Balancing comfort expectations and greenhouse gas emissions

Thermal comfort in office buildings in a changing climate

Dissertation

Dem Promotionsausschuss der HafenCity Universität Hamburg zur Erlangung des akademischen Grades Doktor Ingenieurin (Dr.-Ing.) vorgelegt von:

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2009

Vollständiger Abdruck der vom Promotionsausschuss der HafenCity Universität Hamburg zur Erlangung des akademischen Grades eines Doktor-Ingenieurs (Dr.-Ing.) genehmigten Dissertation.

Vorsitzender des Prüfungsausschuss:

Prof. Dr.-Ing. Wolfgang Dickhaut

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Die Dissertation wurde am 21.12.2009 vom Prüfungsausschuss der HafenCity Universität in Hamburg angenommen.

Acknowledgements

I would like to express my sincere gratitude to all of those who contributed to the completion of this work.

This dissertation would not have been possible without my two supervisors Prof. Udo Dietrich and Prof. Sabine Busching from HafenCity University Hamburg, Germany, and Prof. Aris Tsangrassoulis from University of Thessaly, Volos, Greece.

I am very grateful to Prof. Udo Dietrich and Prof. Sabine Busching for the great latitude they allowed me regarding the focus of my work, their faith and unconditional support in my project, as well as helpful comments and the valuable and inspiring discussions.
I am very much obliged to Prof. Dietrich and my colleagues at HafenCity University Hamburg for counselling and the support during my time as a research assistant. It was a pleasure to work with you; thank you very much for your help and collaboration.
I also want to thank everyone at the 'City Nord' library for their immediate help whenever I was looking for literature, and Dr. Joachim Thiel, Mrs. Nommsen and the administration department, for never running out of solutions. I would also like to thank Christof Fielstette for the advice on office lighting in practice.
Additionally it would not have been possible to finish this work without the financial support of the Henri Benthack Foundation in Hamburg, whom I owe sincere thankfulness for funding my work and conference participation during the final period.

Since the provision of summer thermal comfort is a greater challenge in a southern climate, I spent the final year of my PhD in Greece. There I had the pleasure to experience the great hospitality of its people and their enriching culture. I am deeply thankful to the Department of Architecture at the University of Thessaly in Volos, and to my colleagues for kindly hosting and supporting me.
Especially, I wish to express my deepest gratitude to Prof. Aris Tsangrassoulis for all the unconditional support, background information on the Greek context, help with the field studies in Athens, and simulation advice. Your comments and our enriching discussions have been an invaluable source of inspiration and motivation.

My field study in Athens would not have been possible without the support of Dimand S.A. Real Estate Development, and A.N.Tombazis & Associates Architects in Athens and everybody who completed the questionnaires. I especially would like to thank Olga Itsiou and Sandra Bär at Dimand, Despina Tombazi at Tombazis Architects, as well as Vassilis Geros for helping me conduct the field study in Athens and giving me background information.

Finally, I am deeply grateful to my parents and my friends. I would not have been able to complete this thesis without their constant support.

Abstract

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the construction sector has the greatest potential for climate change mitigation. This work investigates the potential for climate change mitigation in naturally ventilated and mixed mode office buildings, by evaluating the range of influence of building design and occupants on greenhouse gas emissions as well as thermal- and visual comfort. Thermal comfort is evaluated according to the EN 15251 adaptive thermal comfort model, visual comfort is based on daylight autonomy and view. Parametric studies have been conducted based on building simulation for the climate of Athens, Greece. Input data are based on a literature review, and on results from a field study conducted among office occupants and architects in Athens.

The results show that the influence of occupants on greenhouse gas emissions is larger than the influence of building design. Energy saving office equipment, as well as active use of building controls for shading and lighting by occupants are crucial parameters regarding the reduction of CO2 emissions. In mixed mode buildings, the coefficient of performance of the cooling system is an important parameter as well. Regarding thermal and visual comfort, the influence of building design is predominant. A green building, well protected against heat from the sun and able to balance solar and internal heat gains, provides higher comfort levels and is less affected by the influence of occupants. In mixed mode buildings, building design is the predominant influence on the magnitude of cooling loads. A hot summer including heat waves can significantly reduce thermal comfort and increase the resulting greenhouse gas emissions. Green buildings are least affected by these influences.

The EN 15251 adaptive thermal comfort model provides a thermal comfort evaluation method valid throughout Europe. However, for the Mediterranean climate of Athens, Greece, most of the configurations investigated within this study do not meet the requirements according to this model. EN 15251 refers to an adaptive thermal comfort model for naturally ventilated and to a static model for mechanically ventilated buildings. For mixed mode buildings, the static model is recommended, but literature indicates that occupants in those buildings might be more tolerant towards higher temperatures. The hypothetical application of the EN 15251 adaptive thermal comfort model in mixed mode offices, as investigated in this study, shows potential for greenhouse gas emission savings. However, this influence is small compared to that of building design and occupants. Conclusions are drawn regarding the categorisation and exceeding criteria according to EN 15251 adaptive thermal comfort model for offices in a Mediterranean climate.

The results of this work show, that not only green buildings, but also green occupants can significantly contribute to the mitigation of the climate change. Mechanisms of the real estate market as well as the lifestyle of occupants are important influences in this context. Sustainability therefore refers to finding the right balance between occupant's comfort expectations and resulting greenhouse gas emissions for a specific building, rather than optimisation of single parameters.

Entsprechend des ‘Fourth Assessment Report’ des Intergovernmental Panel on Climate Change (IPCC), bietet der Gebäudesektor das größte Potential für Einsparungen von Treibhausgasemissionen. Die vorliegende Arbeit untersucht das Potential zur Verminderung des CO2 Ausstoßes in natürlich belüfteten und saisonal klimatisierten Bürogebäuden. Schwerpunkt ist die Spannweite des Einflusses von Gebäudedesign und Nutzern auf Treibhausgas Emissionen sowie thermischen und visuellen Komfort.

Die Bewertung des thermischen Komforts erfolgt anhand des adaptiven thermischen Komfortmodells nach EN 15251, die des visuellen Komforts basiert auf Tageslichtautonomie und Ausblick. Für das Klima in Athen, Griechenland, wurden parametrische Studien mit der Gebäudesimulationssoftware Energyplus durchgeführt. Die entsprechenden Eingabedaten basieren auf einer Literaturrecherche sowie auf Ergebnissen einer Feldstudie unter Büronutzern und Architekten in Athen.

Die Ergebnisse zeigen, daß der Einfluß der Gebäudenutzer auf Treibhausgasemissionen größer ist als der Einfluß des Gebäudedesigns. Energiesparende Bürogeräte, sowie aktive Steuerung von Verschattung und Kunstlicht durch Nutzer sind entscheidende Parameter bezüglich der Reduktion von CO2 Emissionen. In saisonal klimatisierten Gebäuden ist auch der ‚Coefficient of performance‘(COP) des Kühlsystems ein ausschlaggebendes Kriterium.

Bezüglich thermischem und visuellem Komfort ist dagegen der Einfluß des Gebäudedesigns entscheidend. Ein robustes Gebäude, das gut vor solarer Einstrahlung geschützt ist und in der Lage ist solare und interne Wärmegewinne auszubalancieren, bietet besseren Komfort und ist weniger anfällig gegenüber dem Einfluß von verschiedenen Nutzern. In saisonal klimatisierten Gebäuden ist das Gebäudedesign auch ausschlaggebend für die Größenordnung der Kühllasten. Ein warmer Sommer mit Hitzewellen kann sich erheblich negativ auf thermischen Komfort auswirken und die resultierenden Treibhausgasemissionen erhöhen. Nachhaltige Gebäude stehen solchen klimatischen Phänomenen robuster gegenüber.

Das adaptive thermische Komfortmodell nach EN 15251 ist eine Methode zur Evaluierung des thermischen Komforts, gültig für alle Europäischen Klimazonen. Allerdings konnte für die in dieser Studie untersuchten Varianten im Athener Klima festgestellt werden, daß sie in der Mehrheit die Kriterien nach EN 15251 nicht erfüllen. Dies ist im Wesentlichen auf die Komfortkategorisierung und die Definition des Überschreitungskriteriums im EN 15251 adaptiven thermischen Komfortmodell zurückzuführen.

EN 15251 enthält ein adaptives thermisches Komfortmodell für natürlich belüftete und ein statisches Modell für mechanisch belüftete Gebäude. Für saisonal klimatisierte Gebäude wird ebenfalls das statische Modell empfohlen, aber die Literatur deutet an, daß Nutzer in diesen Gebäuden toleranter gegenüber höheren Raumtemperaturen sein könnten als in mechanisch belüfteten Gebäuden. Die hypothetische Anwendung des adaptiven thermischen Komfortmodells auf die Kühltemperaturen in saisonal klimatisierten Gebäuden, wie in dieser Studie untersucht, bietet Potential für Einsparungen von Treibhausgas Emissionen. Allerdings ist dieses Potential im Vergleich zur Spannweite des Einflusses von Gebäudedesign und Nutzern eher klein.

Die Ergebnisse zeigen, daß nicht nur nachhaltige Gebäude, sondern auch nachhaltige Nutzer erheblich zur Verringerung des Klimawandels beitragen können. Mechanismen des Immobilienmarktes sowie der Lifestyle der Gebäudenutzer sind wesentliche Einflußfaktoren in diesem Kontext. Nachhaltigkeit bedeutet in diesem Zusammenhang die Suche nach der richtigen Balance zwischen Komforterwartungen der Nutzer und resultierenden Treibhausgasemissionen für ein spezifisches Gebäude, und weniger die Optimierung einzelner Parameter unabhängig voneinander.

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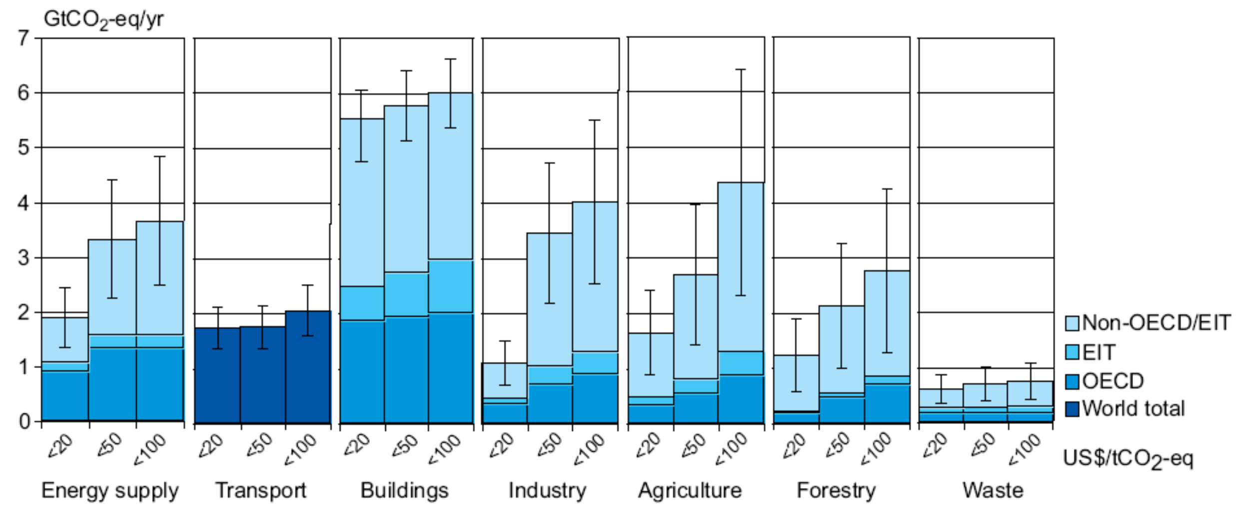
0. Introduction

0.1 Description of the context

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change the buildings sector has the greatest potential for climate change mitigation (figure 1), and under the Kyoto Protocol, the participating countries committed themselves to a reduction of related greenhouse gas emissions. On a European level, the Energy Performance of Buildings Directive (EPBD) [1] provides a framework for national climate change mitigation schemes in the building sector. However, the requirements to reduce greenhouse gas emissions are standing vis-à-vis to an increasing demand for comfort by occupants. This is especially obvious in office buildings, where internal and solar heat gains occur concurrently, leading to an increasing concern about the provision of satisfying thermal comfort. Additionally, strong heat waves within the last decade, as well as climate change scenarios, have caused a tendency towards mechanical ventilation in office buildings, in order to be able to guarantee satisfying comfort levels and to be competitive on the real estate market.



Energy supply	Transport	Buildings	Industry	Agriculture	Forestry	Waste
(potential at <US$100/ tCO_2-eq: 2.4 - 4.7 Gt CO_2-eq/yr)	*(potential at <US$100/ tCO_2-eq: 1.6 - 2.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 5.3 -6.7 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.5 - 5.5 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 2.3 -6.4 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 1.3 - 4.2 Gt CO_2-eq/yr)*	*(potential at <US$100/ tCO_2-eq: 0.4 - 1 Gt CO_2-eq/yr)*

Figure 1: Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. The potentials do not include non-technical options, such as lifestyle changes [Source Climate Change 2007: Mitigation of Climate Change. Working Group III, contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Figure SPM.6. Cambridge University Press.].

The current European thermal comfort regulation 15251-2007 [2] differs between an adaptive thermal comfort model for naturally ventilated and a static model for mechanically ventilated buildings, based on the results from field studies. In naturally ventilated buildings, occupants were observed to prefer room temperatures related to the outside environment, when they are able to play an active role in creating their preferences, by operating windows or adjusting clothing. In mechanically ventilated buildings, they were observed to prefer constant room temperatures, thus being passive recipients of their thermal environment.

An initial parametric study for naturally ventilated offices in the climate of Hamburg, Germany, indicated, that satisfying thermal comfort according to the EN 15251 adaptive model was limited for south facing offices in case of high internal heat loads. This leads to the question in how far thermal comfort in naturally ventilated buildings can be maintained in a future climate or in a warm European climate.

Additionally, the majority of office buildings in warm European climates are operated in mixed mode, using a cooling system only for a limited part of the year, in the remaining time they are naturally ventilated. According to EN 15251, these buildings should be evaluated like mechanically ventilated buildings, according to the static model. However, research [3, 4, 5] indicates, that occupant's preferences in mixed mode buildings are likely to be more relaxed than assumed in this model. Although further research would be necessary, this could indicate a potential for energy savings in mixed mode buildings when using higher cooling set points. Nevertheless, the currently safest option for building professionals in a warm European climate is the equipment of mixed mode buildings with a cooling system according to the requirements for mechanically ventilated buildings.

Based on the Energy Performance of Buildings Directive, European countries have developed national regulations in order to limit the energy consumption of buildings. These regulations are designed to improve the average building stock, and to achieve comparability among different buildings. For parameters, which in real buildings show a large variability, e.g. the influence of occupants, and local climate they refer to standard values as input data for calculations or simulations. Thus, evaluation often focuses only on the performance of the building alone, and excludes the influence of climate or occupants. Recent research [6] indicates that this might be an explanation for often-observed differences [7] between measured and calculated energy consumption and comfort in buildings.

0.2 Aims of the study

Aim of this study is to evaluate the range of influence of building design, occupants and heat waves on thermal comfort, visual comfort and greenhouse gas emissions in offices in the Mediterranean climate of Athens, Greece. The potentials and limits for optimisation of these parameters are investigated in the context of naturally ventilated and mixed mode offices. Investigations are based on a parametric study for a typical cellular office room, using the building simulation software energyplus [8]. Input data are based on literature research and results from a field study in two office buildings in Athens. Thermal comfort is evaluated according to EN 15251. In order to consider the contradictory effect of shading use on thermal and visual comfort, daylight autonomy and view are evaluated as well.

Current legislation and related building codes in Germany and Greece [9, 10], predominantly focus on the optimisation potential of the building, excluding the variability of influence of occupants, by using average standard values for parameters concerning the use of a building. In this work, a strategy is developed in order to be able to reflect the variability of occupant behaviour in building simulation.

