10	5	**151**
SS-100%-Cell-NS45-normal (1)	92	30	12.9	22	8	10	5	**180**
SS-100%-Cell-NS45-normal (2)	59	37	13.5	22	8	10	5	**155**
SS-100%-Cell-NS45-normal (3)	65	27	14.0	22	8	10	5	**151**
SS-100%-Cell-NS-normal (3)	66	28	13.9	22	8	10	5	**153**
SS-100%-Cell-EW-normal (3)	66	24	14.0	22	8	10	5	**149**
SS-100%-Cell-NS45-normal (4)	68	19	14.2	22	8	10	5	**147**
SS-100%-Cell-NS45-normal (5)	58	54	13.4	22	8	10	5	**170**
SS-100%-Cell-NS45-normal (6)	66	24	13.9	22	8	10	5	**149**
SS-100%-Cell-NS45-normal (7)	72	9	14.3	22	8	10	5	**141**
SS-100%-Cell-NS45-poor (1)	84	22	12.7	22	8	10	5	**164**
SS-100%-Cell-NS45-poor (2)	53	28	13.3	22	8	10	5	**140**
SS-100%-Cell-NS45-poor (3)	59	20	13.8	22	8	10	5	**138**
SS-100%-Cell-NS45-poor (4)	61	13	14.1	22	8	10	5	**134**
SS-100%-Cell-NS45-poor (5)	52	44	13.2	22	8	10	5	**154**
SS-100%-Cell-NS45-poor (6)	59	17	13.7	22	8	10	5	**136**
SS-100%-Cell-NS45-poor (7)	66	6	14.2	22	8	10	5	**131**

Where (a) is annual energy use

Table 5.6 Energy use for the 100% glazed alternatives (open plan type).

	Energy use for heating (kWh/am^2)	Energy use for cooling (kWh/am^2)	Energy use for lighting (kWh/am^2)	Energy use for equipment (kWh/am^2)	Energy use for pumps, fans (kWh/am^2)	Energy use for server rooms (kWh/am^2)	Energy use for cooling server rooms (kWh/am^2)	Total (kWh/am^2)
SS-100%-Open-NS45-strict (1)	86	48	19	21	6	13	6	**199**
SS-100%-Open-NS45-strict (2)	58	56	19	21	6	13	6	**179**
SS-100%-Open-NS45-strict (3)	63	41	19	21	6	13	6	**169**
SS-100%-Open-NS45-strict (4)	64	33	19	21	6	13	6	**162**
SS-100%-Open-NS45-strict (5)	56	71	19	21	6	13	6	**193**
SS-100%-Open-NS45-strict (6)	63	39	19	21	6	13	6	**167**
SS-100%-Open-NS45-strict (7)	68	21	19	21	6	13	6	**154**
SS-100%-Open-NS45-normal (1)	82	36	19	21	6	13	6	**183**
SS-100%-Open-NS45-normal (2)	53	44	19	21	6	13	6	**161**
SS-100%-Open-NS45-normal (3)	58	30	19	21	6	13	6	**152**
SS-100%-Open-NS45-normal (4)	59	22	19	21	6	13	6	**146**
SS-100%-Open-NS45-normal (5)	51	58	19	21	6	13	6	**174**
SS-100%-Open-NS45-normal (6)	58	27	19	21	6	13	6	**150**
SS-100%-Open-NS45-normal (7)	63	11	19	21	6	13	6	**140**
SS-100%-Open-NS45-poor (1)	75	27	19	21	6	13	6	**167**
SS-100%-Open-NS45-poor (2)	45	34	19	21	6	13	6	**144**
SS-100%-Open-NS45-poor (3)	51	21	19	21	6	13	6	**136**
SS-100%-Open-NS45-poor (4)	52	15	19	21	6	13	6	**132**
SS-100%-Open-NS45-poor (5)	44	47	19	21	6	13	6	**157**
SS-100%-Open-NS45-poor (6)	51	19	19	21	6	13	6	**135**
SS-100%-Open-NS45-poor (7)	56	6	19	21	6	13	6	**127**

Where (a) is annual energy use

Alternatives with increased heating and cooling capacity

For the first 100% glazed alternative the high thermal transmittance of the windows results in insufficient heating capacity. As a result, during 7% to 11% of working hours (depending on the set point and the plan type) the air temperatures exceed the set point limits. The opposite problem (insufficient cooling demand) is noticed in the fifth alternative (mostly in the cell type) due to the high solar factor (and also $g_{effective}$) of the window. These 9 extreme cases were simulated again with increased heating and cooling capacity in order to determine the energy use for keeping the air temperature within the set point limits in the working areas. However, since the original reference building was designed with a certain heating and cooling capacity, the parametric studies are carried out considering the original alternatives. In the cases where the cooling or heating capacity is insufficient, the PPD values are increasing due to the low or high temperatures respectively. Furthermore, on the zone level, the thermal discomfort problems are pointed out in the zones where they occur (e.g. the overheating problems are more probable in the corner offices due to the higher glazed area to office volume ratio. In Table 5.7 the energy use for alternatives with increased heating and cooling capacity is presented.

Table 5.7 Energy use for the 1st and 5th (cell type) 100% glazed alternatives (increased heating and cooling capacity).

	Energy use for heating (kWh/am^2)	Energy use for cooling (kWh/am^2)	Energy use for lighting (kWh/am^2)	Energy use for equipment (kWh/am^2)	Energy use for pumps, fans (kWh/am^2)	Energy use for server rooms (kWh/am^2)	Energy use for cooling server rooms (kWh/am^2)	Total (kWh/am^2)
SS-100%-Cell-NS45-strict (1-cor)	99	43	14.7	22	8	10	5	**202**
SS-100%-Cell-NS45-normal (1-cor)	95	31	12.9	22	8	10	5	**184**
SS-100%-Cell-NS45-poor (1-cor)	87	22	12.7	22	8	10	5	**167**
SS-100%-Open-NS45-strict (1-cor)	90	48	19.0	21	6	13	6	**203**
SS-100%-Open-NS45-normal (1-cor)	85	36	19.0	21	6	13	6	**186**
SS-100%-Open-NS45-poor (1-cor)	77	27	19.0	21	6	13	6	**168**
SS-100%-Cell-NS45-strict (5-cor)	62	68	14.7	22	8	10	5	**190**
SS-100%-Cell-NS45-normal (5-cor)	58	55	13.4	22	8	10	5	**171**
SS-100%-Cell-NS45-poor (5-cor)	52	45	13.2	22	8	10	5	**155**

Where (a) is annual energy use

5.2.2 Impact of floor plan type

In order to study the impact of the floor plan type on the energy use, the 30% glazed alternatives were studied. The impact of plan type on the total energy use for 60% and 100% glazed alternatives is briefly discussed at the end of this section.

In order to study the influence of plan type on energy use, 30% glazed alternatives with the same control set points and orientations should be compared. This would give 9 different comparisons. However, as shown in Tables 5.1 and 5.2, the building's orientation does not really influence its energy use, either for the cell or the open plan type. Thus, in order to decrease the number of comparisons, an average energy use was assumed for the 3 building orientations. The energy use for the normal control for the cell and open plan type is shown in Figure 5.1. Due to the higher internal loads caused by the higher occupant density and the set points and power for the lights (6 W/m^2 for the corridors of the cell type and 12 W/m^2 for all the open plan space) the energy use for heating the open plan type is slightly lower than for the cell type. For the same reason, the cooling demand of the building and the server rooms is higher on the open plan (the energy demand for the operation and cooling of the server rooms is proportional to the number of occupants). As described in chapter four, for the normal set points (cell type) the lights were switched on in order to assure a minimum level of 500 lux at the workplace while for the open plan the lights are always switched on (since IDA can not handle any set point for artificial lighting in the non rectangular zones of the open plan type). Additionally, power of 12 W/m^2 was assumed for the working spaces (offices and meeting rooms for the cell type and the whole space of the open plan) while power of 6 W/m^2 was assumed for the corridor of the cell type). Thus the energy use for lighting of the open plan is 5 kWh/am^2 higher as shown in Figure 5.1. Although the open plan is denser and one would assume that the energy use for the equipment should be higher, the larger number of meeting rooms of the open plan reduces the number of printers and faxes, bringing the internal loads (equipment) of the two layouts to almost the same level.

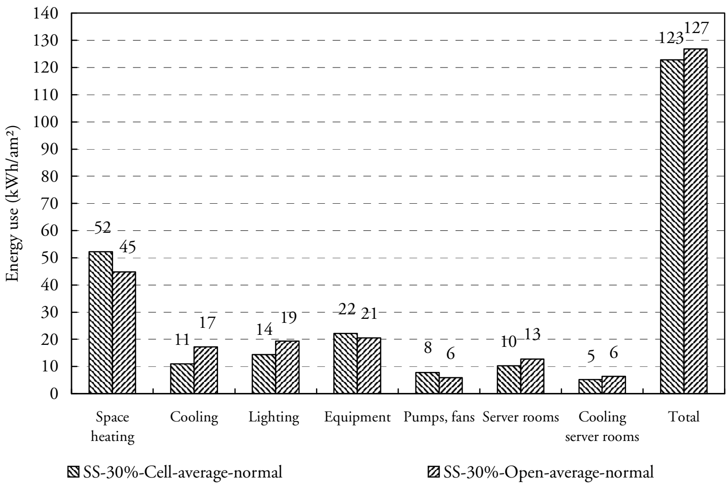


Figure 5.1 *Impact of plan type on the energy use of the reference building (normal control set points).*

In Figure 5.2, the difference in energy use for heating, cooling and lighting the reference building is compared between the two plan types for the three control set points. The energy use for heating the cell type office building (with strict set point) is 10% higher than for the open plan one. The increase in energy use for the normal and poor control is 14% and 19% respectively. As the allowed temperature variation gets wider (due to the different control set point strategy), there is a higher use of the thermal mass. As a result, the difference in the heating demand for the two plan types increases for "less strict" set points. The positive value in Figure 5.2 shows higher energy use for the cell plan. As expected, in all the cases the energy use for heating is higher for the cell type due to the lower internal gains.

On the contrary, the cooling demand of the open plan type is much higher (41.6%, 56.3%, and 47.8%) due to the higher internal gains and the different ventilation strategy. As described in chapter four, the air supplied to the offices (cell type) passes through the doors (or leaks) to the corridor from where it is extracted, while for the open plan type the air is supplied and exhausted from the same zone. Since in the cell type office building there are no cooling beams installed in the corridor, the air temperature in the corridor at times rises above the upper control set point limit. This may cause an increase in the air temperature in the corridors, but since there are no occupants (used as sensors) placed in that zone of the cell type, no discomfort is considered. On the other hand, for the open plan type building, the whole floor area is considered as working area and thus cooled according to the upper set point temperature limit.

The corridor of the cell type is almost 44% of the total floor area and the rated input per unit (light) is 6 W/m^2 instead of 12 W/m^2 (open plan and working spaces of cell plan). For the strict set points the lights are assumed switched on during the working hours both for the cell and open plan type. However, the increased demand for proper lighting of the working area results in a 32% increase in energy use. For the normal and poor control this difference increases even more, up to 35% and 36% respectively due to the control set points (500 lux and 300 lux) applied for the offices and meeting rooms of the cell plan.

Finally, there is a 24% higher energy demand for the operation and cooling of the server rooms (regardless of the set point) for the open plan due to the increased number of occupants (the assumed energy use is 175 kWh/am^2 per occupant for the server rooms and 87.5 kWh/am^2 per occupant for cooling the server rooms).

The total energy use for the strict set point is 6% higher in the open plan than in the cell type. For the normal set point the difference decreases by up to 3%. For the poor set point, however, the cell plan uses slightly less energy as shown in Figure 5.4. As expected, the stricter the set points, the higher the impact of the plan type on the energy use.

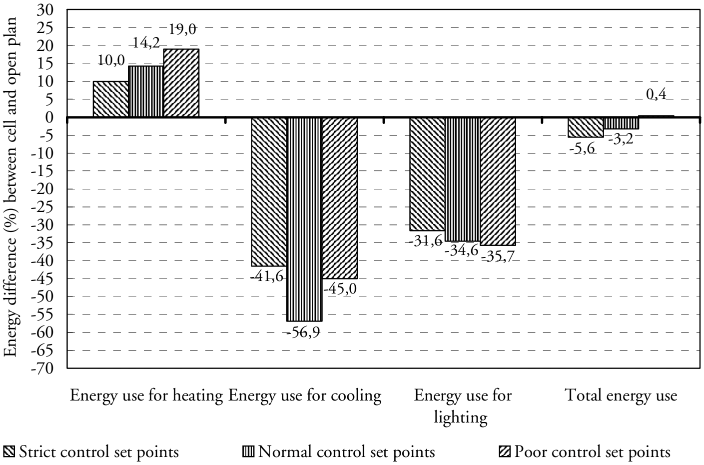


Figure 5.2 Impact of the plan type on the energy use of the reference building.

For the 60% and 100% glazed alternatives the impact of plan type on the energy use for heating and cooling is similar to that of the reference building (higher heating demand for the cell type and higher cooling demand for the open type). The energy use for lighting depends on the solar factor of the window system (with and without the use of the shading devices); usually the lower the g values, the higher the energy demand for artificial lighting.

The difference in total energy use between the two plan types depends mostly on the difference in the cooling demand. As shown in Figure 5.3, for the strict set points the low upper allowed temperature limit of 23°C combined with narrow allowed air temperature variation increases the impact of plan type on the energy use regardless of the window type. However, when the upper set point increases to 24.5°C the difference in energy use of cell and open plan alternatives decreases in proportion to the cooling demand of each alternative (the cell type uses less energy in all the alternatives except the 7th). The wider allowed variation of the poor set points (21°-26°C) allows the open plan to use less energy than the cell type due to the dramatic decrease in cooling demand. The impact of plan type in this case is the opposite to that of the normal set points, since the cell type alternatives with lower cooling demands seem to require a higher total energy use. Thus, it is obvious that the energy efficiency of different plan types depends both on the building envelope performance (e.g. windows and shading devices used) and on the control set points. The 5th alternative however demands less energy use than the second one regardless of the control set point. This can be explained by the insufficient cooling capacity of the cooling beams (mostly for the corner offices). Proper combination of set points and window selection can improve the energy efficiency for a certain plan type.

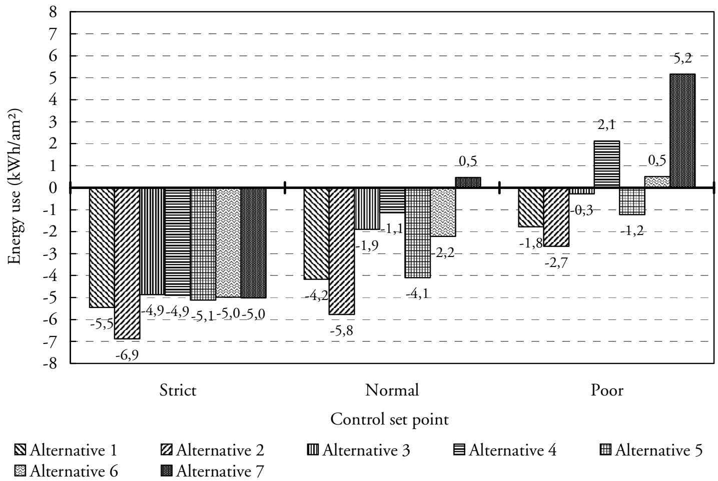


Figure 5.3 *Impact (difference between cell and open types) of plan type on the total energy use of 60% glazed alternatives with different window types.*

5.2.3 Impact of the orientation

As pointed out above, the orientation has a very small impact on the energy use of the reference building. However, the EW alternatives (short façades facing east and west) require slightly less energy (H”0.1%). The stricter the control set points, the smaller is the difference between the orientations. The difference in the energy use for the north south and east west oriented 100% glazed alternatives (3) increases to 3%. Due to the small impact of the orientation on the total energy use of the building, no further study of the influence of orientation on the total energy use has been made on a building level.

5.2.4 Impact of the control set points

Since the orientation of the reference building does not really affect the total energy use, an average use for the three orientations was assumed. As can be expected, for the cell type office building the energy use for heating decreases by 7% for the normal and by 16% for the poor control set point (compared with the strict one) as shown in Figure 5.4. For the open plan type the heating demand decreases by 11% and 24%. Although the minimum temperature limit is the same for the strict and normal control set points (22ºC), the strict set points reduce the capacity for storing heat (thermal mass), increasing the heating demand. The thermal mass is not really exposed to the inside air in the building, due to the suspended ceiling and the flooring.

For the normal control set points the maximum allowed temperature is 24.5°C while for the strict and poor set points it is 23°C and 26°C respectively. The cooling demand for the normal (compared with the strict) set point is 45.5% lower for the cell type and 39% lower for the open plan type. The decrease for the poor type reaches 65.3% and 64.5% respectively.

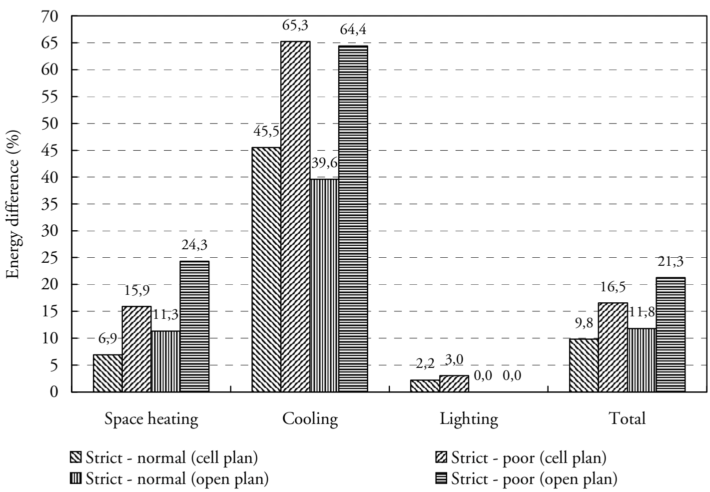


Figure 5.4 Impact of control set points on the energy use of the reference building.

The minimum limit of 500 lux and 300 lux applied for the normal and poor set points results in an almost negligible decrease in the energy use for lighting, 2% and 3% for the two control set points for the cell type plan. The impact of different control set points on the energy use for lighting should be calculated only for the working spaces (excluding the corridors) of the cell type building since it is only in this area that the set points were applied. Thus, out of 14.7 kWh/am^2 (total energy use for the strict control) 10.5 kWh/am^2 (71.8%) are used in the working areas and 4.2 kWh/m^{2}a (28.2%) in the common spaces. For the normal set points the energy reduction (0.3 kWh/am^2) refers only to the working areas, so the energy use is reduced for this control to10.2 kWh/am^2, and to 10 kWh/am^2 for the poor set points. For the open plan type, the lights were assumed switched on during the working hours for all the three types of control set points, thus the energy use remains the same. The conclusion is that the three different lighting strategies (for the reference building alternatives) result in small differences in energy use for lighting.

Finally, as can be expected, the total energy use is lower for alternatives with less strict control set points. The total energy use of the cell type reference building decreases by 10% for the normal and 17% for the poor set point, compared with the strict control set points. For the open plan type, the decrease is 11.8% and 21.3% respectively.

5.2.5 Impact of windows and shading devices for the 60% and 100% glazed alternatives

A comparison (in terms of energy use) of 60% and 100% glazed alternatives with different windows and shading devices applied is presented below. In order to reduce the amount of information, only cell type offices were studied.

The first (60% and 100%) glazed alternatives have a triple clear pane window (U_{window} of 1.97 W/m^{2}K, see Subsection 4.2.2 window properties). When the thermal transmittance of the windows (U_{window} = 1.27 W/m^{2}K) in the second alternative is reduced, the total energy use of the 60% glazed buildings decreases 10% for the strict, 12% for the normal and 13% for the poor control set point (see figure 5.5). The decrease in energy use for the 100% glazing alternatives is higher (12%, 14% and 25% respectively for the three set points).

For the second (60% glazed) alternative the energy use for heating is reduced dramatically, since the decrease is as much as 31% for the normal set point (29% and 33% for the strict and poor set points). The decrease in energy for the 100% glazed alternative is slightly higher (35%, 33% and 37% respectively). The reduced thermal transmittance of the window causes a 20% increase in cooling demand for the normal, 16% for the strict and 27% for the poor control set points (for the 60% glazed alternatives). The increase in energy use for cooling is slightly higher for the 100% glazed alternatives (22%, 17% and 30% respectively for the three set points).

The energy use for lighting in the 60% glazed offices increases in the second alternative due to the lower solar transmittance (T_{sol}). For the strict set point the energy use for lighting is the same since the lights are switched on according to the occupants' schedule. However, when a set point of 500 lux at the desktop (normal set point), is applied the energy use for lighting is 4% higher for the second alternative. For a set point of 300 lux (poor set point) the increase is as much as 5%. For the 100% glazed alternatives the energy use for lighting increases by 4% and 5% respectively.

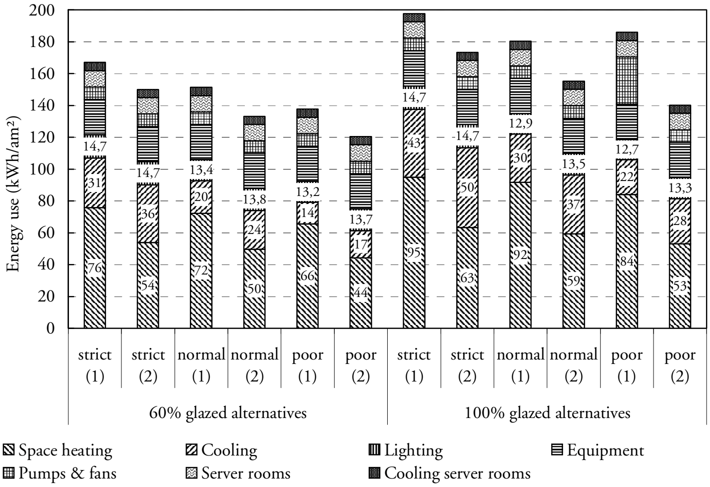


Figure 5.5 *Comparison of energy use for the 1st and 2nd glazed alternatives (cell type).*

In the third alternative the triple glazing is replaced by double glazing with a lower solar factor ($g = 0.354$ instead of $g = 0.584$). The intermediate venetian blinds ($g_{effective} = 0.225$) are also replaced by internal ones ($g_{effective} = 0.276$). The total energy use for the 60% glazed buildings is almost the same, the additional reduction is only 3% for the strict, 1% for the normal and 0.4% for the poor control set point of the third alternative (see Figure 5.6). The decrease in energy use for the 100% glazing alternatives is higher (4%, 4% and 2% respectively for the three set points).

For the third alternative the energy use for heating increases (by 6%, 6% and 9% for the three set points of the 60% glazed alternatives and by 9%, 10%, and 11% for the three set points of the 100% glazed alternatives) due to the lower solar factor. For the same reason cooling demand drops by 22% 26% and 29% for the three set points of the 60% glazed alternative and by 25%, 28% and 31% for the 100% glazed ones, i.e. to cooling demands somewhat lower than the first alternative.

The energy use for lighting in the 60% glazed offices increases in the third alternative due to the lower solar transmittance (T_{sol}). For the set points of 500 lux and 300 lux the energy use for lighting is 3% higher for the third alternative. For the 100% glazed alternatives the energy use for lighting increases by 4% for both set points.

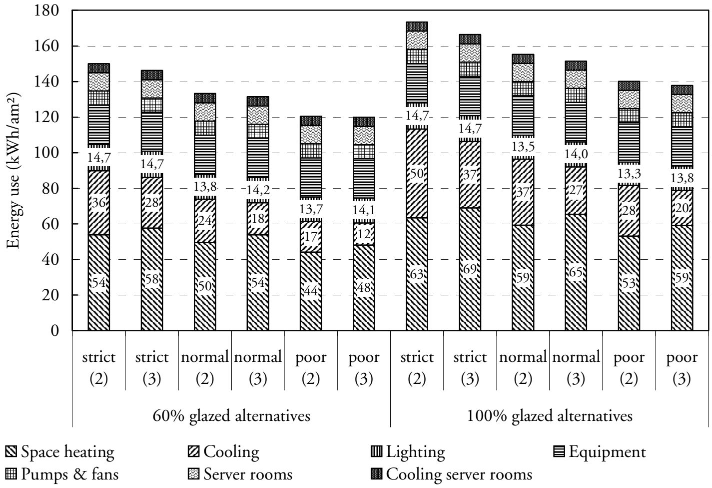


Figure 5.6 *Comparison of the energy use for the 2nd and 3rd glazed alternatives (cell type).*

In the fourth alternative the double glazing is replaced by one with a lower solar factor (g = 0.227 instead of g = 0.354). The total energy use for the 60% glazed buildings is reduced very little, by 3% for the strict, 2% for the normal and 1% for the poor control set point of the third alternative as shown in Figure 5.7. The decrease in energy use for the 100% glazing alternatives is higher (4%, 3% and 3% respectively for the three set points).

The energy use for heating the 60% glazed buildings increases by 3% for all the three control set points of the fourth alternative. The increase in energy use is the same for the 100% glazing alternatives for the three set points. The cooling demand drops by 21%, 26% and 29% for the three set points of the 60% glazed alternative and by 22%, 27% and 31% for the 100% glazed ones.

The energy use for lighting the 60% glazed offices increases in the third alternative due to the lower solar transmittance (T_{sol}). For the set points of 500 lux and 300 lux the energy use for lighting is 1% higher for the third alternative. For the 100% glazed alternatives the energy use for lighting increases by 2% for both set points.

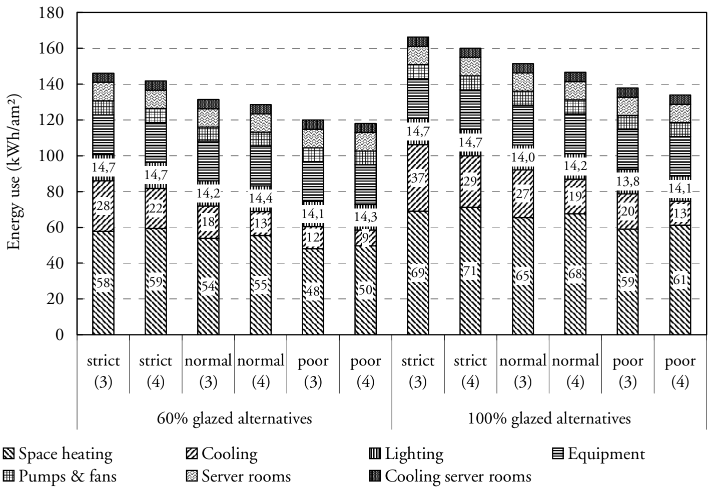


Figure 5.7 *Comparison of energy use for the 3rd and 4th glazed alternatives (cell type).*

In the fifth alternative the double glazing is replaced by one with a solar factor higher than in the third alternative ($g = 0.584$ instead of $g = 0.354$). The total energy use for the 60% glazed buildings increases by 10% for the strict, 9% for the normal and 10% for the poor control set points of the fifth alternative as shown in Figure 5.8. The increase in energy use for the 100% glazing alternatives is higher (13%, 12% and 15% respectively for the three set points).

The energy use for heating the 60% glazed buildings decreases by 9% for the strict, 10% for the normal and 13% for the poor control set points of the fifth alternative due to the higher solar factor. The reduction in energy use for the 100% glazing alternatives for the three set points is 11%, 12% and 16%. The cooling demand in this case increases dramatically by up to 69%, 99% and 217% for the three set points of the 60% glazed alternative and by 80%, 102% and 230% for the 100% glazed ones.

The energy use for lighting the 60% glazed offices decreases in the third alternative due to the high solar transmittance (T_{sol}). For the set points of 500 lux and 300 lux the energy use for lighting is 3% and 5% higher for the third alternative. For the 100% glazed alternatives the energy use for lighting increases by 4% and 6% for the two set points.

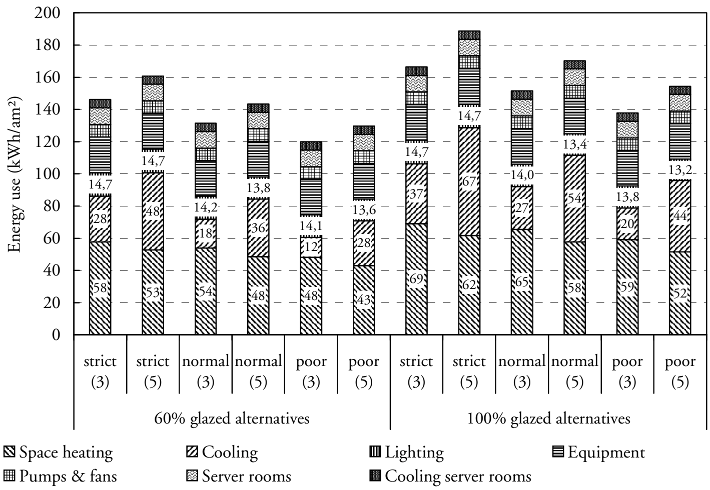


Figure 5.8 *Comparison of energy use for the 3rd and 5th glazed alternatives (cell type).*

The glazing and frame properties of the second and fifth alternative are the same. The only difference between these two alternatives is the position of the shading devices. When the venetian blinds are placed in between the panes the solar factor of the system (window and shading device) is much lower than when they are internal ($g_{effective}$ = 0.225 instead of $g_{effective}$ = 0.469). The total energy use for the 60% glazed buildings increases by 7% for the strict, 8% for the normal and 8% for the poor control set points of the fifth alternative as shown in Figure 5.9. The increase in energy use for the 100% glazing alternatives is higher (9%, 10% and 10% respectively for the three set points).

Since the shading devices are not often used during the heating period, the higher $g_{effective}$ of the fifth alternative has a limited impact on the heating demand. The energy use for heating the 60% glazed buildings is almost the same for the second and fifth alternative. The reduction in energy use for the 100% glazing alternatives for all the three set points is 3%. During the cooling periods, however, the cooling demand of the fifth alternative increases dramatically since the venetian blinds are used more often (so the solar factor of the fifth alternative is higher). The increase is as much as 33%, 47% and 62% for the three set points of the 60% glazed alternative and 34%, 45% and 45% for the 100% glazed ones.

The energy use for lighting the 60% and 100% glazed offices is almost the same due to the similar solar transmittance (T_{sol}) of the two alternatives.

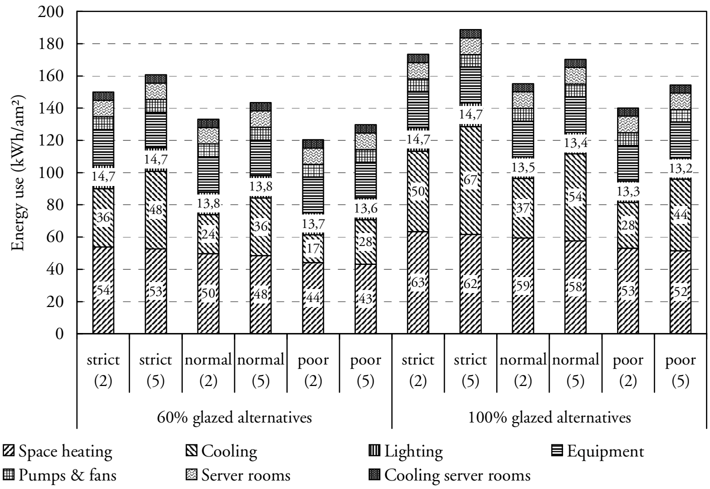


Figure 5.9 *Comparison of energy use for the 2nd and 5th glazed alternatives (cell type).*

In the sixth alternative internal screens were applied. When this is compared with the third alternative (same window with internal blinds), the effective solar factor and solar transmittance are slightly lower for the case with internal blinds. This results in a small reduction in energy use for cooling and it does not much affect the heating demand since the shading devices are used mostly during the cooling seasons. In Figure 5.10 a comparison of the energy use for the third and sixth alternative is presented.

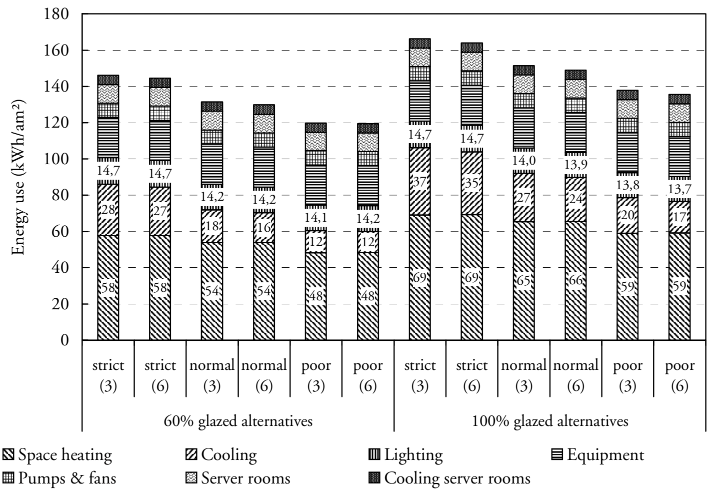


Figure 5.10 *Comparison of energy use for the 3rd and 6th glazed alternatives (cell type).*

In the seventh alternative the internal blinds of the third alternative are replaced by fixed external louvres (with lower solar factor). The energy use for heating the 60% glazed buildings increases by 8% for the strict, 9% for the normal and 11% for the poor control set point of the seventh alternative as shown in Figure 5.11. The increase in energy use for the 100% glazing alternatives is 9%, 11% and 11% respectively for the three set points. The cooling demand drops by 49%, 60% and 59% for the three set points of the seventh 60% glazed alternative and by 57%, 66% and 69% for the 100% glazed ones.