Regarding thermal comfort evaluation, Greek building regulation refers to EN 15251. This norm introduces an adaptive thermal comfort model for naturally ventilated and a static model for mechanically ventilated buildings. An initial study for Hamburg, Germany indicated that the requirements according to this model are difficult to meet even in a moderate climate for South facing rooms with high internal heat loads. This study therefore investigates, in how far naturally ventilated offices in Athens, Greece can meet the requirements according to this model.

In Mediterranean climates like Greece, the majority of office buildings are operated in mixed mode, using a cooling system only for a limited part of the year while the rest is naturally ventilated. Following EN 15251-2007 [2], they would have to be evaluated according to the static comfort model. However, research [3, 4, 5] indicates, that occupant's preferences in mixed mode buildings might be more relaxed than assumed in the static model. The savings potential for greenhouse gas emissions for the hypothetical application of the EN 15251 adaptive thermal comfort model on cooling set points in mixed mode offices is evaluated in this study.

Climate change characteristics [11], and the need to reduce greenhouse gas emissions in office buildings, seemingly contradict with the increasing comfort expectations of occupants throughout the last decades. In this work, indications to better balance these different requirements in future are discussed.

0.3 Structure and methodology

Chapter 1 contains two initial studies, which have predefined the focus of this work. In the first study, the evolution of comfort expectations of office occupants within the last decades is investigated in relation to concurrent technical and social trends and development. This initial study influenced the preparations for the field study in Athens, in order to include questions regarding the occupant's lifestyle and their willingness to contribute actively to the climate change mitigation by adjusting their comfort expectations.

The second initial study is a parametric study regarding the influences of building design and occupants on comfort and energy consumption in naturally ventilated offices in the climate of Hamburg, Germany. This study indicated a need to investigate the range of influence of occupant behaviour and internal heat loads, and to consider different building design variations according to requirements of the real estate market. Additionally, thermal comfort according to the EN 15251 adaptive model could be maintained for most of the investigated variations in Hamburg, except for South facing room with high internal heat loads. This lead to the decision to focus the main part of this work on the Mediterranean climate of Athens, Greece, where the balance between comfort expectations of occupants and the need to reduce the related energy consumption is a bigger challenge.

Chapter 2 describes the development of input data for the energyplus simulation model of a typical cellular office in Athens, Greece. Since the model for Hamburg from the initial study was not originally created for applicability in another climate, a new model had to be developed, so the results for both countries are not directly comparable.
In order to obtain necessary information on occupant behaviour and mechanisms of the real estate market, a field study has been conducted among office occupants and architects in two mixed mode office building in Athens (2.1). The next section, 2.2, investigates the climate for the location of Athens. Since no weather data sets reflecting climate change scenarios for Athens were available for this study, two different weather data sets based on observed data within the last decade are developed. Based on the results from the field study, in the following paragraph (2.3), different building properties are investigated, and the final characteristics of three different models of a typical cellular office room are defined. Paragraph 2.4 focuses on the occupant behaviour and internal heat loads in offices. Based on a literature review and results from the field study, a strategy to reflect the variability of these parameters in real buildings is developed.

Chapter 3 describes the evaluation methods used in this study, regarding energy consumption and related greenhouse gas emissions, thermal comfort, daylighting and view.

Chapter 4 presents the detailed results from the parametric study with energyplus, for naturally ventilated as well as for mixed mode offices.

Chapter 5 presents a summary of the general conclusions, which can be derived from this work.

CHAPTER 1, INITIAL STUDIES

1.1. Evolution of office space and thermal comfort evaluation in the context of technical and social development

The history of office buildings begins with government buildings in the 13th century. These buildings represent a “domestic model” in combining spaces for living and spaces for trading. Only with the industrialization in the 19th century, office buildings became an own type of structure [12]. However, the characteristics of the structure have been changing constantly with time, influenced by technological inventions, changing office tasks, spatial requirements, and a changing lifestyle and perception of the role of office occupants. As investigated by Brager and de Dear, the notion of comfort has evolved in history influenced by various social, technological, economic and cultural influences [13]. It has many layers of meaning and is a complex and dynamic combination of the user’s state of mind and experience of space. Thus in practice it is often described as the absence of discomfort [13].

These changes in office design, lifestyle and comfort perception are a continuous process of merging influences and emerging trends and fashions, superposing or substituting each other or coexisting, so a strict categorization does not seem possible. However, the following paragraph proposes a rough attempt for a typology of the predominant trends influencing thermal comfort perception in the particular era. It is based on technical and social trends, other influences like historic events, floor plan layouts, the attitude towards the function of the facade, and comfort philosophy in corresponding legislation. An overview is presented in table 1.

	New technical trends affecting the design of office buildings	**New social trends concerning office lifestyle**	**Other influences**	**Typical office type**	**Attitude towards the function of the facade**	**Thermal comfort legislation**
19th century until World War II	-Cast iron -Steel constructions -Elevator -Light bulb	-Scientific management (Taylorism)	-Industrial Revolution -World War II	-Cellular office -Office factory	Occupant controlled interaction between inside and outside environment	Comfort not considered a measurable quality, later first comfort standards defining temperature boundaries
World War II until 1970s	-Fluorescent lamps -Air-conditioning -Float glass -Curtain wall	-Socio-psychological values	-Nuclear power plants -Mass production -Pre-fabrication	-Open plan office -Landscape office	Protection of the inside- from the outside environment	Code of minimum Comfort for Air-Conditioning defining "comfort as a condition of mind which expresses satisfaction with thermal environment"
1970s until 1990s	-IT technology -Mirrored / tinted glazing -Compact fluorescent lamps	-Human relations movement -Environmentalism -Workplace-ergonomy	-Energy crisis -Chernobyl disaster -Sick Building Syndrome	-Combi office	High-tech facades, automatic controlled interaction of the inside with the outside environment	Static heat balance models, assuming occupants as passive recipients of thermal stimuli.
1990s until today	-Internet	-Workplace health + comfort -Teamwork -Flexible working times -Tele-working	-Kyoto Commitment	-Reversible office	Occupant controlled interaction of the inside with the outside environment	Adaptive thermal comfort models considering people to play an active role in creating their preferences by using physiological, behavioural + psychological adaptation.
Estimates for the (near) future	-LED	-Social comfort -Individual negotiability of working conditions	-Financial crisis	-Tele-office	Facade= Occupant controlled flexible interface between inside and outside environment	General comfort models integrating thermal-, visual- and acoustic comfort as well as indoor air quality

Table 1: Evolution of office spaces and thermal comfort evaluation in the context of technical and social development

19th century until 2nd world war

In the beginning of the 19th century, a growing demand for office space encouraged the construction of office buildings as speculation objects. At the same time cast iron, steel and glass became popular construction materials, which allowed for new construction techniques, and the construction of high-rise buildings. This trend was further supported by the beginning use of passenger elevators around 1860. However, construction was performed only on site and the typology followed traditional buildings.

Common office types in this period were cellular offices along central or external corridors or the “office factory” with rows of desks in a larger office (figure 3) [14].

At the same time, the idea of scientific management emerged, aiming to increase efficiency of work and productivity of single individuals. Assuming workers to be inherently lazy, breaking down complex tasks into linear work processes, accompanied by a stricter management control and constant surveillance seemed to be effective solutions. However, the necessity to meet, to share information and socialize was still important [12, 15].

During this period, the comfort level inside the offices was predominantly influenced by architectural design. Vice versa, building and room dimensions were limited by the requirements for natural lighting and ventilation until at the end of the 19th century the commercial use of light bulbs allowed for artificial lighting. Thus, interaction of the inside with the outside environment was needed, at the state of technical development unavoidable, and it was controlled by occupants (figure 2).

However, the word “comfort”, although first used in the 19th century to refer to environmental comfort related to light, heat and ventilation, was not yet common in terms of a measurable quality [13]. Comfort was rather associated with well being and satisfaction, in terms of tolerability and health, rather than luxury. In 1924, the first thermal comfort standard, based on laboratory studies defining comfort temperature boundaries for 50% humidity was published by ASHVE [16]. Additionally after the wide spread use of air-conditioning since the 1930s, the people’s attitude towards comfort was influenced dramatically [13] and research focused on defining optimum environments for thermal comfort. Consequently, in 1938 a first code for comfort requirements for air conditioning was published [17].

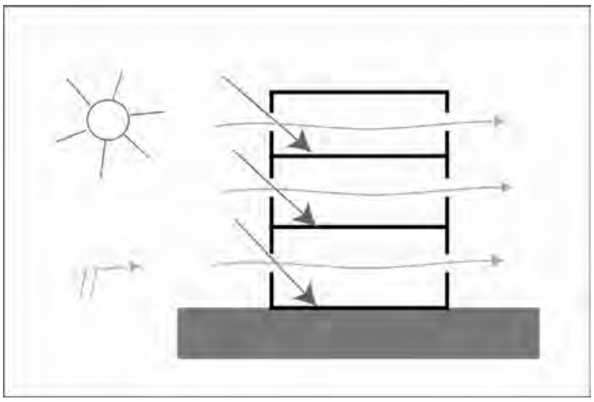


Figure 2: The facade as an occupant controlled interface between inside- and outside environment, 19th century until 2nd World War

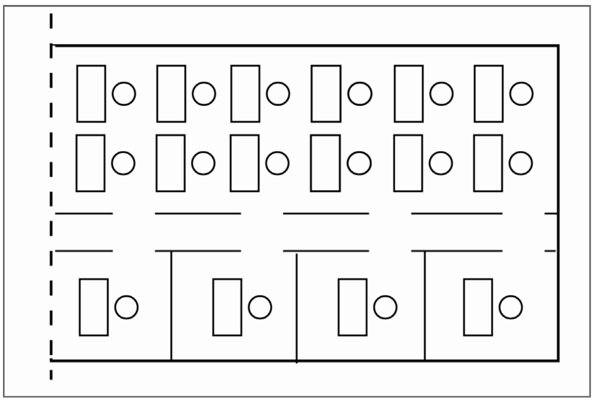


Figure 3: Cellular office and office factory

Second World War until the 70s

The period after 1945 can be characterized by the beginning civil use of nuclear power plants and the increasing commercial use of fluorescent lamps and air conditioning [13, 14]. These technologies marked a step towards a decoupling of the office spaces from the outside environment. They allowed for larger dimensions of office buildings since the rooms were no longer depending on natural ventilation and the provision of daylight. Thus, it facilitated the development of deep floor plan layouts, providing cost efficient space for a large number of office workers. The open plan office reflected this trend. Additionally it suited the still prevailing idea of scientific management principles, assuming socializing being a waste of time [15]. However, socio-psychological values were now introduced in office life and were expressed in the design of landscape offices (figure 5), with a less strict spatial separation for different hierarchy levels.
Another new trend in this period was the design of curtain wall facades, fostered by the continuing industrialization, and the beginning development of mass production methods and pre-fabrication [12]. Due to the float glass production technique, it was now possible to produce large windowpanes. However, these curtain walls were still assembled on site and their quality depended largely on the workmanship on site [18].

Regarding comfort, this introversive development of deep plan artificial office environments was an expression of an attitude in an age of technology where people had faith in the power of engineering to create the perfect indoor climate and to manipulate nature [13]. In residential context, air conditioning was advertised as a necessity for an ideal home providing a more healthy and comfortable environment for housework and family life. Additionally, the perception or definition of comfort was influenced dramatically by the changing expectations of occupants due to air-conditioning [13]. Thus, buildings became independent from their natural sites, and the creation of perfect indoor environments a challenge for engineers. This was also expressed in the function of building envelopes. With air conditioning, openable windows became superfluous or even counterproductive, and as a result, office-building facades turned into a fully sealed protection shield between the inside and the outside environment. The provision of indoor comfort was no longer an issue of building design, but of engineering. Curtain walls, the word is originally describing a line of defence in medieval villages, now became a line of defence against the environment [18] (figure 4). In 1966, a ‘Code of minimum Comfort for Air-Conditioning’ (Ashrae Standard 55-1966) was published, defining “comfort as a condition of mind which expresses satisfaction with the thermal environment” [19]. The condition of mind was determined by a subjective assessment of the acceptability of the environment based on ambient temperature, relative humidity and air velocity [20]. These parameters are based on the balance of heat exchange between the body and the environment, which has to be maintained for basic survival of humans.

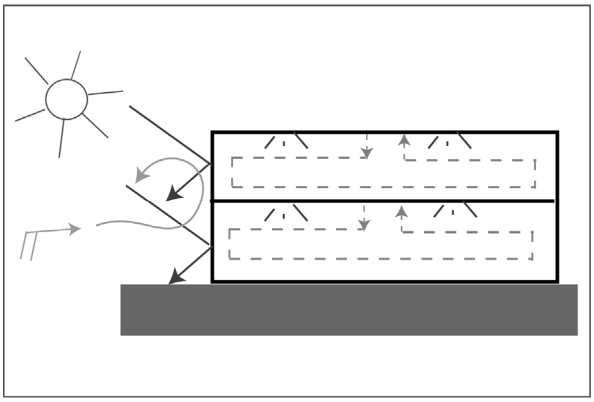


Figure 4: The facade as a protective shield for the inside- against the outside environment, 2nd World War until 1970s

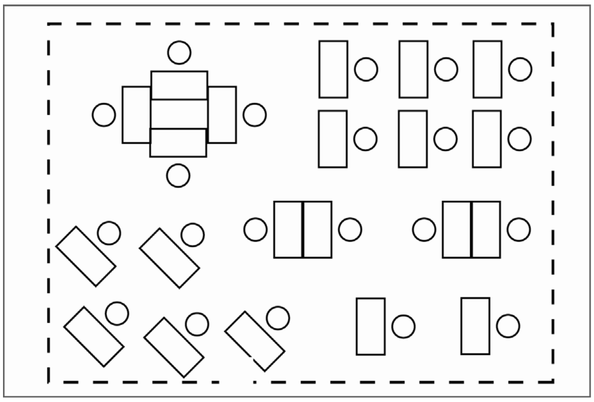


Figure 5: Landscape office

1970s until 1990s

The development of office buildings and office work from the 70s to the 90s is characterised by the use of information and communication technologies and their impact on workflows, office tasks and lifestyle, and a starting environmentalism. The commercial use of personal computers and other office equipment increased rapidly and this had to be considered in the design of workplaces [14]. In this context, a trend towards an increase of ergonomic quality in offices emerged [14]. Following the concept of “landscape offices”, the development of teams and work zones, based on communication patterns and workflows began [21]. This was also an expression of the beginning discussion of sociologic and psychological theories in office context [14], and started a human relations movement as a counter movement to the principles of scientific management before. This lead to a development of more workflow-oriented group offices [22] followed by the design of combi offices (figure 7) [21]. This office type was supposed to combine the advantages of private cellular offices with shared spaces for common resources and communication [22].

Regarding the façade, unitized curtain walls now became common, which could be pre-assembled in a factory. However, since the energy crisis in 1973 and the Chernobyl disaster had demonstrated the scale and the complexity of environmental problems, and brought aspects of sustainability to a global attention, the energetic optimization of buildings became an increasingly important issue. This also led to the development of energy saving compact fluorescent lamps. However the building was often not evaluated as a whole complex system, so building optimization often focused only on single parameters, which were optimized at the expense of others [18]. For example, the use of coloured or mirrored (coated) glazing increased, in order to minimize solar heat gains. However, this often lead to darker building interiors and increased the need for artificial lighting. Additionally in the context of complaints of occupants in air-conditioned buildings and the recognition of the Sick Building Syndrome by the World Health Organisation in 1984 [23], ventilation by outside air and daylighting became more popular again. However, the general philosophy of the façade being a protection shield against the outside environment remained. Facade designs were therefore often based on automatic or mechanically controlled interaction of the inside- with the outside environment (figure 6), often expressed in the design of high tech and double facades.

This philosophy concerning the facade, protecting the inside- from the various influences of the outside environment, is also reflected in thermal comfort legislation of this era. Office users were considered passive recipients of thermal stimuli, and the definition of comfort was based on the physics of heat transfer concerning the heat balance of the human body as observed in climate chambers. The model of Ashrae Standard 55 was further developed in 1981 [24] and 1992 [25], now considering seasonal variations of clothing, humidity, air movement, and control of air movement by occupants. This model defined two different comfort zones for summer and winter. A similar model was implemented in ISO 7730:1984 [26], assessing thermal comfort using an index based on the predicted mean vote (PMV) and predicted percentage dissatisfied (PPD). The considered parameters were air temperature, mean radiant temperature, relative humidity, air velocity, and estimates of subject metabolic rate and clothing insulation.