The total energy use for the 60% glazed buildings decreases by 6%, 4% and 2% for the three set points of the seventh alternative. The decrease in energy use of the seventh 100% glazed alternatives is 9%, 7% and 5% respectively.

The energy use for lighting the 60% glazed offices is only slightly higher in the seventh alternative, since the shading devices are applied throughout the year. For the set points of 500lux and 300lux the energy use for lighting is 1% and 2% higher for the third alternative. For the 100% glazed alternatives the energy use for lighting is 2% and 3% for the two set points.

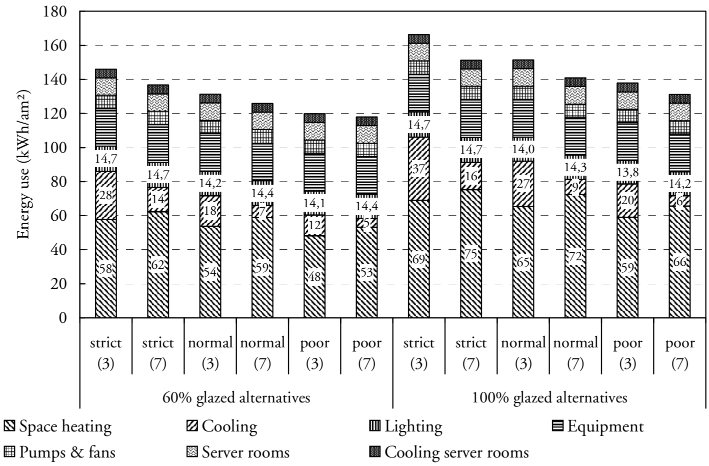


Figure 5.11 *Comparison of energy use for the 3rd and 7th glazed alternatives (cell type).*

5.3 Indoor climate on a building level

5.3.1 Weighted average mean air temperatures

In order to study the impact of control set points, orientation and plan type on the weighted average air temperature, different reference building alternatives were considered. For parametric studies concerning the impact of window and shading device type on the average air temperature, 100% alternatives with normal control set points were also compared.

As can be expected, control set points have a high influence (compared with the orientation and plan types) on the mean air temperatures of the working area of the reference building. As shown in Figure 5.12, the temperature difference between the cell and open plan type of the reference building is very small for strict set points and it increases as the allowed temperature variation (normal and poor set points) increases. As expected, the open plan type is warmer due to the higher internal loads.

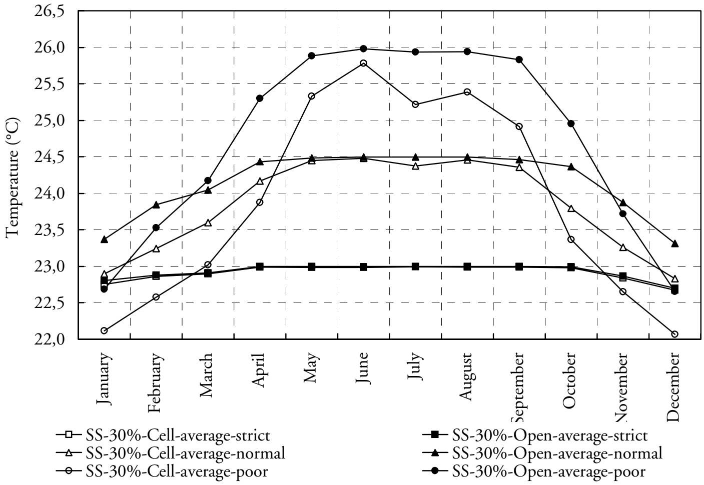


Figure 5.12 *Weighted average mean air temperatures for the working area of the reference building.*

For the normal control set point the maximum allowed temperature (24.5°C) results in higher temperature differences during February (0.6°C) while the poor set point (26°C) results in higher differences during April (1.4°C). In the same way the minimum allowed temperature of 21°C of the poor set points instead of 22°C of the normal one results in bigger temperature differences earlier (during October instead of November).

As already pointed out in Subsection 5.2.3, the building orientation has a minor influence on the weighted average indoor temperature of the building. Although the average air temperature is a good indicator to study the impact of set points or plan type on the building performance, it does not provide any information about minimum and maximum temperatures in individual zones. Thus, two zones with different orientations with mean air temperatures outside the allowed temperature variation of the strict set points (e.g. 21°C and 24°C for the corner office rooms facing north and south) can give an acceptable average air temperature of 23°C. For this reason, the impact of orientation on the indoor temperature will be described further on a zone level.

In Figure 5.13 the weighted average air temperature of the reference building with three different orientations is presented.

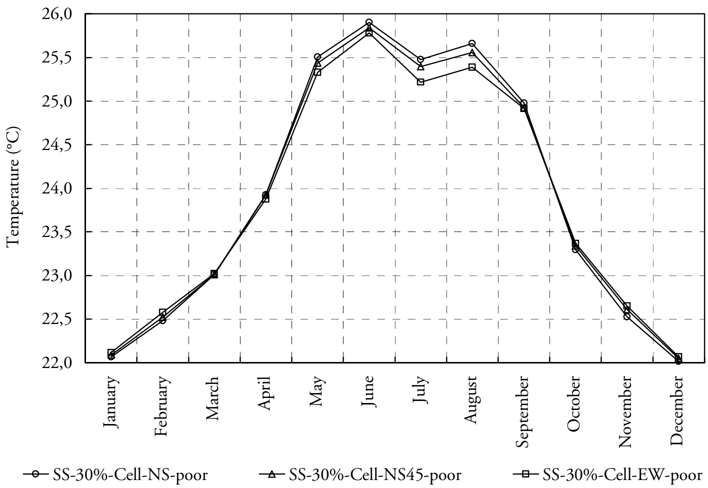


Figure 5.13 *Impact of the orientation on the indoor climate (cell type, poor control set points).*

The diagrams above are a good indicator of the average temperature variation during the year. However, they do not provide any information concerning the number of hours with a certain temperature variation. Therefore the number of hours between certain (weighted) average mean air temperatures for the working space of the reference building (for the cell and open plan and for the three control set points) is presented below.

The open plan office building (normal control set point) is warmer than the cell type one as shown in Figure 5.14. The number of hours close to the upper allowed temperature limit is as high as 45% for the cell and 70% for the open plan type i.e. potential overheating.

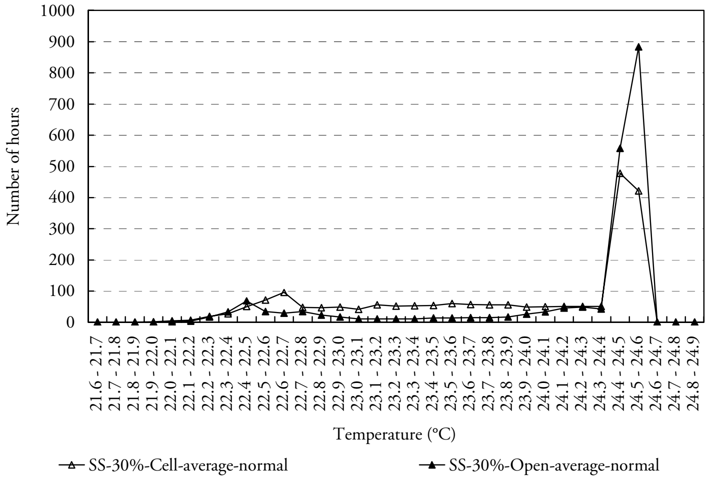


Figure 5.14 *Number of hours with certain average weighted air temperatures (normal control set points, reference building).*

For the poor control set points only 18% of the working hours are close to the upper limit for the cell and 44% for the open plan type. The number of hours close to the upper allowed limit is a good indicator of the potential overheating problem. The number of hours between air temperatures for the three control set points of the cell type office plan is shown in the Figure 5.15.

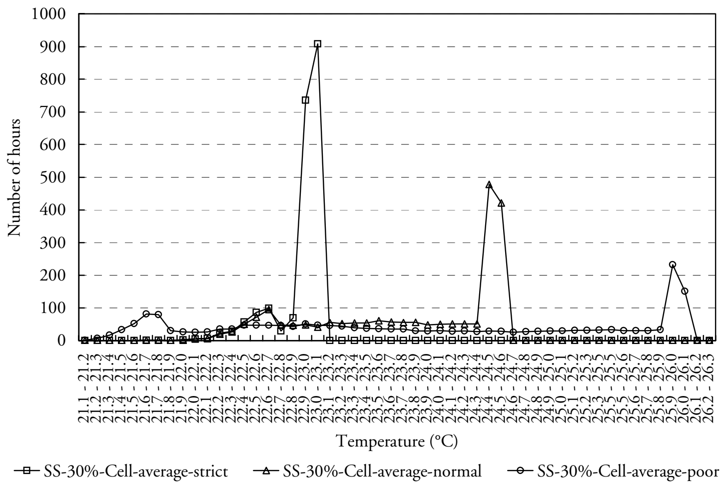


Figure 5.15 *Number of hours with certain average weighted air temperature for the reference building (cell type).*

Although the variation in the air temperature of the reference building greatly depends on the set point applied in each case, the increase in the glazing area (in the 60% and 100% glazed alternatives) results in an increase in the potential number of hours outside the allowed temperature limits, because of insufficient heating and/or cooling capacity, which may occur in highly glazed buildings (this can be the case when in buildings with typical HVAC installations the choice of glazing was not studied properly). In most of the cases the number of working hours exceeding the temperature limits is lower than 5%. For the first 100% glazed alternative, however, the temperatures are lower for almost 10% of the working hours due to the high thermal transmittance of the windows. The opposite problem (high air temperatures) occurs in the fifth alternative due to the increased g and $g_{effective}$ values of the window. In Figure 5.16 the average air temperature of the first and fifth alternative are compared. The temperature difference between these two cases is obvious, with the fifth one exceeding the upper temperature limit during the summer months. The insufficient radiator power and cooling beam capacity are examined in greater detail on the zone level. These two cases (both cell and open plan) are recalculated (and presented in Table 5.7) with increased heating and cooling power in order to calculate the energy demand needed for each alternative. However, for the rest of the parametric studies the original alternatives were used in order to study the impact of window type on the perception of thermal comfort.

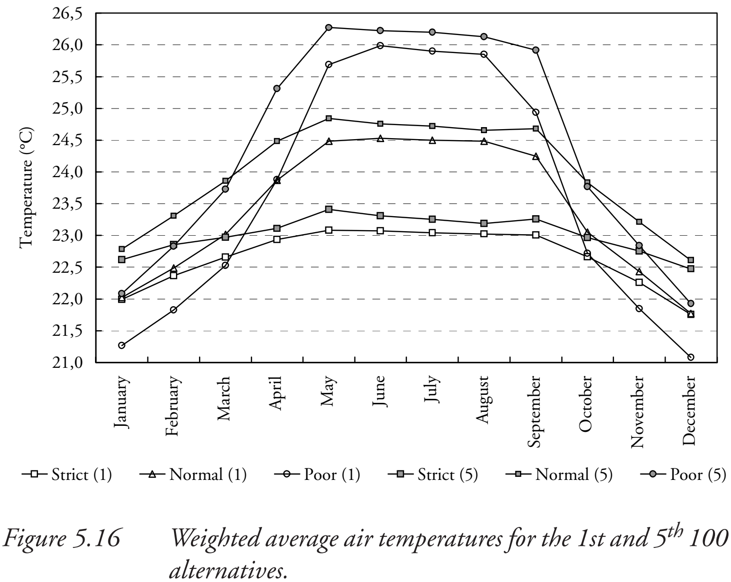


Figure 5.16 Weighted average air temperatures for the 1st and 5th 100% glazed alternatives.

5.3.2 Perception of thermal comfort for the reference building

The PMV and PPD for the cell and open plan type were calculated (by IDA) in different ways. Due to the non rectangular geometry of the zones, the simulations (in IDA) for the open plan type were simplified (energy model of IDA). Therefore, an average radiant temperature of the external walls was assumed. Thus, when the operative temperature is calculated, the position of the occupant is not important. This is an acceptable assumption since we assume that in the open plan type the occupants interact more with each other and therefore move more inside the space. On the contrary, in the cell type reference building the climate model of IDA takes into account the radiant temperature of each surface (glazed vs. opaque wall) of the facade, so the position of the occupant is important. This is necessary in order to calculate the directed operative temperatures at the zone level so as to study the influence of the façade on the occupants' comfort (see Subchapter 1.2.3).

Impact of office layout on the perception of thermal comfort

For the strict control of the cell type reference building the PMV varies form -0.58 to -0.05 while for the open plan type the variation is from -0.51 to 0, as shown in Figure 5.17. The average difference in the PMV between the two interior types is very small (0.07) throughout the year.

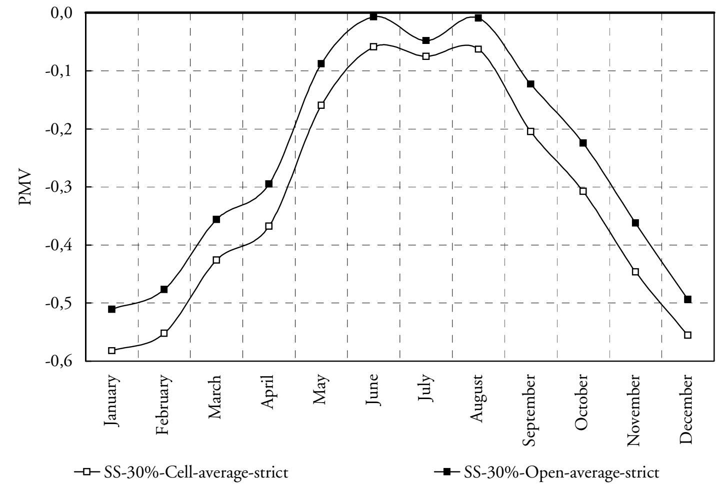


Figure 5.17 *Weighted average PMV for strict set points of the reference building.*

As expected, due to the higher internal loads the open plan type is slightly warmer than the cell type in the reference building. For the strict control set points, in which the PMV reaches the comfort limit of -0.5, the open plan gives a slightly better indoor climate as shown in Figure 5.18. For the cell type an average PPD of 10% corresponds to 66% of the working hours while for open plan the same PPD corresponds to 78%. For the cell type a weighted average of 15% PPD corresponds to 93% and for the open plan to 95% of the working hours.

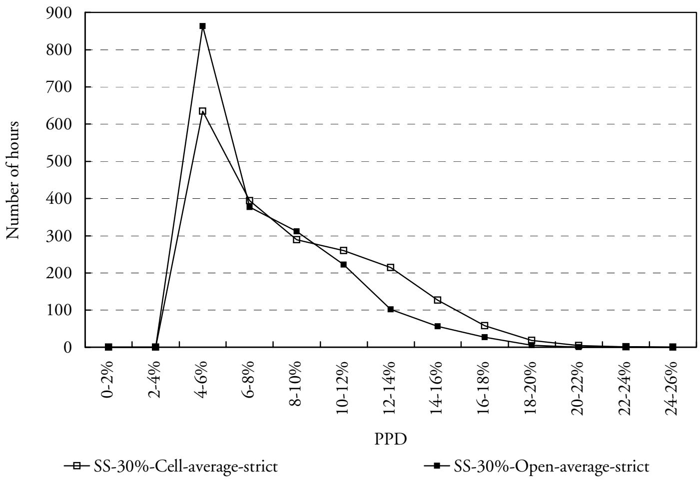


Figure 5.18 *Number of working hours for certain average PPD for strict set points of the reference building.*

For the normal control set points, the PMV of the open plan varies between -0.4 and +0.4, while the PMV of the cell type varies between -0.55 and +0.3 as shown in Figure 5.19. The difference in the PMV between the two interior types is slightly higher during the winter. The tendency can be explained by the lower occupancy during the summer months. The yearly average PMV difference is 0.13.

For the normal control set points, the PPD for the open plan gives the most acceptable indoor thermal climate as shown in Figure 5.20. For the cell type an average PPD of 10% corresponds to 73% of the working hours while for open plan the same PPD corresponds to 82%. For the cell type a weighted average of 15% PPD corresponds to 93% and for the open plan to 96% of the working hours.

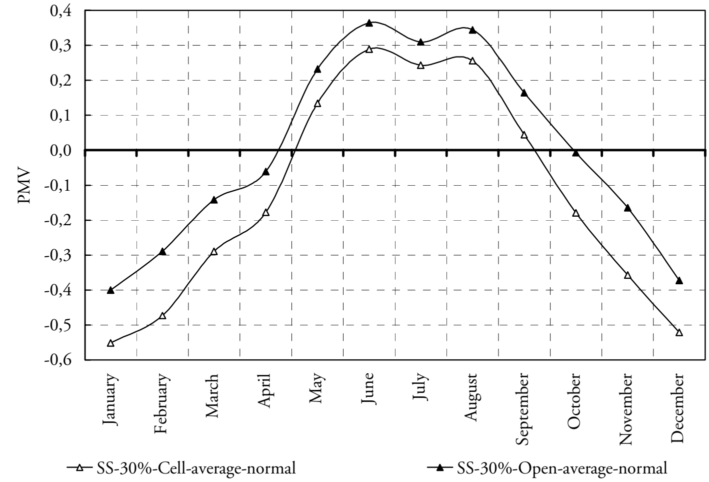


Figure 5.19 *Weighted average PMV for normal set points of the reference building.*

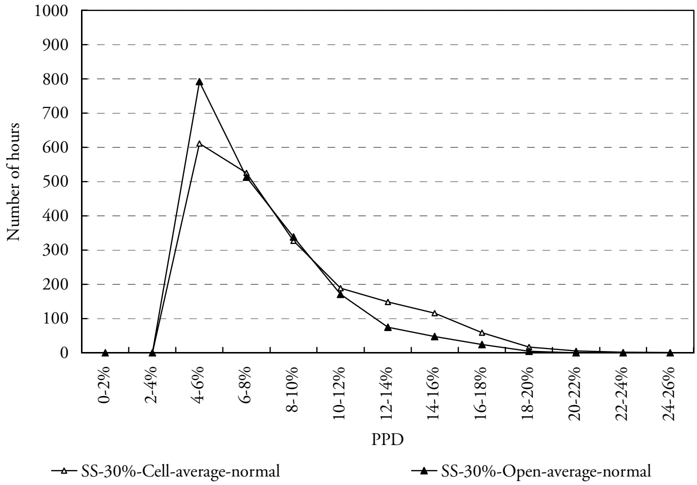


Figure 5.20 *Number of working hours for certain average PPD for normal set points of the reference building.*

For the poor control set points, the PMV of the open plan varies between -0.6 and +0.72, while the PMV of the open plan varies between -0.77 and +0.6 as shown in Figure 5.21. The difference in the PMV between the two interior types increases even more during the winter. The yearly average PMV difference is 0.23.

For the poor control set points, the PMV for the open plan gives a somewhat better indoor thermal climate as shown in Figure 5.22. For the cell type an average PPD of 10% corresponds to 39% of the working hours while for open plan the same PPD corresponds to 43%. Both for the cell and open plan type a weighted average of 15% PPD corresponds to 63% of the working hours.

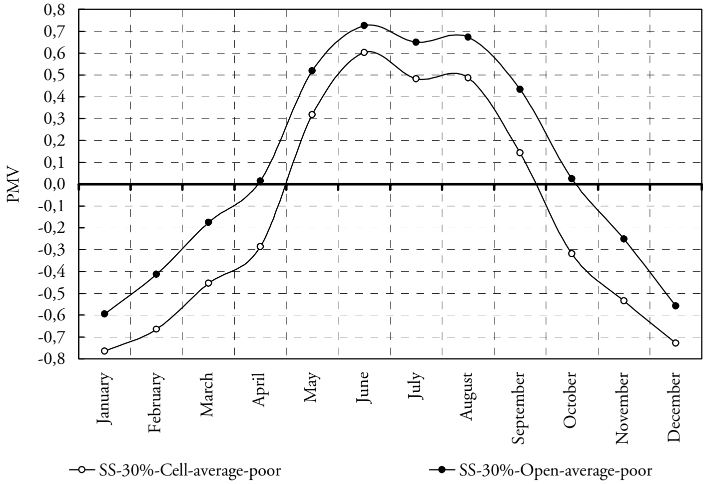


Figure 5.21 *Weighted average PMV for poor set points of the reference building.*

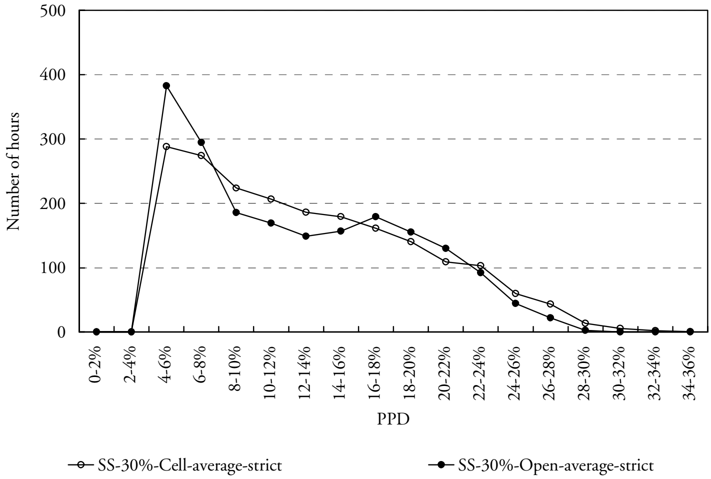


Figure 5.22 *Number of working hours for certain average PPD for poor set points of the reference building.*

Impact of control set points on the perception of thermal comfort

The impact of the strict, normal and poor control set points on the perception of the thermal indoor climate for the cell type is shown in Figures 5.23 and 5.24. From January until May and from the middle of September to the end of December the normal control provides higher comfort for the occupants since the PMV for the strict control are quite low. The difference might be quite small but shows an expected tendency of the influence of the set points on the perception of thermal comfort. From May until the beginning of September the temperature with the normal control increases, creating slight discomfort for the occupants. Both controls are very close to the recommendations of the ISO Standard 7730 since the PMV almost varies from -0.5 to +0.5. For the poor control set points the PMV varies from -0.8 to +0.6, exceeding the comfort levels.

For the strict control an average 10% of PPD corresponds to 66% of the working hours while for the normal and poor ones the same average corresponds to 73% and 40%. The same values for a weighted average of 15% PPD correspond to 93%, 93% and 63% of the working hours.

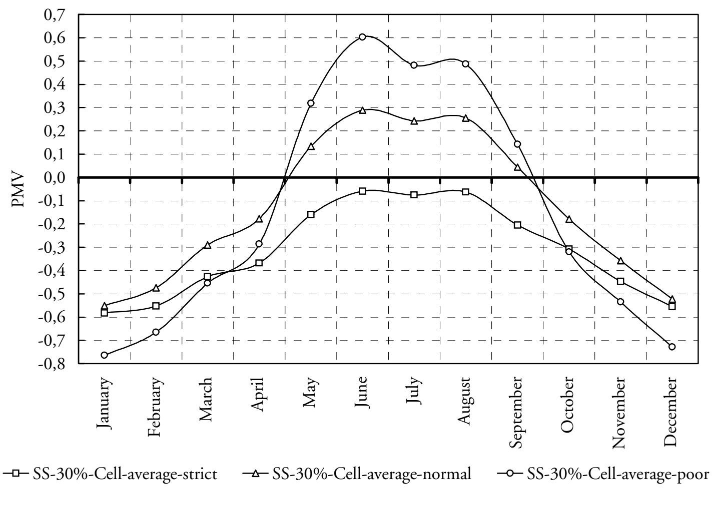


Figure 5.23 Weighted average PMV for the cell type plan of the reference building.

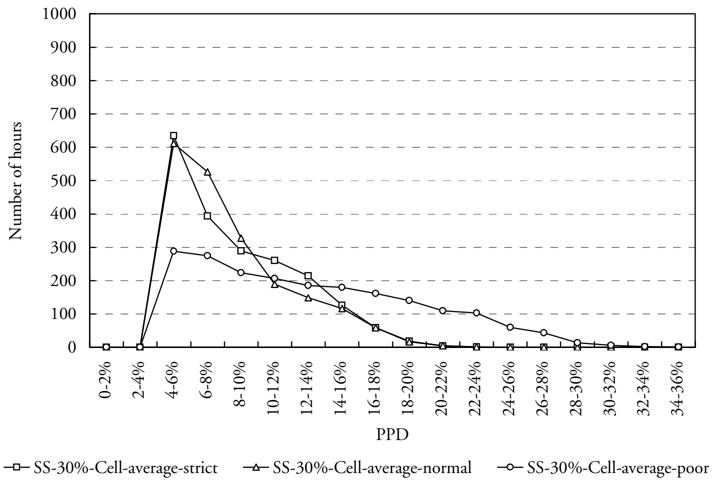


Figure 5.24 *Number of working hours for certain average PPD for cell plan (reference building).*

The impact of the strict, normal and poor control set points on the perception of the indoor climate for the open plan type is shown in Figures 5.25 and 5.26. As already stated, due to the higher internal loads in the open plan the PMV slightly increases. From January until the beginning of May and from the end of September to the end of December the normal control provides better comfort for the occupants. From May till the beginning of September the PMV in the normal control increases, creating slight discomfort. The PMV of the normal control set points varies between -0.4 and +0.4 while the strict one varies between -0.5 and 0. For the poor control the PMV varies from -0.6 to +0.75, exceeding the comfort levels.

For the strict set points a weighted average PPD of 10% corresponds to 78% of the working hours while for the normal and poor set points the same average corresponds to 82% and 43% respectively. The same values for a weighted average PPD of 15% correspond to 95%, 96% and 63% of the working hours.

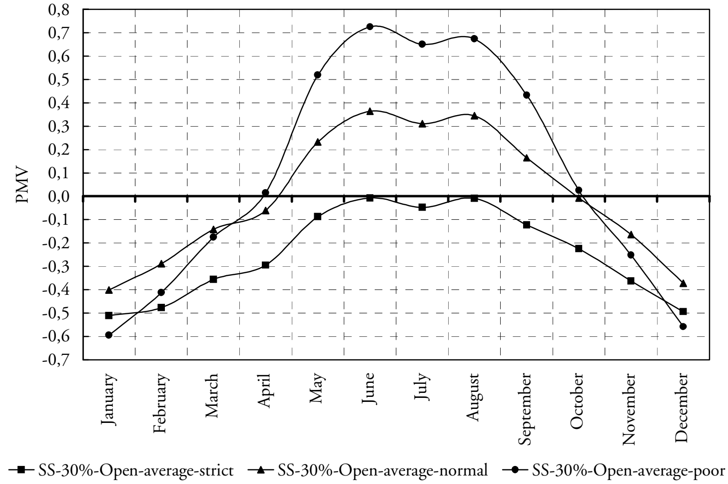


Figure 5.25 *Weighted average PMV for the open type plan of the reference building.*

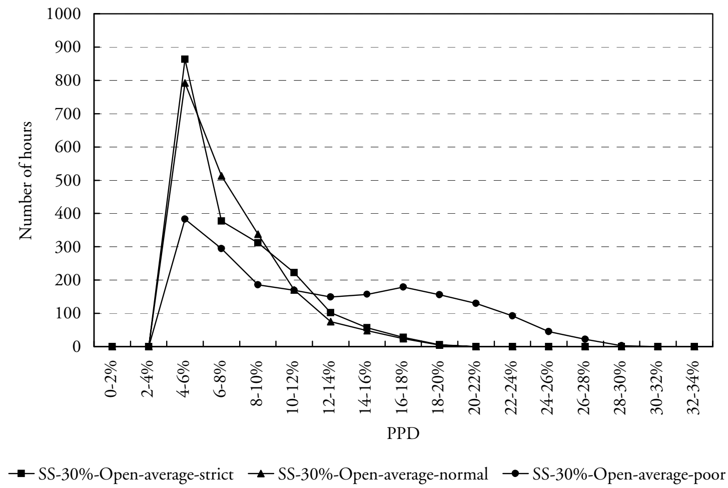


Figure 5.26 *Number of working hours for certain average PPD for open plan (reference building).*

5.3.3 Impact of window and shading type on the perception of thermal comfort for the 60% and 100% glazed alternatives

Since the poor control set points give high PPD values (not acceptable according to ISO standard 7730), the perception of thermal comfort will be studied only for the strict and normal set points of the two plan types. A comparison of the weighted average PMV values and the number of hours with certain PPD values of the 30% and 60% alternatives follows in order to study the influence of the façade elements on the perception of the thermal environment.

When the thermal transmittance of the first 60% glazed alternative is reduced, the PMV values are improved during the heating season (for the strict set points, during January the weighted average PMV of the first alternative is -0.67 while for the second one it is -0.55; for the normal set points the weighted average PMV of the first alternative is -0.67 while for the second one it is -0.51) as shown in Figure 5.27. During the summer months, however, the weighted average PMV values of the strict set points are around 0 and between 0.3 and 0.4 for the normal set points.

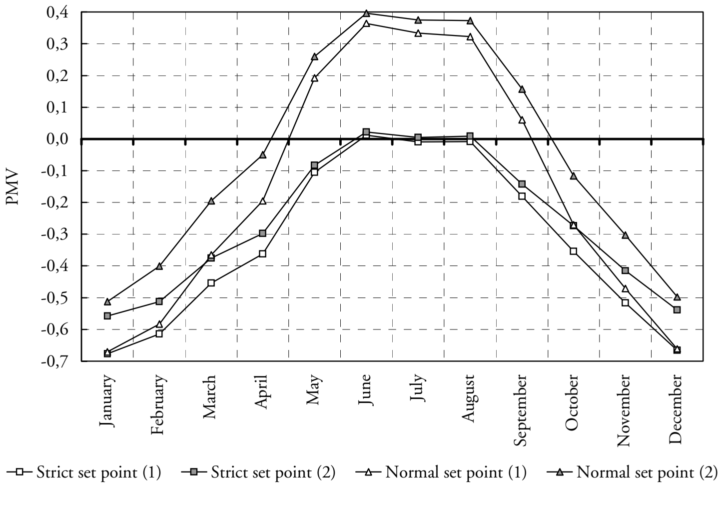


Figure 5.27 Weighted average PMV for the 1st and 2nd 60% glazed alternatives (strict and normal control set points).

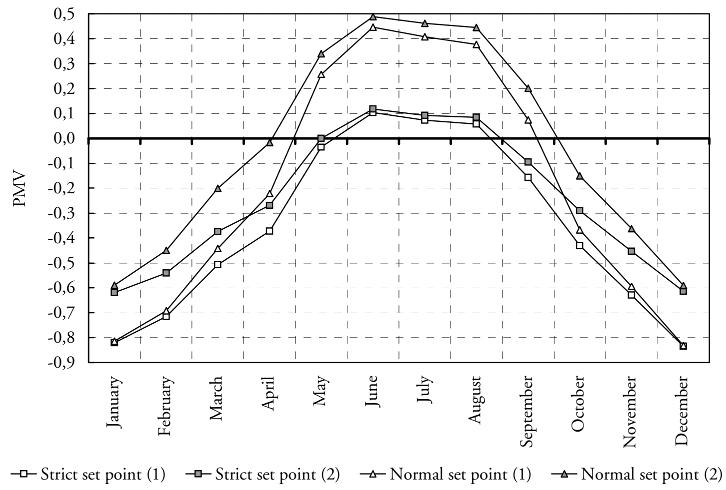


Figure 5.28 Weighted average PMV for the 1st and 2nd 100% glazed alternatives (strict and normal control set points).

For the 100% glazed alternatives the PMV values are reduced even more during the heating season (for the strict set points, during January the weighted average PMV of the first alternative is -0.82 while for the second one it is -0.62; for the normal set points the weighted average PMV of the first alternative is -0.81 while for the second one it is -0.59) as shown in Figure 5.28. During the summer months, however, the weighted average PMV values of the strict set points are around 0.1 and between 0.4 and 0.5 for the normal set points.