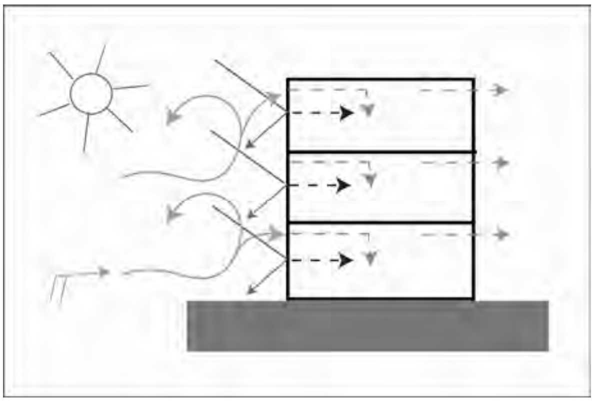


Figure 6: Automatic controlled interaction of the inside- with the outside environment, high tech facades, 1970s – 1990s

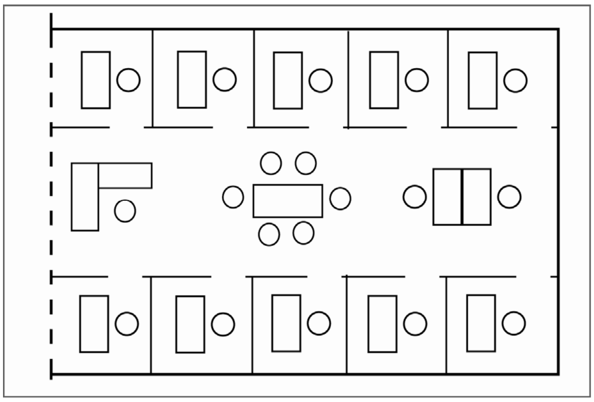


Figure 7: Combi office

1990s until today

Since the 1990s, the trend towards more efficiency and profitability [27] intensified. Also encouraged by a changing office lifestyle influenced by internet and the new economy, another trend towards work in flexible teams, as well as towards more spatial and temporal flexibility increased. Alternative office concepts like teleworking and desk sharing became more popular and encouraged the development of office concepts like the business club, where spaces were not committed to single individuals any more, but could be used by all occupants according to their needs [21]. However, due to increasing prices for office space on real estate markets, the design of building zones for common or shared use decreased, since profitability can only be provided in case of multiple use [27]. In this context the reversible office became a common solution, providing a flexible shell in which different office layouts can be implemented according to the particular tenant's needs (figure 9) [22]. This especially encouraged the use of construction elements providing maximum flexibility (and minimum thermal mass), i.e. false floor constructions, light walls, and suspended ceilings.

At the same time another trend towards an increasing concern about occupant's health and comfort in offices intensified. Since in the course of time occupants have become the most important and most expensive parameter for office work [27], increasing occupant's satisfaction with their environment had become a means of improving profitability and productivity in offices [15]. This is also reflected in a changing focus in research.

The heat balance model had considered comfort to depend only on physically measurable variables, and satisfying comfort was assumed to be best defined in climate chambers. However, the occurrence of the Sick Building Syndrome and related complaints of occupants directed the focus of research to field studies in real office environments. Based on this research, the adaptive thermal comfort theory which had already been developed in the 70s, was first transposed into legislation, the Ashrae Standard 55 in 2004 [28].
In contrast to the static model, adaptive thermal comfort theory assumes building occupants to play an active role in creating their own thermal preferences [29]. Given the opportunity to influence their environment, "if a change occurs producing discomfort, people react in ways which tend to restore their comfort" (Humphreys and Nicol) [30]. According to Brager and de Dear [29], this theory introduced three categories of adaptation. Behavioural adaptation (e.g. adjustment of clothing, body movement, opening windows, adjusting thermostats, using fans, redirecting air, changing blinds), physiological adaptation (e.g. body's acclimatisation to long term exposure to thermally stressful environments, vasodilatation, vasoconstriction, shivering, sweating) and psychological adaptation (e.g. complex combination of factors, past thermal experiences, expectations). The most important adaptive opportunity observed in field studies, leading to higher preferred room temperatures was the possibility for occupants to control natural ventilation by openable windows. This led to the differentiation in the evaluation models for naturally ventilated- and air conditioned buildings in thermal comfort standards like Ashrae Standard 55-2004 [28], ISSO74 [31] or EN 15251-2007 [5]. For all three models the operative indoor temperatures is plotted against comfort limits based on outdoor temperature, however calculated according different formulas. Additionally the three models differ regarding the categorisation, the allowance for exceeding hours, and the requirements regarding building controls. An overview on the characteristics of those three adaptive comfort standards is given in table 2.

Since the possibility to open a window was now considered an important adaptive behavioural opportunity, the perception of the façade changed again. This change was also encouraged by the adoption of the Kyoto commitment, and the following new energy performance regulations for buildings aiming to limit energy consumption and mitigate the climate change. Possibilities for control of the thermal environment were now at least partly shifted from engineers to occupants and natural ventilation was considered a means to improve indoor air quality, thermal comfort as well as to save energy. Thus, the function of the façade changed again from a "protection shield" in the preceding period to a philosophy of occupant-controlled interaction [18] (figure 8).

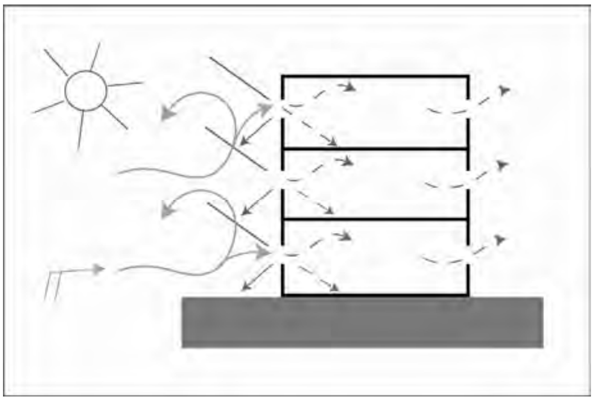


Figure 8: Occupant controlled interaction of the inside- with the outside environment, 1990s until today

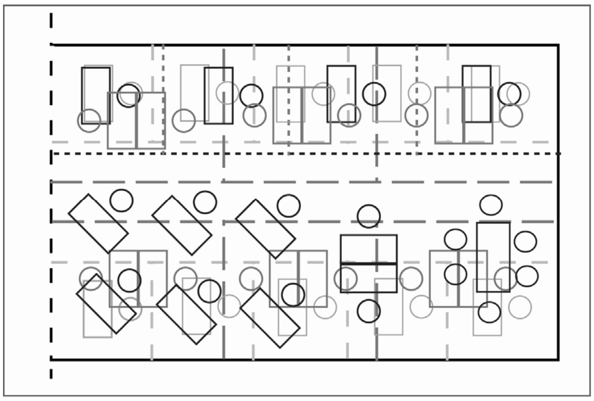


Figure 9: Reversible office

Future

From this rough typology for office building design and office lifestyle, some general trends or characteristics can be derived. It can be observed that a change in building design regarding the development of office types, and the attitude towards the facade has always been initiated by new technological trends or inventions, new social trends or historic events. For example, the deep plan office types would not have been possible without air conditioning and fluorescent lamps, and the use of these energy-consuming systems was facilitated by the civil use of nuclear power plants. The belief in artificial environments was altered towards more interaction between the inside and the outside environment by the occurrence of the Sick Building Syndrome and the environmental movement after the energy crisis and the Chernobyl disaster. In addition, the latest trend towards more spatial and temporal flexibility of work is facilitated by the use of IT technology and internet. However, office types have also always been influenced by new social trends of office lifestyle. For example, the ideology of scientific management is reflected in rows of cellular offices or the office factory and the combi-office considers the human relations movement by providing common areas, for meetings or teamwork. Concerning the recognition of the people working in offices, this typology shows a strong development. While in early periods in office factories the “office worker” was considered a part of a hierarchical system without any special rights or needs, “office occupants” nowadays are considered the most valuable part of the company’s budget, and their well-being is related to the productivity of the company.

Concerning thermal comfort evaluation it can be observed, that legislation always reflected the prevailing attitude towards the function of the facade as well as the relation of the inside with the outside environment. To estimate possible future developments in thermal comfort evaluation, the interaction with expected changes in technology and lifestyle can be important. Although future developments are not easy to estimate and predictions often wrong, some trends might be derived. Concerning technical trends, one development, is the introduction of LEDs in office lighting. This can significantly reduce energy consumption. The use of LEDs might reduce the strong impact of daylight autonomy on greenhouse gas emissions in offices. However, it might also cause a similar trend towards less daylight oriented facade designs like the influence of fluorescent lamps after the Second World War. Since social trends are often expressions of a general change in lifestyle, influenced also by a variety of parameters beyond the office context, future trends are difficult to estimate. However, the increasing recognition of the value of office occupants and the concern about their satisfaction at the work place might indicate a further increasing spatial and temporal autonomy of employees from their work place. In addition, in terms of productivity an increasing focus on occupant’s social well-being in their office context might be possible. Thus, a trend to tailor working conditions individually to single employees might be encouraged.

Another possible influence on office type and the organisation of office work might be the financial crisis. Limited budgets might have an effect on the possibility to commute over long distances, and for building owners, they emphasize a need to reduce running and initial costs. In this context teleworking might become an alternative, with the office as a central base for socialising and meeting, but independent home- or tele-offices for employees (figure 11). For individuals this might increase the flexibility regarding working times and improve possibilities to interconnect work, family and leisure [27, 32]. Additionally, the focus of the real estate market on lowest initial costs for office space might be altered towards benefits for buildings with lowest running costs.

Concerning the attitude towards the function of the facade and the interaction of inside and outside environment, it seems likely that the trend towards increasing occupant control, encouraged by adaptive thermal comfort models will be continued and extended to more opportunities of behavioural adaptation in office buildings. Additionally, the ideal facade would have changeable properties according to season. Thus, occupants could adjust solar and thermal properties according to their comfort preferences. In addition, the ideal shading system would provide a full view while protecting from glare and overheating. This would make the facade a flexible occupant controlled interface between the inside and the outside environment (figure 10).

The development of thermal comfort evaluation over the last decades showed, that it typically reflected prevailing social trends as well as the attitude towards the interaction of the inside with the outside environment. If future social trends increase the focus on social well-being of occupants in their work environment, and the individual flexibility to negotiate about working conditions, this might influence thermal comfort evaluation as well. Both parameters mainly refer to psychological possibilities for adaptation. As indicated by Bischof et al. [33], psychosocial variables are able to superpose the importance of building-/room characteristics and the thermal environment. This could lead to an extended adaptive thermal comfort model, including further behavioural and psychosocial parameters. Additionally an integrated evaluation strategy for thermal-, visual- and acoustic comfort as well as indoor air quality could better reflect occupant behaviour and comfort perception.

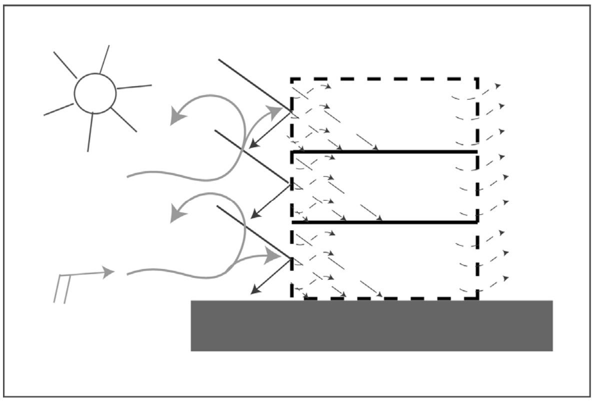


Figure 10: The facade as an occupant controlled flexible interface between the inside- and the outside environment, future estimate

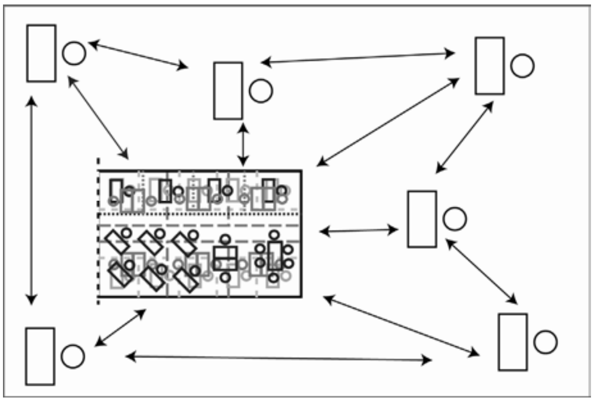


Figure 11: Tele-office

Adaptive thermal comfort standard	categorisation	Exceeding criteria	Ventilation requirements	Clothing	Active cooling control	Valid temp. range	Comfort temperature
Ashrae Standard 55-2004	Two acceptability limits depending on percentage of satisfied occupants: 80% acceptability limits for typical applications and when other information is not available 90% acceptability limits may be used when a higher standard of thermal comfort is desired	No exceeding criteria	„Operable windows that open to the outdoors and that can be readily opened and adjusted by the occupants of the space“. „Mechanical ventilation with unconditioned air may be utilized, but opening and closing of windows must be the primary means of regulating the thermal conditions in the space“.	No dress code	No active cooling	$T_{m,mot}$ = 10°C – 33,5°C	Comfort temperature (indoor operative temperature) related to mean monthly outdoor air temperature: $T_{m,mot}$= arithmetic average of the mean daily minimum and mean daily maximum outdoor (dry-bulb) temperatures for the month in question Upper 80% Limit = $0.31T_{m,mot} + 21.3$ Upper 90% Limit = $0.31T_{m,mot} + 20.3$ Lower 80% Limit = $0.31T_{m,mot} + 14.3$ Lower 90% Limit = $0.31T_{m,mot} + 15.3$
ISSO 74-2004	Three comfort classes depending on percentage of satisfied occupants: A= 90 % satisfied, very good indoor climate B= 80 % satisfied, good indoor climate C= 65 % satisfied, acceptable indoor climate	No exceeding criteria	One ventilation opening for max 2 persons	No dress code	“One thermostat for max. 2 persons”	$T_{e, ref}$= ~10°C-30°C	Limit values for indoor operative temperatures related to the running mean outdoor temperature: $T_{e, ref}$= $(1\,T_{today} + 0{,}8T_{yesterday} + 0{,}4T_{day\ before\ yesterday} + 0{,}2\,T_{day\ before\ day\ before\ yesterday})/\,2{,}4$ A upper limits: $T_{oper} < 20.3 + 0.31T_{e,ref}$ A lower limits: $T_{oper} < 22.7 + 0.11T_{e,ref}$ B upper limits: $T_{oper} < 21.3 + 0.31T_{e,ref}$ B lower limits: $T_{oper} < 23.45 + 0.11T_{e,ref}$ C upper limits: $T_{oper} < 22.0 + 0.31T_{e,ref}$ C lower limits: $T_{oper} < 23.95 + 0.11T_{e,ref}$
EN 15251-2007	4 comfort categories, depending on percentage of dissatisfied occupants: I = minimum % dissatisfied, high level of expectation II= ~ 25% dissatisfied, normal level of expectation III= ~ 35% dissatisfied, moderate level of expectation IV= > 35% dissatisfied, only acceptable for a limited part of the year	„95 % of the occupied space is not more than 3 % (or 5 %) of occupied hours a day, a week, a month and a year outside the limits of the specified Category“	„easy access to operable windows“	No dress code	No active cooling	Θ_{rm} = 10°C – 30°C	Comfort temperature related to the exponentially weighted running mean of the daily mean external air temperature: $\Theta_{rm} = (1-\alpha)\,\theta_{ed-1} + \alpha\,\theta_{rm-1}$ Comfort temperature limits: *Θi upper limits* = $0{,}33\Theta rm + 18{,}8 + x$ *Θi upper limits* = $0{,}33\Theta rm + 18{,}8 - x$ X= 2 for category I, x=3 for cat. II and x=4 for cat.IV

Table 2: Comparison of different adaptive thermal comfort standards

1.2. Parameters influencing office comfort in the climate of Hamburg, Germany

The first part of this work investigates for the climate of Hamburg, Germany and a naturally ventilated typical office room, the optimisation potential of building-, user-and climate-related parameters for thermal comfort, daylighting and view when using realistic input data for building simulation. The study has been conducted with the energyplus-based simulation software Primero-Komfort [34].

1.2.1 Description of input parameters

Climate change and weather data

The commonly used weather data for Hamburg are standard values for the 20th century or test reference years, e.g. energyplus weather data sets [35]. According to investigations [36], these data are not valuable for the evaluation of overheating in summer, since simulation results underestimate the amount of overheating hours significantly.
Greenhouse gas emissions within 1970 and 2004 have increased by 70% (IPCC) and projections of the Intergovernmental Panel on Climate Change [37] for the 21st century predict a global warming of about 0,2°C per decade for the next two decades.
Considering these predictions, two weather data sets for the city of Hamburg have been chosen for the investigation. One is representing an average summer within the last decade, corresponding with measured temperature data [38] for the year 2007. The second data set is corresponding to measured weather data for the hot summer of the year 2003, possibly representing an average summer in future. All weather data have been generated with Meteonorm 6.0 [39].

Room geometry

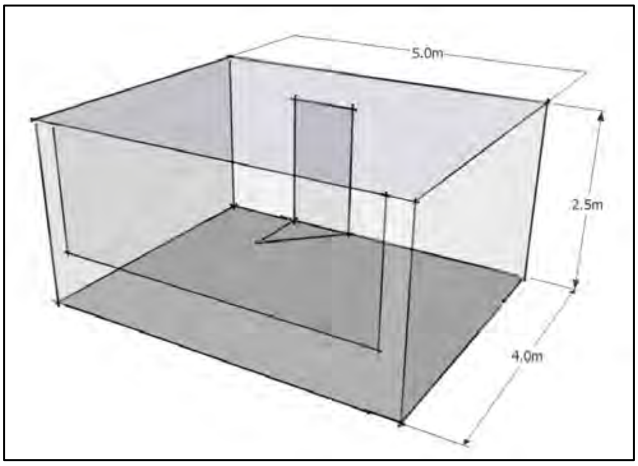


Figure 12: Office room geometry, pre-study Hamburg

The investigated room is a typical cellular office, which can be occupied by one or two persons. It is assumed to have one façade, and to be surrounded by rooms with similar temperature. The façade orientation is considered north or south.

Width (facade) = 5,0m
Room depth = 4,0m
Room height = 2,5m

Construction and thermal mass

Three different constructions types have been chosen for the investigation, representing different thermal storage capacities. “Light” provides flexibility regarding future changes of the room geometries, but does not offer any thermal storage with a light construction of the façade, interior walls made of gypsum plasterboard, acoustic ceilings, and false floor construction. “Medium” differs from “Light” in providing thermal storage in the façade (solid wall) and in a ceiling with suspended gypsum boards. “Heavy” provides most thermal storage to the disadvantage of flexibility with solid façade and interior walls as well as solid slap and screed floor finish instead of false floor.
For all façade types, the heat transfer coefficient is assumed to be 0,18 W/m²K.
As research regarding the airflow within a room [40] revealed, it is optimistic to assume that the complete thermal mass of a room can be considered as effective for heat storage. Usually the fresh, cold air soon drops to the floor after entering the room, and does not necessarily reach the rear part of ceiling or walls. To consider this effect in simulations, only the façade oriented half of walls, ceiling and floor is assumed to have storage capacity.

Glazing

Two different glazing systems have been used for the simulations. A double structure thermal insulation glass (U= 1,1W/m²K, energy transmission = 60%) with a good cost/performance ratio which is widely used in new or renovated buildings. And a double structure solar control glass (U=1,3W/m²K, energy transmission= 33%), which is more expensive but provides a better thermal protection in case of high solar gains. Both glazings are colour-neutral in order not to affect the view.

Window area

The window size in buildings is usually a design-related decision by architects and owners with the intention to create a special appearance or a philosophy on the one hand. On the other hand, window size is often a reference to neighbour buildings, the urban situation with streets, views and historical background, as well as a matter of privacy and overheating protection. Due to this variety of parameters, the decision process for the window area of buildings and rooms cannot be separated from the location of a building.
Another aspect is the satisfaction of occupants with the window area of their room regarding quantity and quality of the view, privacy, and daylight distribution. Field studies [41] lead to the conclusion that occupants tend to prefer horizontal windows, and that they would accept a minimum window area of 20-30% as satisfying. Satisfaction is increasing with window area ranging to 100% depending on the situation. Therefore 30%, 60% (horizontally placed) and 100% window area have been chosen for this investigation, to exemplary demonstrate the influence of window size.

Shading, Shading control, daylighting and view

For this investigation all windows are considered not to be shaded by opposite or neighbour buildings. This might not be realistic for all inner city locations, but it results in higher solar heat gains and is therefore a safe assumption regarding the evaluation of thermal comfort and view.

The investigated shading device for the room is a widely used exterior venetian blind, colour white aluminium (RAL 9006), and façade integrated in a way that ensures natural ventilation even in activated mode. The blind is wind resistant up to a wind force of six Beaufort (Bft.) which is suitable for the climate in Hamburg, where wind forces above 6 Bft. rarely occur in combination with a sky condition requiring shading. Blinds are considered either as fully lowered or fully retracted.
Compared to other shading devices, the advantage of a venetian blind is the flexibility regarding daylighting and view in activated mode by adjusting the slat angle.

User control of blinds is based on the adaptive principle *'If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort'* (Humphreys and Nicol) [30]. As Rea [42] states there is a variety of factors influencing the occupant positioning of window blinds like orientation of the window, time of the day, weather conditions, seasons, latitude, work station position, occupant activities and habits and artificial lighting characteristics and on the average occupants tend to control shadings in order to block solar radiation (heat and light).

As recent field studies [43] revealed, the behaviour of occupants may be active or passive. Concerning the blinds, active users switch the shading on or off or adjust the slat angle more often and therefore probably have a stronger need for visual comfort than passive users. Because interactions of thermal and visual comfort are therewith more obvious, in this study active users are assumed, who are keeping the blinds open as often as possible in order the improve daylighting and view.

The most common reason for activation of the shading device is therefore assumed to occur, if discomfort by solar heat gains or glare or the need for privacy predominate the desire for daylight and view. Moreover, the main reason for opening the shading again, is assumed to occur if perceived discomfort by heat, glare or lacking privacy is reduced and the desire for daylight and view is becoming predominant. Unless heat or glare, regarding the privacy, the user behaviour will not be depending on climate or weather conditions, but on the building, floor level and surroundings. Therefore, this aspect will not be considered in this study.

While the discomfort sensation "heat" can be defined using the operative indoor temperature, "glare" is far more difficult to predict. As Bülow-Hübe [44] states, there seems to be a large individual range regarding how much glare people tolerate and that it is difficult to predict the need for shading devices by common measurable factors, although a correlation between the activation of shading devices and the existence of sun patches in the room could be found. Tuaycharoen et Tregenza [45] investigated the interactions of glare and view, revealing that the occupant's interest in a view has a greater effect on comfort than the relative brightness range and that natural scenes were considered less glaring than urban scenes and three layer views were associated with less discomfort glare than one-layer views. Sutter et al [46] showed that the higher the quality (=screen luminance) of a VDU screen, the more likely an occupant was to tolerate high levels of diffuse reflections on it. They also indicated an increased percentage of opened blinds when the temperature in the office was below 26°C.

In building simulation, it is very difficult to consider all those interdependencies, and especially the attractiveness of a view can only be considered in connection with a specific location. Therefore, only the coverage of the window by an activated blind and the resulting amount of view can be considered in this parametric study. Regarding the shading control, an approximation has been used: It is assumed, that glare is most likely to occur if the sun is shining on the façade, so this has been chosen to be the "glare"- criteria to close the shading device. The discomfort criteria "heat" assumes that both, a room air temperature above 26,0°C and at the same time direct sunlight on the façade will cause blind closing by occupants. As the glare criteria assumes that direct sunlight hardly enters the room, regarding thermal comfort, this control principle can be considered as too optimistic because if it is not causing glare or heat the sun is very welcome in most offices in Hamburg. On the other hand the heat criteria does not consider the fact that glare may occur at temperatures below 26°C as well, therefore the "real" user behaviour will be somewhere in between those two criteria, and for thermal considerations simulations with the heat criteria will be on the safe side. This differs regarding daylighting and view. An activated Venetian blind is useful to prevent overheating, but concurrently it decreases the provision of daylight and view to the outside. Therefore, daylight autonomy is reduced, and the use of artificial lighting will increase affecting energy consumption as well as the heat balance of the room.

Facade design, air exchange rates and window opening behaviour

Usually for thermal comfort simulations, air exchange rates are considered constant during occupancy as well as at nights or on weekends. Common values for natural ventilation via one facade are 1 1/h for occupied periods and 1,5 - 2 1/h for night ventilation.

According to investigations regarding the effectiveness of air exchange in naturally ventilated office rooms [47, 48, 49, 50] these values are changing significantly during day or night and depending strongly on a variety of factors. These are particularly the difference between indoor and outdoor temperature, wind speed -direction and -fluctuation, placement of windows within the façade, cross-sectional area for air exchange of ventilation openings, horizontal and vertical arrangement of ventilation openings, depth of window reveal, placement of heating devices related to windows, window decoration (flowers, curtains), and window opening behaviour of occupants.

Using simulations based on measured data Richter et al [47] showed for a typical naturally ventilated (via one facade) office room a strong dependency of the energetic efficient air exchange rate on differences between inside and outside air temperature as well as on location and dimensions of ventilation openings within the façade.

The influence of these aspects on the interactions of thermal and visual comfort has been investigated in this study, adapting the façade configurations and dimensions used by Richter et al. [47] (figure 13) in order to ensure applicability of results. Regarding the resulting air exchange rates (figure 14), hourly values for outdoor air temperature (weather data) and room air temperature (simulation results) have been used.

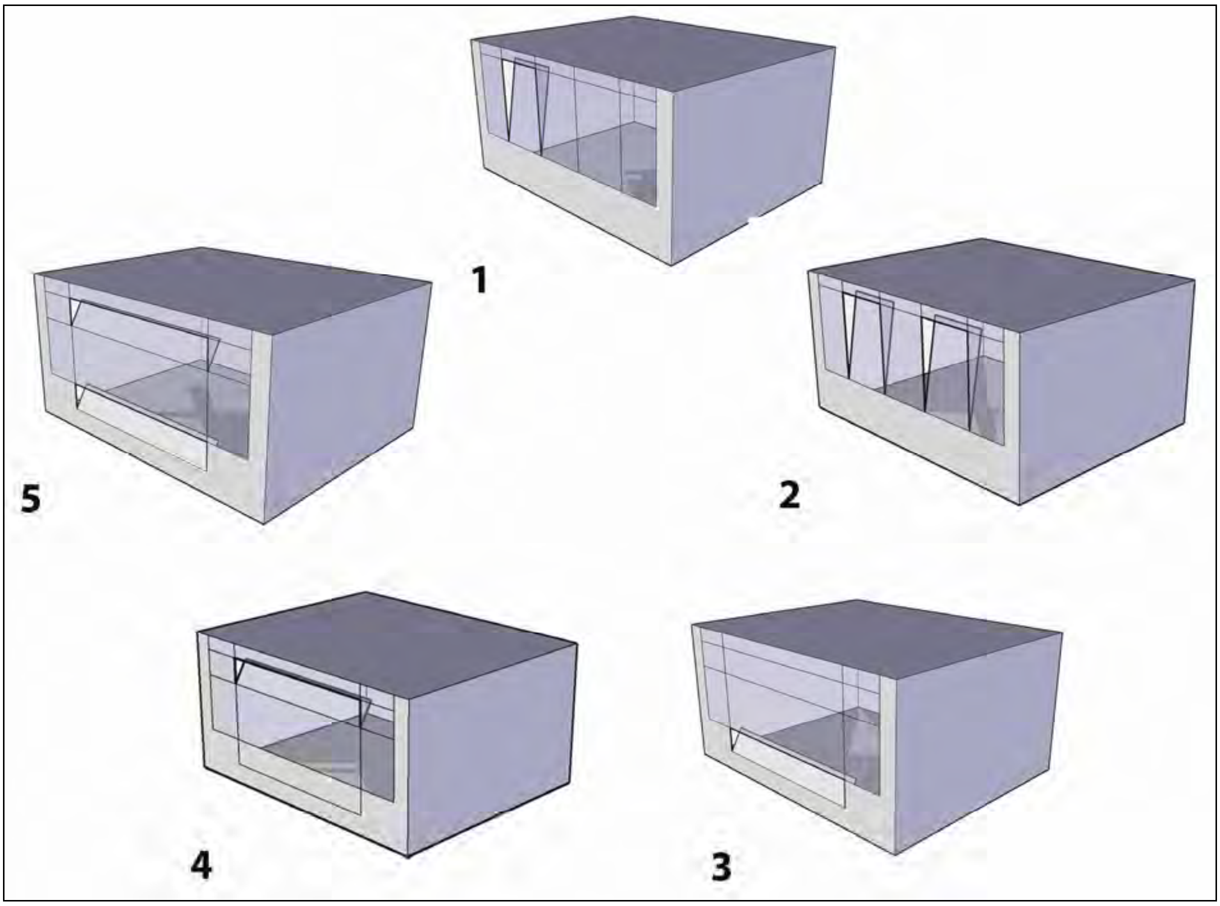


Figure 13: Facade configurations according to Richter et al. [47]

Exemplary for window area 60%, the different investigated façade (design) configurations are shown in pictures above.

The chart below shows the energetic efficient air exchange rate [1/h], depending on the temperature difference average indoor air temperature - outdoor air temperature for different façade variations with bottom hung windows (angle 6°, for horizontal windows angle adjusted in order to create a similar area of air exchange) [47].

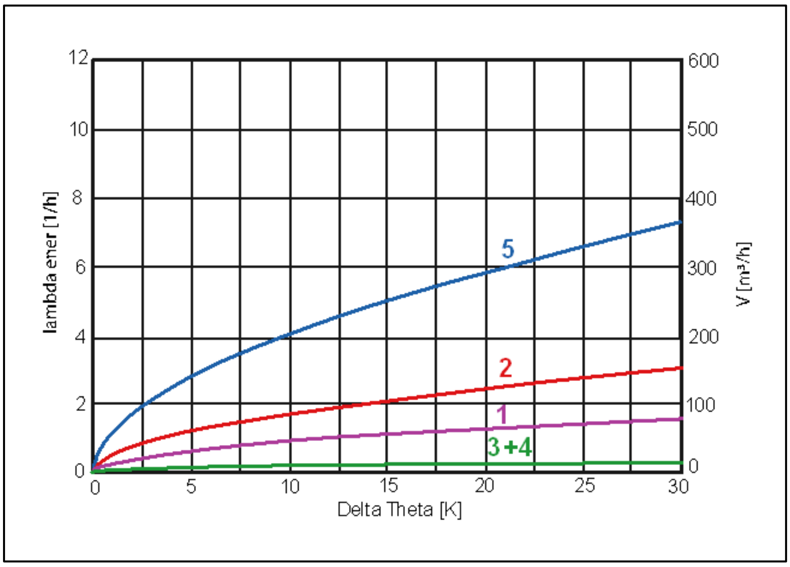


Figure14: Ventilation rates for different facade configurations (figure 13) according to Richter et al. [47]

Another important aspect of natural ventilation by manually operated windows is the window opening behaviour of occupants. Based on field studies during occupied hours, Rijal et al [7] showed that the proportion of windows open is a function of indoor and outdoor temperature. They found out that people are most likely to open windows when both temperatures are high. The resulting Humphreys adaptive algorithm offers the possibility to implement these findings into building simulation by providing a probability of windows open for each calculated time step.
In this study for occupied periods, the hourly air exchange rates resulting from the findings of Richter et al. [47] have been multiplied with the hourly probability for windows open resulting from the Humphreys adaptive algorithm. For periods beyond working hours, at nights or on weekends, there are no data available regarding the window opening behaviour. As recommended by the authors the Humphreys adaptive algorithm is used for these periods as well assuming the occupants decide whether to keep their windows open.