The increase in glazed area results in a greater difference in the weighted average PMV values between the alternatives 1 and 2 mostly during the heating periods (for the strict set points of the 60% glazed alternative it is 0.12 during January while for the 100% glazed one it is 0.2; for the normal set point the difference is 0.16 and 0.22 respectively). This is a result of the difference in the weighted average air temperature, but mainly of the difference in the radiant temperature. Since the directed operative temperature is an average of the air temperature and the radiant temperatures of the surfaces between the occupant and the external wall (see Subsection 1.2.3), and since the difference in the weighted average directed operative temperatures between the first and second alternative is larger than the weighted average air temperatures (Figure 5.29), the impact of the radiant temperature is greater (the negative values show that the 1st alternative is colder than the 2nd).

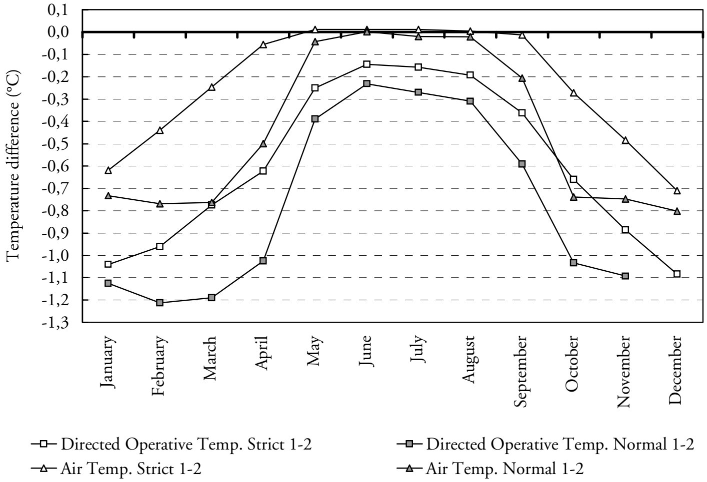


Figure 5.29 *Difference between weighted average directed operative temperature and air temperature for the 1st and 2nd 100% glazed alternatives.*

The reason that the average air temperature was not compared with the average radiant temperature (but with the directed operative temperature) is that in this way the distance of the occupants from the façade (1 m) is also considered. Thus, if this distance increases (e.g. open plan type) the impact of the façade on the occupants' comfort will be lower.

A diagram with the number of hours with certain (weighted average) directed operative temperatures is shown in Figure 5.30. The lower thermal transmittance of the second alternative increases the number of hours with directed operative temperatures closer to the maximum allowed temperature limit for each set point.

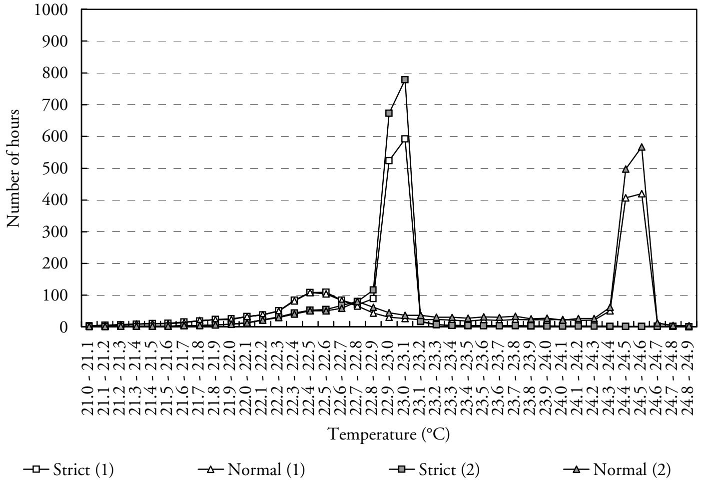


Figure 5.30 *Number of hours with certain (weighted average) directed operative temperatures for 1st and 2nd 100% glazed alternatives.*

For the strict control set points of the 60% glazed buildings, the PPD values are lower than 10% during 72% of the working hours for the second alternative, and during 61% of the working hours for the first alternative for the cell type (Figure 5.31). For the normal set point the number of hours decreases to 70% and 57% respectively. The number of hours with PPD values lower than 15% increases up to 94% for the second and 83% for the first alternative(for the strict control set points). For the normal set point the number of hours is 94% and 82% for the two alternatives.

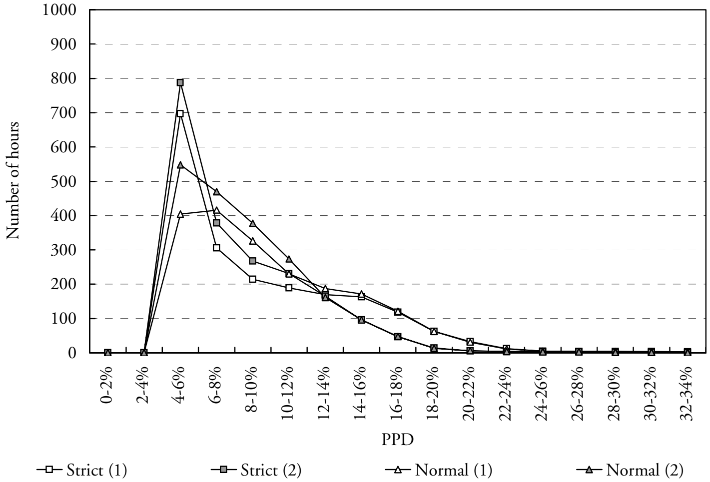


Figure 5.31 *Weighted average PPD for the 1st and 2nd 60% glazed alternatives.*

For the 100% glazed building, the PPD values are lower than 10% during 68% of the working hours for the second alternative, and during 55% of the working hours for the first alternative for the cell type (Figure 5.32). For the normal set point the number of hours decreases to 55% and 44% respectively. The number of hours with PPD values lower than 15% increases up to 93% for the second and 76% for the first alternative(for the strict control set points). For the normal set point the numbers of hours is 92% and 75% for the two alternatives.

When the triple window is replaced by a double one (with a lower solar factor) and the blinds are placed inside in the third alternative, the PMV values decrease as shown in Figure 5.33. Since the thermal transmittance of the glazing was kept the same, the difference in the PMV values is small during the winter months. The difference, however, increases when cooling is needed. A diagram of the weighted average PMV for the second and third 100% glazed alternatives is shown in Figure 5.35. The results for the 60% glazed buildings are similar.

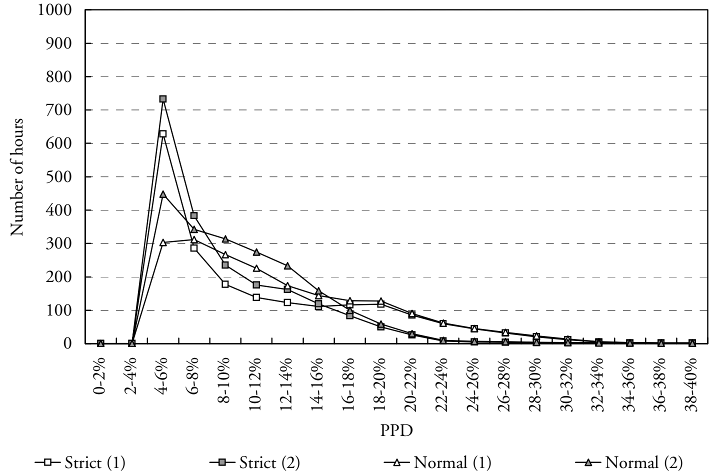


Figure 5.32 *Weighted average PPD for the 1st and 2nd 100% glazed alternatives.*

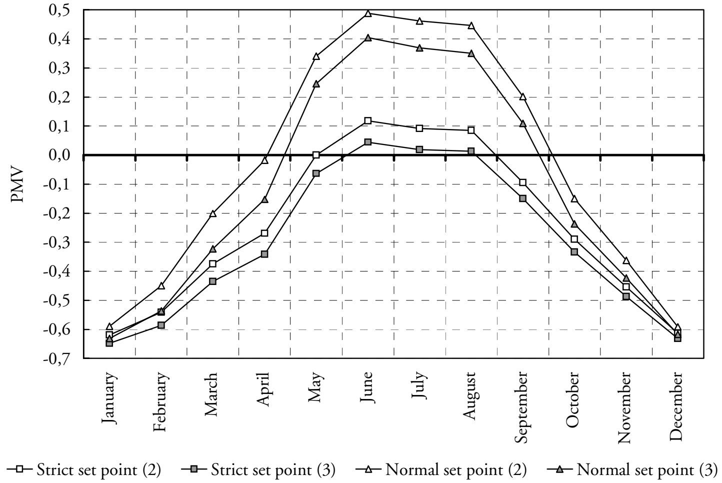


Figure 5.33 *Weighted average PMV for the 2nd and 3rd 100% glazed alternatives.*

For the 60% glazed building, the PPD values are lower than 10% during 72% of the working hours for the second, and during 68% of the working hours for the third alternative for the cell type (Figure 5.34). For the normal set point the number of hours decreases to 70% and 70% respectively. The number of hours with PPD values lower than 15% increases up to 94% for the second and 93% for the third alternative (for the strict control set points). For the normal set point the number of hours is 94% and 93% for the two alternatives.

For the strict control set points of the 100% glazed buildings, the PPD values are lower than 10% during 68% of the working hours for the second, and during 55% of the working hours for the third alternative for the cell type (Figure 5.35). For the normal set point the number of hours decreases to 62% and 57% respectively. The number of hours with PPD values lower than 15% increases up to 93% for the second and 92% for the third alternative (for the strict control set points). For the normal set point the number of hours is 92% and 90% for the two alternatives.

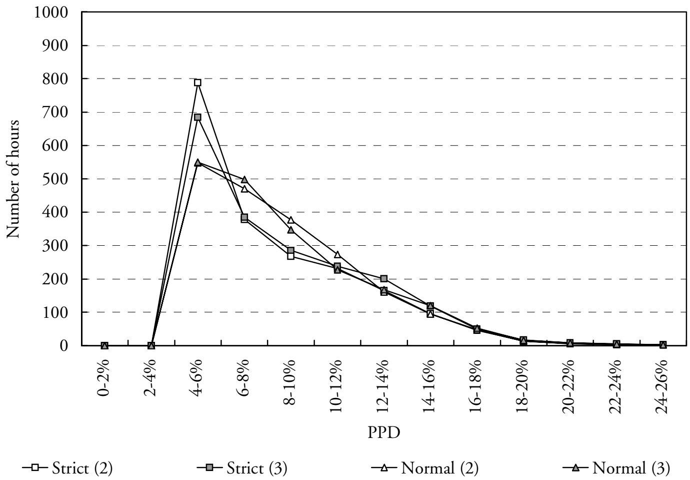


Figure 5.34 Weighted average PPD for the 2nd 3rd 60% glazed alternatives.

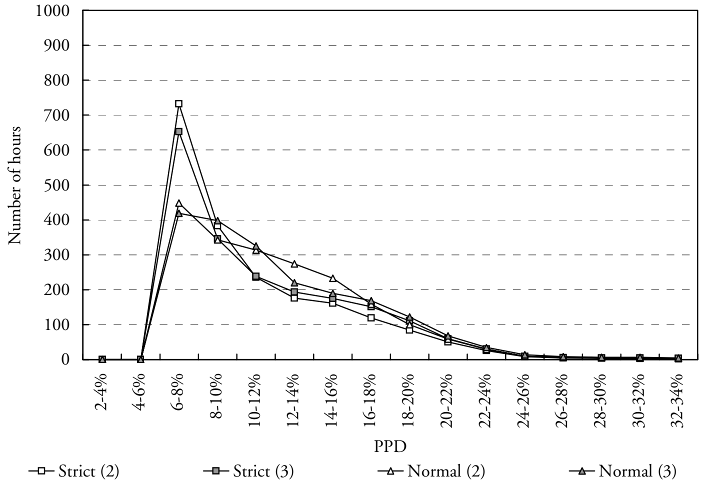


Figure 5.35 *Weighted average PPD for the 2nd and 3rd 100% glazed alternatives.*

A further decrease and increase in the solar factor in the fourth and fifth alternative respectively, result in lower and higher weighted average PMV values as shown in Figure 5.36. The PMV values of the fifth alternative vary between the recommended limits of -0.5 and +0.5 (which correspond to lower than 15% of PPD values), but on the other hand they exceed the limits of -0.3 and +0.3 (which correspond to lower than 10% of PPD values) for a longer time.

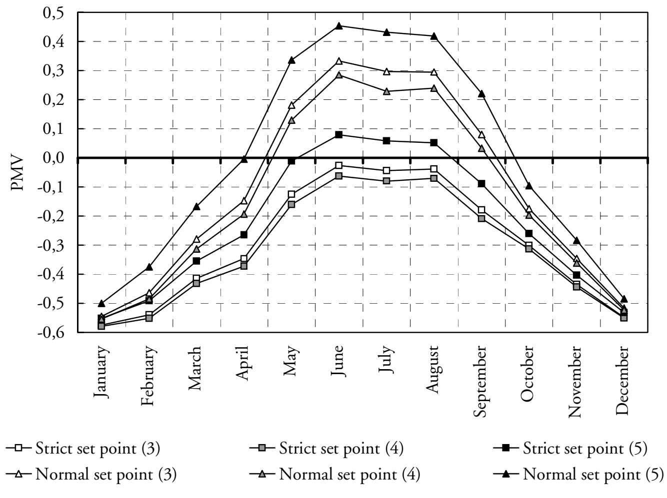


Figure 5.36 *Weighted average PMV for the 3rd, 4th and 5th 60% glazed alternatives (strict and normal control set points).*

A diagram with the number of hours with certain (weighted average) directed operative temperatures for the 100% glazed building is shown in Figure 5.39. The larger difference in the number of hours, between the fourth and fifth alternative for the normal set point, results in a greater difference in the PMV values. The duration diagram that corresponds to Figure 5.37 (60% glazed building) is similar to the one presented for 100% glazed buildings.

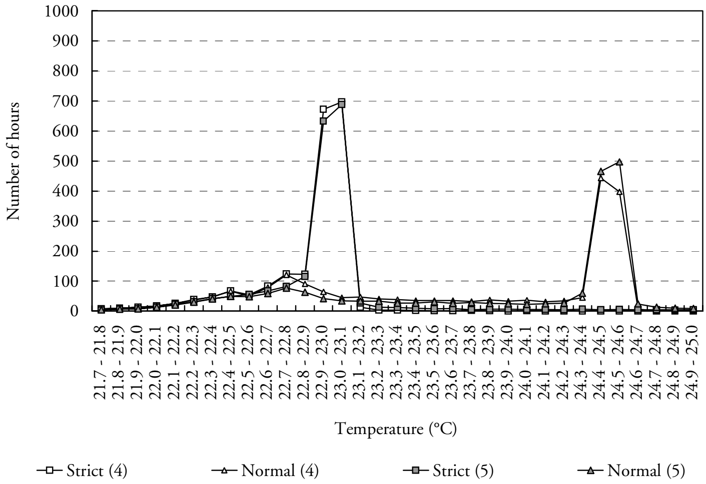


Figure 5.37 *Number of hours with certain (weighted average) directed operative temperatures for 4th and 5th 100% glazed alternatives.*

For the 60% glazed building, the PPD values are lower than 10% during 66% of the working hours for the fourth, and during 71% of the working hours for the fifth alternative for the cell type (Figure 5.38). For the normal set point the number of hours decreases to 71% and 65% respectively. The fifth alternative gives lower PPD values for the strict set points since the PMV is between -0.3 and +0.3 between the beginning of April and the end of October while the for the fourth one the PMV varies between these limits between end of April and middle of October. For the normal set points, however, the PPD values are lower for the fourth alternative since the high solar factor (of the fifth alternative) results in higher than +0.3 PMV values from the middle of May until the end of August while for the fourth alternative they are lower than +0.3 during these months. The number of hours with PPD values lower than 15% increases up to 92% for the fourth and 93% for the fifth alternative (for the strict control set points). For the normal set point the number of hours is 93% and 94% for the two alternatives. The number of hours with PPD values lower than 15% is lower in the fourth alternative mostly due to the higher directed operative temperatures during January, February and December (PMV higher than -0.5).

For the strict control set points of the 100% glazed buildings, the PPD values are lower than 10% during 60% of the working hours for the fourth, and during 63% of the working hours for the fifth alternative for the cell type (Figure 5.39). For the normal set point the number of hours decreases to 58% and 50% respectively. The number of hours with PPD values lower than 15% increases up to 83% for the fourth and 84% for the fifth alternative (for the strict control set points). For the normal set point the number of hours is 83% and 78% for the two alternatives.

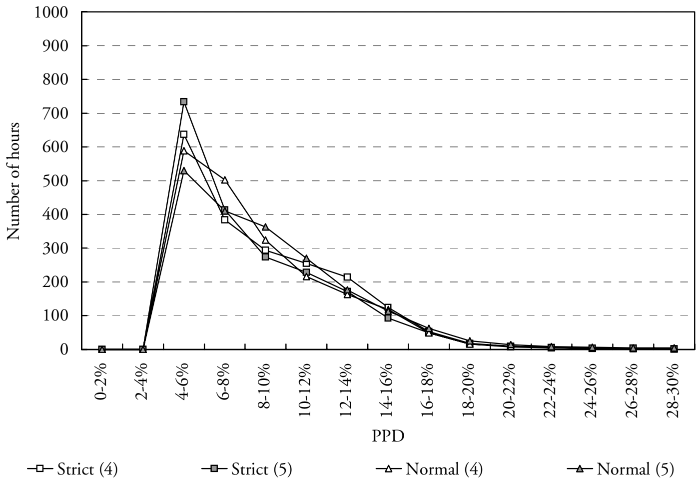


Figure 5.38 *Weighted average PPD for the 4th and 5th 60% glazed alternatives.*

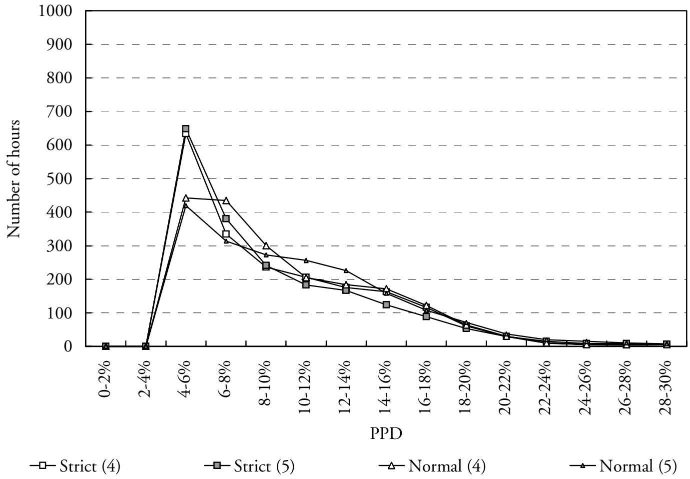


Figure 5.39 *Weighted average PPD for the 4th and 5th 100% glazed alternatives.*

The sixth and seventh alternatives have the same glazing as the third alternative. Instead of internal blinds the sixth alternative has internal screens and the seventh one fixed external louvres. The effective g value of both alternatives is lower than in the third alternative, as described in Chapter 4. The main difference between the alternative with the fixed external louvres and the other two is that in the first the shading devices are always applied while in the others they are drawn for a set point of 100 W/m^2 on the surface of the glass. As shown in Figure 5.40, the weighted average PMV for the strict set points of the seventh alternative is quite low. However, the 6th alternative does not really differ from the 3rd one. For this reason, the sixth alternative will not be studied further.

For the seventh 60% glazed alternative, the PPD values are lower than 10% during 68% of the working hours for the strict, and during 71% for the normal set point. The number of hours with PPD values lower than 15% increases up to 93% for the strict and 92% for the normal set point. For the strict control set points of the 100% glazed buildings, the PPD values are lower than 10% during 57% of the working hours for the strict and during 60% for the normal set point (Figure 5.41). The number of hours with PPD values lower than 15% increases up to 82% for the strict and 83% for the normal set points respectively.

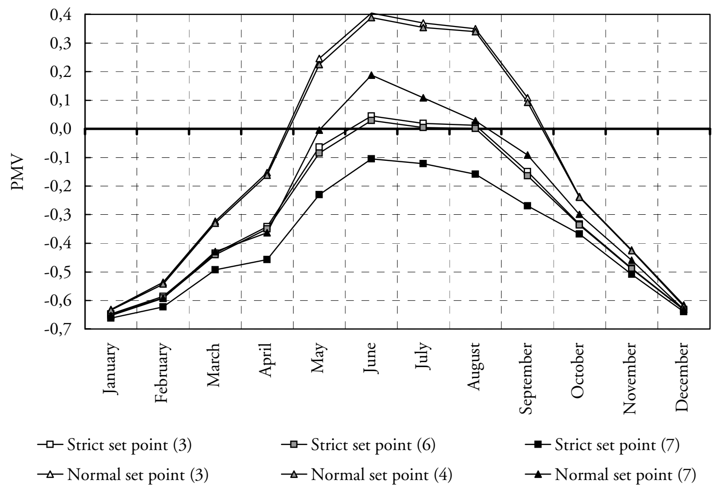


Figure 5.40 *Weighted average PMV for the 3rd, 6th and 7th 100% glazed alternatives (strict and normal control set points).*

Table 5.8 Percentage of working of hours with PPD below 10% for the cell type alternatives.

	Cell type plan						**Open type plan**					
	30% glazed alternatives		60% glazed alternatives		100% glazed alternatives		30% glazed alternatives		60% glazed alternatives		100% glazed alternatives	
	PPD 10%	PPD 15%	PPD 10%	PPD 15%	PPD 10%	PPD 15%	PPD 10%	PPD 15%	PPD 10%	PPD 15%	PPD 10%	PPD 15%
strict (1)	66	93	61	83	46	65	63	97	69	90	50	70
normal (1)	73	93	57	82	31	60	84	97	65	90	36	64
poor (1)	39	63	27	45	15	30	44	64	27	42	19	34
strict (2)			72	94	68	87			81	97	75	92
normal (2)			70	94	55	84			73	96	60	87
poor (2)			31	52	27	42			32	49	34	49
strict (3)			68	93	62	84			78	96	70	91
normal (3)			70	93	57	82			79	97	67	90
poor (3)			34	57	27	45			32	51	34	52
strict (4)			66	92	60	83			77	96	69	90
normal (4)			71	93	59	83			82	97	71	91
poor (4)			38	61	30	49			34	56	35	56
strict (5)			71	93	64	84			82	97	72	92
normal (5)			65	90	50	78			68	93	56	80
poor (5)			30	49	25	40			31	46	32	47
strict (6)			68	93	62	84			78	96	70	91
normal (6)			70	93	58	83			80	97	69	91
poor (6)			33	57	27	45			32	51	34	53
strict (7)			68	93	57	82			78	96	66	90
normal (7)			71	92	60	83			80	97	77	91
poor (7)			33	57	40	58			78	96	46	71

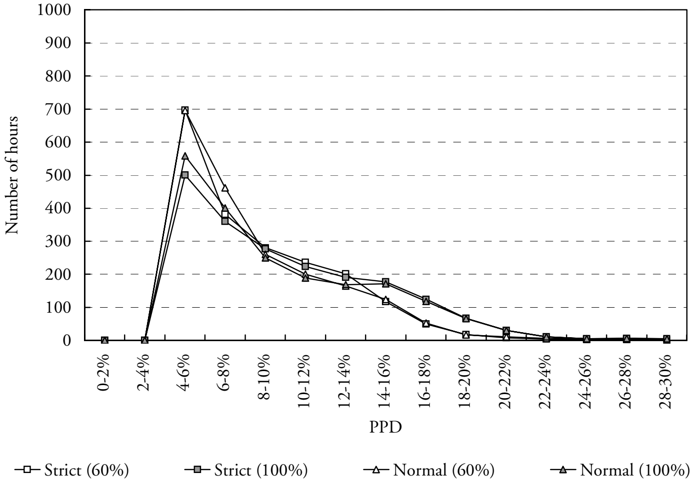


Figure 5.41 *Weighted average PPD for the 7th 60% and 100% glazed alternatives.*

5.4 Productivity

The productivity (lost working hours due to the poor thermal environment) is presented in this section. According to Wyon (2000) no work is regarded as lost for operative temperatures between 20 and 25 °C. Above and below these limits experiments show an average loss of 2% in performance per degree.

The lost work for all the 18 building alternatives is presented in Figure 5.44. Since the operative temperatures and thus the productivity refer to each zone individually the building orientation affects the results. For the strict control set point the PPD does not fulfil the recommendations (PPD of 10% more than the 90% of the working hours), but on the other hand the operative temperature hardly exceeds the limit of 20°C and 25°C. This has the result that both for the cell and open plan type there are almost no lost working hours. For the case with normal control set points the PPD values of 10% are slightly lower than the ones of the strict control (for PPD of 15% the number of hours is almost the same). The operative temperatures however exceed the limit of 25°C during the summer months and consequently the lost working hours in the alternatives with normal control increase. The lost working hours of the poor control increase dramatically since the maximum allowed air temperature is 26°C (higher than the limit of 25°C). For the cell type there are 2732 lost working hours (for an average orientation for the poor control set points) while for open plan there are 4975. As shown in Figure 5.42, it is evident that almost all the lost work is caused by high temperatures during the cooling period. It is worth mentioning that for the open plan type there are 643000 working hours while for the cell type there are 595000 hours i.e. the lost work is 0.5 % of the total working hours for the cell type and 0.7 % for the open plan type.

Although the south orientation is the warmer one, the north orientation has reduced overheating problems (and thus a reduced possibility that the operative temperature will exceed 25°C. Thus the sum of the lost working hours in the north-south orientation is higher than in the east-west one. Consequently, when the short facades face north-south there is a greater possibility that the operative temperature will exceed the temperature limits and thus the lost working hours will increase. This possibility increases as the maximum temperature limit increases. The impact of orientation on the potential overheating problem will be described in greater detail on the zone level.

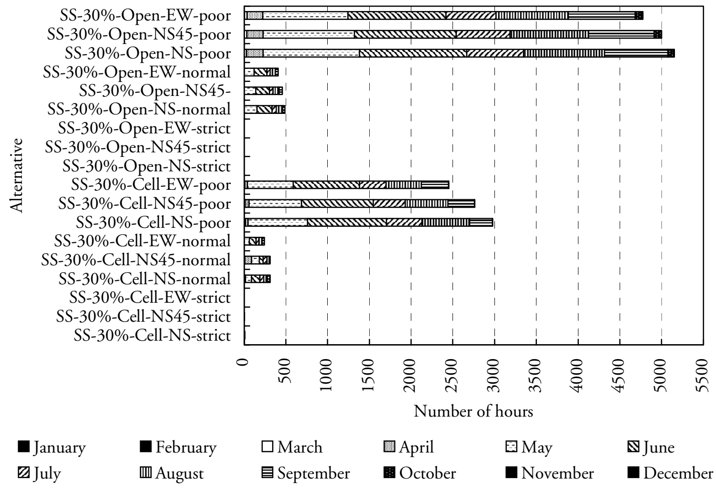


Figure 5.42 *Lost working hours for reference building alternatives. The total number of working hours in a year is 643 000 for the open plan and 595 000 for the cell type.*

The lost working hours in the 60% and 100% glazed alternatives are shown in Table 5.9. The first and fifth 100% glazed alternatives set out in this Table are the originally simulated alternatives. As expected, most lost hours are in the fifth alternative due to the high air temperatures and the insufficient capacity of the cooling beams. There are more lost working hours in the glazed alternatives than in the reference building, because of the difference in thermal comfort.

Table 5.9 Lost working hours for 60% and 100% building alternatives.

	60% glazed alternatives (cell plan)	100% glazed alternatives (cell plan)	60% glazed alternatives (open plan)	100% glazed alternatives (open plan)
Strict (1)	81	643	40	504
Normal (1)	838	2186	1289	2698
Poor (1)	4517	6322	6456	7962
Strict (2)	6	190	18	332
Normal (2)	984	2268	1720	3368
Poor (2)	6081	7970	8486	10289
Strict (3)	7	214	18	185
Normal (3)	620	1505	891	1770
Poor (3)	4103	5648	6802	7164
Strict (4)	0	59	1	58
Normal (4)	336	866	498	1007
Poor (4)	2867	4100	4789	5544
Strict (5)	328	1714	299	1498
Normal (5)	2128	4653	2901	5576
Poor (5)	7819	10824	10416	12919
Strict (6)	1	84	3	85
Normal (6)	478	1202	722	1426
Poor (6)	3865	5278	6407	6664
Strict (7)	0	18	0	0
Normal (7)	38	150	63	130
Poor (7)	611	1188	2529	2179

5.5 Indoor climate on a zone level

The mean air temperature, the directed operative temperatures and the perception of thermal comfort for each zone are studied in this section. The orientation of the zones is north, east, south and west for the strict, normal and poor control set points. The studied zones are the double and single office rooms, the meeting rooms and the corner office rooms in the cell type office building alternatives. The 30% and 100% glazed buildings were studied. The third 100% glazed alternative (typical construction) was chosen as a 100% glazed reference case for the comparisons on a zone level. The main purpose is to study the impact of glazing on each orientation.

5.5.1 Mean air temperatures and potential overheating problem

The reference building has a 30% window to façade area ratio. Along the long and the short façades the percentage of the window area in the offices remains the same as described in Subsection 4.1.1. However, the meeting room (external wall in the short façade) of the reference building has a higher glazing area than the rest of the zones (65% window to wall area ratio). Due to the different glazing areas in the same building alternative (reference case), it is decided to study the impact of glazing on the overheating problem for the reference building, providing useful information on the impact of window area on the potential overheating problem. Although the south oriented zones of the reference building appear to be slightly warmer, for the strict control set points, the mean air temperature is not really influenced by the zone orientation due to the narrow allowed temperature variation. The zone type, however, is the meeting room which has many hours with the mean air temperature close to the cooling set point due to the highly glazed area (see figure 5.43).

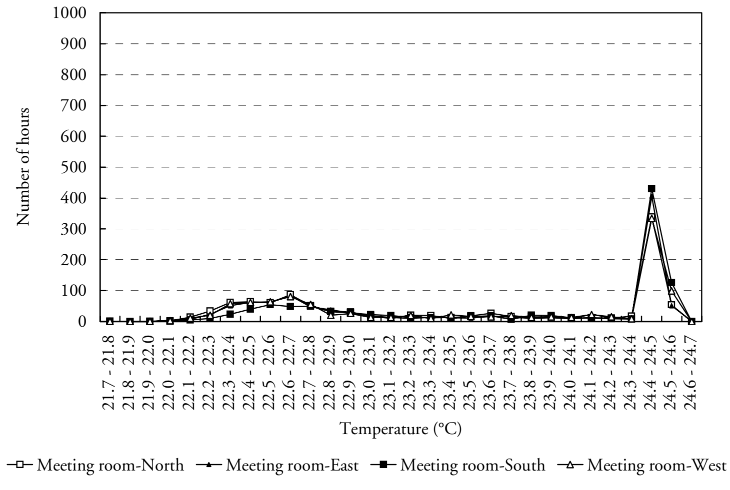


Figure 5.43 *Hours between certain mean air temperatures for the meting room (reference building, cell type plan, and normal control set points).*

Since the mean air temperature variation in the different zones is pretty similar in between the temperature limits of each set point, the potential overheating problem was studied. One way to study this is to calculate the cooling load for each zone, but IDA provides this information only for the whole building. Simulating each zone separately can take a large amount of time. Instead, the number of hours close to the upper allowed temperature limit was analyzed, as this is almost equal to the hours with cooling demand in order to keep the air temperature within the allowed limits. This indicator is not precise but in a comparative study it can show the risk of overheating problems for different orientations, glazed areas, control set points and internal loads for each zone type.

As expected, the south orientation is slightly warmer (see Figure 5.44). Due to the relatively high internal gains and the low upper temperature limit of 23ºC, the single and double offices have similar numbers of hours with cooling demand. However, due to the lower internal gains (15 m^2/person instead of 10 m^2/person and 7.65 m^2/person for the single and double office respectively), the corner room reaches the temperature limit of 23ºC for fewer hours as shown in Figure 5.44. All the offices have 30% window to façade area ratio.

The meeting rooms' schedule however is different. Both the number of hours per day (4 instead of 8) and the time of the day that they are occupied (10:00-12:00 and 13:00-15:00) make the comparison of this zone type with the rest useless. However, a comparison of the potential overheating problem for different orientations of this zone type could be a good indicator of what high temperatures occur for zones with a larger glass area (window area to room volume ratio in this zone type is 0.67 m^2/m^3 while for the single and double office room it is 0.258 m^2/m^3 and 0255 m^2/m^3 respectively).

The high internal gains of the single and double office rooms combined with the low upper temperature limit, result in a large number of hours with cooling demand, decreasing the effect of the orientation (for the single room, the difference between the north and south oriented single office is 3% and for the double office 1%). The lower internal gains of the corner room, however, result in a larger difference in the amount of hours when cooling might be needed. As expected, the south orientation is the warmest, and the north one is the one with the lowest cooling demand, as expected. The number of hours (curve) with temperature of 23ºC for the meeting rooms is similar for the different zone orientations.

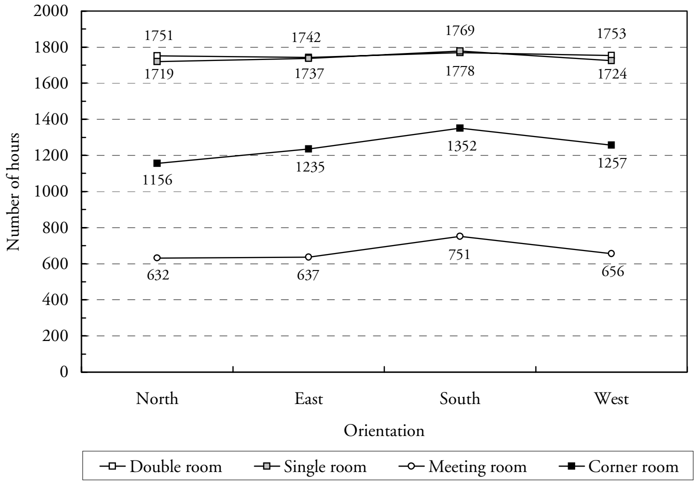


Figure 5.44 *Potential overheating problem of the reference building for the strict control set points.*

For the normal control the maximum allowed temperature limit is 24.5°C. Due to the higher upper limit (compared with the one for the strict control), the number of hours with potential cooling demand in the double office room is much higher than that in the single room. This can be explained by the higher impact of the internal gains (i.e. higher in the double office) due to the wider allowed temperature variations. Since the window area to room volume ratio of the single and double office room is almost the same (0.258 m^2/m^3 and 0255 m^2/m^3 respectively) the temperature difference can be explained by the higher internal loads of the double office room (10 m^2/person and 7.65 m^2/person respectively). The variation in the number of hours close to the cooling set point for these two office types is very similar for different orientations as shown in Figure 5.45.

For the corner office room the number of hours in the higher allowed mean air temperature limit is almost the same between the east and south orientation (1.7% more hours for the south façade). When the curves of the strict and normal control set points for the corner offices are compared, it is obvious that the south oriented one is cooler for the normal set points. This can be explained when the south and east orientation of this zone type are compared for the normal set points. The south oriented corner office reaches the limit of 23°C for more hours than the east oriented one; however, the same thing does not happen for the limit of

24.5°C. The south facing offices get warmer during the late working hours, while the east ones get warmer during the morning. Due to the schedule of the occupants and equipment, after 17:00 the internal loads reduce to the minimum, decreasing the cooling demand of the south oriented corner zone. For the same reason the number of hours with maximum allowed temperature is higher for the west oriented zones (compared with the east ones) for the strict set points and lower for the normal ones. In the two other office types however the higher internal loads increase the cooling demand before 17:00

The low upper limit of the allowed air temperature of the strict set points results in a larger (almost double) number of hours with potential cooling demand. However, as for the single and double offices, the strict set points reduced the impact of orientation on the cooling since, due to the larger glazed area, the temperature could easily rise up to 23°C. The upper limit of 24.5°C reduced the cooling demand but increased the impact of orientation on the hours when the maximum allowed temperature limit is reached.

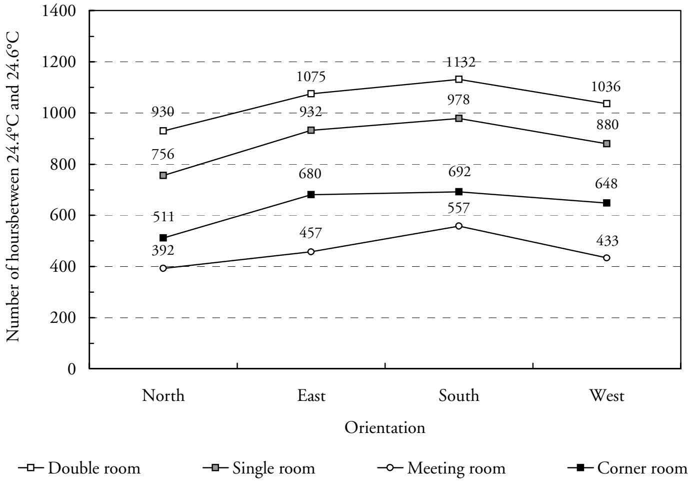


Figure 5.45 Potential overheating problem of the reference building for the normal control set points.

For the poor set points the number of hours that cooling is used is reduced dramatically for offices as shown in Figure 5.46. Especially for the north facing single and double offices the cooling demand is the same as in the meeting rooms (although the meeting rooms are used half the time). The further rise in the upper allowed temperature limit of the poor control set points increases the impact of schedule on the hours when cooling is used. The curve type of the offices changes for this set point. As for the south oriented corner office room (for the normal control set points) the further upper temperature limit reduces the cooling need of the south orientation. However, for the poor set point, the number of hours with air temperatures up to 26ºC in the south facing offices is even lower than in the east facing ones. When the internal loads are even lower (corner office), the number of hours that cooling is used is higher even for the west orientation. For the meeting room, however, the south orientation remains the warmer. From the above it is evident that as the glazing increases in a zone, the impact of schedule or control set points decreases.

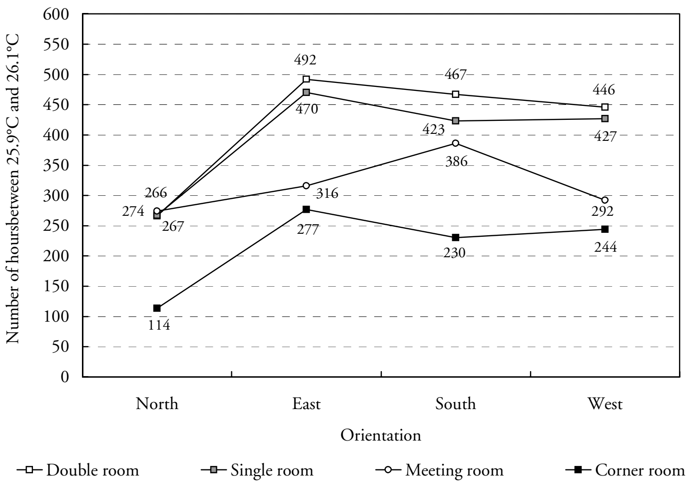


Figure 5.46 Potential overheating problem of the reference building for the poor control set points.

Similar results were obtained for the potential overheating problem of the zones of the 100% glazed alternatives.

5.5.2 Directed operative temperatures

The directed operative temperatures for different zones, control set points and orientations are studied for the 30% and 100% glazed building in order to find the impact of the façade on the occupants' comfort. The occupants are placed 1 m from the façade in all the zones.

The corner offices (for the reference building) have two orientations, one façade with window and one with an opaque wall. The one denoted by capital letters refers to the orientation where the window is placed. The other one refers to the opaque wall. For the comparisons of the number of hours close to the upper temperature limit an average mean air temperature was assumed between the rooms in which the window has the same orientation (e.g. southeast and southwest corner offices with the window facing south in both case; see Appendix C). For the 100% glazed building, however, all the facades of the building (regardless the orientation) are fully glazed.

For the strict control set points (22°C-23°C) the directed operative temperature varies from 21.5°C to 25°C for the single, double and corner offices and from 20°C to 28°C for the meeting rooms as shown in Figure 5.47 (south orientation). As expected, the variation in the directed operative temperature in the meeting room (due to the larger window area and the different schedule) is larger than in the rest of the zones.

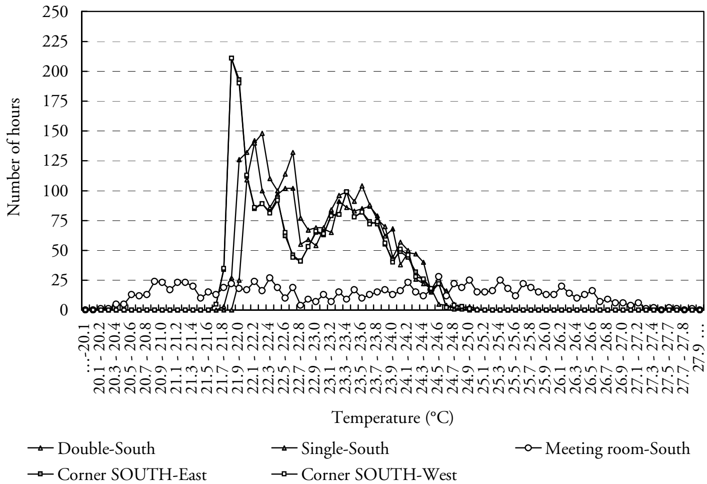


Figure 5.47 Number of hours between certain directed operative temperatures for south oriented zones for the reference building (strict control set points). The lower case letters refer to the opaque wall.

In Figure 5.48 a diagram of the number of hours with certain directed operative temperatures is presented for meeting rooms (of the reference building) with strict control set points for the four orientations. The results for the east and west facing meeting rooms are quite similar (maximum temperature 26.5°C and 27°C respectively), while the north facing meeting room is cooler (maximum temperature 25.4°C). The results for the other zones are similar. The main reason, however, that the meeting room was picked for the comparison of different orientations is that, due to the larger glazed area, the variation in the directed operative temperatures is even more evident.

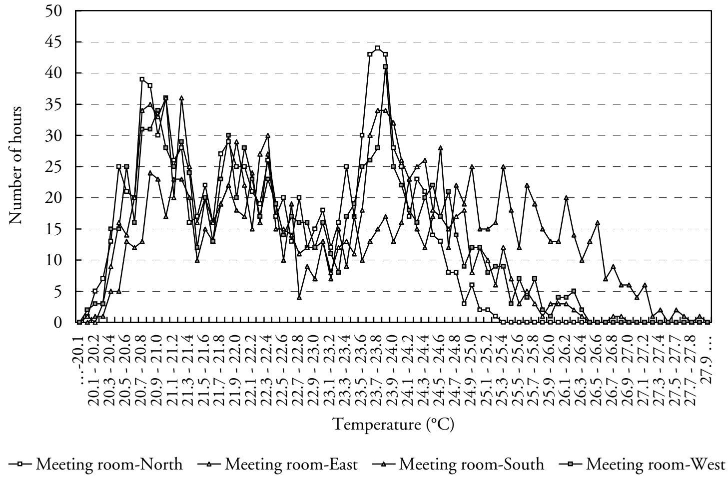


Figure 5.48 *Number of hours between certain directed operative temperatures for the 65% (reference) glazed meeting room strict control set points).*

The variation in the directed operative temperatures in the 100% glazed meeting rooms is similar, as shown in Figure 5.49. However, the lower thermal transmittance of the window in this case results in higher minimum temperatures. Thus, the minimum directed operative temperature in this case is 21.3°C while for the reference building (windows with triple clear pane) it is 20.1°C.

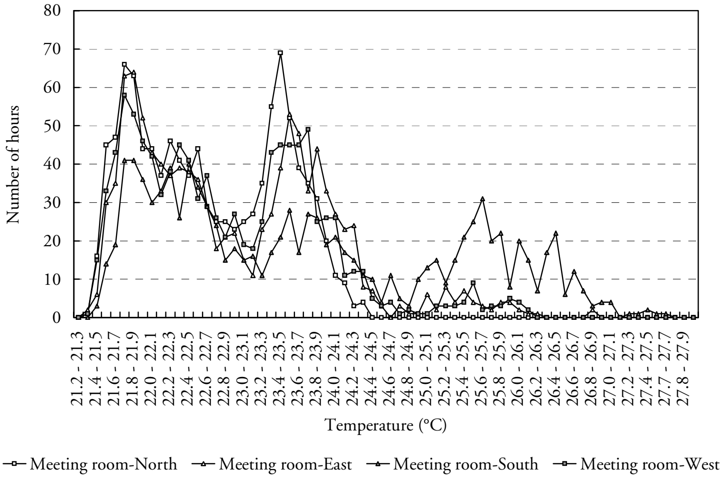


Figure 5.49 *Number of hours between certain directed operative temperatures for the 100% glazed meeting room (strict control set points, 3rd alternative).*

In order to study the impact of the control set points on the directed operative temperatures, the north and south single offices are compared, as shown in Figure 5.50. Since the lower set point for both cases is the same (22°C), the minimum directed operative temperature is the same. For the north orientation the maximum directed operative temperature reaches 24°C for the strict set points and 25.4°C for the normal ones. For the south orientation the temperature reaches 25°C and 26.4°C respectively. For both set points the directed operative temperature is 1°C higher than the allowed air temperature limit for the north orientation and 2°C higher for the south orientation.

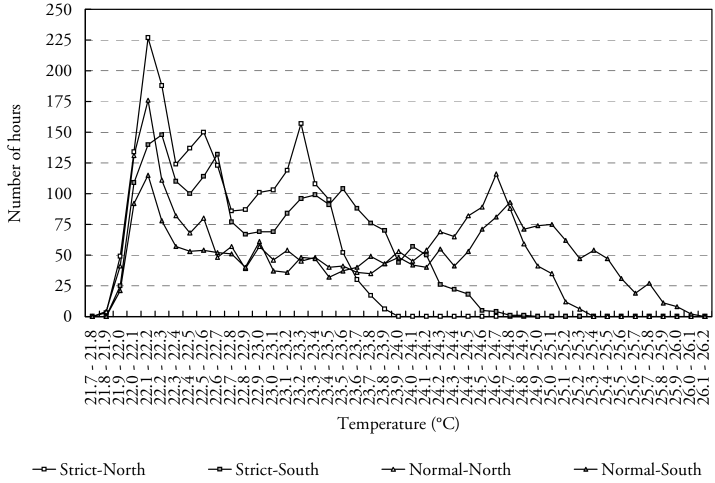


Figure 5.50 *Impact of control set points on directed operative temperature in north and south oriented single offices of the reference building.*

When the number of hours with certain directed operative temperatures (Figure 5.51) in the north facing single office (of the reference building) are compared with the north facing meeting room (strict and normal control) the large impact of the glass area is obvious. The directed operative temperature in the single office for both set points exceeds the allowed temperature limit by 1°C (regardless of the set point) while for the meeting rooms the difference is 2.5°C for the strict and 3°C for the normal set points. The impact of the glass area on the directed temperature is more intense for the south oriented zones.

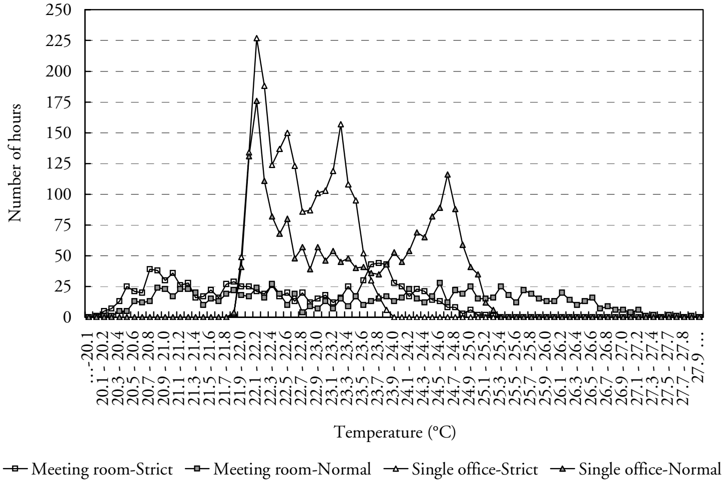


Figure 5.51 *Impact of control set points on directed operative temperature in single offices and meeting rooms for the reference building (north orientation, 3rd alternative).*

For the normal control set points, the directed operative temperature varies from 20ºC to 28ºC for the meeting room (south orientation) and from 21.5ºC to 26.5ºC for the other zones (as shown in Figure 5.52). For the poor control set points the variation in directed operative temperature is even wider as shown in Figure 5.52. The impact of the directed operative temperature on the occupants' comfort will be shown in the PMV and PPD diagrams.

The results for different oriented zones for the 60% and 100% glazed building are similar. However, in the 100% glazed corner offices the potential overheating problem is evident since both external walls are fully glazed (resulting in a higher window area to room volume ratio). The directed operative temperatures in the south oriented corner rooms vary much more than in the other zones as shown in Figure 5.52.

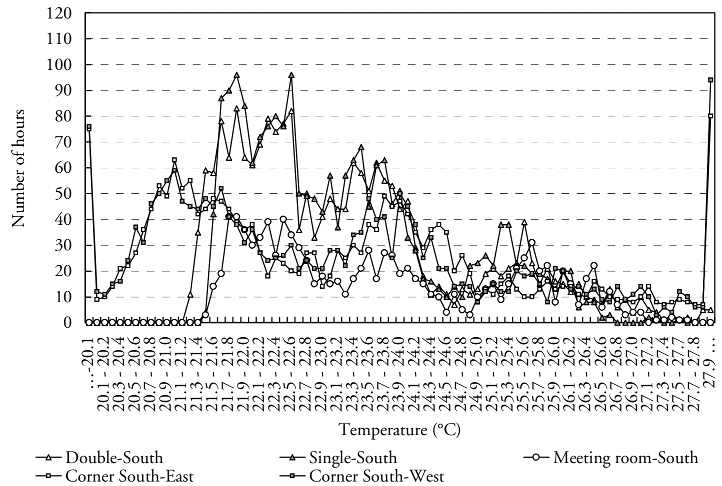


Figure 5.52 *Number of hours between certain directed operative temperatures for the 100% glazed south oriented zones (strict control set points, 3rd alternative).*

5.5.3 Perception of thermal comfort (PMV, PPD) in the reference building

The perception of thermal comfort for zones with different facades, orientations and set points is studied in this section. As stated above, the occupants were placed 1m from the external wall (window).

For the strict control set points in the reference building, neither the PMV nor PPD values differ much between the alternatives. The PMV is always below 0 for the offices (regardless of the orientation) while for the meeting rooms (higher glazing area) it is positive, mostly during the summer months. A diagram with the monthly average PMV for the south oriented zones is presented in Figure 5.53. Clearly, the corner office room is the one with the lower PMV values due to the lower internal gains (lower occupant density). For the meeting room, the PMV is positive from the beginning of May until the end of September.

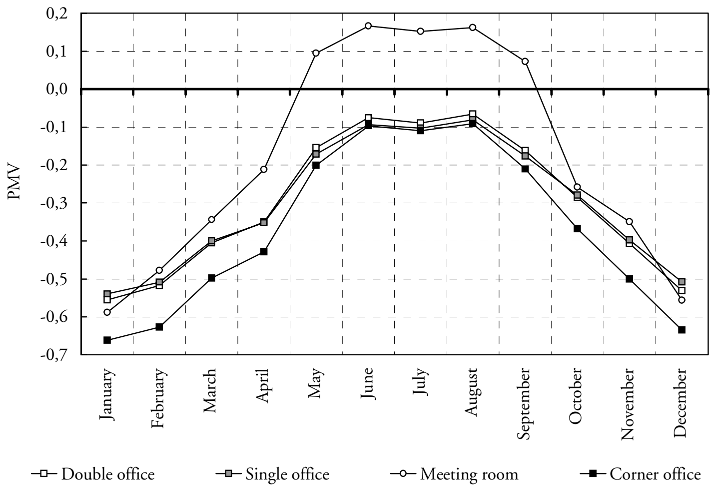


Figure 5.53 *Monthly average PMV for south oriented zones of the reference building with strict set points.*

For the north oriented zones, the meeting room is slightly colder than the single and double offices during the heating seasons (while for the south oriented ones, it was warmer almost throughout the year) as shown in Figure 5.54. The PMV values for the offices do not change dramatically for the north and south orientations due to the low variation in the allowed air temperature and the small (compared at least with the meeting rooms) glazed area.

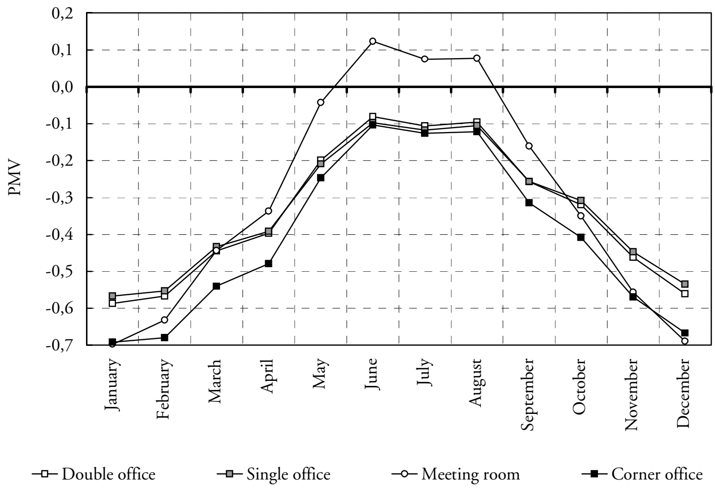


Figure 5.54 *Monthly average PMV for north oriented zones of the reference building with normal set point.*

When the warmest (during the cooling period) and coldest zone for the warmest and coldest orientations are compared (Figure 5.55), it is obvious that the upper temperature set point of 23°C is quite low for the cell type reference building, since the recommended (ISO Standard 7730) PMV variation is within the limits of -0.5 and +0.5. During the summer the negative PMV values show that the upper set points are pretty low for the assumed occupant clothing and activity.

The lower PMV values during July are not caused by the lower outdoor temperatures, but are due to the lower internal gains (75% of the occupants are working during June and August and 50% during July). The larger glass area of the meeting room increases the difference in the PMV for the south and north orientations compared with the corner offices. The schedule for the occupation of the meeting room is also another parameter that can explain the higher PMV values in the meeting room.

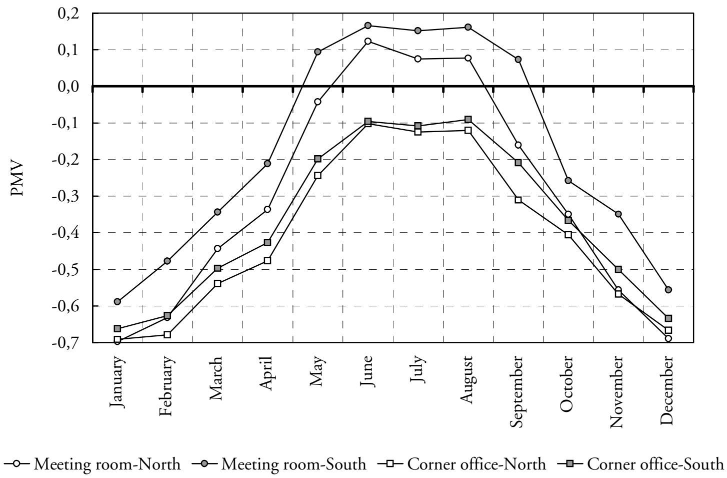


Figure 5.55 *Monthly average PMV for south and north oriented corner offices and meeting rooms with strict set points (reference building).*

Since the strict control set points result in low PMV values, the south orientation appears to give the lowest PPD values. In Figure 5.56 a diagram of the number of hours with certain PPD for north facing zones is presented. The single and double offices have similar PPD due to the similar internal loads. The lower loads of the corner office result in higher PPD values. The reason that the PPD curve is lower than the other ones is that the meeting room is occupied for fewer hours (50% less).

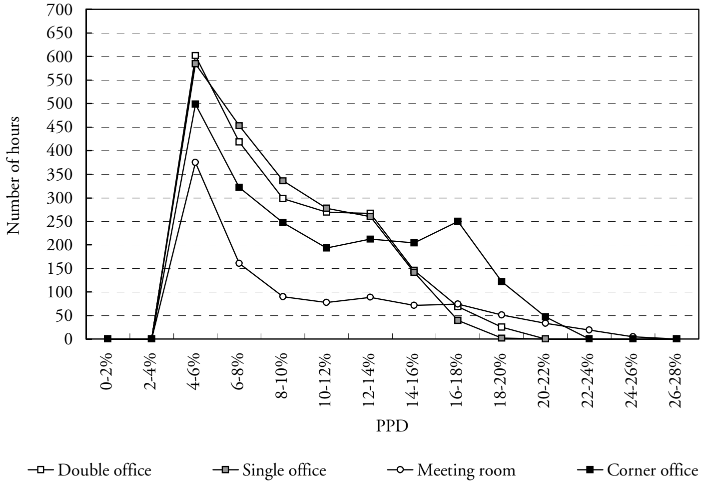


Figure 5.56 *Number of hours with certain PPD for north facing zones of the reference building with strict set points.*

The impact of orientation on the PPD is limited for the strict set points due to the narrow allowed air temperature variation. In Figure 5.57 the percentage of working hours with PPD of 10% and 15% is presented. For a PPD of 10% the single and double offices provide a better indoor thermal environment for the north, east and west orientations, while for the south orientation the meeting room appears to be better. The higher glazed area allows more solar gains (and thus the south orientation gives PMV values closer to 0 and consequently lower PPD values), but on the other hand the triple clear glazing of the reference building is a poor insulator causing discomfort mostly in the north oriented zones (during the heating periods).

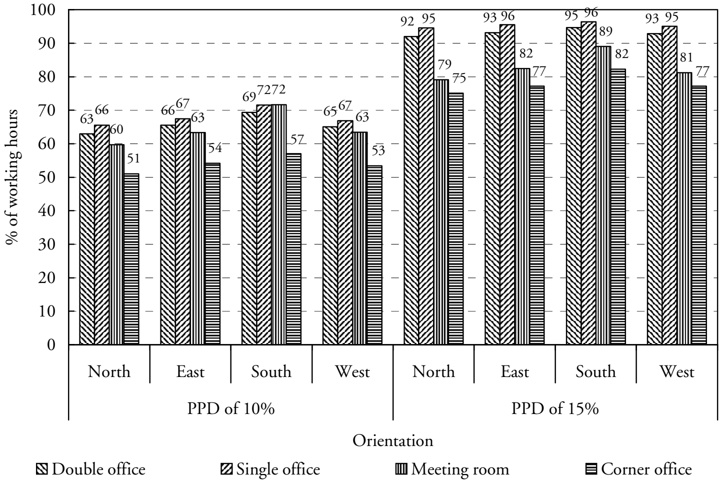


Figure 5.57 PPD of 10% and 15% for zones with strict control set points (reference building).

For the normal control set points the monthly PMV values of the south oriented zones are shown in Figure 5.58. The meeting room appears to be warmer (compared with the single and double offices) between March and October. The PMV in this case varies between -0.65 and +0.53 while for the same case (but for strict set points) the PMV was between -0.65 and +0.15.

For the north oriented zones the monthly PMV values are shown in Figure 5.59. The meeting room appears to be warmer (compared with the single and double offices) between April and September. The PMV in this case varies between -0.7 and +0.5 while for the same case (but for strict set points) the PMV was between -0.7 and +0.1.

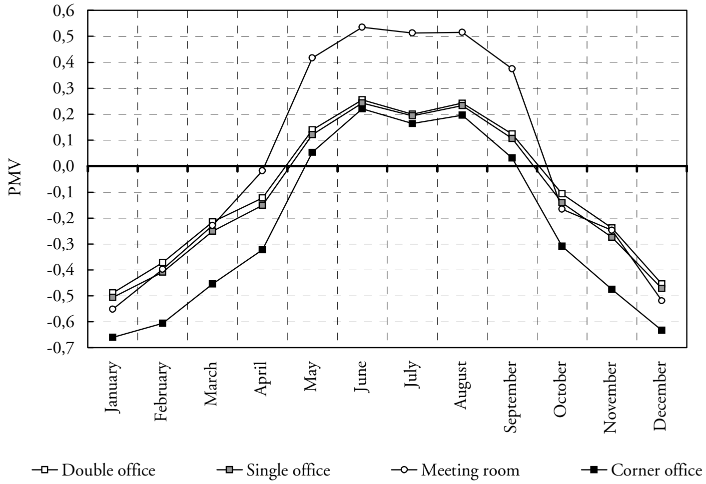


Figure 5.58 *Monthly average PMV for south oriented zones of the reference building with normal set points.*

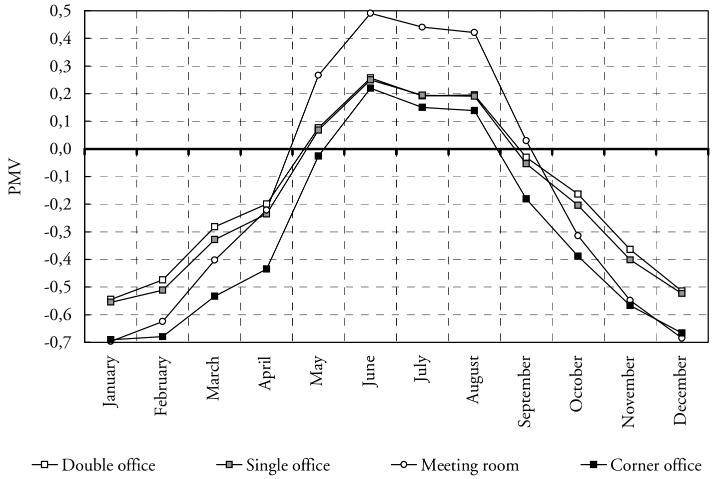


Figure 5.59 *Monthly average PMV for north oriented zones of the reference building with normal set points.*

When the warmest (during the cooling period) and coldest zone for the warmest and coldest orientations are compared (Figure 5.60), it is evident that the upper temperature set point of 24.5ºC allows a wide variation (at least compared with the strict set points) in PMV values. However, it is only the south oriented meeting room that slightly exceeds the recommended PMV limit of +0.5 (ISO Standard 7730). In the case of the normal set points the PMV variation between different orientations of the corner office increases (compared with the strict set points), making it obvious that the wider the allowed temperature limits, the greater is the impact of the orientation (even in zones with smaller glazed areas).

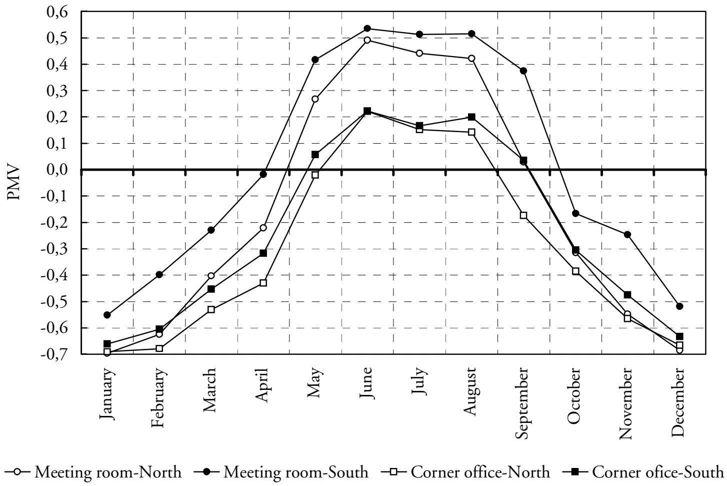


Figure 5.60 *Monthly average PMV for south and north oriented corner offices and meeting rooms with normal set points (reference building).*

Since the strict control set points result in low PMV values, the south orientation appears to give the lowest PPD values. In Figure 5.61 a diagram of the number of hours with certain PPD for north facing zones is presented. The single and double offices have similar PPD due to the similar internal loads. The lower loads of the corner office result in higher PPD values. The reason that the PPD curve of the meeting room is lower than the rest is that the meeting room is occupied for fewer hours (50% less).

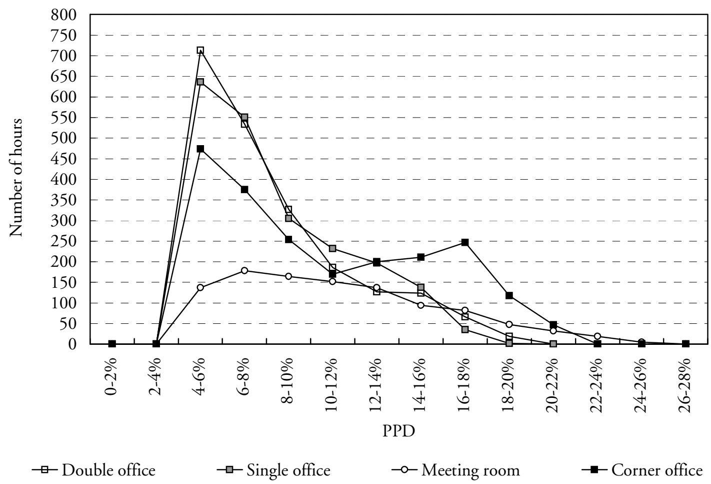


Figure 5.61 *Number of hours with certain PPD for north facing zones with strict set points (reference building).*

The impact of orientation on the PPD of the reference building is shown in Figure 5.62. Mostly for the meeting room, it is for no more than half the working hours that the PPD values are lower than 10%. However, the PPD values of 15% increase dramatically for all the zones reaching the levels of the strict controls.