Occupant density

Usually the occupant density in a room is a matter of hierarchies and / or the task. Employees in a higher hierarchical position often have single rooms and more m² per person than colleagues in lower hierarchical positions. Additionally some specific tasks might require single occupancy in order to provide privacy or not to disturb colleagues. The number of persons working in a room, as well as the related office equipment influence internal heat loads in offices.

Occupancy

Usually the diversity profile in office buildings varies from one company to another. Additionally the amount of time employees spend in their office is individually different according to their task.
For building simulation, there are different diversity profiles for offices available. In order to use realistic data for this study a profile has been developed which is comparable to the findings of Rubinstein [51] who investigated occupancy profiles in field studies. It assumes a working time from 7am to 7pm as shown in figure 15.

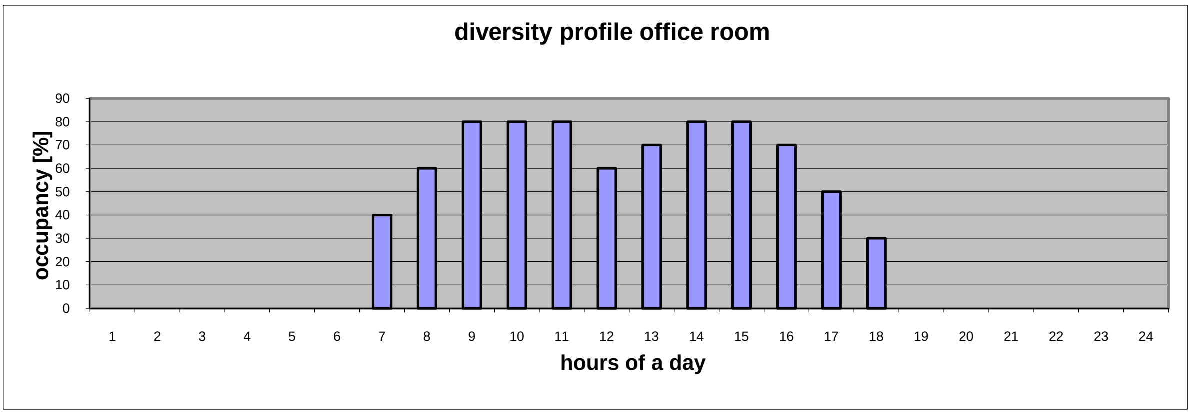
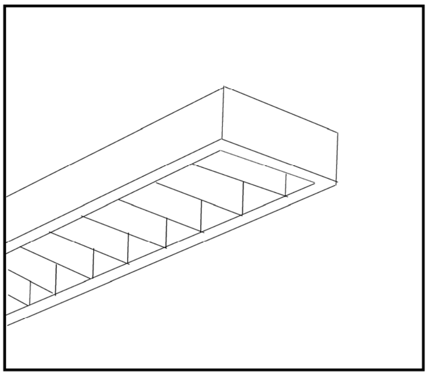


Figure 15: Occupancy profile for a cellular office room

Artificial lighting and lighting controls

Artificial lighting in offices is in the first place depending on the specific office task and the question, in how far the lighting concept is supposed to be decorative (e.g. high prestige offices, and offices with customer traffic) or purely functional.
Regarding the installed lighting power, it is always a question of the combination of luminaire, lamp and ballast, and therefore there is a broad variety of possibilities, each resulting in different energy consumption.
To show the range of influence the artificial lighting design has on thermal and visual comfort, two different variants for the investigated room have been developed using the light design software "Relux" [52], each fulfilling the requirements of DIN EN 12464-1 [53] (figure 16+17).

artificial lighting system "standard"

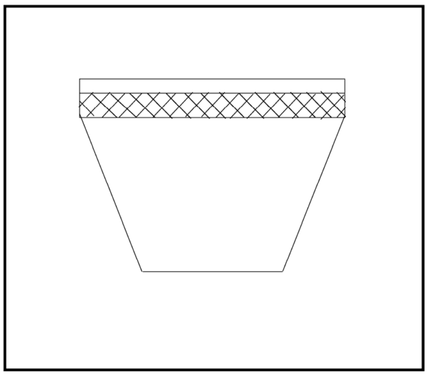


Room related lighting, surface mounted luminaire with specular louvers, 6x 1FD, 58W, 5200lm (T8) with magnetic ballast

installed lighting power: 20,1W/m²

Figure 16: Characteristics of a typical lighting system (standard)

artificial lighting system "optimised"



Task area lighting, pendant luminaires with micro.prismatic light redirection, 4x 1FDH, 54W, 4450lm, (T5) with electronic ballast

installed lighting power: 12,4W/m²

Figure 17: Characteristics of a sophisticated lighting system (optimised)

It is possible to define active or passive users for lighting controls in the same way as for shading controls. Active users are supposed to switch/dim the light on or off according to the daylight illuminance and passive users are assumed not to switch off or dim the light if there is enough daylight. The latter may result in lighting being switched on the whole day. For this study different lighting control strategies have been investigated, "lighting on during working hours", representing the behaviour of passive users, "lighting on/off according to daylight" representing an active user, and “lighting dimmed + on/off according to daylight” representing automatic control or (very optimistic) active users using the dimming control.

Office equipment and intensity of use

The use of equipment in offices is strongly depending on the performed task, there is not only one configuration applicable to all office environments.
First, the needed equipment has to be chosen. For screen handling, equipment per person range from e.g. processing task using a standard computer, screen and printer to e.g. an advertising agency needing powerful computers and special screens and high resolution colour printers plus additional devices consuming much more energy than the processing task.
Second the intensity of use of these devices is important, that is the question how many hours they spend in “on-“, “standby-“ or “off-“ mode.
A third aspect is the fact that most devices are still consuming energy in “off” mode, when they are connected to the power supply. This cannot be avoided for devices, which are needed during non-office hours like phones, faxes or servers, but for all other devices it would be energy saving to disconnect them from the power supply (e.g. switchable power strip) at nights or on weekends. Therefore two different versions for „off“-mode have been considered, one connected to power supply and the other disconnected.

To be able to investigate the range of influence different tasks and equipments have on thermal and visual comfort in offices, three exemplary configurations have been chosen, representing a low- medium- and high energy-consuming task (tables 3-5). The values for “on”, “standby”, and “off” mode (table 6) as well as profiles for use have been taken from EU-energy-star database [54], representing a state of the art (2/2008) level of energy consumption.
Copiers and servers, although very energy consuming devices, have not been considered in these configurations. Due to their negative effect on indoor air quality, it is not recommended to place them in the office.

LOW, e.g. processing task	Power [W/person] in different modes		
devices	on	standby	off
Value PC	100	10	5
Value 19" LCD monitor	38	1,5	1,2
Phone + answering machine	2	2	2
Ink jet colour printer	1	1	1
total (off = connected to power supply)	141	14,5	9,2
total (off= disconnected from power supply)	141	14,5	0 (2)
PC and LCD replaced by value laptop			
total (off = connected to power supply)	25	14	6
total (off= disconnected from power supply)	25	14	0 (2)

Table 3: Technical characteristics for a low energy consuming office equipment configuration, suitable for a processing task, based on data from energy star [54]

MEDIUM, e.g. secretary task	Power [W/person] in different modes		
devices	on	standby	off
multimedia PC	146	10	5
Value 19" LCD monitor	38	1,5	1,2
Phone + answering machine	2	2	2
Value Laser printer (20ppm)	7	7	7
Fax (fast >10ppm)	12	12	12
total (off = connected to power supply)	205	32,5	27,2
total (off= disconnected from power supply)	205	32,5	0 (14)
PC and LCD replaced by large laptop			
total (off = connected to power supply)	57	26	24
total (off= disconnected from power supply)	57	26	0 (14)

Table 4: Technical characteristics for a medium energy consuming office equipment configuration, suitable for a secretary task, based on data from energy star [54]

HIGH, e.g. advertising agency	Power [W/person] in different modes		
devices	on	standby	off
workstation	250	20	10
1x system 17" CRT or 2x value 22" LCD	74	2	2
Phone + answering machine	2	2	2
Colour laser multi function device 6-12ppm	15	15	15
Value A4 scanner	11	11	11
total (off = connected to power supply)	352	50	40
total (off= disconnected from power supply)	352	50	0 (2)
PC and one screen replaced by large laptop			
total (off = connected to power supply)	82	15	13
total (off= disconnected from power supply)	82	15	0 (2)

Table 5: Technical characteristics for a high energy consuming office equipment configuration, suitable for an advertising agency or an architectural office, based on data from energy star [54]

Intensity of use	Hours in different modes [h]		
profile	on	standby	off
Light	2	9	13
Average	4	5	15
Busy	8	2	14
Never off	4	20	0
Always on (e.g. servers)	24	0	0

Table 6: Office equipment, intensity of use, source energy star [54]

1.2.2 Evaluation of thermal comfort, daylighting and view

Thermal comfort

In this study thermal comfort is evaluated according to the adaptive principle, assuming that in naturally ventilated buildings the preferred thermal sensation of occupants is not a fixed neutral temperature, but varying depending on indoor and outdoor temperature, the amount of personal control provided, expectation, and possibilities for adaptation. Therefore, the adaptive thermal comfort model of EN 15251-2007 [5] is applied. Aim of this study is a classification in category II for all variations. As recommended in EN 15251 a maximum of 5% overheating hours are allowed for each category.

Daylighting

As Dietrich [55] describes, the required amount of artificial light in interior spaces is set at a level required for minimum comfort. Daylight in interior spaces often reaches considerably greater light levels, which is perceived to be more pleasant. A further advantage of daylight is its potential for energy savings, if artificial lighting is switched off when there is enough daylight.
Additionally as Webb [56] states, daylight has a range of influences on the human. In addition to vision, it has implications for sleep/wake states, alertness, mood and behaviour. Therefore optimising daylighting in buildings can result in health benefits as well as increased safety and productivity. For this study, daylight autonomy is considered the indicator for daylighting, because it demonstrates the amount of working hours with sufficient daylight, and conclusions regarding the related energy consumption for artificial lighting can be drawn.

View

To be able to evaluate the amount of view depending on the coverage of the window by an activated blind, a prototype for a classification has been developed, applicable for the specific venetian blind used for this investigation (slat width= 8cm, slat separation= 5cm, slat thickness= 0,1cm). Therefore, two aspects are considered important: window area and shading. Although further investigation would be needed, as a first approximation the following classification of view depending on the shading is considered only to be applicable to window areas of >= 30% due to the findings of Galasiu [41].
The classification of view obstructed by a venetian blind is based on the assumption that occupant satisfaction of view as seen from the workplace is decreasing with the percentage of available information from life outside which is covered by an activated shading. For the specific Venetian blind used in this study the following classification has been developed, but has not been validated yet and should only be considered as a first attempt to classify the quantity of view (figure 18). However, for the investigated configurations, only view categories A (=full view) and D (= no view) have been applied, since for this first study only two blind conditions have been considered: Fully opened blinds, and completely closed blinds with slats adjusted so they do not allow for any view.

view classification	description	example
A	minimum window area =30%, unobstructed view with deactivated blinds	 (no blinds / deactivated)
B +C	View with activated venetian blinds, slat angle 0°- <40° to horizontal. The field of vision is partly obstructed, but it can still be observed what is going on outside.	 (slat angle 0°)  (slat angle 30°)
D	A angle >=40° to horizontal. The field of vision is mostly obstructed, no view.	 (slat angle 40°)

Figure 18: Classification of the quantity of view (pictures: Roetzel)

1.2.3 Simulation results

General remarks

The results of all simulations refer to a standard configuration of parameters, which is described in table 7. All other configurations have been named after the changed parameters compared to the standard configuration in order to improve comprehensibility.
Although the impact individual parameters have on thermal and visual comfort might change according to the chosen configuration, the possible range of influence can be demonstrated.

configuration: standard	
Investigated parameter	**Chosen configuration**
Weather data	Year 2007
Orientation	South
Window area	60%
Occupant density (persons per room)	2
Artificial lighting configuration	Optimised
Illuminance	500 lux
Lighting control	On/off + dimmed (active user)
Office equipment	Medium, laptops
office equipment: Intensity of use	Average, disconnected at nights + weekends
Thermal mass	Medium
Glazing	Solar control glass
Shading control	Heat criteria
Slat angle Venetian blind	Closed (=80°)
Configuration of ventilation openings	Façade design variation 5

Table 7: Standard configuration of input parameters, applied for the following investigation if not mentioned otherwise

Weather data

The chosen weather data are a very important factor of influence on the resulting comfort. Using Hamburg standard weather data, leads to the most optimistic but at the same time least realistic results, regarding the comparison of weather data with measurements. The weather data set for 2007 represents an average of the last decade. The results, although depending on façade orientation as well, show a different thermal comfort evaluation compared to the standard weather data. An east facing room with standard weather data would be classified as category I, and using 2007 weather data the same room would be classified as category II, which would still be acceptable for new and renovated offices. Regarding daylight autonomy and view the difference between those two weather data is not significant, resulting in slightly better results for standard weather data. Using weather data for a hot summer like 2003 results in a more significant difference. For the above-mentioned east facing room and 2003 weather data, the resulting thermal comfort will be classified as category III. The resulting daylight autonomy and view vary depending on the resulting hours with shading on. The comparison shows the impact of the chosen weather data for summer comfort simulation, and indicates a significant influence of the climate change on thermal and visual comfort in future.

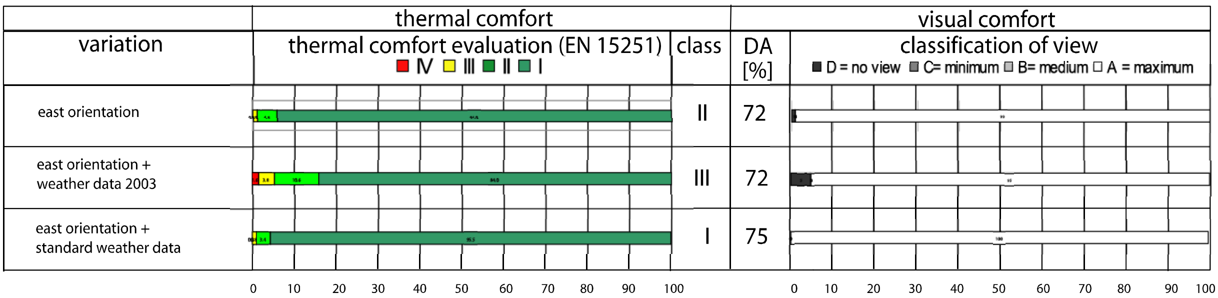


Figure 19: Thermal and visual comfort for different weather data sets

Orientation

For the chosen configuration using thermal insulation glass, the resulting comfort differences are significant regarding the façade orientation. While the room with south orientation only reaches category IV, the same room facing north reaches in category I. Changes in daylight autonomy are not very significant, but differences regarding view range about 10% from south to north for the investigated configuration of parameters. These results indicate a thermal comfort optimisation potential regarding the orientation of building facades as well as concerning the placement of rooms with different internal heat loads within the building.

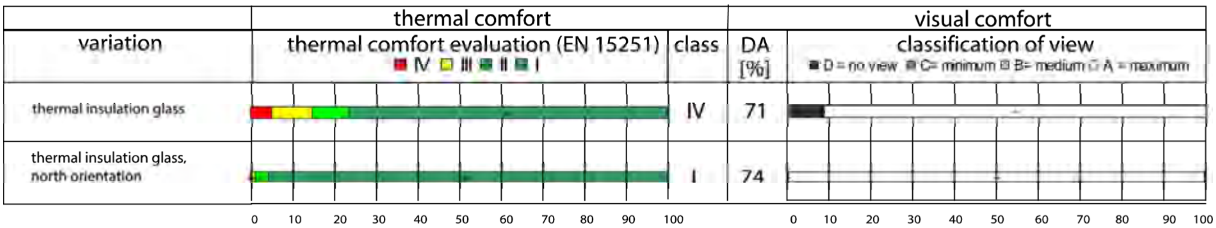


Figure 20: Thermal and visual comfort for different facade orientations

Window area

Simulation results indicate that window area plays a very important role in comfort evaluation. The investigated standard configuration with a window area of 60% results in thermal comfort category II, while with 100% window area resulting thermal comfort will only correspond to category III. A smaller window area of 30% leads to even better thermal comfort. Generally, it can be concluded that the smaller the window area, the better thermal comfort in the room. Here the interactions with visual comfort are important, too. Regarding view, the amount of hours when no shading is needed increases with decreasing window area. Because of lower solar heat gains the “heat”-criteria (indoor air temperature >26° + sun is shining on the façade) for activation of the shading is less often met, resulting in more hours with a full view. For a high user satisfaction with smaller window areas it should be ensured that all windows are placed within the field of vision from the workplace, e.g. above parapet height. Daylight autonomy for the investigated window areas does not differ significantly, but it is interesting that for this configuration a window area of 60% provides the highest daylight autonomy. The lower value for 30% window area may be due to the smaller window, while the lower value for 100% window area might be caused by an increased amount of hours with activated shading.