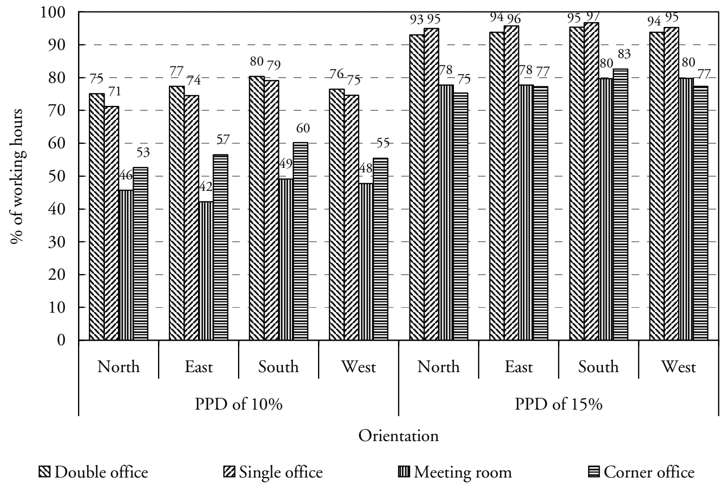


Figure 5.62 *PPD of 10% and 15% for zones with normal control set points (reference building).*

A comparison of the PPD of 10% and 15% for north and south facing zones (with strict and normal control set points) is presented in Figure 5.63. Both for the north and south oriented offices the number of hours with PPD values lower than 10% is higher for the normal set points. However, the meeting rooms with the strict set points seem to provide better thermal environment. It is evident that zones (with no temperature gradient, assumed in IDA ICE 3.0) with higher glazed areas need lower temperature set points in order to keep a low PPD level. On the other hand, draughts caused by (air and radiant) temperature difference can increase discomfort.

The number of hours with PPD lower than 15% is at the same levels for all the zones for the two set points. Only the south oriented meeting room (with normal set points) has fewer hours with PPD lower than 15%. For the meeting room the hours with PPD values lower than 10% are really reduced. However, the number of hours with PPD values of 15% increases for all the zones, reaching the levels of the strict controls (see Figure 5.62). This can explained by the wider PMV variation. The PMV of the normal control increases during the summer, increasing the number of dissatisfied occupants. The closer the PMV values are to 0, the lower are the PPD values. For the strict set points the PMV values exceeded the limits of +0.3 and -0.3 (which corresponds approximately to a PPD of 10% - see definition of PPD, PMV in Chapter 1) for a shorter time than those with normal set points, resulting in a higher number of hours with PPD values lower than 10%. However, since the PMV values do not exceed +0.5 (which corresponds approximately to a PPD value of 15%), the number of hours with PPD values lower than 15% is at the same level for the two control set points. The only zone where the PMV values exceed the limit of +0.5 is the south oriented meeting room (see Figure 5.64) and for this reason the hours with PPD values lower than 15% are fewer for the south oriented meeting room with normal set points.

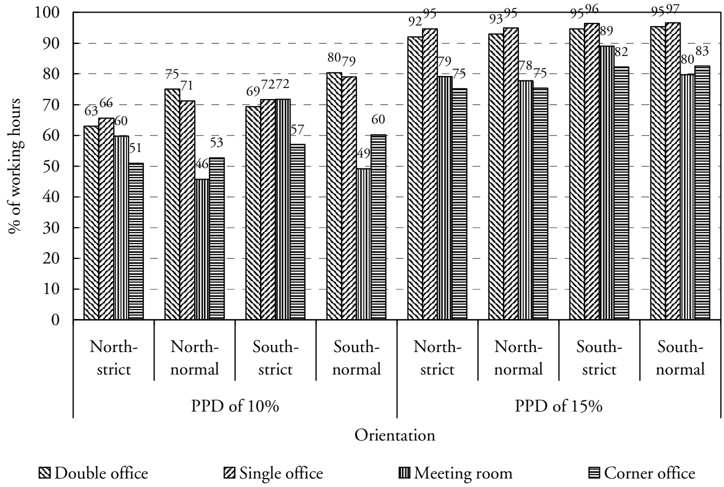


Figure 5.63 *PPD of 10% and 15% for north and south facing zones with strict and normal control set points (reference building).*

For the poor control set points the indoor thermal climate is not acceptable as shown in Figure 5.64. The variation in PMV for the south oriented zones is between -0.9 and +0.9.

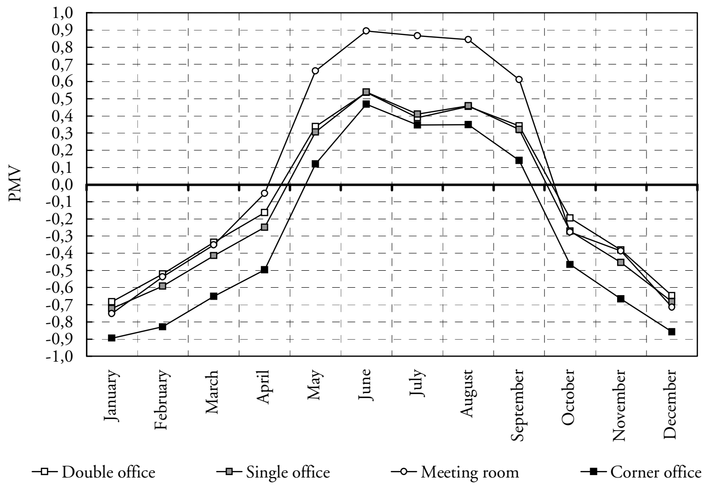


Figure 5.64 *Monthly average PMV for south oriented offices and meeting room with normal set points (reference building).*

Mostly for the meeting room, it is for no more than 27% of the working hours that PPD values are lower than 10% (the PPD values of 15% do not exceed 43%) as shown in Figure 5.65. For this reason the PMV and PPD are not studied further in this section.

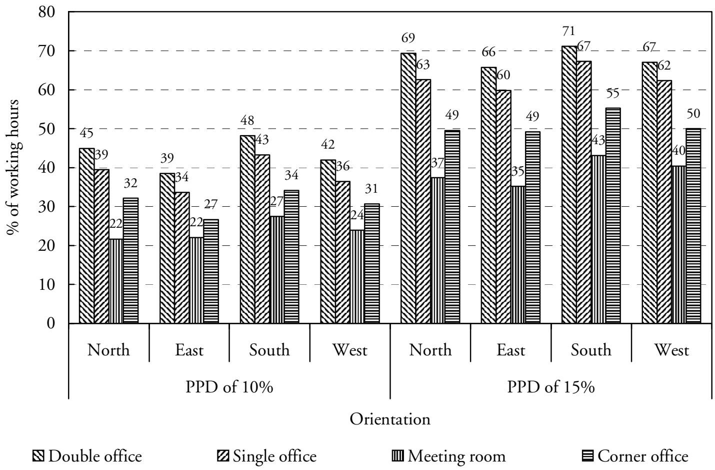


Figure 5.65 *Monthly average PMV for south oriented zones of the reference building with normal set points.*

5.5.4 Perception of thermal comfort (PMV, PPD) in the 60% and 100% glazed building

When the glazing area of the building is increased up to 100% the PMV values of the corner offices drop to -2 during December while for the rest of the working areas the PMV varies at reasonable levels (strict set points), as shown in Figure 5.66. The discomfort problem (both high and low PMV values) of the 100% glazed corner offices is caused by the higher glazing area to room volume ratio (compared with the rest of the zones) combined with the high thermal transmittance and solar factor of the windows. The insufficient heating capacity of the water radiators combined with the low thermal transmittance of the glazing result in low air temperatures during the heating seasons in the corner zones.

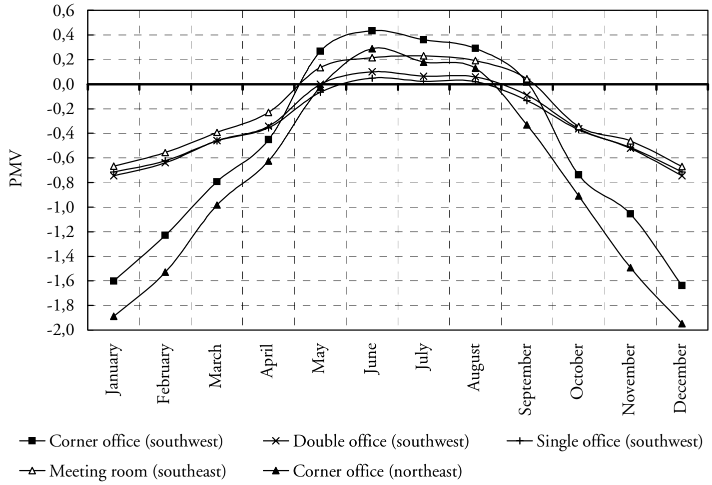


Figure 5.66 Monthly average PMV for south oriented zones of the 1st 100% glazed building with strict set points.

The influence of the window thermal transmittance on the air temperature of the 100% glazed corner offices (strict set point) is obvious when Figures 5.66 and 5.67 are compared. The difference in the PMV values during January and December between the first and third alternative reaches 0.5. The south oriented single and double rooms of the third alternative have similar PMV values as shown in Figure 5.67. The slightly higher window to room volume ratio of the double office results in slightly higher PMV values during the summer. The PMV values in the meeting room are higher than in the single and double offices due to the higher occupant density and the occupants' schedule (the room is empty during the early morning hours).

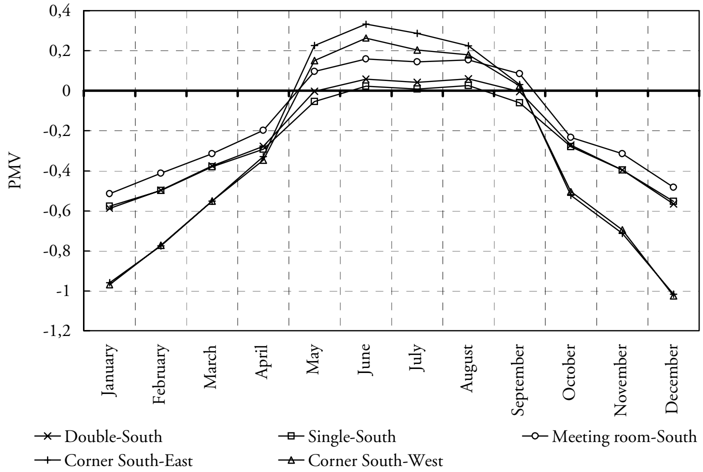


Figure 5.67 Monthly average PMV for south oriented zones of the 3rd 100% glazed building with strict set points.

In order to study the impact of window and shading device type on the perception of thermal comfort in the highly glazed corner offices, the southwest facing alternatives (1-7) were compared (Figure 5.68). As already pointed out, the first alternative with the triple clear pane gives really low PMV values due to the low thermal transmittance of the windows. The second alternative is the second warmest (due to the high solar factor of the glazing; g_{value}= 0.584). The only alternative warmer than the second one is the fifth. In this alternative the same glazing was used while the intermediate blinds were replaced by internal ones, increasing the effective solar factor and thus the directed operative temperatures and the PMV values. The curves of the third and fourth alternatives are quite close, with the third one being slightly warmer due to the higher solar factor of the glazing (g_{value}= 0.35 instead of g_{value}= 0.28). The sixth alternative, with the same solar factor as the third one, is slightly warmer due to the internal screens (lower $g_{effective}$ than the internal blinds). Finally, the seventh alternative with the fixed external louvres is colder throughout the year.

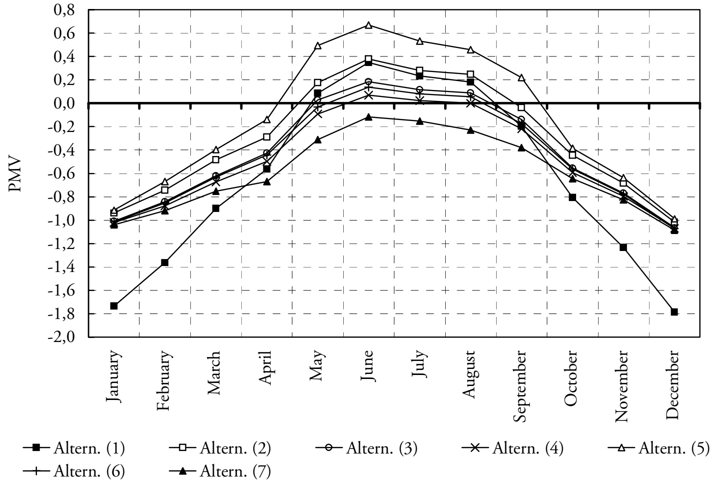


Figure 5.68 PMV for 100% glazed southwest corner offices (strict set points).

The impact of set point on the perception of thermal comfort (number of hours with PPD lower than 10% and 15%) is shown in Figure 5.69. For the first alternative the number of hours with PPD values lower than 10% is higher when strict set points are applied (positive values for the PPD of 10%). The zone most dependent on the set point in this case is the south east facing meeting room (due to the schedule of occupancy and the high internal loads, overheating problem occurs; thus, a stricter upper temperature set point of 23°C instead of 24.5°C improves the perception of the thermal climate). For PPD values lower than 15% the difference between the two set points decreases in most of the cases. In the case of the north west meeting room the higher temperature set point allows higher PMV values (increase in the low temperatures) while for the southwest it allows lower ones (increase in the already high temperatures).

For the second alternative, there are more PPD values lower than 10% for the case of the strict set points, while for PPD lower than 15% the normal set point is better for the northeast facing single and double office and the southeast facing meeting room. The results for the third, fourth and sixth alternative are similar. However, since there is a serious overheating problem in the fifth alternative, the strict control is better for both the PPD values of 10 and 15%. The exact opposite problem occurs for the seventh alternative in which the fixed horizontal louvres combined with the temperature limit of 23°C increase the PPD (low PMV values).

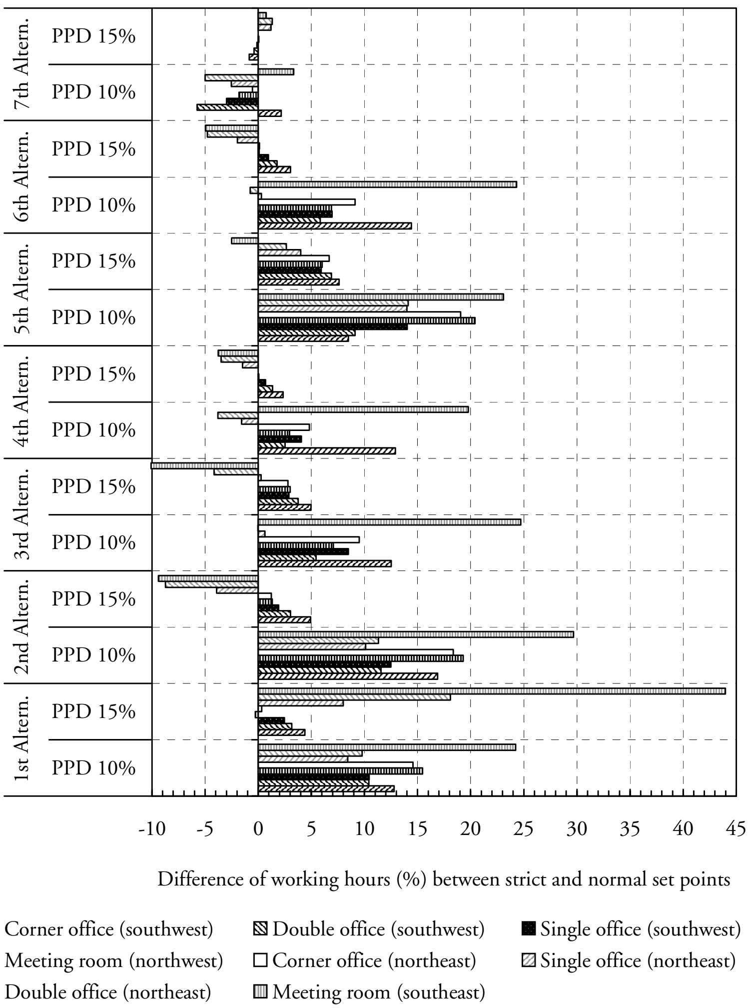


Figure 5.69 Impact of set point on the percentage of working hours with PPD lower than 10% and 15% for the 100% glazed alternatives.

6 Discussion and conclusions

In this chapter the energy and thermal comfort performance of the building is discussed for the simulated building alternatives. The studied parameters that influence the building performance (energy use and indoor climate) are the

- Plan type
- Building orientation
- Control set points
- Façade construction (type and size of window, type and position of shading devices)

Suggestions for further studies in order to improve the building performance are also discussed at the end of the chapter.

6.1 Plan type

Two office plan types were studied in this report. These plan types differ in the use of space (the open plan has more and bigger meeting rooms), the density and the total number of the occupants (319 and 395 occupants are present on average for the cell and open plan type respectively), the ventilation rates (higher total ventilation rates in the cell type plan) and the internal loads (equipment, lights and occupants).

The plan type of the office building is crucial for the building performance and the occupants' productivity. The energy use, the quality of the indoor climate and the acoustics are some of the performance parameters which are influenced by the plan type.

6.1.1 Energy use

Mainly due to higher internal loads and a different ventilation strategy (mainly lower ventilation rates), the open plan type tends to be warmer than the cell type and thus the cooling demand increases while the space heating demand decreases, especially for the strict heating and cooling set points. The difference between the total energy use for the two plan types is rather small and similar for all the building alternatives. For the reference building (window area 30% of external wall area) the energy use for heating the cell type office building (with normal set points) is 14% higher than for the open plan one. For the 60% and 100% glazed alternatives with the same window type (triple clear pane) the increase is 11%. A real highly glazed office building would of course have windows with a lower U-value and g-value. On the contrary, the cooling demand of the open plan type is much higher for the 30% glazed alternative (57%), while for the 60% and 100% glazed ones the cooling demand of the open plan type increases by 28% and 20% respectively. In any case, the impact of plan type is reduced for highly glazed alternatives (the large window area of the 100% glazed alternatives combined with the high thermal transmittance of the windows reduce the impact of plan type on the cooling demand as shown in Figure 6.1).

The higher glass area leads to a (small) decrease in the energy use for lighting. The higher energy use of the open plan type than the cell type (Figure 6.1) can be explained by the need for lighting properly the whole building (for the open plan type), since all of it is used as working area (for the corridor of the cell type half the lighting power is required).

The impact of plan type on heating and cooling demand is quite similar regardless of the window type used (see Figure 6.1). Generally, the impact of plan type on the cooling demand tends to increase for the alternatives with lower g and $g_{effective}$ values (e.g. the 7^{th} one with the fixed external louvres).

Finally, there is a 24% higher energy demand for the operation and cooling of the server rooms (regardless of the set point) for the open plan due to the increased number of occupants (assuming an energy use of 175 kWh/am^2 per occupant for the server rooms and 87.5 kWh/am^2 per occupant for cooling the server rooms).

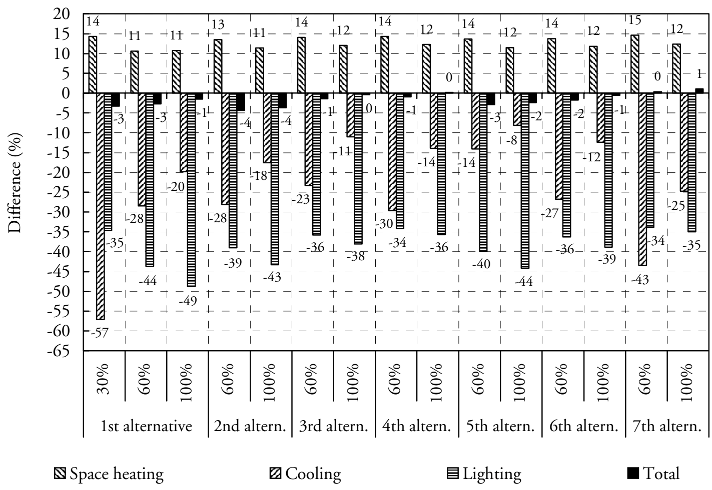


Figure 6.1 *Impact of the plan type on the energy use of the glazed alternatives. A detailed description of the highly glazed alternatives can be found in Subsection 3.3.2.*

6.1.2 Indoor Climate

As already pointed out, the open plan type is warmer than the cell plan type due to the higher internal loads and the different ventilation strategy. For strict set points the difference in monthly average air temperatures is rather small for the two plan types, while it tends to increase as the allowed temperature variation gets wider, as can be expected. The air temperature differences are larger during spring and autumn, when both heating and cooling are required.

There is a greater possibility of overheating in the cell type 100% glazed alternatives due to the insufficient cooling capacity. Mainly in the corner offices where the glass area to office volume ratio is high (almost double that in the rest of the zones) the air temperatures can exceed the allowed temperature limits. The alternatives where this is more likely to happen (due to insufficient capacity of traditional cooling) are the ones with windows with high solar factor values and internally placed shading devices. Similar problems with low temperatures due to insufficient power of the heating system can be noticed in alternatives with windows with high thermal transmittance values. The open plan type appears to be more stable in terms of temperature variation due to the increased office volume to window area ratio. Overheating problems are less likely to occur even if the total number of occupants is higher. The reason that these alternatives (in some cases with insufficient heating and cooling capacity) were studied was to simulate building alternatives with typical building installations and investigate whether these installations are sufficient for highly glazed alternatives.

Regarding the perception of thermal comfort, the open plan appears to provide a better thermal environment (lower monthly average weighted PPD values), mostly in the alternatives in which strict set points were applied. Due to low monthly average weighted PMV values (for certain clothing and activity of the occupants) caused by the low upper allowed temperature limit of 23°C, the higher internal loads of the open plan appear to be a positive influence on the perception of the indoor thermal environment. Low PMV values are also noticed during winter, in the glazed alternatives with external shading devices and in the ones with windows with reduced solar factor values, resulting in lower PPD values in the open plan building alternatives. However, in the cases with high allowed temperature limits (i.e. poor set points) the increased internal loads of the open plan type lead to thermal discomfort due to the high PMV values during mostly the summer months. The overheating problem leads to an unacceptable indoor environment in the cases with internal shading devices or high solar factor values.

The position of the occupants in the office space is also crucial for the perception of thermal comfort. Generally, in the cell offices most of the occupants are usually sitting close to the façade (1 m), while in the open plan type they are using all the office space i.e. some of them are not close to the window. Since the PMV depends on the directed operative temperature and consequently on the distance of the occupant from the window, the occupants far from the windows are more likely to be satisfied with the thermal environment. Moreover, there are more dissatisfied occupants when they are placed close to highly glazed facades, with high radiant temperatures, than when they are close to conventional facades with low radiant temperatures. For this reason the impact of floor plan on the perception of thermal comfort increases for highly glazed alternatives.

Parameters such as the use of space and the occupancy can also be important for the perception of thermal environment for all the occupants; e.g. open plan office buildings, for instance, tend to have more meeting rooms. Due to the higher density of this zone type, high PMV values are likely to occur during the summer months, increasing the discomfort problem. The number and activity of occupants (internal loads) and the periods of occupancy (vacations, etc) are also crucial for the perceived quality of the thermal environment. In the studied alternatives the assumed occupancy was 75% during June and August and 50% during July.

6.2 Orientation

6.2.1 Energy use

On a building level the orientation does not have much effect on the energy use, partly due to the fact that the two short facades and the two long facades are identical. The stricter the control set points, the smaller are the differences in the energy use for different orientations. The difference in energy use for the north-south and east-west oriented 100% glazed (3^{rd}) alternatives does not exceed 2.7%. Due to the small impact of the orientation on the total energy use, no further study has been made on a building level.

6.2.2 Potential overheating problem

The indoor climate (air temperatures and perception of thermal comfort) was studied on a zone level in order to better understand the influence of orientation, use of space and type and position of different façade elements on individual zones. The thesis is focused mostly on the cell type plan alternatives since in this plan type a variety of different kinds of zones was built for the simulated model.

The monthly mean air temperatures and directed operative temperatures, and the perception of thermal comfort (including numbers of hours with certain PPD values) for each zone were studied. One way to study the potential overheating is to calculate the cooling load for each zone, but the chosen IDA model provides this information only for the whole building. Simulating each zone separately with its own cooling unit, on the other hand, would take a large amount of time. The number of hours close to the upper allowed temperature limit was analyzed, as this is almost equal to the hours with cooling demand in order to keep the air temperature within the allowed limits. This indicator is not precise but in a comparative study it can show the risk of overheating problems for different orientations, glazed areas, control set points and internal loads for each zone type. The orientation of the zones is north, east, south and west for the strict, normal and poor control set points. The studied zones are the double and single office rooms, the meeting rooms and the corner office rooms. In this section only the 30% and the third 100% glazed alternative were studied. The main purpose was to study the impact of glazing type on different oriented zones, based on a realistic solution, pointing out the potential problems of single skin facades.

For the reference building and for the strict control set points, the monthly mean air temperature is not really influenced by the zone orientation, as can be expected (due to the narrow allowed air temperature variation). However, the zone type, with the larger mean air temperature variation (within the allowed air temperature range for a particular case) is the meeting room due to the highly glazed area. Since the mean air temperature variation in the different zones is pretty similar between the temperature limits of each set point, the potential overheating problem was studied.

For the strict set points of the reference building (cell type plan) the south orientation is slightly warmer i.e. more hours close to the upper temperature limit. The corner room, however, due to the lower internal gains (15 m^2/person instead of 10 m^2/person and 7.65 m^2/person for the single and double office respectively), reaches the temperature limit of 23°C for fewer hours as shown in Figure 5.44.

The high internal gains of the single and double office rooms (reference building), combined with the low upper temperature limit, result in a large number of hours with cooling demand, decreasing the effect of the orientation. The lower internal gains of the corner room, however, result in a larger difference in the number of hours when cooling is needed. As expected, the south orientation is the warmest. The west orientation is slightly warmer than the east, and the north one is the one with the lowest cooling demand. Similar is the situation for the meeting rooms (reference building) for the different zone orientations. The east orientation is however slightly colder (compared with the east oriented corner room) due to the different schedule (the meeting rooms are occupied from 10 o'clock in the morning, so the higher solar gains during the early morning hours do not affect the cooling load).

For the normal control set points the maximum allowed temperature limit is 24.5°C. Due to the higher allowed upper limit (compared with the limit of the strict set points where the impact of orientation on the cooling demand is reduced), the number of hours with cooling demand in the double office room is higher than that in the single room. Since the window area to room volume ratio of the single and double office room is almost the same (0.258 m^2/m^3 and 0.255 m^2/m^3 respectively), the temperature difference can be explained by the higher internal loads of the double office room (10 m^2/person and 7.65 m^2/person respectively). The impact of orientation on the number of hours with potential overheating (type of curve) for these two zones is very similar as shown in Figure 5.45. For the corner office room the number of hours close to the higher allowed air temperature limit is almost the same between the east and south orientations (1.7% more hours the south façade). When the curves with potential overheating in the corner offices for the strict and normal control set points are compared, it is obvious that the south oriented one is “cooler” for the normal set points. This can be explained when the south and east orientation of this zone type are compared for the normal set points (Figure 5.45). The south oriented corner office reaches the limit of 23°C for more hours than the east oriented one; however, the same thing does not happen for the limit of 24.5°C. The south facing offices get warmer during the late working hours, while the east facing ones get warmer during the morning. Due to the schedule of the occupants and equipment, after 17:00 the internal loads reduce to the minimum, decreasing the cooling demand of the south oriented corner zone. For the same reason the number of hours with the maximum allowed temperature is higher for the west oriented zones (compared with the east ones) for the strict and lower for the normal set points. In the two other office types, however, the higher internal loads increase the cooling demand before 17:00. These conclusions can provide useful information regarding the proper use of space for different oriented zones in order to avoid overheating problems or high cooling demands. It is clear that the impact of set points on overheating for a zone with certain internal loads and façade construction can differ for different orientations. Moreover, the overheating problem increases in highly glazed buildings due to fact that the external skin is much more sensitive to the outdoor climatic conditions.

For the poor set points the number of hours that cooling is used decreases dramatically for all offices, regardless of the orientation as shown in Figure 5.46. For the north facing single and double offices the cooling demand is the same as for the meeting rooms (although the meeting rooms are used half of the time). The further increase in the upper allowed temperature limit of the poor control set points results in an increase in the impact of the occupants’ schedule on the hours when cooling is used. The curve type of the potential overheating (for different orientations), when poor set points are applied (Figure 5.46), is different from that for the normal set points (Figure 5.45). As for the south oriented corner and single office rooms the further upper temperature limit of 26°C results in a smaller number of hours with potential overheating compared with the east facing ones. The lower the internal loads of a zone, (and the higher the maximum allowed temperature limit), the less the south oriented zones tend to overheat (compared e.g. with the west oriented ones). Thus, as shown in Figure 5.46, the number of hours with potential overheating in the west oriented zones is higher for the single and corner offices. For the highly glazed meeting room, however, the south orientation remains the warmer. From the above it is obvious that as the glazing increases in a zone, the impact of schedule or control set points decreases.

6.2.3 Directed operative temperatures

For the parametric studies of the directed operative temperatures for the reference building, the meeting room gives more obvious results due to the larger window area. For this reason this zone was chosen for the comparisons. As expected (see Figure 5.48), for strict control set points the number of hours with certain directed operative temperatures for the east and west facing meeting rooms are quite similar (maximum hourly temperatures of 26.5ºC and 27ºC respectively), while the north facing meeting room appears to be "cooler" (maximum directed operative temperature 25.4ºC) and the south facing one warmer (maximum directed operative temperature 28ºC). The impact of orientation on the directive operative temperature is similar for the rest of the zones of the reference building.

Generally, the impact of orientation increases as the window to external wall area ratio increases as shown for the 100% glazed meeting rooms (Figure 5.49). However, the lower thermal transmittance of the window (3^{rd} 100% glazed alternative) in this case results in higher minimum temperatures. Thus, the minimum directed operative temperature in this case is 21.3°C while for the reference building (windows with triple clear pane) it is 20.1°C.

6.2.4 Perception of thermal comfort (PMV, PPD) in the reference building

The impact of orientation on the PPD is limited for the strict set points due to the narrow allowed air temperature variation (see Figure 5.57). For a PPD of 10% the single and double offices provide a better indoor thermal environment for the north, east and west orientation while for the south one the meeting room appears to be better. As already described, the upper temperature limit of 23ºC is rather low since the PMV values during the summer months hardly reach the neutral (0) PMV values. Thus, the higher glazed area of the meeting rooms when facing the south allows more solar gains (resulting in PMV values closer to 0 and consequently lower PPD values). On the other hand, since the triple clear glazing (used in the reference building) is a poor insulator (due to the high thermal transmittance) the PMV values reduce even more for the rest orientations. The same problem can be noticed in all the zone types, but due to the larger window area of the meeting room this tendency increases, showing clearly that the impact of orientation increases in highly glazed building alternatives.

When the upper allowed temperature limit increases to 24.5°C (normal set points, Figure 5.62), the thermal comfort improves for all the zones but the meeting rooms, regardless of the orientation (PPD values of 10%). The high glazed area of the south oriented meeting rooms that improved the thermal environment for the maximum air temperature limit of 23°C (raising the PMV values closer to 0) brings the opposite results when the upper temperature limit of 24.5°C is applied, since it raises the PMV values causing discomfort due to a warm indoor climate. The same but less intense effect is noticed for the other orientations. From the above it is obvious that the selection of the allowed air temperature variation should be considered more in highly glazed alternatives since PMV variation tends to increase in a different way depending on the orientation of the zone. The PPD values of 15% are similar for the strict and normal set points.

For the poor control set points the indoor thermal climate is not acceptable as shown in Figure 5.64. The variation in PMV for the south oriented zones is between -0.9 and 0.9. Mostly for the meeting room, PPD values lower than 10% do not occur for more than 27% of the working hours (the PPD values of 15% do not exceed 43%) as shown in Figure 5.65. For this reason the PMV and PPD are not studied further.

For the 100% (1st) glazed alternative the perception of thermal comfort is studied mostly for a cross comparison with the reference building. When the glazing area of the building increases up to 100% the range of the PMV values increases dramatically regardless of the set point. Especially during the winter months the PMV values can reach -1.9. The discomfort problem (both high and low PMV values) in the 100% glazed corner offices is caused by the higher glazing area to room volume ratio (compared with the rest of the zones), combined with the high thermal transmittance and solar factor of the windows. The low PMV values, however, increase when a window with lower thermal transmittance is applied as shown in Figure 5.68. On a zone level the corner offices appear to have low PMV values (Figure 5.67) during the winter months (for the strict set points) even in the case with improved windows.

6.3 Control set points

The control set point is a parameter that has a great influence on the energy use of the building alternatives. Strict set points have the highest energy demand since the allowed air temperature variation stays in the narrow limits of 22ºC and 23ºC. For the normal set points the upper temperature limit increases up to 24.5ºC and for the poor one the allowed air temperatures are between 21ºC and 26ºC.

6.3.1 Energy use

A cross comparison of the impact of set points on the 30%, 60% and 100% glazed alternatives with triple clear glazing is shown in Figure 6.2. For the cell type office reference building the energy use for heating decreases by 7% for the normal control set point and by 16% for the poor set point (compared with the strict one). For the open plan type the heating demand decreases even more, by up to 11% and 24%. Although the minimum temperature limit is the same for the strict and normal control set points (22ºC), the strict set points reduce the possibility of storing heat (thermal mass), increasing the heating demand. For a larger window area (60% alternatives) the difference drops to 5% and 7% for the cell type and to 14% and 19% for the open plan type. As the window area increases even more the impact of set points decreases even more (3% and 5% for the cell and 12 % and 13% for the open plan respectively) as shown in Figure 6.2.

For the normal control set points the maximum allowed temperature is 24.5°C while for the strict and poor set points it is 23°C and 26°C respectively. The cooling demand for the normal (compared with the strict) set point is 45% lower for the cell and 39% lower for the open plan type. The decrease for the poor type is as much as 65% and 64% respectively. The decrease in the impact of the set point on the cooling demand is similar to the decrease in the impact on the heating demand as the window area increases to 60% and 100%.

The impact of the set point on lighting properly the cell type offices, however, increases somewhat as the window area increases, due to the provision of daylight.

A cross comparison of the impact of set points on the 100% glazed cell type alternatives is shown in Figure 6.3. The impact of set points on heating demand tends to be higher in the “warmer” alternatives (e.g. those with windows with high solar factor values). In a similar way, the impact of set points increases in the “colder” alternatives (e.g. those with windows with low solar factor values). Since the thermal transmittance is kept the same in the 2nd to 7th alternatives, the heat balance depends mainly on the solar factor. As expected, the impact of set points on alternatives with high g values is larger than on those with low g values.

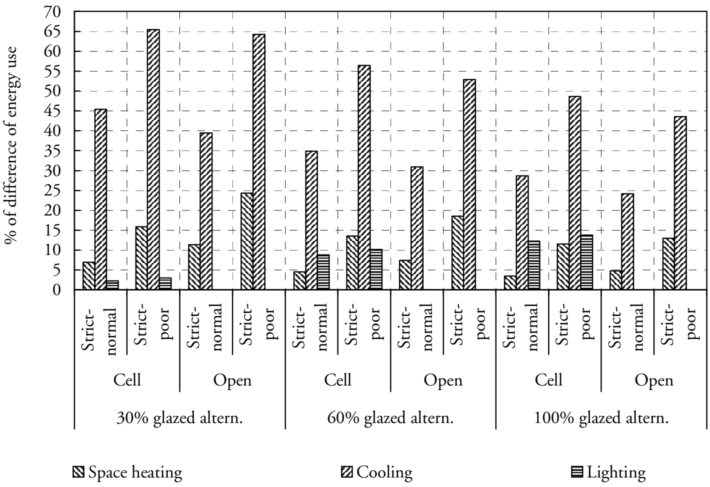


Figure 6.2 *Impact of set points on the energy use for the 30%, 60% and 100% glazed alternatives with triple clear glazing.*

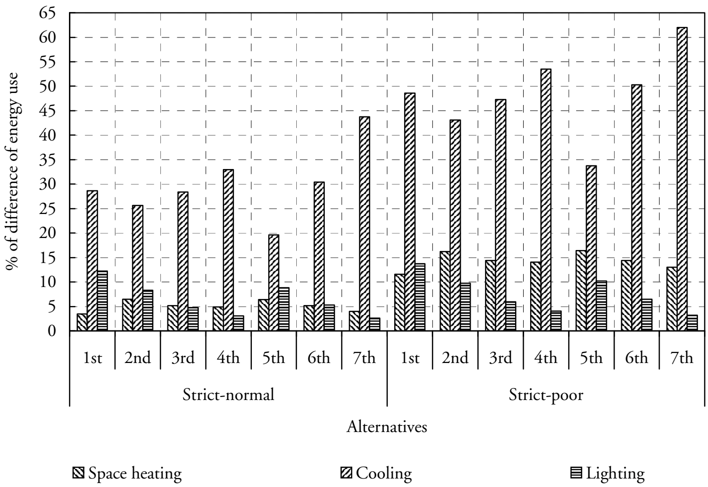


Figure 6.3 *Impact of set points on the energy use for the 100% glazed cell type alternatives.*

From the above, it is obvious that the impact of set points (regarding energy use for heating and cooling) is higher in the alternatives where it is easier to control the indoor environment. Thus, the higher impact of set points on the energy use is noticed in alternatives with reduced window area, lower solar factor and smaller zones (cell type). Windows with high thermal transmittance and solar factor decrease the impact of set points on heating and increase it on cooling.

6.3.2 Indoor climate

Often people relate a narrow variation in air temperature with a more pleasant indoor thermal environment. However, a constant temperature throughout the year may often cause discomfort problems mainly due to different clothing levels (e.g. occupants are wearing fewer clothes during the summer increasing the possibilities to feel colder as the temperature level remains the same all the year round) and times with increased difference between the air temperature and radiant temperature. The risk of high difference between radiant and air temperature increases with the glazing area of the façade. The occupancy (number of occupants, schedule, activity level, etc), the clothing level, the position of the occupants in the office space, the façade construction (window type and size, type and position of the shading devices), orientation and other parameters should be considered carefully before determining the proper indoor air temperature limits. Individual controls (e.g. openable windows) can improve the quality of the thermal environment since the occupants can influence the indoor temperatures. This is easier to arrange in cell than in open plan offices.

Generally, the strict set points result in smaller variations in monthly average weighted PMV values. When these values are close to neutral (= 0, or between -0.3 and +0.3) the PPD is lower than 10%. The normal and poor set points, however, result in a larger variation in PMV values. When these values do not exceed the limits of -0.5 and +0.5, the PPD values are lower than 15%. According to ISO Standard 7730 a good indoor environment is provided when PPD values of 10% (or lower) are provided 90% (or more) of the time. This goal is not reached in most of the alternatives. However a PPD of 15% is provided instead. Liddament, (1996) mentions that even when the average of the predicted mean vote was zero, i.e. a neutral thermal environment, the 5% of the test occupants were dissatisfied.

Due to the lower variation in the monthly average weighted PMV values, the strict control gives PPD values of 10% or lower for more hours in a year than the normal set points. The number of hours, however, with PPD values of 15% or lower is similar for the two control set points (often the normal set points result in a slightly higher number of hours).

Apart from the range of variation in the PMV values that can be ensured with narrow variation in air temperatures and windows with low thermal transmittance and solar factor (see Figures 5.27 and 5.28), the most important requirement is for these values to be as close as possible to 0. This can be achieved by selecting appropriate minimum and maximum temperature limits according to the clothing, the activity level, the façade construction, or even the orientation of the zone. The strict set point of the 5th alternative gives very similar PMV values with the normal set point of the 7th one for the 60% glazed alternative (see Figure 6.4). This means that a proper choice of façade construction can allow a wider range of temperature set points, providing similar quality of thermal environment with lower energy demand. However the upper temperature limit of 23°C (strict set point) appears to be low in the case with the fixed external louvres (alternative 7) while the upper temperature limit of 24.5°C appears to be high for the alternative with high g and $g_{effective}$ values (alternative 5).

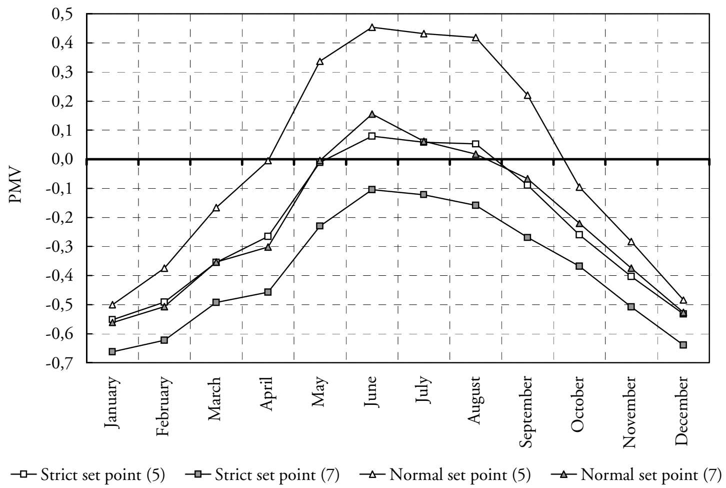


Figure 6.4 Weighted average PMV for the 5th and 7th 60% alternatives (strict and normal control set points).

The conclusions from the study of individual zones are similar. South oriented zones tend to be warmer, so lower upper temperature limits can ensure PMV values closer to 0 during the summer months. On the other hand occupants placed in north oriented zones with low internal loads tend to feel slightly cold during the summer when an upper limit of 23°C is applied.

A parameter that also influences the control set point strategy is the window area. Highly glazed buildings tend to need more constant air temperatures throughout the year in order to keep the PPD values low. Big differences between mean air and radiant temperatures, however, can in result in discomfort caused by low or high PMV values and draughts. Since the PMV values depend on the directed operative temperatures and consequently on the radiant temperatures, constant air temperatures can ensure a more neutral indoor environment.

6.4 Façade construction

In this section a cross comparison is carried out in order to study the influence of window area and type on energy use and indoor climate. Different windows and shading devices were applied in the 60% and 100% glazed alternatives.

6.4.1 Energy use

In order to study the impact of glass area on the energy use, 60% and 100% glazed alternatives with triple clear glazing (as in the reference building) were generated (in reality windows used for highly glazed alternatives have lower thermal transmittance). A cross comparison diagram of energy use of the 30%, 60% and 100% glazed alternatives (cell type) with strict and normal set points is presented in Figure 6.5.

The increase in the total energy use for the 60% glazed building is 23% regardless of the set point (compared with the reference building). The increase for the 100% glazed alternatives is 45% for the strict and 47% for the normal set points. Both the heating and cooling demand increase in the highly glazed building alternatives as shown in Figure 6.5. However, the increase in cooling demand of the 100% glazed building that reaches 112% for the strict and 177% for the normal set points, is impressive.

One of the main arguments for using increased glazed areas in buildings is the provision of better indoor environment due to daylight. However, the increased window area does not necessarily lead to a reduction in energy use for lighting the building properly. To make the use of daylight more efficient attention has to be paid to how the daylight is controlled and brought into the building. Traditional control of solar shading and lighting was applied to the cases studied in this report.

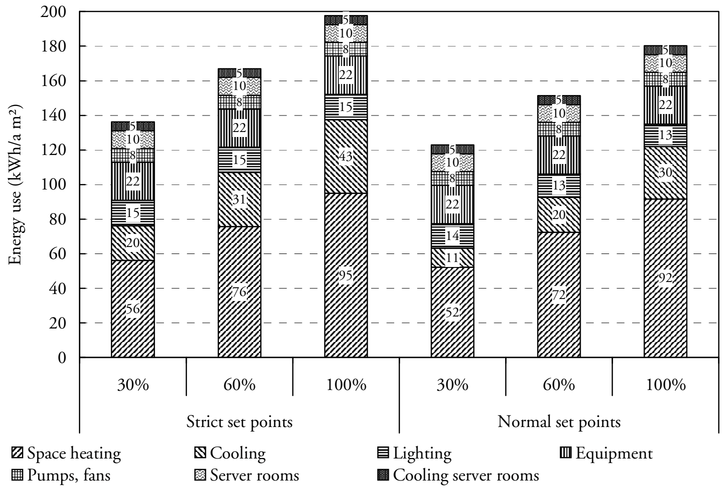


Figure 6.5 *Energy use of the 30%, 60% and 100% glazed alternatives (cell type, triple clear glazing) with strict and normal set points.*

A cross comparison of the 60% and 100% glazed alternatives with different windows and shading devices applied, shows that the difference in the total energy use (compared with the reference building) is reduced when the thermal transmittance and the solar factor decrease. In order to study briefly the impact of the windows and shading devices on the energy use, the seven 100% glazed alternatives with normal set points (cell type plan) are compared (Figure 6.6). For the best alternative the total energy use of the glazed alternative is only 20 % higher than for the reference building

A decrease in the thermal transmittance of the window (alternatives 2-7) results in a reduction in the energy use for heating and a smaller increase in cooling demand (comparison of alternatives 1 and 2). The alternatives (2nd and 5th) with high solar factor values (0.584) have also a slightly lower heating demand (compared with the 3rd one with g=0.354), while the one (4th) with lower g values (0.27) has slightly higher ones. The effect on cooling demand is the opposite; the 4th alternative uses less energy for cooling than the 3rd and 5th.

Another parameter studied was the position of shading devices on the energy use. Intermediate blinds result in lower $g_{effective}$ values and thus lower energy use for cooling. When the 2nd and 5th alternatives (same window and shading devices properties) are compared, it is obvious that the cooling demand increases dramatically (37%) when the blinds are placed inside. The heating demand is almost the same (slightly higher in the 2nd alternative), since the blinds were used mostly during the warm periods. When fixed external louvres are applied (7th alternative) the cooling demand reduces dramatically while the heating demand increases. Different types of internal shading (blinds in the 3rd and screens in the 6th) with similar properties do not much influence the energy use.

The type of glazing (solar factor values) influences the energy use for lighting in the building. For a set point of 500lux at the work place the energy use increases up to 14.3 kWh/m^{2}a when fixed external louvrers are applied (seventh alternative) from 12.9 kWh/m^{2}a (first alternative). Generally, the low g and $g_{effective}$ values lead to increased lighting demand.

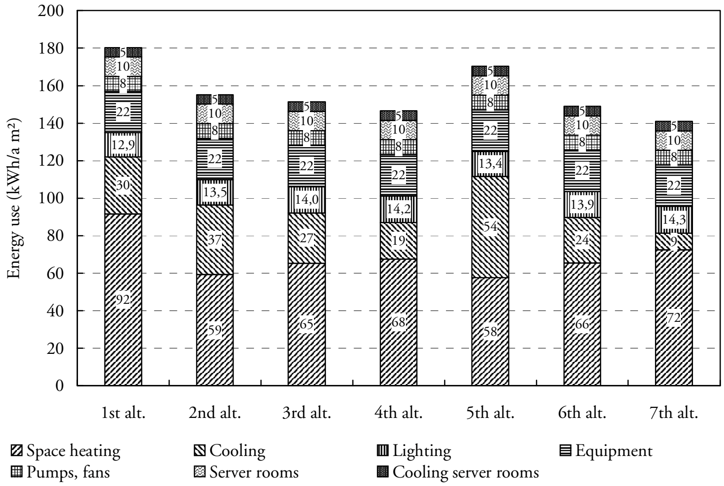


Figure 6.6 *Impact of the window and shading devices on the energy use. The different glazing alternatives are described in detail in Subsection 5.2.5.*

Finally a comparison of the energy use for the reference building with the 60% and 100% 3rd (typical highly glazed alternative) and 7th (alternative with the lowest energy use) alternatives follows (Figure 6.7). For the strict set points the increase in (total) energy use of the 3rd 60% glazed alternative is 7% (compared with the reference case) while for the 100% glazed one it is 22%. The energy use of the 7th 60% glazed alternative is almost the same (0.4% higher) as in the reference case, while the 100% glazed one uses 11% more energy. The differences for the normal set points are slightly increased as shown in Figure 6.7 (the total energy use of the 100% glazed alternative was 15% higher than for the reference building). It is obvious that a proper choice of windows and shading devices can dramatically reduce the energy difference between the reference and the highly glazed case.

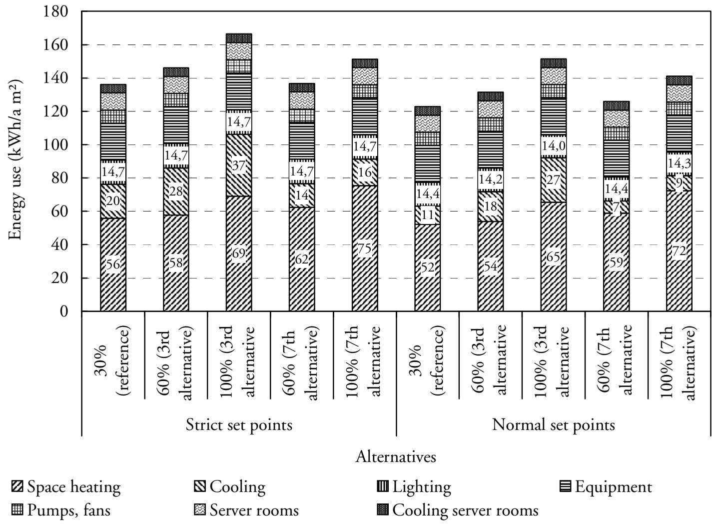


Figure 6.7 *Energy use for the reference and the suggested building alternatives.*

6.4.2 Indoor climate

As already stated, the perception of thermal comfort depends on different parameters (clothing, occupancy activity level, orientation, control set points, etc). In this section, general comments are made regarding the impact of the window and the shading devices on the perception of thermal comfort.

The first glazed alternative (triple clear glazing) tends to give both high and low PMV values due to the high thermal transmittance and solar factor. The upper allowed air temperature of 23°C appears to be fairly low since the PMV during the summer months hardly reaches the neutral conditions (= 0). When the thermal transmittance of the windows (second alternative) is increased the heating problem of the corner zones is solved and the (minimum) PMV values during the winter increase (from -0.7 to -0.5 for the 60% and from -0.8 to -0.6 for the 100% glazed alternatives). The (maximum) PMV values during the summer months are almost the same since the solar factor values were kept the same. The difference in the thermal transmittance values results in a slight increase in the PMV values of the second alternative during the cooling periods. When the solar factor of the glazing in the third alternative is reduced the PMV values drop during the summer resulting in a lower number of hours with PPD up to 10% (for a PPD of 15% the number of hours for the 2nd and 3rd alternatives is almost the same). A further decrease in the solar factor of the fourth alternative brings the same results as before, increasing the number of dissatisfied occupants. When the solar factor increases (as in the second alternative) and intermediate blinds are place instead of internal ones (that give higher $g_{effective}$ values) then an overheating problem occurs. The cooling capacity of the cooling beams is insufficient in the corner zones and the PMV values increase. For the strict set points the fifth alternative appears to provide better thermal environment while for the normal set points the temperature rises causing discomfort problems. The alternative with internal screens (sixth) provides a quality of thermal environment similar to that in the third alternative. Finally, when the fixed horizontal external louvres are applied (seventh alternative) the upper limit of 23°C appears to be very low, increasing the PPD values. For the normal control however the PMV increases giving PPD values similar to those in the third alternative.

A cross comparison of the 30%, 60% and 100% glazed alternatives with triple clear panes shows (Figure 6.8) that the larger window to external wall area ratio leads to larger discomfort problems during the whole year. During the winter the PMV drops from -0.55 (reference building) to -0.82 (100% glazed alternative) and during the summer it increases from 0.3 (reference building) to 0.45 (100% glazed alternative). This corresponds to a decrease in the number of hours with PPD values lower than 10%. The number of hours with PPD values lower than 10% is 73% for the reference building, 57% for the 60% glazed alternative and 44% for the 100% glazed alternative. A window type (3rd 100% glazed alternative) with lower thermal transmittance and solar factor results in an increase in the minimum PMV values (-0.62) during the winter (Figure 6.8) and a slight decrease during the summer. The number of hours with PPD values lower than 10% in this case is 57%. From the above it is obvious that the quality of thermal comfort decreases for the highly glazed alternatives due to the high or low surface temperatures of the external wall.

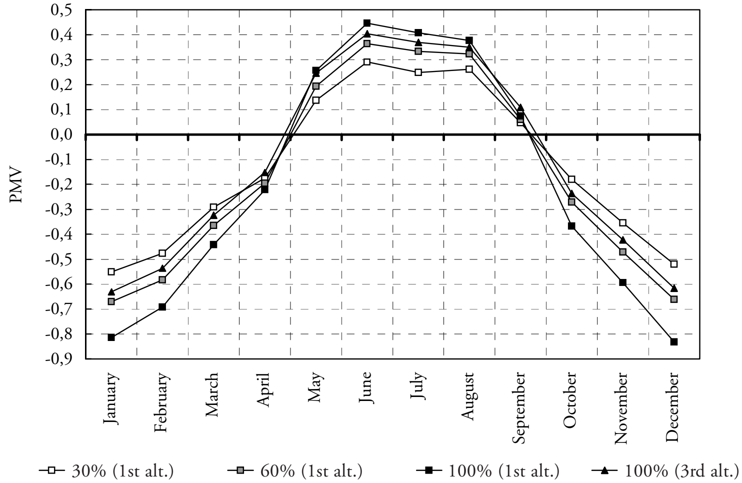


Figure 6.8 *Cross comparison of the 30%, 60% and 100% glazed 1st and 3rd alternatives (cell type, normal set points).*

6.5 Further study

Highly glazed single skin glazed office buildings tend to use more energy than buildings with a conventional façade (30% window to external wall area ratio) since the external skin is more sensitive to the outdoor climatic conditions. Moreover, the temperatures of the inner (glass) layer can often become a problem since they may provide a poor thermal environment mostly for the occupants sitting close to the façade. A proper combination of window type, shading devices and control set points can partly solve this problem for certain building alternatives. In order to further improve the building performance new technologies should be evaluated e.g. double skin facades

Therefore the integration of double skin facades will be studied during the next phase of the "Glazed Office Buildings" project. The main focus is given to the reduction of energy use and the improvement of indoor climate, primarily compared with highly glazed single skin glazed alternatives, but also with the traditional building (reference building). Some of the potential advantages of double skin facades are described below.

The cavity of the double skin facade can function in several ways. During the winter, the cavity can function as a thermal buffer, increasing the air temperature and thus improving the temperatures of the inner layer and consequently the thermal comfort of the occupants (radiant temperatures closer to the air temperature increase the directed operative temperatures and in the same way reduce the possibility of draughts). It might also be possible to succeed in energy reduction when this air is introduced to the inside (as natural ventilation or through the air handling unit) due to the higher air temperature.

The position of shading devices can play an important role in reducing the temperature of the air in the cavity during the summer months, thus decreasing the energy use for cooling. As studied for the single skin façade alternatives, the fixed external louvres dramatically reduce the energy use for cooling but also increase the heating demand since they are used all the year round. If the double skin facades are designed properly, they can probably result in similar cooling reduction during the summer months (by extracting the warm air) and during the winter by warming it. The protection of the shading devices, since they are placed inside the cavity, is also an important aspect regarding the maintenance cost.

The users often have a positive perception of natural ventilation. Since the double facades are more burglar proof than the single skin ones, the building can be also naturally ventilated. During the night, the natural ventilation can reduce the indoor temperature during the summer months.

Cavities with different material types (panes, shading devices), geometries (depth and height), position of shading devices and ventilation strategies will be studied in order to succeed in energy reduction and improved indoor environment. “Cold” cavities can be achieved with cavities of large depth, shading devices placed closed to the external pane and proper choice of panes, resulting in lower cooling demand. “Warm” cavities can be achieved with narrow depths, shading devices placed closed to the internal pane and proper choice of panes, resulting in lower heating demand. The optimisation of the cavities regarding the energy use and thermal comfort of the building will be the main aspect of further research into double skin facades.

Within the “Glazed Office Buildings” project additional aspects will be studied (life cycle cost estimation, visual comfort, exposed thermal mass, night cooling etc) in order to improve the overall performance of office buildings. Clearly the traditional office building as well as the single skin glazed office building can be improved as to indoor climate and energy use.

7 Summary

Highly glazed office buildings are considered to be airy, light and transparent with more access to daylight than traditional buildings, but their energy efficiency is often questioned. During the nineties many highly glazed office buildings with single and double skin glass facades were built. In order to improve the building's performance, while maintaining the concept of transparency, double skin facades have been developed. Today the knowledge of function, energy use and visual environment of office buildings with highly glazed facades for Scandinavian conditions is insufficient. Therefore, a project was initiated to gain knowledge of possibilities and limitations with glazed office buildings in Scandinavian climates regarding energy use and indoor climate. This means further development of calculation methods and analysis tools, improvement of analysis methodology, calculation of life-cycle costs (LCC), compilation of advice and guidelines for the construction of glazed offices and strengthening and improving the competence on sustainable buildings in Sweden.

The choice of the envelope type is crucial for the energy efficiency and the indoor climate. The energy use for different highly glazed building alternatives may vary more than for buildings with traditional façades since the glazed alternatives are particularly sensitive to the outdoor climatic conditions. In this thesis the energy use and indoor climate of single skin office buildings in Sweden are analysed using a dynamic energy simulation program, IDA ICE 3.0. In order to study the impact of glass on the building performance, different building alternatives were studied with 30%, 60% and 100% window to external wall area.

7.1 Methods

A virtual reference building was created, which was considered to be representative regarding design, energy and indoor climate performance, of Swedish office buildings built in the late nineties (SCB 2001, REPAB, 2003). The design of the building was determined by researchers from the Division of Energy and Building Design, architects and engineers from WSP and Skanska. First, detailed performance specifications for energy and indoor climate were established and then typical constructions were determined for the reference building. System descriptions and drawings were prepared. The building was approved by a reference group. Finally a validation of the simulated performance of the reference building showed that the performance specifications were fulfilled.

For this building a parametric study of energy use and indoor climate was carried out, where in the simulations the building construction, HVAC system and control system were described in great detail. The building's orientation, plan type, control set points, façade elements (window type and area, shading devices, etc) were changed while other parameters such as the building's shape, the occupants' activity and schedules, etc were kept the same. A sensitivity analysis based on the simulated alternatives was carried out regarding the occupants' comfort and the energy used for operating the building.

The simulation tool used was IDA ICE, a dynamic energy simulation tool, used by consultants and researchers in Sweden, Finland and Switzerland for advanced energy and indoor climate analysis of buildings including the HVAC systems (Bring, 1999; Equa, 2002). Validation tests have shown the program to give reasonable results and to be applicable to detailed buildings physics and HVAC simulations (Acherman, 2000 and 2003). In order to analyse the large amount of output data from the simulations a post processor in MS Excel was developed. The output of the IDA simulated will be stored in a database which will be used as a building performance tool.

The parametric studies were carried out both at building and at zone level. The performance parameters examined in this report are:

- Energy use for heating (i.e. demand), cooling (i.e. demand), lighting, pumps and fans, etc
- Weighted (average) air temperatures for the working area
- Number of hours between certain (weighted) average air temperatures for the working space
- Weighted average PMV
- Number of working hours for certain average PPD
- Productivity
- Indoor Air Quality

The energy use, the average air temperatures, the thermal comfort indices, the indoor air quality and the productivity are examined and compared on a building level. The mean air and directed operative temperatures and the perception of thermal comfort (PPD, PMV, directed operative temperature, etc) were examined in detail on a zone level. Due to the large amount of output, the presentation of the results is done selectively.

7.2 Description of the building model

7.2.1 Description of the reference building

The reference building is a 6 storey building with a height of 21 m, a length of 66 m and a width 15.4 m. The floor area of the building is 6177 m^2. The room height is 2.7 m and the distance between floors is 3.5 m. Two plan types were assumed for the simulations; cell and open plan.

In order to reduce the simulation time in IDA, but still be able to analyse the indoor climate for individual rooms, the number of zones was reduced to 11 per floor for the cell type and to 7 per floor for the open plan type. The different types of zones are: corner office rooms, double office rooms, single office rooms, meeting rooms and corridor for the cell type and corner zones, intermediate zones and meeting rooms for the open plan. In order to calculate the total building energy use, each zone type was multiplied with the number of identical ones (the number of times that each zone is repeated in the whole building).

The thermal transmittance of the building elements used is shown in Table 7.1.

Table 7.1 Thermal transmittance of building elements.

Building element	U value (W/m^2K)
External wall (long façade)	0.32
External wall (short façade)	0.25
Internal walls	0.62
Roof (above 6th floor)	0.18
Ground floor	0.32
Intermediate floors	1.74

As already mentioned, the window to external wall area of the simulated building alternatives varies (30%, 60% and 100% of the façade area). For the 30% glazed alternatives a triple-glazed (clear glass) window with a venetian blind in between two of the panes was assumed. However, for the 60% and 100% cases, several glazing alternatives were generated, see Table 7.2. The g-value is the total solar transmittance of the glazing and $g_{effective}$ is the total solar transmittance of the system including shading. The effective values are calculated with the shading devices on. The thermal transmittance of the frame is 2.3 W/m^{2}K when triple-glazed (clear glass) window is used (30% glazed alternative and the first of the 60% and 100%) otherwise it is 1.6 W/m^{2}K.

Table 7.2 Glazing and frame properties for glazed alternatives. The glass data were taken from the Pilkington Glass Catalogue, 2002.

Glazing alternative	$U_{glazing}$ **(W/m²K)**	g	$U_{eff.}$ **(W/m²K)**	$g_{effective.}$	**Glazing**	**Shading**
1	1.85	0.69	1.65	0.30	Triple clear(1)	Intermediate blinds
2	1.14	0.58	1.08	0.22	Triple with low-e and argon(2)	Intermediate blinds
3	1.14	0.35	1.07	0.28	Advanced solar control coating with low-e and argon(3)	Internal blinds
4	1.11	0.22	1.04	0.22	Advanced solar control coating with low-e and argon(4)	Internal blinds
5	1.14	0.58	1.08	0.47	Low-e coating and argon(5)	Internal blinds
6	1.14	0.35	0.92	0.19	Advanced solar control coating with low-e and argon(3)	Internal screens
7	1.14	0.35	1.14	0.2	Advanced solar control coating with low-e and argon(3)	External fixed louvers

(1)4+30+4-12-4: Triple clear
(2)4+30+4-12Ar-Ot4: Triple with low-e and argon
(3)6Hbl-12Ar-4 (brilliant 66): Advanced solar control coating with low-e and argon
(4)6Hbm-12Ar-4 (brilliant 50): Advanced solar control coating with low-e and argon
(5)4SN-15Ar-4 (optitherm SN): Low-e coating and argon

7.2.2 Occupancy

For the reference building it was assumed that 80% of the occupants are present during office hours, which is considered to be a typical value for an office with e.g. building designers. The occupants' schedule is from 08:00 -12:00 and 13:00 – 17:00 for the offices and from 10:00 – 12:00 and 13:00 – 15:00 for the meeting rooms every workday. The occupancy, however, drops during Christmas (by 50%) and summer vacations (by 50% during June and August and by 75% during July). The activity level of the occupants was assumed to be sitting and reading i.e. 1 met (108 W/occupant). The occupant's clothing was assumed to be 1 clo (trousers, long-sleeve shirt, long-sleeve sweater, T-shirt) during winter and 0.6 clo (trousers, long-sleeve shirt) during summer.

The total number of occupants is different for the open and cell plan type. For the cell type the "theoretical" number of occupants is 454 and the "practical" one (80% occupancy for the offices and 40% for the meeting rooms) is 319. For the open plan type, an increase in occupants of 20% for the office space was assumed, while the density of the meeting rooms was kept the same. This gives a total "theoretical" number of occupants of 590 and a "practical" one of 395. The open plan has more meeting rooms than the cell type. This results in an occupant density of 18 m^2/employee for the cell type plan and 15.5 m^2/employee for the open type plan.

7.2.3 HVAC strategy

For the cell type, it is assumed that the air is supplied in the offices and extracted from the corridors. For the offices there is a CAV control supplying 10 l/s of pre-heated outdoor air for each person. For the meeting rooms a VAV CO_2 control is assumed. For the open plan it is assumed that the air is supplied and exhausted from the office space (since there is no separation between offices and corridors). The supply air for each person is assumed to be 7 l/s for the office space (CAV control) and a VAV CO_2 control is assumed for the meeting rooms.

The infiltration rate including some window airing is assumed to be 0.1 ach for both plan types. The heat recovery efficiency was set to 60%. The central air handling unit (AHU) is in operation from 06:00 till 20:00 during weekdays and from 8:00 till 17:00 during weekends for both plan types. The supply temperature of the AHU is 19 °C in winter and 17 °C in summer.

7.2.4 Control set points

Three different control set point intervals for the indoor temperature (VVS 2000) were chosen for the simulations of the reference building. The normal control set point (22 – 24.5°C) is considered the standard (reference) case, since the lower and upper temperature limit is common practice in Swedish modern offices. However, the two other control set points (21 – 26°C (poor) and 22 – 23°C (strict)) can provide useful information concerning the energy use variation with indoor temperature, the perception of thermal comfort and the occupants' productivity. For the water radiators a proportional control was used and for the cooling beams a PI control.

Another parameter changed for the three control set points is the set points for artificial light provided at the workplace. For the strict control set point it is assumed that the lights are switched on during occupancy, regardless of the amount of daylight inside the offices. For the normal and poor control set points, however, there was assumed a set point of 500 lux and 300 lux respectively at the workplace. The main reason that these set points were assumed is to calculate the energy use for heating and cooling and the use of electricity for artificial lighting for different control set points, glazing, shading devices and proportion of glass in the building.

7.3 Generation of glazed building alternatives

For the 30% glazed building (reference building) 18 alternatives were simulated. The building construction was kept the same. The building's performance was studied for three orientations (short façade facing NS, EW and NS45-degrees), three control set points (strict, normal and poor) and two plan types (cell and open).