It is obvious, that the window area of a room provides a large optimisation potential for comfort, which in combination with other parameters might help to avoid air-conditioning.

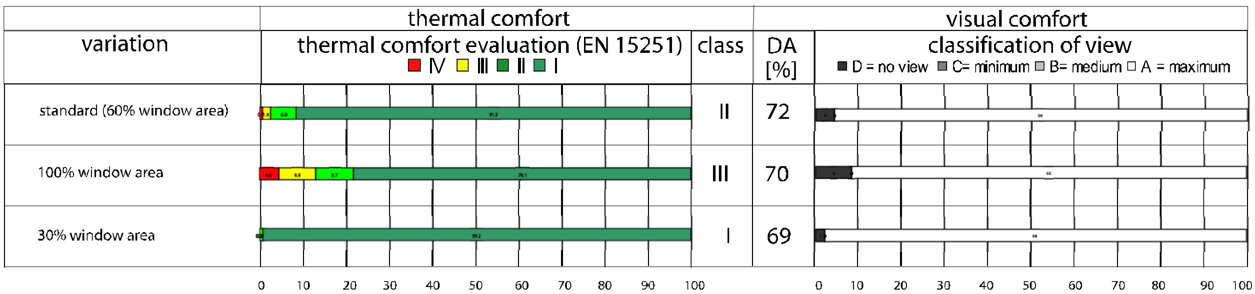


Figure 21: Thermal and visual comfort for different window area

Thermal mass

Another important influence on comfort in offices is thermal mass, and different constructions of walls floor and ceiling “light”, “medium” and “heavy” are each resulting in a different thermal comfort classification. The heavier thermal mass, the better the resulting comfort as well as daylight autonomy and view, due the fact that the “heat”-criteria for shading activation is less often met. The problem with thermal mass in office walls is usually the required flexibility regarding a possible conversion of the layout with a tenant change, as well as the fact that gypsum walls are less expensive than solid walls. The floor in larger office buildings is usually a false floor construction, which is needed for cables and ducts, and suspended ceilings (acoustic or gypsum) are common as well. For this reason, although it would have a significant positive effect on thermal comfort, a heavy construction is hardly realistic in offices. To make nevertheless use of this effect, new thermal storage capacities e.g. phase change materials might be helpful, as well as the question in how far the airflow might better reach the whole storage capacity of the room.

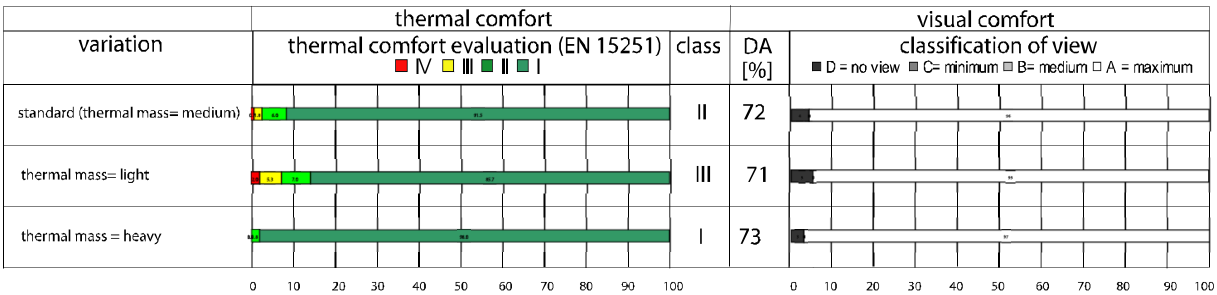


Figure 22: Thermal and visual comfort for different thermal mass

Glazing

The influence of the glazing is significant as well, and for the investigated configuration, replacing thermal insulation glass by solar control glass would correspond to an improvement in thermal comfort classification from category IV to category II. However, solar control glass is considerably more expensive, and therefore thermal insulation glass is usually preferred. On the other hand, if by integration of solar control glass air conditioning can be avoided, those costs should be compared, and the glass might have the advantage of lower maintenance costs.

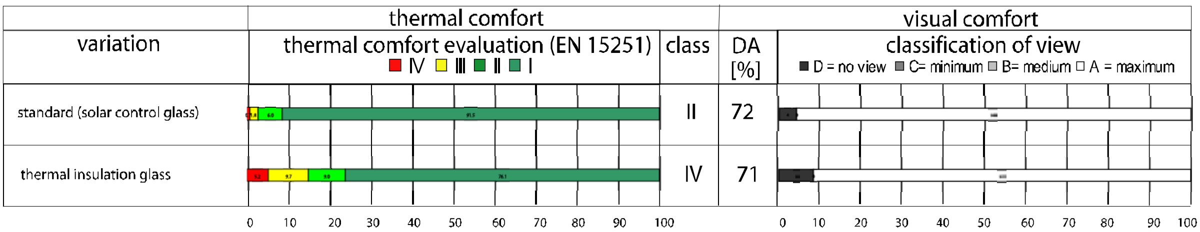


Figure 23: Thermal and visual comfort for different glazing

Facade design / air exchange rates

Another influencing parameter for comfort in naturally ventilated offices, the placement of ventilation openings, is also a matter of façade design. Generally, ventilation openings do not necessarily have to be windows, as their main function is to enable air exchange.

For the investigated variations differences concerning air exchange, as observed by Richter et al [47], have direct impact on thermal and visual comfort. Variation 3 and 4 (one horizontal opening either in the upper or lower part of the facade) can be considered as equal regarding the air exchange rates, resulting in a very uncomfortable classification with more than 50% of working hours corresponding to category IV. The low air exchange leads to high indoor temperatures, which results in the shading being activated about 30% of the working time. This in turn causes poor daylight autonomy of about 50%. Variation 1 (one vertical window open) shows similar characteristics with better values, but thermal comfort still remains in category IV while daylight autonomy and view are improved for about 10% of the working time. Compared to these variations, number 2 (two vertical windows open) is an improvement of the resulting comfort, leading to thermal comfort category III, a higher daylight autonomy and view. The most efficient variation is number five, due to thermal buoyancy between the two openings. With this configuration thermal comfort category II can be achieved, resulting again in an increased daylight autonomy and view once again.

Although transferability of the results to other geometrical configurations is very limited due to the variety of room specific influencing parameters on the airflow, the resulting air exchange rates give rise to the assumption that there might be an optimisation potential for other geometries as well. Additionally there are no data available for air exchange rates for the same room using cross ventilation, which would be another realistic option to improve thermal comfort without air conditioning.

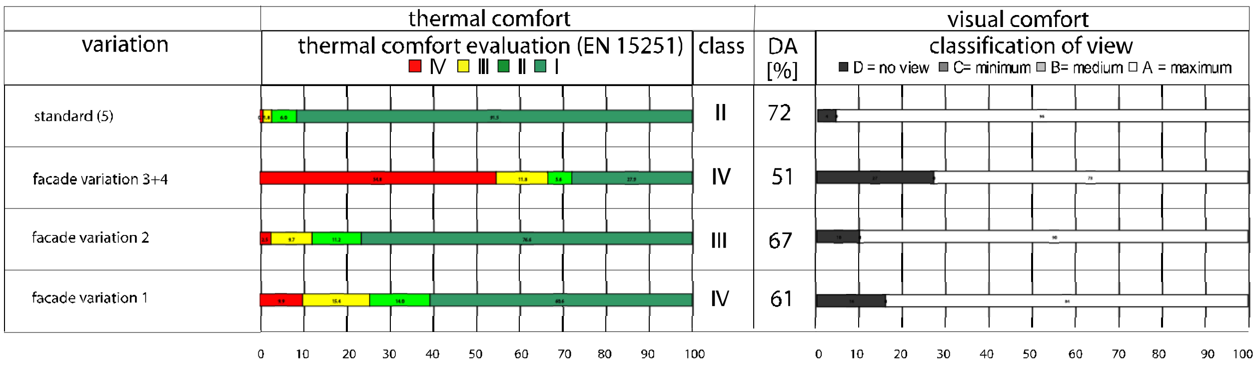


Figure 24: Thermal and visual comfort for different facade design

Office equipment

The office equipment provides a large optimisation potential regarding thermal and visual comfort. This is exemplary demonstrated for the equipment configuration "high" which could e.g. represent an advertising agency or other users needing high performance devices. Regarding the profile for "on"-, "standby"- and "off" –mode a high intensity of equipment use ("busy") is assumed. With devices connected to the power supply beyond working hours this results in thermal comfort category IV and relatively low daylight autonomy of about 60%. The same configuration but disconnecting devices from power supply at nights is an improvement but the thermal comfort classification remains in category IV. A similar configuration, but using notebooks instead of desktop computer and screen, results despite power connection of devices at nights and on weekends to a significant improvement in thermal comfort category III, 7 % better daylight autonomy and 8% better view compared to the first variation. The same configuration with notebooks but without power connection of devices at night is another improvement, resulting in thermal comfort category II.

Although changing task or intensity of use of devices is not an option in offices, it can be concluded that replacing standard desktop computers by more energy-saving ones or by notebooks is a helpful contribution to thermal comfort improvement. The resulting higher prices should be compared with lower running costs for energy consumption as well as for cooling. Additionally disconnecting devices from the power supply could tip the scales for reaching a better comfort category.

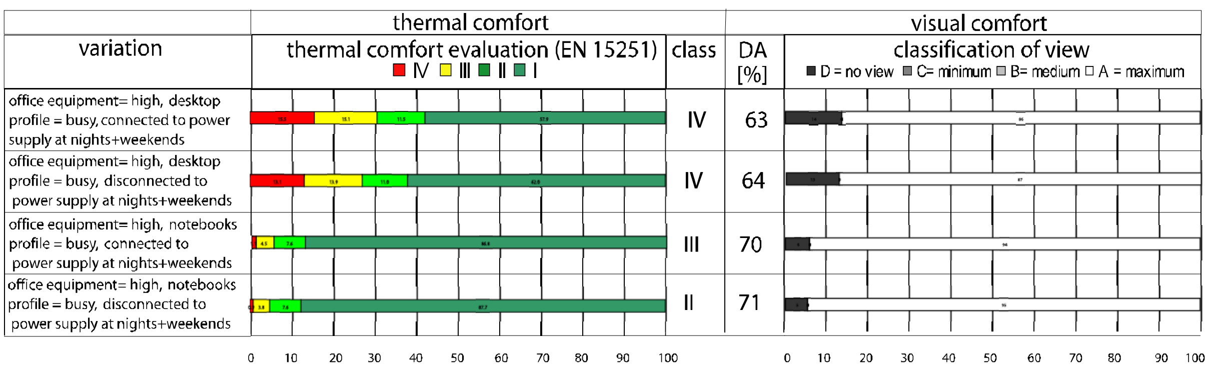


Figure 25: Thermal and visual comfort for different office equipment configurations

Lighting control

The optimisation potential of artificial lighting is depending on the lighting system as well as on the control strategy. The more hours the lighting is switched on, the more important is an optimised lighting system in order to avoid negative influence on thermal and visual comfort. However, vice versa for an optimised and dimmed lighting control, providing artificial light only when there is not enough daylight, the difference between a standard and optimised lighting system regarding the influence on thermal comfort is relatively small. That leads to the conclusion that active users or occupancy sensors combined with photo-controlled dimming or off-switches can essentially contribute to an improvement of thermal comfort and, by reducing the internal heat loads, improve view as well. Nevertheless, in case of automatic systems, presets should be chosen very carefully and manual corrective action should be allowed, as recent field studies showed that user acceptance of automatic control systems tends to be low.
All lighting design concepts have to correspond to the requirements of DIN EN 12464-1 [53], and the investigation showed that for larger rooms (group/open plan offices), it is easier and with lower lighting power to fulfil than for smaller ones (cellular office).

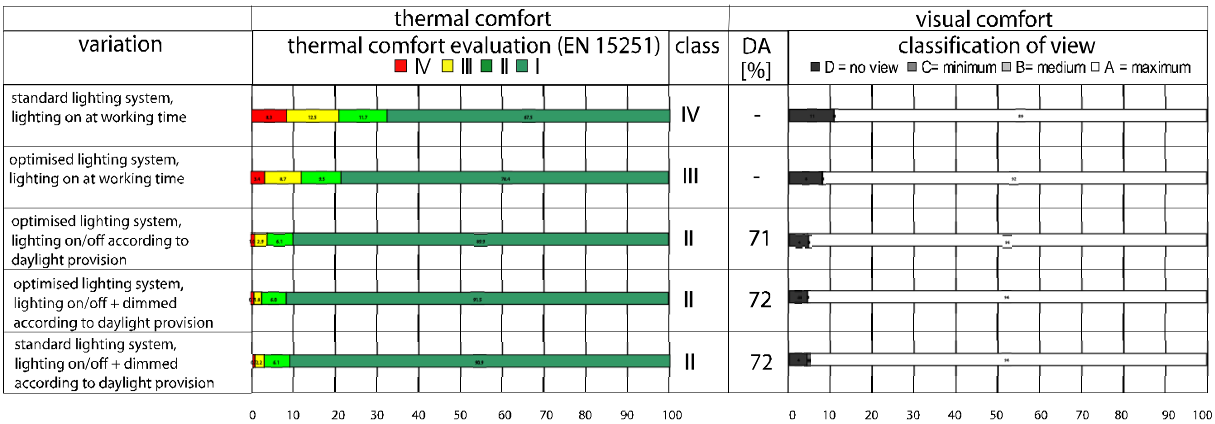


Figure 26: Thermal and visual comfort for different lighting control

1.2.4 Conclusions

A detailed investigation of realistic input values for building simulation demonstrates a significant range of influence each parameter has on thermal comfort, daylighting and view. Especially if not only building related parameters like thermal mass or window area are considered, but also user related parameters like choice of office equipment and user behaviour.

Compared to standard input values this offers a wider optimisation potential, and a careful combination of all parameters may help avoiding air conditioning in offices. However, this potential can only be beneficial for a specific building, if parameters like building properties as well as needs of future occupants are considered already in early design stages. Especially regarding the choice of office equipment or the use of controls, this requires also a certain awareness of occupants.

Some general conclusions from the simulation results for the climate of Hamburg, Germany can be drawn:

- Rooms with north oriented facades provide more flexibility regarding the choice of building and user related parameters, than south- facing rooms.
- Especially in rooms with south facing facades thermal comfort category II is difficult to achieve, if medium or high power desktop computers are used, and/or artificial lighting is switched on for the whole working day (=passive users). Additionally solar control glazing and high air exchange rates using the effect of thermal buoyancy would be required in order to ensure thermal comfort category II as well as an acceptable daylight autonomy and view.
- Especially regarding future effects of climate change and related increase in temperatures, high internal heat loads should be avoided. In case this is not an option, energy-consuming tasks should be placed on the north side of the building.
- Thermal buoyancy between two ventilation openings (Façade variation 5) can approximately double the energetic efficient air exchange rate compared to two openings side by side. Although, from an architectural point of view, this may to some extent limit the flexibility of façade design, it is a very effective possibility to achieve thermal comfort in offices. Especially as the arrangement of windows or ventilation openings within a façade may have no or little impact on costs.
- The impact of users or tenants concerning occupant behaviour, the use of office equipment and lighting systems may be, depending on the specific configuration, as important as the building related parameters defined by architects or engineers. This should be further validated by investigating varying heat loads and occupant behaviour in different room configurations.
- Thermal comfort should not be considered separately from daylighting and view. Shading devices and related control are the interface between thermal and visual comfort. In case of glare caused by the sky, there is hardly a chance to avoid the activation of shading. However, in case heat is the reason for closing a blind, the hours with shading needed can be reduced by reducing internal heat loads and optimisation of façade properties. Thus, daylight autonomy can be increased, running costs for artificial lighting will be lowered and the percentage of working hours with a satisfying view will improved.
- In offices, especially the use of office equipment and lighting systems and the user behaviour are parameters, which can alter with a tenant change, and thus influence comfort and energy performance on a short time scale. A strategy to reflect this variability in building simulation could be useful.

- In this study on a southern facade in the moderate climate of Hamburg it was, depending on the configuration, difficult to achieve thermal comfort category II. This leads to the question how thermal comfort criteria according to the adaptive model of EN 15251-2007 [5] can be met in a Mediterranean climate.
- The influence of different weather data sets on comfort and energy performance in offices is significant. Further research would be needed, to investigate the impact of different weather data in a southern climate, especially regarding the occurrence of strong heat waves.

In order to investigate the above-mentioned aspects, the next part of this work is focused on the Mediterranean climate in Athens, Greece.

CHAPTER 2,
DEVELOPMENT OF THE SIMULATION MODEL FOR ATHENS, GREECE

2.1 Field study in Athens

2.1.1 Focus of the field study and general description

Architectural design and construction as well as occupant behaviour, task and culture are different depending on the context. This context refers to different climates, lifestyles, and national specifications. In order to evaluate the context of Athens, Greece, a field study has been conducted in two mixed mode office buildings. This field study was divided into two parts. One aiming to investigate Greek characteristics of architectural design, construction and the real estate market, mainly targeted at architects. The second part was focused on specific occupant behaviour, task and culture and was targeted at occupants in office buildings.

Questionnaires have been distributed during November 2008 to collect this information in a survey in two different office buildings in Athens, one architectural office and one real estate development company. Since the study could only be conducted in winter, no measurements could be conducted in order to verify the collected data. The questionnaires have been distributed in English, since both offices are working internationally. However, due to the number of employees, the absolute number of responses is small, so the study cannot be considered representative. Further verification would be needed, and the results should be evaluated only as first indications.

The questionnaires focused on the following issues, aiming to provide realistic information to be used as input for building simulation. The complete questionnaires are shown in the appendix.

Questionnaire 1, occupant behaviour, task, culture:

- window opening
- shading control
- lighting control
- use of air-conditioning
- lifestyle and heat waves

Questionnaire 2, architectural design and construction

- Building types
- Typical constructions
- Design
- Use
- Technical equipment
- Green buildings
- Architectural fashions

The key properties of the investigated buildings and the number of subjects who participated in the field study are presented in table 8.

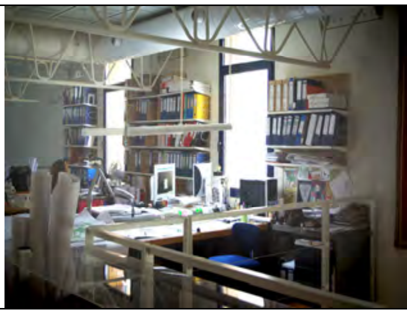
Building properties	**Building 1**	**Building 2**
facade		
Internal structure		
Company description	Architectural office	Real estate company
Office types	Cellular, group	Cellular, group, open plan
Air conditioning / cooling system	yes	yes
Heating	yes	Yes
Openable windows	Yes	Yes
Window opening type	Tilt and turn	Side hung
Windows shared?	Yes	yes
Blinds shared?	Yes	yes
Night ventilation possible?	Not in all offices	no
Shading type	External vertical awnings, some offices venetian blinds	Overhang + internal venetian blind
Lighting system	Task area lighting	Room related lighting
Dress code	no	yes
Subjects participating for architects survey	5	3
Subjects participating in occupant survey	7	9

Table 8: Characteristics of the buildings investigated in the field study in Athens

2.1.2 Results from the field study among occupants

General remarks

This field study has been conducted in order to obtain realistic input parameter for building simulation. Questionnaires have been distributed in two different office buildings in Athens. These buildings differ regarding several building related parameters, i.e. window area, thermal mass and the implementation of “green” parameters in building design. Results therefore have to be evaluated in the context of the specific building. Thus, they have been analysed per building as well as overall.
Due to the small number of buildings and participating subjects, the results cannot be considered representative. However, they can be useful for comparison with results from a literature survey, and they can give indications for occupant behaviour and preferences in the special context of Athens, Greece. Additionally, conclusions for further research needs can be drawn. Further research will be needed to verify the results.

Window opening angles

The window types in the investigated buildings are side hung windows (building 2) and tilt and turn windows (building 1). The opening angles and percentages were reported differently. Side hung windows were opened on a range from 5° up to 180°. Although there seemed to be an increased likelihood for very small (5°) and very large (180°) opening angles, it can be concluded that the whole range of possible opening angles is likely to be used by occupants. However, anecdotal evidence showed that opening angles of only 5° have been caused by a cupboard being placed too close to the window, so that the maximum opening angle was limited to 5°.
Regarding tilt and turn windows the opening percentages are different. The majority of occupants reported window-opening percentages of 15%, which leads to the conclusion that the windows are commonly tilted. Other reported opening percentages are 15-100% and 100%. These percentages seem to refer to the side-hung version of the window. In addition, they support the findings from side-hung windows in building two, where also a tendency for either small or large opening percentages could be observed.
The occurrence of the same window opening percentage for tilted windows can be explained by the construction of this window type, which in tilted condition only allows for a specific opening angle. Side hung operation in contrast does not predefine any opening angle, as long as the hinges are well balanced. This might explain the larger variation of opening percentages and it is likely that issues of placement of furnishing play an important role as well. For example when the window is relatively wide opened, a position might be preferred which does not interfere with work places or traffic zones of occupants.

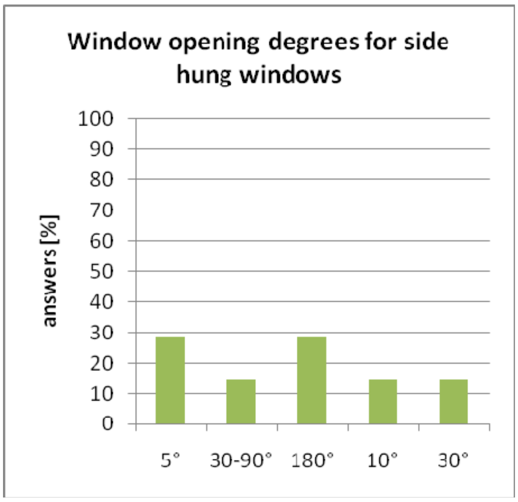


Figure 27: Typical window opening degrees for side hung windows

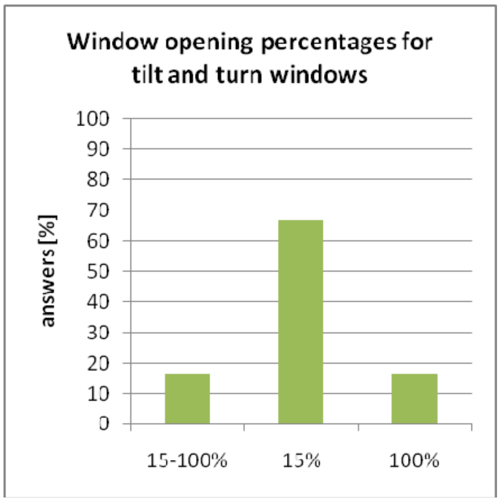


Figure 28: Typical window opening percentages for tilt and turn windows

Shared windows

Except for one single office in building two where the person had a window to operate on their own, all other openable windows had to be shared with colleagues. According to building designs and occupant density, different amounts of openable windows per person could be found. In building two, openable windows per person ranged from 0,17 to 0,66, with an average of 0,38. In building one the range was from 0,1 to 0,5, with an average of 0,2. In building two, 2-3 persons and in building one five persons shared one openable window.

Window opening reasons

Concerning individual reasons for single occupants to open the windows in their office during summer, occupants in both offices had similar preferences. The predominant reason for opening a window for approx. 80% of occupants was to improve the room air quality. Minor further reported reasons for individual window opening were to reduce or to prevent overheating, both mentioned by approx. 10% of occupants.

Another question was aimed to find out how the decision process for opening a window shared by several persons is usually made, and if there would be any differences between window opening reasons for single occupants or the same subjects within a group of colleagues. For both buildings, the most common answer was an attempt to make a compromise or democratic decisions (40-60%). In building 2 equal percentages of occupants reported to open the windows „as soon as somebody desired cooling“ or „as soon as somebody in the room desires a better room air quality“. In building one in contrast, the majority of occupants reported they open the windows „as soon as somebody in the room desires a better room air quality“.

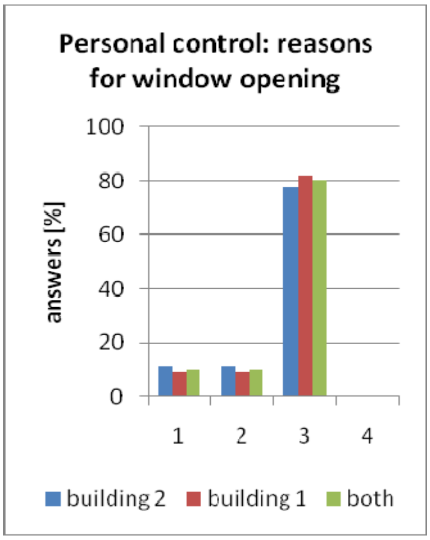


Figure 29: Reasons for window opening in case of personal control

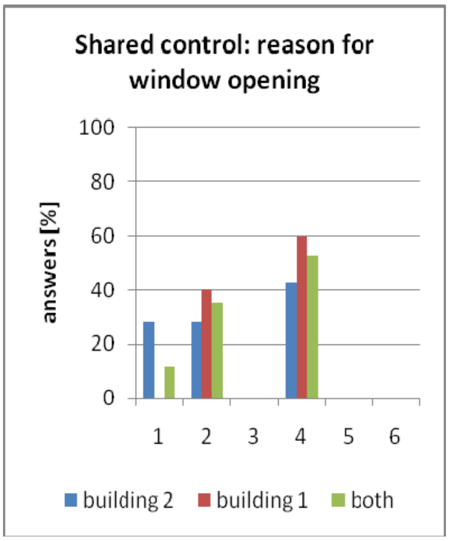


Figure 30: Reasons for window opening in case of shared control

1= Room temperatures are uncomfortably hot and I want to avoid further increase
2= Room temperatures are <u>not yet</u> uncomfortably hot but I want to avoid overheating
3= I want to improve the room air quality (e.g. smell)
4= I want acoustic contact with the outside environment

1= Windows are opened as soon as somebody in the room desires cooling
2= Windows are opened as soon as somebody in the room desires a better room air quality
3= Windows are opened as soon as somebody in the room desires contact to the outside environment
4= We try to make a compromise / democratic decisions
5= The person in senior management position usually decides
6= Other (please describe)

Asked for the most important reason to close the window in their offices, the answers in both buildings were similar. The vast majority (70-80%) reported, "The air entering the room is too hot" as the most important reason to close their window. Minor reasons reported in building two were "the air entering the room is polluted (smog, dust)" and "protection from draft", both mentioned by 10% of occupants. In building one in contrast further reasons for window closing were "the air entering the room is too cold", "the air entering the room is polluted (smog, dust)" and "protection from noise outside". Therefore, it can be concluded, that also the main reason for window closing in Athens climate is the protection from heat, further reasons might only be evaluated in context of the building.

Another question aimed to find out if window closing behaviour of occupants is different, if they share window control with colleagues. In this case, the predominant reason for window closing remains protection from outside heat. However, the influence of this reason for shared control is not as predominant as if single occupants could decide for themselves. In building two, protection from draft was considered equally important as protection from outside heat (both approx. 30% of the votes). In building one, the protection from outside heat was predominant (almost 60%). This leads to the conclusion, that for shared window control, too, the main closing reason during summer in both offices is the protection from outside heat. However, this general control strategy might be superposed for single windows by the sensation of local discomfort of individual occupants.

Generally, many occupants mentioned they try to make compromises or democratic decisions regarding window closing. This leads to the conclusion, that single occupants might be accepting slight discomfort caused by open windows, in order not to interfere with preferences of the majority of the group too early. However, in case of predominant discomfort of a single person e.g. due to draft or outside noise, it seems commonly accepted, that this person „is allowed“ to override the majority’s preferences by closing the window.

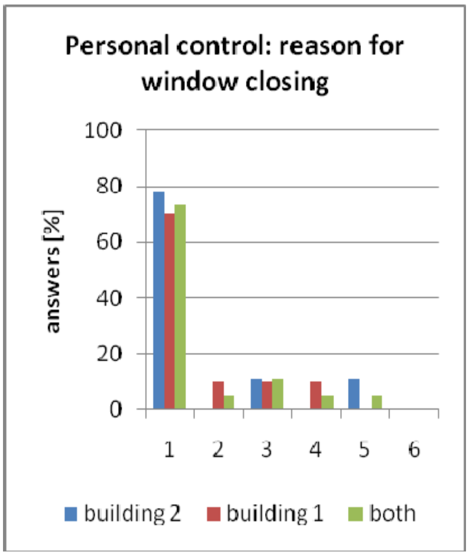


Figure 31: Window closing reasons in case of personal control

1= The air entering the room is too hot
2= The air entering the room is too cold
3= The air entering the room is Polluted (smog, dust,…)
4= Protection from noise outside
5= Protection from draft
6= Other (please describe

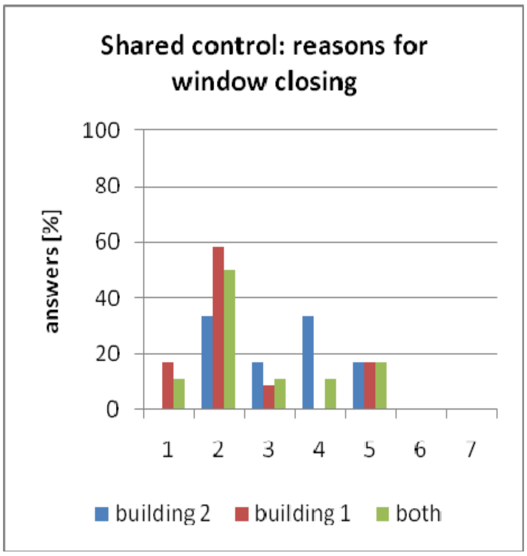


Figure 32: Window closing reasons in case of shared control

1= Windows stay closed as long as somebody wants to prevent cooling
2= Windows stay closed as long as somebody wants to prevent overheating
3= Windows stay closed as long as somebody wants protection from noise outside
4= Windows stay closed as long as somebody wants to prevent draft
5= We try to make a compromise / democratic decisions
6= The person in senior management position usually decides
7= Other (please describe):

Night ventilation

To evaluate the effectiveness of natural ventilation in offices, the possibility for night ventilation is an important aspect. However, neither in building 2 nor in building 1, night ventilation with openable windows played an important role. Only in building one about 20% of occupants answered, to leave the window open during nights and on weekends. In this building, a night ventilation concept based on exhaust fans on the roof is applied, and offices are open spaces connected with one another. Thus, night ventilation by single individuals has to be considered in this context. In building two, night ventilation was reported to be not possible at all.

The majority of office occupants in both offices reported, they cannot leave the windows open at night and on weekends. Asked for the reasons, the vast majority of office occupants mentioned office policy due to security reasons (100% in building 2 and 60% in building 1). While in building 2 this was the only reason preventing night ventilation, in building 1 interference with the cooling system and protection from weather have been reported as well (30% and 10%). This leads to the conclusion that, although in building simulation often considered, night ventilation seems to be difficult to apply in real buildings. Only in building one, some windows were reported to be used for night ventilation. An interesting aspect in this context is that most of the windows in both offices are not located on the ground floor, but on the first up to the third floor. Moreover, most of the upper level windows in both offices did not appear to be too easily accessible for possible burglars. This leads to the conclusion that the reported security reasons preventing night ventilation might not be based on the geometrical accessibility of the specific windows. It seems more likely that office policy to close the windows for the night might be based on the general safety level perceived within the city or the quarter. Additionally the terms and conditions of insurance companies might play an important role as well.