For the 60% and 100% glazed alternatives, 7 different window constructions (commercially available) were studied, see Table 7.2. The rest of the building construction was kept the same as for the 30% glazed alternative. Thus, 2 times 7 façade designs were constructed. Each case was then simulated for both cell and open plan type and for strict, normal and poor control. In total 84 (60% and 100%) glazed alternatives were simulated. A brief description of the generated alternatives follows.

The first glazed alternative (see Table 7.2) works like a "bridge" between the 30% glazed and the two highly glazed buildings. The $U_{glazing}$ and U_{frame} values were kept the same (triple clear pane window, 1+2 construction) in order to study the impact of higher glazing areas on energy use and occupant's comfort.

In the second building alternative the U-value of the window is improved by a low-e coating in order to get a more realistic solution for a modern glazed building. In all other respects, the construction is the same as for alternative 1.

In alternatives 3-5 the triple glazed window is replaced by a double glazed one with the same glass U-value and the intermediate venetian blind is moved to an internal position. This window type was chosen as a typical alternative used for a highly glazed office building. The g-value is varied from 0.35 in alternative 3, 0.22 (alt. 4) back to 0.58 (alt. 5), equal to that of alternative 2. These three cases were selected in order to further investigate the influence of the g-value on heating and cooling demand. Additionally, since the glazing and frame properties are the same as the second alternative, it is possible to investigate the influence of the position of the shading devices on energy use and thermal comfort.

In the sixth alternative internal screens are chosen instead of venetian blinds. The window construction is identical with the third alternative, since this is considered to be the more often used one. With this alternative it is possible to investigate the influence of a different type of shading device on energy use and indoor environment.

In the last alternative fixed external louvers replace the internal screens. The window construction is again identical with the third alternative.

7.4 Results and discussion

In total more than 100 different alternatives were simulated in order to study the impact of orientation, control set point, plan type and façade construction on energy use and indoor climate (both on a building and a zone level) of glazed office buildings. Many of the obtained result were to be expected. However, in this thesis an effort has been made to quantify them and to point out the main problems that occur with highly glazed alternatives (and possibly can be solved with e.g. double skin facades). Regarding indoor climate, general conclusions could not always be drawn since the large number of interacting parameters increases the complexity of the problem. Results were obtained for certain construction types, control set points and plan type. The potential overheating problem and the comfort indices at a zone level were also studied in order to better understand the possible drawbacks of large glazed areas for certain orientations and occupancy.

7.4.1 Plan type

Two plan types where studied (cell and open). A cross comparison of the 30%, 60% and 100% (alternatives with triple clear pain) was carried out in order to study the impact of the window area on the two plan types. Similar study was carried out for the 60% and 100% alternatives with different window and shading devices type. The main results from the parametric studies where:

- Energy use:
  - ¤ The higher internal loads of the open plan type result in higher cooling and lower heating demand than for the cell type. The increase in cooling demand for the reference building is 42% (9 kWh/m²a), 57% (6 kWh/m²a)and 45% (3 kWh/m²a) for the strict, normal and poor set points and the decrease in heating demand is 10% (6 kWh/m²a), 14% (7 kWh/m²a) and 19% (9 kWh/m²a) respectively. The difference between the total energy use for the two plan types is rather small and similar for all the reference building alternatives. The total energy use varies between 113 kWh/m²a and 144 kWh/m²a.
  - ¤ When the window area increases, the impact of the plan type on the energy use for heating, cooling and lighting is higher for the alternatives with wider range of allowed air temperatures (i.e. poor set points)
  - ¤ The window type does not have any significant influence on the impact of the plan type regarding energy use since the maximum difference of energy use is not higher than 3 kWh/m^{2}a (except in the cases with insufficient heating or cooling capacity).

- Indoor climate:
  - ¤ The risk of overheating the cell plan type, compared with the open plan type, increases in the 100% glazed alternatives due to the lower room volume to external wall area (mostly for the corner zones). It was noticed that for the 5th 100% glazed alternative with the double pane with low-e coating and internal blinds the

allowed air temperature limit was exceeded more than 12% of the working hours. This problem was mostly noticed in the corner zones.

- ¤ The position of the occupants in the office space is crucial for the perception of thermal comfort. In the open plan some occupants are not really close to the façade and therefore the influence of radiant temperature on the perceived thermal comfort decreases resulting in an on average improved thermal environment.
- ¤ The mean air temperatures are influenced by the plan type only in the case of insufficient heating and cooling capacity (e.g. 100% glazed alternatives with triple clear pane (alternative 1) and double glazing unit with low e coating and internal venetian blinds (alternative 5)).
- ¤ Higher internal loads (open plan) can provide better PMV values in the cases with low upper temperature limit (23°C), since the PMV values hardly reach the neutral conditions (except of the 100% glazed alternatives with high g and $g_{effective}$ values).

7.4.2 Orientation

The impact of the orientation on energy use and indoor climate issues was studied at a building and at a zone level. At a zone level, the study was focused on the perception of thermal comfort and on the potential overheating problem. These studies were carried out only for the cell type plan.

- Energy use:

    - ¤ At a building level, the influence by the orientation was rather small on the energy use, partly due to the fact that the two long facades and the two short facades are identical. The EW oriented reference building alternatives require 0.1% less energy. For the 100% EW glazed buildings the difference increases to 3%.

- Potential overheating problem: The comparison has been carried out for different zone types. Offices (with 30% window area) were compared with meeting rooms (65% window area) in order to study the impact of glass on the potential overheating problem. Zones were also compared between each other, in order to study the impact of the orientation and the internal loads on the mentioned problem. No cross comparison of 30%, 60% and 100% glazed alternatives was carried out since a construction with triple clear panes can be found (in reality) only in the reference building alternatives. The impact of the set points on the overheating problem for zones with different orientation was also studied. For an upper air temperature limit of 23°C the south oriented zones were the ones with the highest risk of overheating and the north the coldest ones, as expected. A slight difference was noticed between the east and west facing zones. Similar but more pronounced were the results for an upper temperature limit of 24.5°C with the east oriented zones having a higher potential for overheating, compared to the west facing zones. For the poor set points, the east oriented zone is the warmest (even more than the south), with the south, west and north following. The parameters that influence the potential overheating problem are:

¤ Upper temperature limit. The higher the upper limit is, the more the potential overheating of the east oriented zones tends to become "warmer" compared with the south oriented ones. Thus, although the potential overheating for the normal set point in the south facing single room is 980 hours and for the east one 930, for the poor set points the east facing office is warmer than the south one (470 and 425 respectively)
¤ The internal loads. The higher the internal loads are, the larger the impact of the orientation on the overheating problem is. For example, for the south orientation, normal set points for the higher density of occupants (7.65 m^2/occupant) of the double office results in 1130 hours of potential overheating while the single office with lower density (10 m^2/occupant) results in 980 hours.
¤ Window area. The larger the window area is the more the overheating problem depends on the orientation of the zones and less on the control set points. For example the south oriented meeting room (with 65% window to external wall area) with normal set points is still warmer than the east one while the east facing offices (with 30% window to external wall area) are warmer than the south ones. One of the most important drawbacks of highly glazed buildings is the overheating problem.

- Monthly mean air temperatures: The wider the allowed air temperature variation is, the bigger the impact of the orientation in each zone. This could provide useful information when choosing the allowed temperature variation of certain zone types. Thus for zones that tend to overheat the strict set points reduce the effect of orientation increasing the cooling demand.

Perception of thermal comfort: narrow mean air temperature variations ensure a narrow range of PMV values (for certain occupants' position). However, in order to ensure that these values range as close to neutral (PMV = 0) as possible (resulting in low PPD values) an individual study has to be carried out for zones of each orientation, taking into account the façade construction, the internal loads and the use of the office space.

- The radiant temperature varies with orientation for warm and cold days, the more the more glazing and the higher the g-value. This can result in poor thermal comfort.

7.4.3 Control set points

The impact of the three different control set point intervals on energy use, indoor air temperatures and light, is:

- Energy use:
  - ¤ The impact of indoor temperature set points on the energy use for heating and cooling decreases as the window area increases. On the other hand, the larger window areas increase the impact of light set points on the energy use for lighting. For the cell type reference building the difference in energy use for heating is 7% (4 kWh/m²a) and 16% (9 kWh/m²a) between the strict - normal and strict - poor set points respectively. For the 100% glazed building the difference drops to 3% (3 kWh/m²a) and 12% (11 kWh/m²a). The difference in energy use for cooling is 45% (9 kWh/m²a) and 65% (13 kWh/m²a) between the strict - normal and strict - poor set points while for the 100% glazed building the difference drops to 29% (13 kWh/m²a) and 49% (21 kWh/m²a). Finally, the difference in energy use for lighting is 2% and 3% between the strict - normal and strict - poor set points while for the 100% glazed building the difference in energy use for heating is 12% and 14%.
  - ¤ The "warmer" alternatives (glazing with high solar factor values) increase the impact of the set points on the heating demand, while the "colder" alternatives increase the impact of the set points on the cooling demand.
  - ¤ The impact of set points on energy use for heating and cooling is higher for the alternatives where it is easier to control the indoor environment.

- Indoor climate: no obvious conclusions could be drawn for different set points. However, most of the studied alternatives do not fulfil the requirements that 90% of the time PPD should be lower than 10%, as recommended in ISO 7730 (1984). The decision on the set points should be made after considering the:

  - ♦ Zone and/or building orientation.
  - ♦ Internal loads (activity level, occupancy, equipment, etc.)
  - ♦ Construction type of the façade.

  - ¤ Generally, narrow set points ensure narrow PMV variation. Constant air temperatures all year round can cause discomfort problems due to lower clothing levels in summer vs. higher clothing levels in winter.
  - ¤ Correct strict set points can ensure an acceptable directed operative temperature. However, a large difference between radiant and air temperature increases the possibility of poor quality of the thermal environment.

7.4.4 Façade elements (window and shading devices)

First a cross comparison between 30 %, 60 % and 100 % window area was carried out and then seven different window alternatives were studied for the 60% and 100% glazed building alternatives, in order to study their impact on the energy use and indoor climate.

- Energy use:

  - ¤ The total use of energy increases with the glazing area. Assuming triple-glazed (clear glass) window the energy of the 60% glazed building is 23% (31 and 28 kWh/m²a for the two control set points) higher than for the reference building. This occurs regardless of set points. The increase for the 100% glazed alternatives is 45% (62 kWh/m²a) for the strict and 47% (57 kWh/m²a) for the normal set points. Both the heating and cooling demand increase for the highly glazed building alternatives. Impressive, however is the increase of cooling demand of the 100% glazed building that reaches 112% (23 kWh/m²a) for the strict and the 177% (19 kWh/m²a) for the normal set points.
  - ¤ The difference in total energy use (60% and 100 % glazed alternatives compared with the reference building) is reduced when the thermal transmittance and the solar factor (g and $g_{effective}$ value) are reduced. The seven 100% glazed alternatives with normal set points

(cell type plan) were compared. For the best alternative the total energy use of the glazed alternative is only 15% higher than for the reference building, 141 kWh/m²a compared with 123 kWh/m²a.

- ¤ Increased window area does not necessarily mean reduced use of electricity for lighting. The use of electricity for lighting for the studied alternatives was 15 kWh/m²a (approximately 10% of the total energy use). Glare problems e.g. that can be caused by the large amount of daylight entering a highly glazed working space often reduce the quality of visual comfort. Thus, shading devices are used more often in highly glazed cases maintaining often the same levels of the daylight used in a building with a conventional facade. This is especially true for traditional solar shading with traditional control.
- ¤ Low thermal transmittance values of windows decrease the heating demand (during the winter), while they do not influence much the cooling demand. For the studied 100% glazed alternatives the heating demand can vary from 66 to 92 kWh/m²a.
- ¤ Low g and $g_{effective}$ values of windows have a great impact on the cooling demand. Externally placed shading devices lead to reduced cooling demand. For the studied 100% glazed alternatives the cooling demand can vary from 19 to 54 kWh/m²a

- Indoor climate:

  - ¤ The larger window to external wall area the larger the discomfort problems are during the whole year, especially basing the comparison on triple-glazed (clear glass) windows. During the winter the PMV drops from -0.55 (reference building) to -0.82 (100% glazed alternative) and during the summer it increases from 0.3 (reference building) to 0.45 (100% glazed alternative). This corresponds to a decrease of the number of hours with PPD values lower than 10%. The number of hours with PPD values lower than 10% is 73% for the reference building, 57% for the 60% glazed alternative and 44% for the 100% glazed alternative. A window type (3rd 100% glazed alternative) with lower thermal transmittance and solar factor results in an increase of the minimum PMV values (-0.62) during the winter and a slight decrease during the summer. The number of hours with PPD values lower than 10% in this case is 57%. From the above it becomes obvious that the quality of thermal comfort decreases for highly glazed alternatives due to high or low surface temperatures of the external wall.

- ¤ Fixed external shading devices result in lower radiant temperatures during the whole year. This could give impaired thermal comfort i.e. low PPD values during summer, but on the other hand, discomfort problems during the winter.
- ¤ External shading devices seem to be better in terms of energy use and provision of thermal environment during the cooling season. However, due to maintenance and investment reasons, those shading devices are often fixed which does not allow optimal shading all year around or using the solar gains during the heating seasons.

A promising way of improving thermal performance with respect to energy use is proper integration of double skin façades. One of the main challenges of the proper integration is to maintain the advantages of the external shading devices (i.e. by successfully extracting the air from the cavity during the cooling season) and using the heat of the solar gains to improve the temperature of the inner layer and possibly introduce the preheated air inside the building, in cases of natural ventilation. Since the occupants have the option to use the shading devices daylight can be obtained all year round and at the same time ensuring a pleasant thermal environment.

7.5 Conclusions

The use of the dynamic energy simulation tool IDA allows detailed studies of energy use and indoor climate performance of modern office buildings. At a building level conclusions can be made regarding energy use (for heating, cooling, lighting, etc), peak loads, ventilation rates and building envelope construction. The zone level gives more detailed output for air and directed operative temperatures, perception of thermal comfort and indoor air quality. When the results of these two levels are combined properly, one can draw conclusions about the overall building performance.

Detailed energy and indoor climate studies require a lot of attention to the inputs, and are also rather time consuming. Detailed analyses also generate a large amount of output data. For analysis purposes a post processor in MS Excel was therefore developed. Problems encountered were that IDA does not easily or in an accurate way take into account e.g. thermal bridges, air infiltration, window airing, the variation in solar transmittance over a year, daylight and advanced daylight/solar control. Very few dynamic energy simulation programs do this, however. These parameters have to be studied separately and then inputs suitable for

IDA have to be created. There is of course the time-consuming possibility to include new calculation modules into IDA, using the advanced level of the program.

The energy efficiency of a building highly depends on the façade construction. Highly glazed buildings should be studied more carefully during the design stage, using a sufficiently advanced simulation tool, since different types of constructions have a large impact on the energy efficiency compared to 30% or even to 60% window area alternatives. The main aim when designing glazed buildings should be to avoid a high cooling demand since this was shown to ensure a low overall energy use. A sensitivity analysis of a glazed building at an early design stage can provide useful information for the energy use and the thermal comfort of the occupants.

The impact of (temperature) control set points on heating and cooling is crucial for the energy use and the provision of good thermal environment. Narrow heating and cooling set points reduce the effect of thermal mass and increase the energy demand. The combination of glazing with low solar factor and intermediate or external shading devices can reduce the overheating problems to an acceptable level. In terms of thermal comfort, strict controls do not necessarily give the lowest PPD values. One should consider the occupancy density, the clothing, activity level and schedules of the occupants before making a decision as to the allowed temperature interval. The combination of glazing with low solar factor and intermediate or external shading devices can reduce the overheating problems to an acceptable level.

The orientation of the room (or building) is crucial for the directed operative temperatures mostly for highly glazed facades. The expected position of the occupants (distance from the external wall) has to be considered before choosing the window type in order to avoid discomfort.

The drastic increase of glazing area for highly glazed office buildings doesn't necessarily decrease the use of electricity for lighting. Especially if traditional shading with simple control is used the decrease is small.

Office buildings with fully glazed facades are likely to have a higher energy use for heating and cooling. For the building studied the total increase was lowered to 15% when glazing and shading were improved. The risk of poor thermal comfort close to the façade is also higher. To add a second façade to these buildings could solve some of the problems with the single skin façade (Poirazis, 2004). The analyses will therefore be expanded to glazed office buildings with double skin facades and will also include advanced simulations of daylight. A recently developed double skin façade module for IDA will be used and improved upon. Parallel, CFD simulations of double skin facades will be carried out.

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Appendix A

Performance specifications for the reference building.

The project team within the project “Glazed Office Buildings” developed performance specifications for the reference building, a typical office building of the nineties. The performance specifications were approved by a reference group.

Energy use

For the entire building:

Energy use, kWh/m^2a	Reference
District heating	80
Electricity for pumps, fans etc.	20
Electricity for lighting, PCs etc.	50
Electricity for cooling	30
Total use of electricity	100
Total use of energy	180

m^2 refers to non-residential/premises floor area (LOA see SS 021053 Area and volume of buildings)

Energy use, kW/m^3s	Reference
Ventilation	2.5

Indoor environment

The performance specifications below are valid for the whole building

Air tightness

Description	Reference
Air tightness	<1.8 litre/(m^2s) at 50 Pa difference pressure

Performance specifications for rooms

The performance specifications below are valid within the occupied zone for every office room. Work places are in a cell-type or open-plan or combination office.

Description	Reference	Comments
Sound:	from HVAC L_{Aeq}< 35 dB, L_{Amax} < 35 dB, L_{Ceq} < 50 dB;	The performance specifications are applicable during office hours.
	from outside L_{Aeq}< 30 dB;	
	airborne sound insulation to other rooms >44 dB (>40 dB for walls with door), to corridors > 30 dB	
	reverberation time for open-plan < 0.4 s for cell-type office room < 0.5 s	
Light:	should be possible to shade against direct sun light. daylight factor min 1% and max 5%	
Lighting:	Cell-type: 300 -500 lux, < 12 W/m^2 electricity Corridors: > 100 lux, < 6 W/m^2 electricity Open-plan: 300 - 600 lux, < 12 W/m^2	
	colour rendering index (Ra-index) > 80	
	luminance distribution working material : nearest surrounding : surrounding areas 10 : 3 : 1	
	Luminance within the normal visual field < 1000 cd/m^2 Outside the normal visual field < 2000 cd/m^2	
Internal gains:	from office equipment: < 20 W/m^2 from PC + monitors: < 125 W i.e. < 5 W/m^2 from office copier: < 400 W i.e. < 1 W/m^2 from laser printer: 50 W i.e. < 2 W/m^2	
	from persons: 4 W/m^2 (100 W/person)	
Ventilation:	> 0,35 l/sm^2 + > 7 l/sperson, air change efficiency > 40%	
IAQ:	< 1000 ppm CO_2	
Thermal comfort:	air temperature minimum[S] 22°C and maximum[S] 24-26°C	
	air velocityW < 0.15 m/s	
	radiant temperature asymmetry[W] from vertical surfaces < 10 K	
	vertical air temperature difference[W] between 1,1 and 0.1 m < 3 K	

[S] summer conditions where clothing of 0,6 clo is assumed
[W] winter conditions where clothing of 1 clo is assumed

Appendix B

Architectural drawings

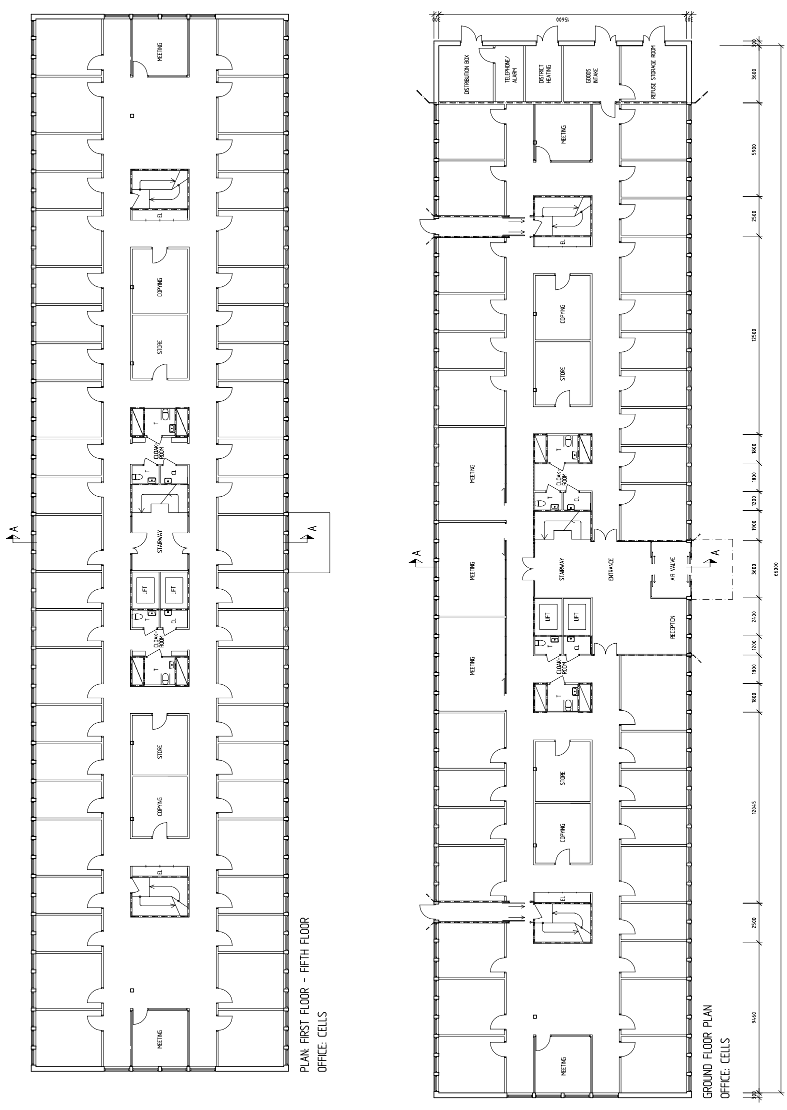

Figure B.1 *Drawings of the cell type office plan.*

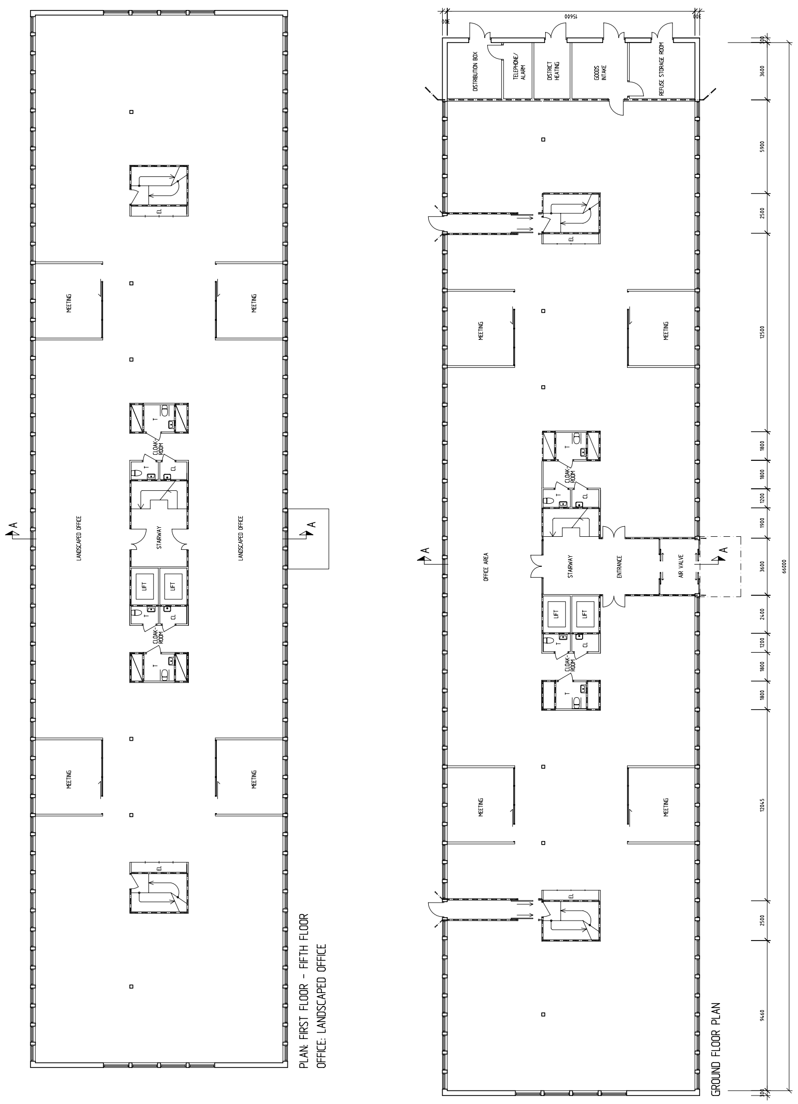

Figure B.2 Drawings of the open type office plan.

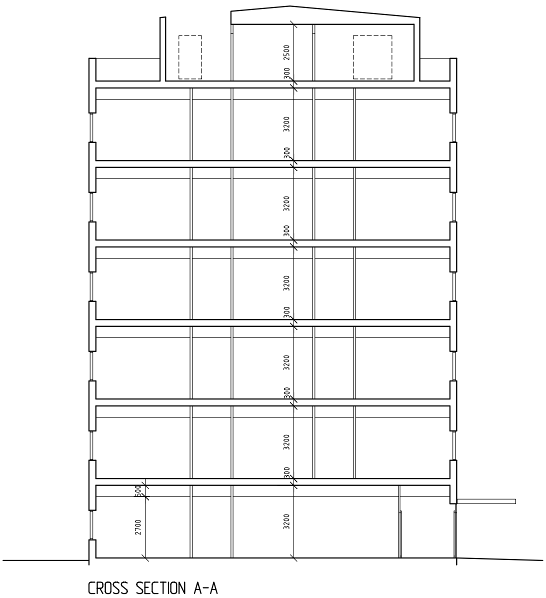

Figure B.3 *Cross section of the reference building.*

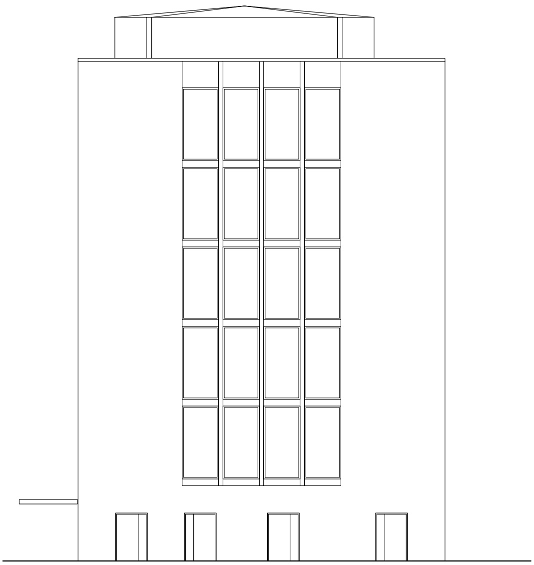

Figure B.4 *Gable elevation of the reference building.*

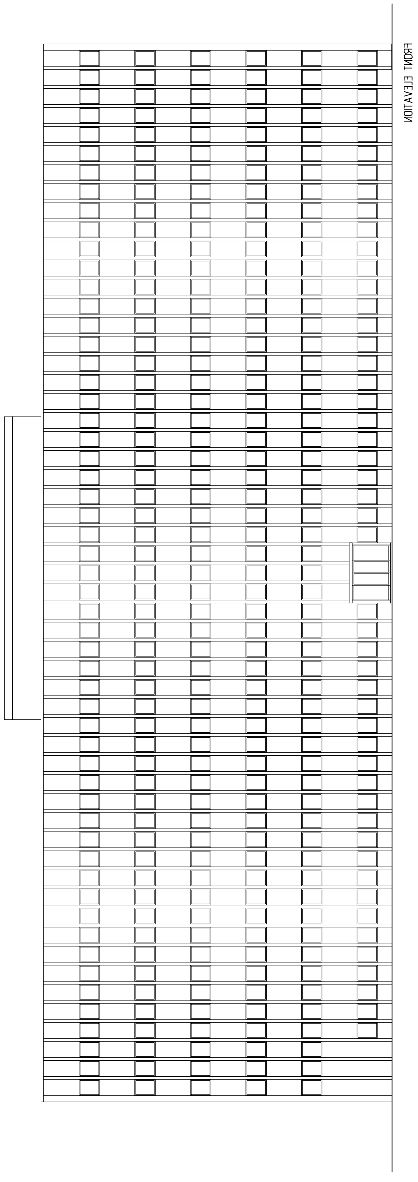

Figure B.5 *Front elevation of the reference building.*

Appendix C

Geometry of the cell and open plan thermal zones

Cell Type: Geometry of the offices - thermal zones

Corner office rooms

Thermal zone type A1(1), A9(1), B1(4), B4(4), B6(4), B9(4), C1(1), C4(1), C6(1), C9(1). The office area is 15.1 m^2 (including half internal wall a and half b). The numbers in the parenthesis show how many identical thermal zones are in the building. Typical corner office room is shown in Figure C.1. The total area of the all the corner office rooms is 331.8 m^2.

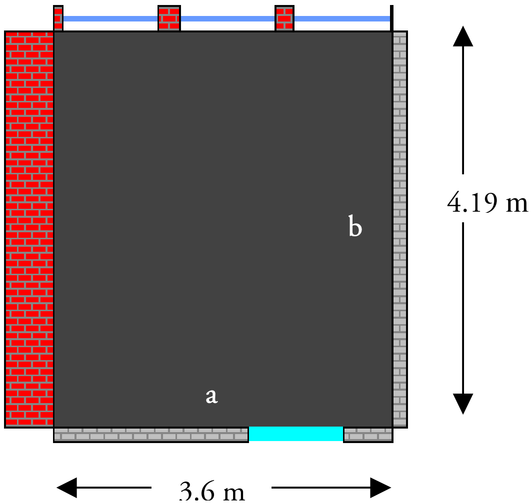

Figure C.1 Typical corner office.

Typical double office rooms

Thermal zone type A2(8), A6(5), B2(28), B8(28), C2(7), C8(7). The office area is 15.3 m^2 (including whole internal wall b and the half a). The numbers in the parenthesis show how many identical thermal zones are in the building. Typical double office room is shown in Figure C.2. The total area of the typical double office rooms is 1272.8 m^2.

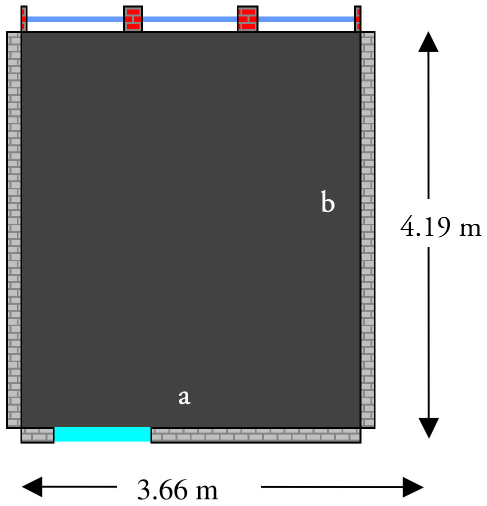

Figure C.2 Typical double office room.

Typical single office rooms

Thermal zone type A3(4), A7(12), B3(56), B7(56), C3(14), C7(14). The office area is 10.05 m^2 (including whole internal wall b and half a). The numbers in the parenthesis show how many identical thermal zones are in the building. Typical single office room is shown in Figure C.3. The total area of the typical single office rooms is 1568 m^2.

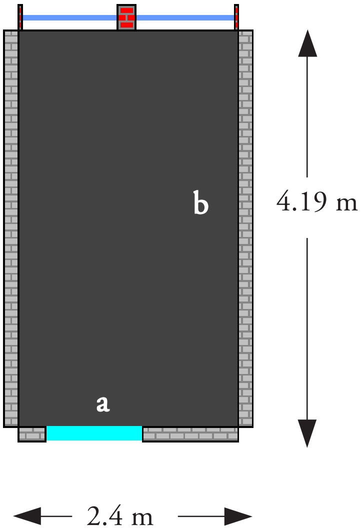

Figure C.3 *Typical single office room.*

Typical meeting rooms

Thermal zone type A10(1), B5(4), B10(4), C5(1), C10(1). The office area is 12.96 m^2 (including whole internal wall b and half a). The numbers in the parenthesis show how many identical thermal zones are in the building. Typical meeting room is shown in Figure C.4. The total area of the typical meeting rooms is 142.56 m^2.

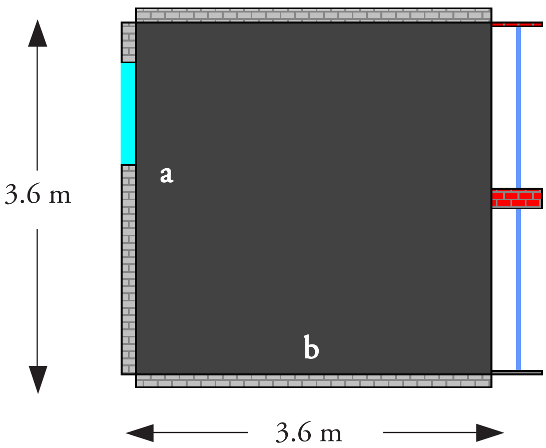

Figure C.4 *Typical meeting room.*

Meeting room (12 persons)

Thermal zone type A4(3). The office area is 25.14 m^2 (including half internal wall b and whole a). The numbers in the parenthesis show how many identical thermal zones are in the building. A 12 persons meeting room is shown in Figure C.5. The total area of the meeting rooms (12p) is 75.42 m^2.

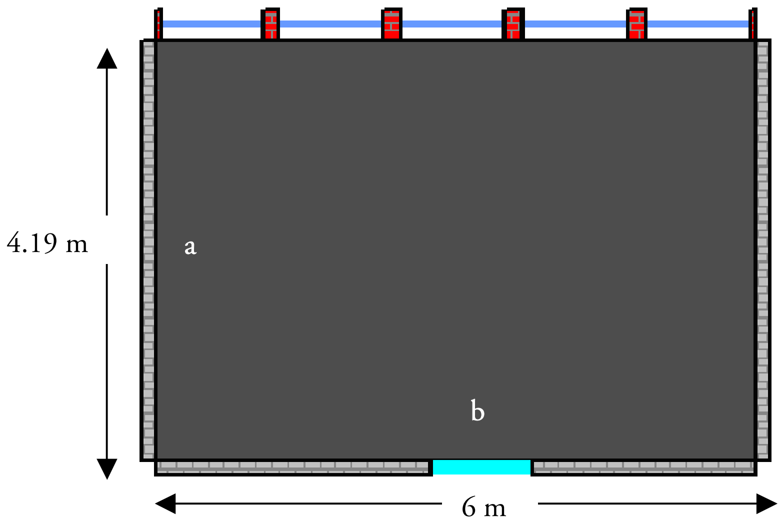

Figure C.5 Meeting room for 12 persons.

Meeting room (8 persons)

Thermal zone type A8(1). The office area is 20.2 m^2 (including half internal wall b and whole a). The numbers in the parenthesis show how many identical thermal zones are in the building. An 8 persons meeting room is shown in Figure C.6. The total area of the meeting room (8p) is 20.2 m^2.

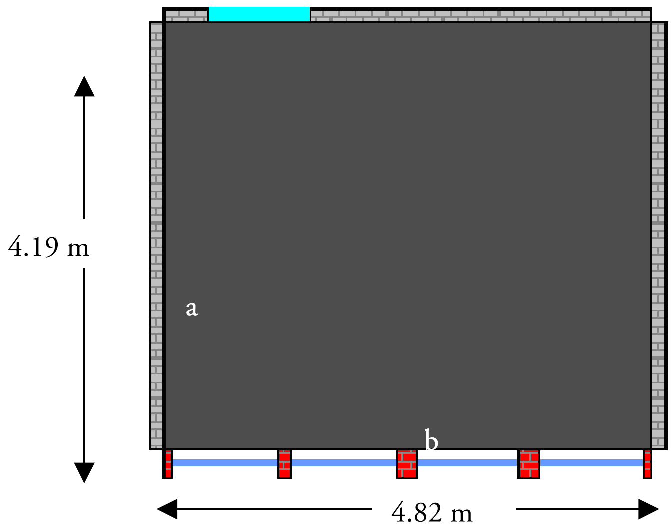

Figure C.6 *8 persons meeting room.*

Storage room (1st floor)

Thermal zone type A5(1). The room area is 56.2 m^2 (including half b). The numbers in the parenthesis show how many identical thermal zones are in the building. The storage room is shown in Figure C.7. The total area of the storage room is 56.2 m^2.

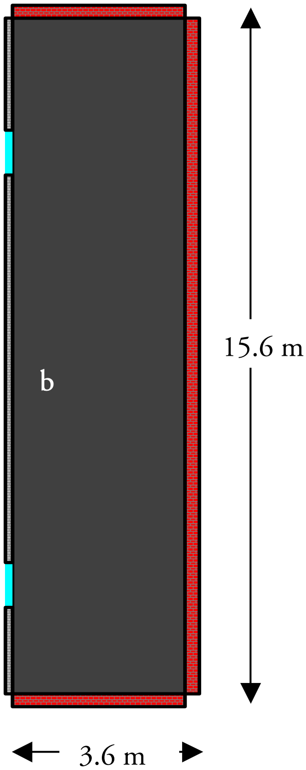

Figure C.7 *Storage room.*

Table C.1 Properties of the cell type officesCorridor for the ground floor.

		Corner office room	Double office room	Single office room	Typical meeting room	Meeting room (12 persons)	Meeting room (8 persons)	Storage room
HVAC	Water radiator (P_{max} = 1000 W/unit)	1 unit	1 unit	1 unit	1 unit	2 units	2 units	4 units
	Cooling Beams (number of units, design air flow)	1 unit d.a.f.= 15 l/s	1 unit d.a.f.= 15 l/s	1 unit d.a.f.= 10 l/s	2 units d.a.f.= 21 l/s (each)	3 units d.a.f.= 28 l/s (each)	2 units d.a.f.= 28 l/s (each)	-
Construct.	External wall with windows	Long external facade	Long external facade	Long external facade	Short external facade	Long external facade	Long external facade	-
	External wall without windows	Short external facade	Short ext. facade	-	-	-	-	-
Occupants	Number of occupants	1	1	1	6	12	8	-
	Occupant's schedule	Schedule for offices	Schedule for offices	Schedule for offices	Schedule for meeting rooms	Schedule for meeting rooms	Schedule for meeting rooms	-
	Clothing (s: during summer, w: during winter)	1 clo (w), 0.6 clo (s)	1 clo (w), 0.6 clo (s)	1 clo (w), 0.6 clo (s)	1 clo (w), 0.6 clo (s)	1 clo (w), 0.6 clo (s)	1 clo (w), 0.6 clo (s)	-
	Activity level (sitting, reading)	1 met	1 met	1 met	1 met	1 met	1 met	-
Equipment	Number of units PC: 125 W, PR: printer: 30 W, Fax: 30 W	1 PC, 1 printer, 1 fax	2 PCs	1 PC	-	-	-	-
	Schedule	Equipment's schedule	Equipment's schedule	Equipment's schedule	-	-	-	-
	Average emitted heat per unit	61.67 W	125 W	125 W	-	-	-	-
Lights	Number of units	1	1	1	1	1	1	1
	Rated input per unit (12W/m²)	175 W	175 W	113 W	148 W	291 W	233 W	233 W
	Luminous efficacy	41.67 lm/W	41.67 lm/W	41.67 lm/W	41.67 lm/W	41.67 lm/W	41.67 lm/W	41.67 lm/W
	Convective fraction	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Furniture	Units desks (d), chairs (c), bookshelves (b)	1 (d), (c), (b)	2 (d), (c), (b)	1 (d), (c), (b)	1 (d), 6 (c)	1 (d), 12 (c)	1 (d), 8 (c)	shelves
	Construction	Default furniture	Default furniture	Default furniture	Default furniture	Default furniture	Default furniture	Default furniture
	Area	10 m²	10 m²	7 m²	15 m²	25 m²	20 m²	50 m²

Since the corridors and the common spaces are (almost) internal thermal zones, they are not so interesting for the energy and thermal comfort simulations. Thus, they were considered as one thermal zone as shown below.

Thermal zone type A11(1). The corridor area (including the reception and 1 meeting room is) 470 m^2. The numbers in the parenthesis show how many identical thermal zones are in the building. The total area of the corridor of the ground floor is 470 m^2 (Figure C.8).

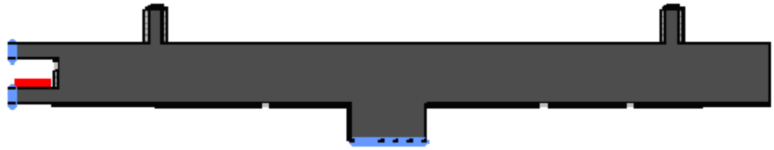

Figure C.8 Corridor of the ground floor.

Corridors for the 1st-5th floor

Thermal zone type B11(4), C11. The corridor area (including the reception and 1 meeting room is) 444.8 m^2. The numbers in the parenthesis show how many identical thermal zones are in the building. The total area of the corridors is 2224 m^2 (Figure C.9).

Figure C.9 Corridor of the 1^{st}-5^{th} floor.

Table C.2 Properties of the cell type corridors.

		Corridor (ground floor)	Corridor (1^{st}-5^{th} floor)
HVAC	Water radiator (P_{max} = 1000 W/unit)	2 units	4 units
	Cooling Beams (number of units, design air flow)	-	-
Construct.	External wall with windows	Short external facade	Short external facade
	External wall without windows	Long external facade	Long external facade
Occupants	Number of occupants	-	0
	Occupant's schedule	-	-
	Clothing(s: during summer, w: during winter)	-	-
	Activity level(sitting, reading)	-	-
Equipment	Number of units Copy machines: 500 W PR: printer: 50 W, Fax: 30 W	4 Printers, 4 Copy machines, 2 Faxes	4 Printers, 4 Copy machines, 2 Faxes
	Schedule	Equipment's schedule	Equipment's schedule
	Average emitted heat per unit	226 W	226 W
Lights	Number of units	1	1
	Rated input per unit (6W/m^2)	2796 W	2460 W
	Luminous efficacy	41.67 lm/W	41.67 lm/W
	Convective fraction	0.3	0.3
Furniture	Units desks (d), chairs (c), bookshelves (b)	Chairs, etc	Chairs, etc
	Construction	Default furniture	Default furniture
	Area	100 m^2	80 m^2

Open Plan Type: Geometry of the offices - thermal zones

Typical corner zones

Thermal zone type A1(1), B1(4), B4(4), C1(1), C4(1). The zone area is 258.7 m^2 (including half internal wall a and half b). The numbers in the parenthesis show how many identical thermal zones are in the building. Typical corner zone is shown in Figure C.10. The total area of the corner office rooms is 2846 m^2.

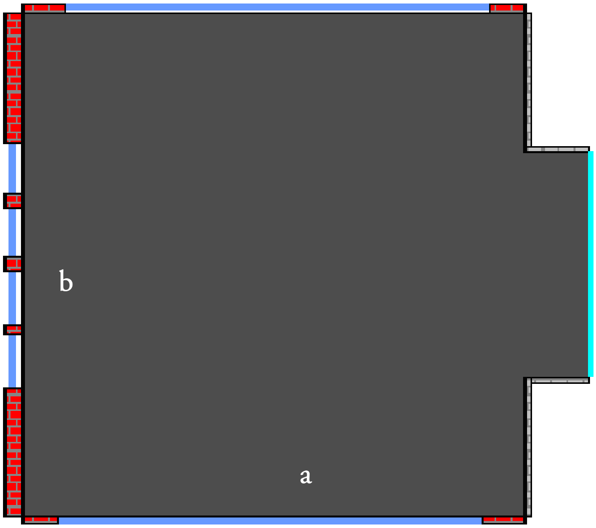

Figure C.10 Typical corner zone.

Intermediate zones

Thermal zone type A8(1), B(8), C8(1). The zone area is 430 m^2 (including half internal wall a and half b). The numbers in the parenthesis show how many identical thermal zones are in the building. Typical corner zone is shown in Figure C.11. The total area of the intermediate zones is 2577 m^2.

Figure C.11 Typical intermediate zone.

Reduced corner zone

Thermal zone type A4(1). The zone area is 203 m^2 (including half internal wall a and half b). The numbers in the parenthesis show how many identical thermal zones are in the building. Typical corner zone is shown in Figure C.12. The total area of the reduced corner zone is 203 m^2.

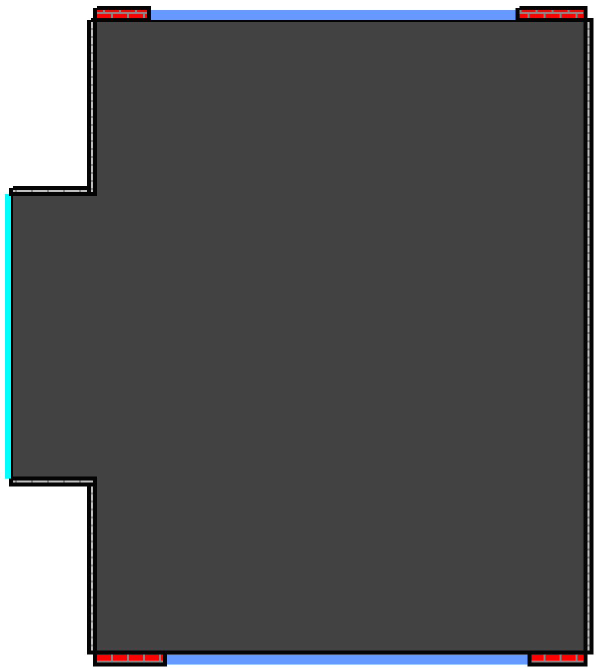

Figure C.12 Reduced corner zone.

Meeting rooms and Storage room

These two zones are completely identical with the meeting room for 8 persons (cell type) and the storage room (cell type) correspondently.

Table C.3 Properties of the open plan type zones.

		Typical corner zone	Intermediate zones	Reduced corner zone	Meeting room (8 persons)	Storage room
HVAC	Water radiator (P_{max} = 5000 W/unit)	2 units	2 units	2 units	4 units	2 units
	Cooling Beams (number of units, design air flow)	1 unit d.a.f.= 131 l/s	1 unit d.a.f.= 202 l/s	2 units d.a.f.= 28 l/s (each)	-	3 units d.a.f.= 28 l/s (each)
Construct.	External walls (a)	Long external facade	Long external facade	Long external facade	-	Long external facade
	External walls (b)	Short external facade	-	-	-	-
Occupants	Number of occupants	16	24	8	-	12
	Occupant's schedule	Schedule for offices	Schedule for offices	Schedule for meeting rooms	-	Schedule for meeting rooms
	Clothing(s: during summer, w: during winter)	1 clo (w), 0.6 clo (s)	1 clo (w), 0.6 clo (s)	1 clo (w), 0.6 clo (s)	-	1 clo (w), 0.6 clo (s)
	Activity level(sitting, reading)	1 met	1 met	1 met	-	1 met
Equipment	Number of units	16 PCs,	24 PCs,	-	-	-
	PC: 125W, PR: printer: 30 or 50 W, fax: 30 W, copy machines: 500 W	4 PR (30W), 4 faxes	4 PR (50W), 4 c.m.			
	Schedule	Equipment's schedule	Equipment's schedule	-	-	-
	Average emitted heat per unit	93.4 W	159.3W	-	-	-
Lights	Number of units	1	1	1	1	1
	Rated input per unit (12 W/m^2)	3104 W	5148 W	233 W	233 W	291 W
	Luminous efficacy	41.67 lm/W	41.67 lm/W	41.67 lm/W	41.67 lm/W	41.67 lm/W
	Convective fraction	0.3	0.3	0.3	0.3	0.3
Furniture	Units desks (d), chairs (c), bookshelves (b), Common furniture (cf)	16 (d), (c), (b), (cf)	24 (d), (c), (b), (cf)	1 (d), 8 (c)	shelves	1 (d), 12 (c)
	Construction	Default furniture	Default furniture	Default furniture	Default furniture	Default furniture
	Area	160 m^2	260 m^2	20 m^2	50 m^2	25 m^2

Appendix D

Corrected theoretical U-values (including thermal bridges)

The thermal bridges caused by the steel columns and the wooden studs were calculated in the two-dimensional software Heat 2 (version 6).

Due to the fact that when defining a thermal zone in IDA one has to insert the loss factor for thermal bridges (W/°C) for each thermal zone type (depending on the geometry of the zone) we decided to calculate the U-value of the external wall including the thermal bridges (using Heat 2) and then design an equivalent new wall in IDA assuming that the loss factor = 0. The 4 steps followed are:

1. We defined wall structure without the steel columns and the material properties in IDA (heat conductivity, density and specific heat). IDA calculated the U-value of the external wall (=0.2201 $Wm^{-2}K^{-1}$) as show in Figure D.1.

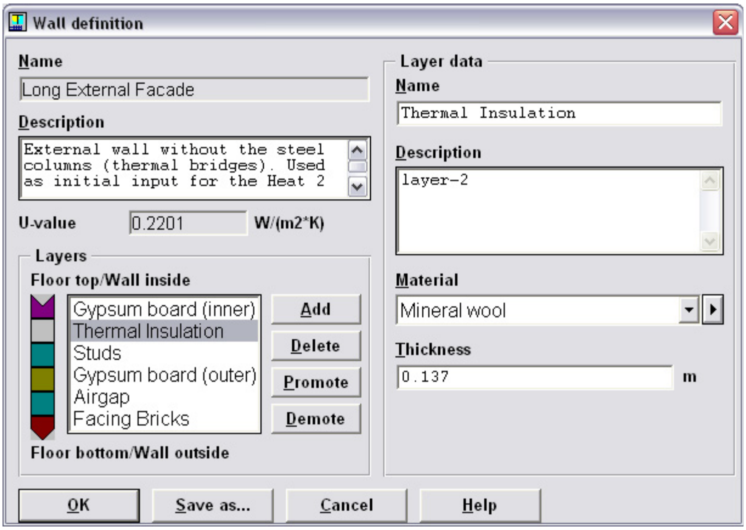

Figure D.1 U-value (without the columns) calculated by IDA.

2. We built the same model in Heat 2 and calculated the U-value. Since the minimum material properties and thickness (minimum thickness 10mm) were not exactly the same, we tuned the model in order to get the same U-value with the one calculated by IDA (step 1) as shown in Figure D.2.

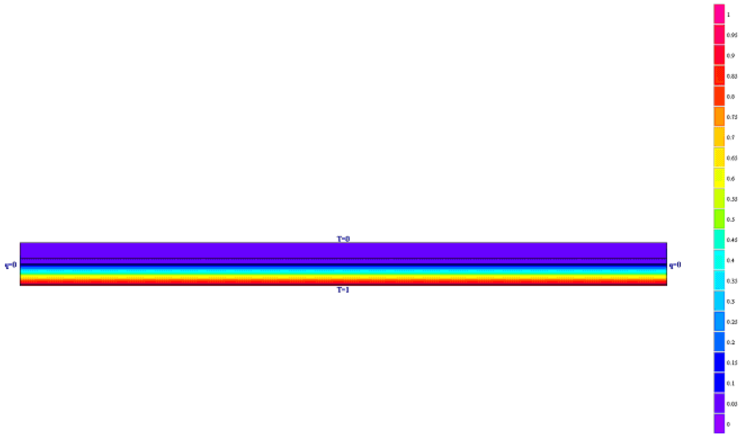

Figure D.2 U-value (without columns) calculated by Heat 2.

The construction was:

- 120mm facing bricks
- 40mm air gap
- 10mmgypsum
- 150mm insulation
- 10mm gypsum

The properties of the materials were the same with the IDA model
The boundary conditions assumed were:

- Inside temperature: 1°C
- Outside temperature: 0°C (temperature difference 1°C in order to get the $Wm^{-2}K^{-1}$)
- Heat flow from both sides q=0 Wm^{-1}, i.e. sideways in the wall

The U value calculated was 0.2027 $Wm^{-2}K^{-1}$. The calculations were steady state.

3. We added the columns in the Heat 2 model as shown in Figure D.3. The distance between the centres of the steel columns is 2.4m, between the centres of studs 0.6m and between centres of the floors 3.5m.

Figure D.3 External wall construction (with columns).

Using the same assumptions as in step 2, we simulated the new model (Figure D.4). The new U-value calculated was 0.27 $Wm^{-2}K^{-1}$.

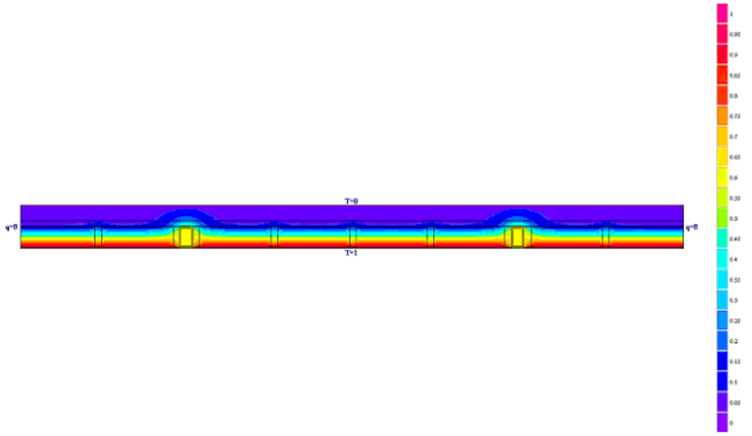

Figure D.4 Simulation with the steel columns (Heat 2).

4. We assumed an equivalent external wall (with the same U-value) in IDA by reducing the insulation from 0.137m to 0.1125m as shown in Figure D.5.

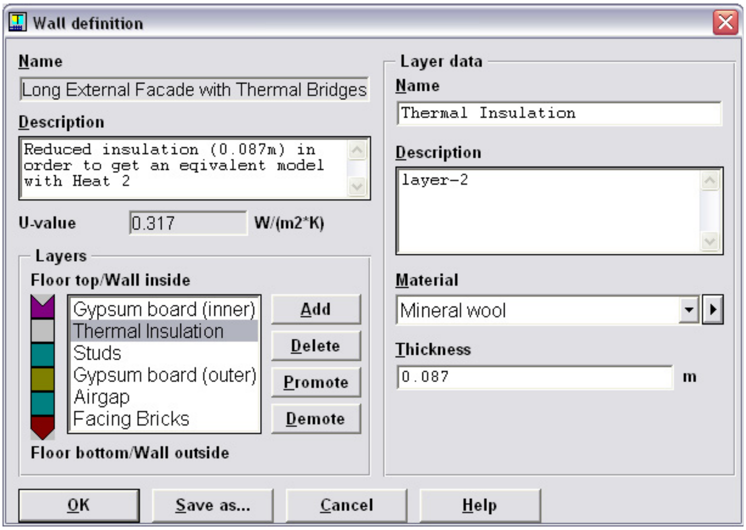

Figure D.5 *Final model of the external wall in IDA (reduced thermal insulation).*

Appendix E

AHU- Ventilation rates

AHU for Cell type

For the cell type air the air exchange with the outdoor environment takes place in 4 different ways:

- Supply air in the offices and meeting rooms during the working hours (mechanical ventilation)
- Infiltration in all the zones always (natural ventilation)
- Exhaust air in the corridors during the working hours (mechanical ventilation)
- Exfiltration in all the zones always (natural ventilation)

In all the offices and the total ingoing air is due to the mechanical supplied air and the infiltration and the total outgoing air is due to the exfiltration. The supplied air in the offices is extracted though leakages to the corridor and exhausted from there through the AHU. The infiltration and exfiltration are assumed to be 0.1ach for all the zones. In the meeting rooms all the air supplied is also exhausted. The reason for that is that if the supplied air (VAV CO_2 control) was extracted to the corridors the total exhaust air would be unknown. This means that any mistake in the estimation of the VAV supplied air would destroy the balance of the total supply – exhaust air influencing the AHU efficiency. However, the VAV CO_2 control applied in the meeting rooms caused 2 problems for the simulations:

- Infiltration (increase the mechanical ventilation) could not be added since the rooms were supplied with the necessary air so we had to add this infiltration had to be added to the offices.
- The supplied air was not known so it was not possible to know how much the efficiency of the AHU should be decreased. In order to solve the problem the airflow was estimated

The Table E.1 below shows the ventilation rates of each zone as inserted in IDA.

- The Supplied air per zone (mech. ventilation) shows the air that is provided by the AHU as mechanical ventilation. In the corridors there is not any supplied air and in the meeting rooms is shown the estimation we made.
- The supplied air per zone (mech. ventilation) is increased in the offices (natural ventilation in the offices, corridor and meeting rooms). In the meeting rooms the airflow is the same since infiltration was added to the offices.
- The Total Exhaust air (l/s) per floor shows in each zone the exhaust air. There is not any exhaust air in the meeting rooms since they do not contribute in the total exhaust air from the corridors. However in reality it should be considered in order to find the proper amount of total airflows which will give the correct decrease of the AHU efficiency.

Table E.1 Ventilation rates for cell type.

Room type	Zone	Supplied air per zone (mech. vent.) (l/s)	Supplied air per zone (total) (l/s)	Total Exhaust air (l/s) per zone	Supply air/ Exhaust air	Input for IDA
Corner office rooms	B1	15	17.01	0	1000	0.017008
	B4	15	17.01	0	1000	0.017008
	B6	15	17.01	0	1000	0.017008
	B9	15	17.01	0	1000	0.017008
	C1	15	17.01	0	1000	0.017008
	C4	15	17.01	0	1000	0.017008
	C6	15	17.01	0	1000	0.017008
	C9	15	17.01	0	1000	0.017008
	A1	15	17.01	0	1000	0.017008
	A9	15	17.01	0	1000	0.017008
Double office rooms	A2	20	22.04	0	1000	0.022042
	A6	20	22.04	0	1000	0.022042
	B2	20	22.04	0	1000	0.022042
	B8	20	22.04	0	1000	0.022042
	C2	20	22.04	0	1000	0.022042
	C8	20	22.04	0	1000	0.022042
Single office rooms	B3	10	11.34	0	1000	0.011339
	B7	10	11.34	0	1000	0.011339
	C3	10	11.34	0	1000	0.011339
	C7	10	11.34	0	1000	0.011339
	A3	10	11.34	0	1000	0.011339
	A7	10	11.34	0	1000	0.011339
Meeting rooms (6p)	B5	21	21	0	1000	0.022726
	B10	21	21	0	1000	0.022726
	C5	21	21	0	1000	0.022726
	C10	21	21	0	1000	0.022726
	A10	21	21	0	1000	0.022726
Meeting rooms (8p)	A8	28	28	0	1000	0.03069
Meeting rooms (12p)	A4	42	42	0	1000	0.045349
Storage room (1st floor)	A5	62	70.58	0	1000	0.070576
Corridor (1st floor)	A11	0	0	577.10	0.001	577.10
Corridor (2-6 floors)	B11	0	0	699.67	0.001	699.67
	C11	0	0	699.67	0.001	699.67
Natural Ventilation (not including the corridors and the meeting rooms)						**242.5**
Natural Ventilation (including the corridors and the meeting rooms)						**462.9**
Weighted Natural Ventilation)						**462.9**
Total Weighted Natural Ventilation						**4075.4**
Total Mechanical Ventilation						**3612**
Recovered heat (60%)						**2398.2**
Equivalent percentage for recovered (%)						**53.773**
AHU on Value						**1**
AHU off Value						**0.1038**
Weekends off value (=50% mechanical ventilation +100% natural ventilation)						**0.551**

AHU for Open plan type

For the open plan type the calculations were much simpler since both supply and exhaust air were provided in all the thermal zones. However, the meeting rooms were treated exactly in the same way with the cell type office building. In Table D.2 are shown the airflows of the building.

Table E.2 Ventilation rates for open plan type.

Room type	Zone	Supplied air per zone (mech. vent.) (l/s)	Natural ventilation per zone (l/sec)	Ventilation per zone (l/s)	Supply air/ Exhaust air	Input for IDA
Typical corner zones	B1	112	19.4	131.4	1	133.0366
	B4	112	19.4	131.4	1	133.0366
	C1	112	19.4	131.4	1	133.0366
	C4	112	19.4	131.4	1	133.0366
	A1	112	19.4	131.4	1	133.0366
Reduced corner zone	A4	84	15.2	99.2	1	100.4822
Intermediate zones	A8	168	32.22	200.22	1	202.938
	B8	168	32.22	200.22	1	202.938
	C8	168	32.22	200.22	1	202.938
Meeting Rooms	A2	0	1.5	29.5	1	0
	A5	0	1.5	29.5	1	0
	B2	0	1.5	29.5	1	0
	B5	0	1.5	29.5	1	0
	C2	0	1.5	29.5	1	0
	C5	0	1.5	29.5	1	0
Storage room (1st floor)	A9	62	4.83	66.83	1	67.23745

Natural Ventilation (not including the meeting rooms)	**426.75**
Natural Ventilation (including the meeting rooms)	**462.75**
Weighted Natural Ventilation (the natural ventilation of the meeting rooms is added as nat. vent. In the offices)	**462.75**
Total Weighted Natural Ventilation (the natural ventilation of the meeting rooms is added as nat. vent. In the offices)	**3520.75**
Total Mechanical Ventilation	**3074**
Recovered heat (60%)	**1844.4**
Equivalent percentage for recovered (%)	**52.387**
AHU on Value	**1**
AHU off Value	**0.1314**
Weekends off value (=50% mechanical ventilation +100% natural ventilation)	**0.5679**

Appendix F

Frame Construction

The "improved" frame constructions were suggested by Schüco International. For the first to sixth 60% glazed alternatives the frames used are the Royal FW 50^+ Hi and FW 60^+ Hi as shown in Figure F.1 and F.2.

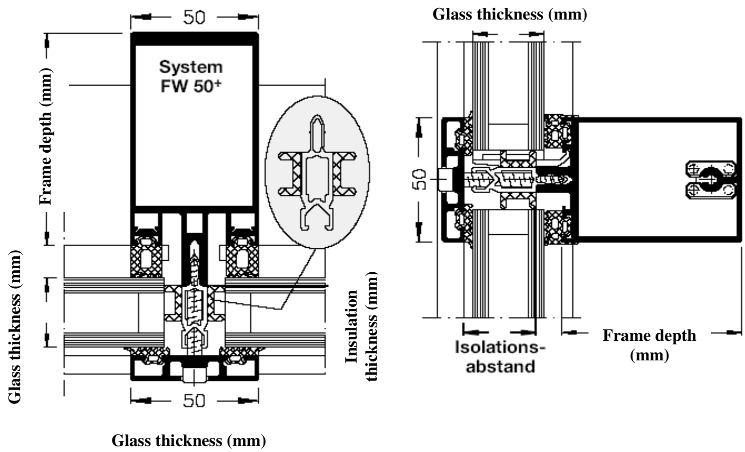

Figure F.1 *System FW 50+ Hi.*

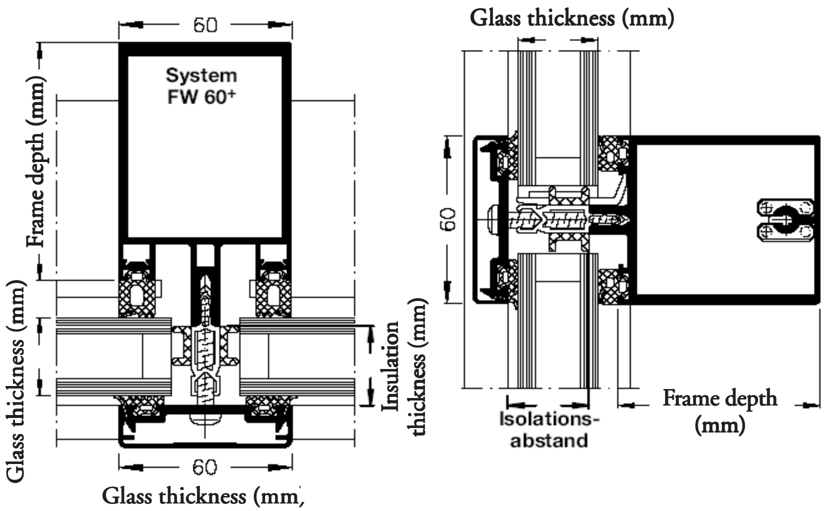

Figure F.2 *System FW 60+ Hi.*

The U_{frame} depends on the frame depth. As shown in Figure F.3

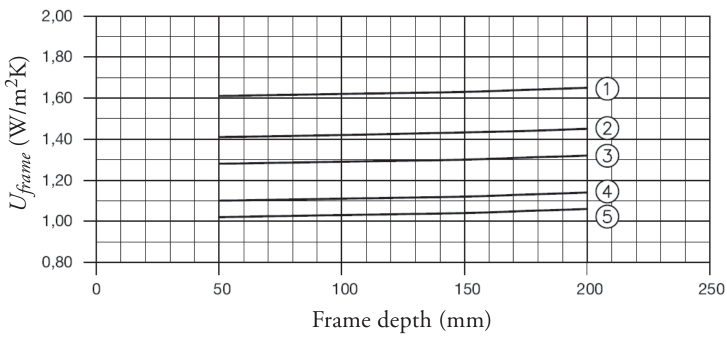

Figure F.3 *Relationship between U_{frame} and frame depth.*

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