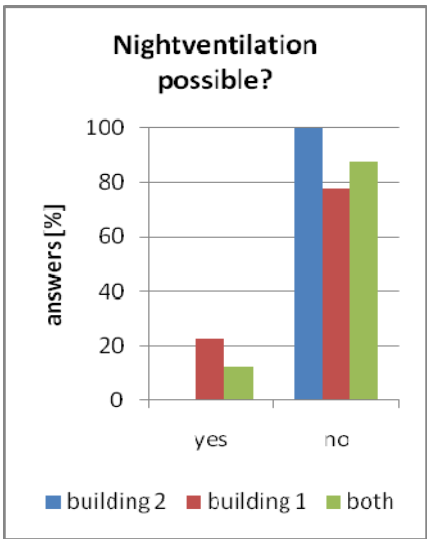


Figure 33: Possibility for night ventilation

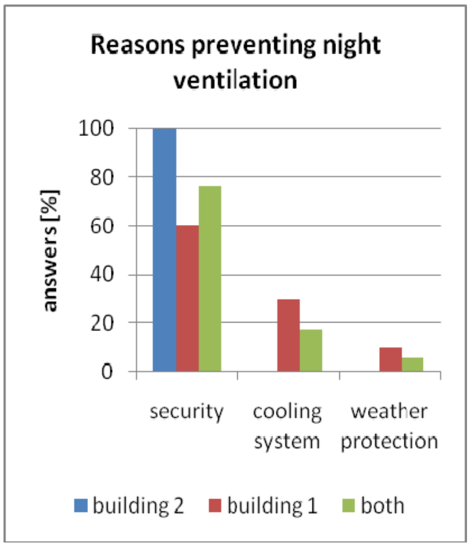


Figure 34: Reasons preventing night ventilation

Shading control: blind closing reasons

Concerning the use of switchable blinds, occupants have been asked to name the most important reason to close blinds in their office during summer. In building two, answers were distributed equally for three main and equally important reasons. These are "Room temperatures are uncomfortably hot and I want to avoid further increase", "protection against glare, caused by the sun shining in the office" and "I never close my shadings". In building 1, the main reason reported for blind closing was "protection against glare, caused by the sun shining in the office" (approx. 60%), followed by "Protection against glare, caused by overcast sky, sun is not shining in the office" (~30%) and "Room temperatures are not yet uncomfortably hot but I want to avoid overheating" (~10%). Overall, the most important reason was "protection against glare, caused by the sun shining in the office", followed by "Protection against glare, caused by overcast sky, sun is not shining in the office". This leads to the conclusion that the most important blind closing reasons are glare protection, followed by overheating protection. These results have been validated for differences regarding the corresponding façade orientation. The investigated buildings had facades facing North, West, South, East and Northeast.

Although the validity of the results might be limited due to the small number of responses from the different facade orientations, it seems that blind switching behaviour does not differ significantly with facade orientation. The predominant blind closing reason for all orientations is “protection against glare, caused by the sun shining in the office”. Minor and equally important further reasons were observed to be “Protection against glare, caused by overcast sky, sun is not shining in the office”, “Room temperatures are uncomfortably hot and I want to avoid further increase” and “Room temperatures are not yet uncomfortably hot but I want to avoid overheating”. Only on the north side noticeable deviations could be found, where a number of persons reported to never close their blinds.

Another question was aimed to find out if blind closing is operated differently when blind control has to be shared with colleagues. For both offices together, the hierarchical order of blind closing reasons was found to be:

1. Shadings are closed as soon as somebody complains about glare from the sun
2. Shadings are closed as soon as somebody complains about heat
3. Shadings are closed as soon as somebody complains about glare from sky
4. Shadings are closed as soon as somebody wants to prevent overheating in advance
5. Shadings are never closed

These results lead to the following conclusions: Protection from glare by the sun seems to be the most important reason to close the blinds in case of shared control. This effect is stronger on east and west facades than on north and south facades. In building one, protection from glare by the sun and overheating prevention are with equal percentages the most important blind closing reasons on the south side.

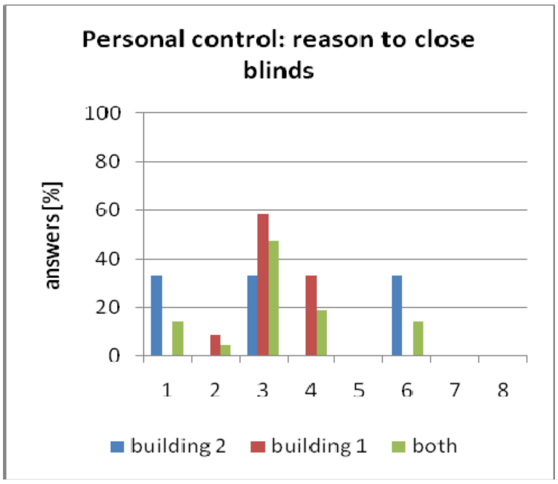


Figure 35: Blind closing reasons in case of personal control

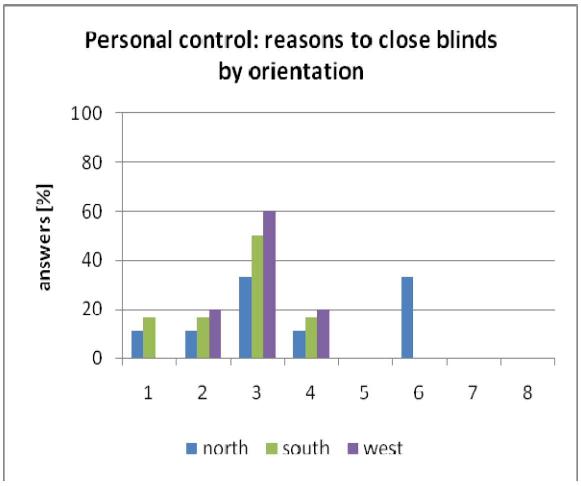


Figure 36: Blind closing reasons in case of personal control according to facade orientation

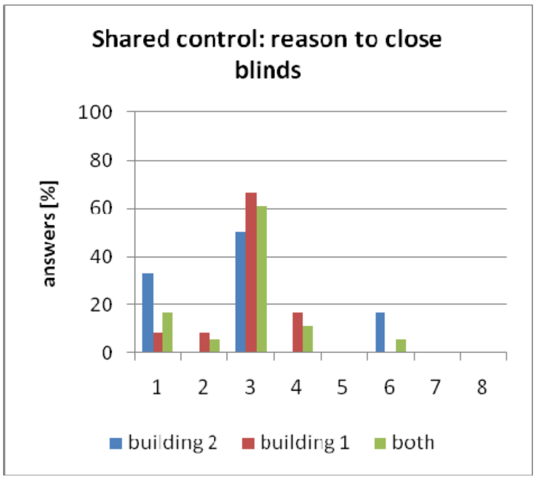


Figure 37: Blind closing reasons in case of shared control

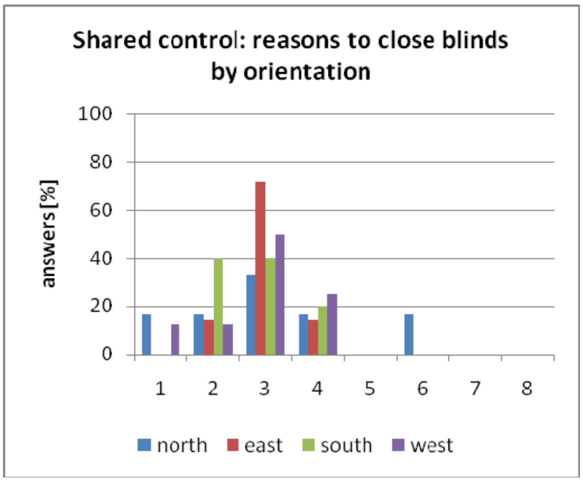


Figure 38: Blind closing reasons in case of shared control according to facade orientation

Explanations for figures 35-38:

1= Room temperatures are uncomfortably hot and I want to avoid further increase
2= Room temperatures are not yet uncomfortably hot but I want to avoid overheating
3= Protection against glare, caused by the sun shining in the office
4= Protection against glare, caused by overcast sky, sun is not shining in the office
5= Wish for privacy
6= I never close my shadings
7= I always keep shadings closed
8= Other(please describe)

Additionally occupants were asked for individual reasons to open blinds again. In building two, the predominant reason was to increase both, daylighting and view. In building one in contrast, the most important reason for re-opening of blinds was reported to increase daylighting. For both offices together, the main window opening reason reported was to increase daylighting, followed by „to increase both, daylighting and view“. From the results it can be concluded, that the increase of daylighting is an important blind opening reason in both offices. However, regarding the increase of view, the differences are significant. While in building two the increase of view seems very important, in building 1 the view seems to play a less important role. This effect might be explained by the window area of the buildings. While in building two, a window strip provides a view to almost everybody within the offices, in building 1 the windows of the punctuated facade only provide a view to those whose workplaces are placed directly at a window. For the other occupants, whose workplaces are not located directly at a window, the influence of an opened blind might only be perceptible in terms of daylighting. For shared control, the most important reason to re-open blinds was to increase daylighting for both offices. Further reasons in building two were to increase both, daylighting and view, or to improve ventilation. In building one, the second important reason to re-open blinds was "as soon as the sun is not shining on the façade any more", followed by less important reasons to increase the view or to increase both, daylighting and view.

These results are different compared to the responses from individuals. In case of shared control, the view as a reason to re-open the blinds seems to play a less important role than for single individuals. One possible explanation might be that increasing daylight levels is a direct improvement for the working conditions, as daylight is generally more convenient for the eyes than artificial lighting.

Improving the view in contrast, does not affect the actual office task directly. It is more an indirect psychological improvement and as such, it could be considered as a sort of luxury, which does not have a common level of significance among colleagues in case of shared control.

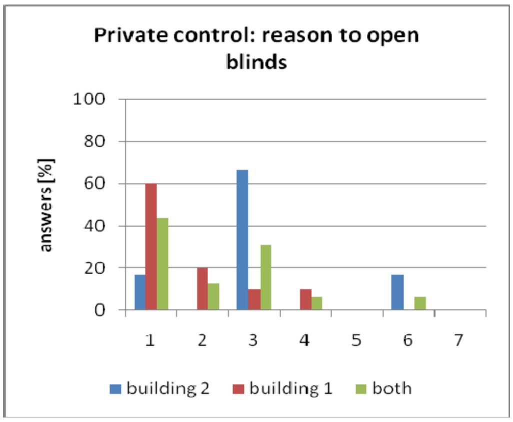


Figure 39: Blind opening reasons in case of personal control

1= To increase daylighting
2= To have a better view out of the window
3= Both, daylighting and view
4= To feel the warmth of the sun
5= I want to improve ventilation
6= I never open my shading
7= Other (please describe):

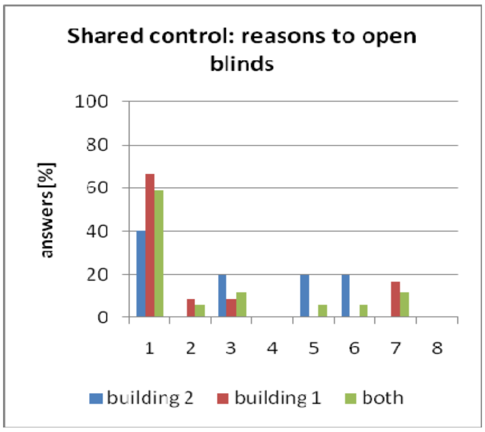


Figure 40: Blind opening reasons in case of shared control

1= Shadings are opened as soon as somebody wants to increase daylighting
2= Shadings are opened as soon as somebody wants to increase the view
3= Shadings are opened as soon as somebody wants to increase both daylighting and view
4= Shadings are opened as soon as somebody wants to to feel the warmth of the sun
5= Shadings are opened as soon as somebody wants to improve ventilation
6= Shadings are never opened
7= Shadings are opened as soon as the sun is not shining on the façade any more
8= Other (please describe)

Another question referred to the adjustment of the slat angle for venetian blind during the day. As in building one the majority of windows has screens instead of venetian blinds, the number of answers from this office was too small for a comparison. In building two, the vast majority of occupants (~85%) reported to adjust the slat angle rarely, 0-1x per day. Only approx. 15% stated they adjust the slat angle 2-5x per day. In the context of façade orientation, 100% of occupants on the north and east façade reported to adjust the slat angle rarely, 0-1x per day. On the south side ~75% of occupants adjusted the slat angle 0-1x per day and the other 25% reported to adjust it 2-5x per day. On the west side adjustment of slat angles seemed most frequent. 50% of the subjects reported to adjust the slat angle 2-5x per day, while the other 50% stated to adjust it only 0-1x per day.

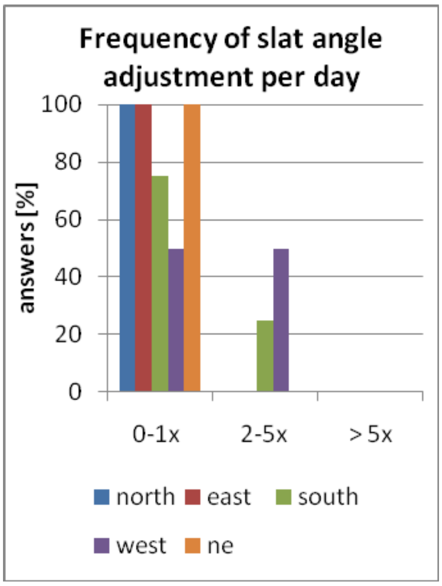


Figure 41: Frequency of slat angle adjustment per day according to facade orientation

Blinds: Window coverage

Additionally occupants have been asked about the typical percentage of the window that is covered by an activated venetian blind. In building two, the majority of occupants reported to close the blinds completely, only few answers stated that blinds are closed at lower percentages (25 and 75%). In building one in contrast, the responses did not show any strong preference for a certain closing percentage, it ranged from 50-100%. In total, the likelihood of occlusion percentages was '100% closed' (60%), followed by '75% closed' (20%), and '25/50% closed' (each 10%). In context of façade orientation, some differences could be observed. On the north side, the majority of occupants reported to close the blinds completely but a minority also stated too close them only 25%. On the east side, as well a preference for complete occlusion could be observed, however not as strong as on the north side. Those occupants who do not close the blinds completely reported to close them 75%. On the south side, in contrast all occupants reported to completely close their blinds. Only on the west side, closing percentages were significantly different from the other orientations. Here, no preference for a certain occlusion value could be found. Equal percentages of occupants reported to close the blinds to either 50, 75 or 100%.
Generally it can be concluded, that if blinds are activated, occupants tend to close them completely in north, east and south facing rooms. In west facing rooms in contrast, a variability of blind closing from 50-100% could be observed.

Slat angle

Another aspect of the field study was to find out about the most common slat angles used in offices. The slat angle has been evaluated according to the resulting quantity of view, assuming horizontal slats provide a relatively good view, medium slat angles (approx. 45° to the horizontal) a limited view and closed slat angles (close to vertical) no view.

In building two, a slight preference for horizontal slats could be observed. In building one, a preference for medium slat angles could be found. In total, this results in equal preferences for horizontal and medium slat angles, and shows a tendency to avoid closed slats.
In context of façade orientation, preferred slat angles were observed to be differently. On the north side occupants reported a preference for horizontal slat angles, followed by almost vertical slats while a medium slat angle was chosen less often. On the east side equal percentages of occupants reported horizontal, medium and vertical slat angles. However, on the south façade, a strong preference of occupants for a medium slat angle could be observed, while horizontal and vertical slat played a minor role. On the west façade, too, there was a strong preference of occupants for a medium slat angle. However, horizontal slat settings, too, seem to be a common setting on the west side. It can be concluded, that occupants tend to choose a slat angle allowing for a minimum view, whenever possible.

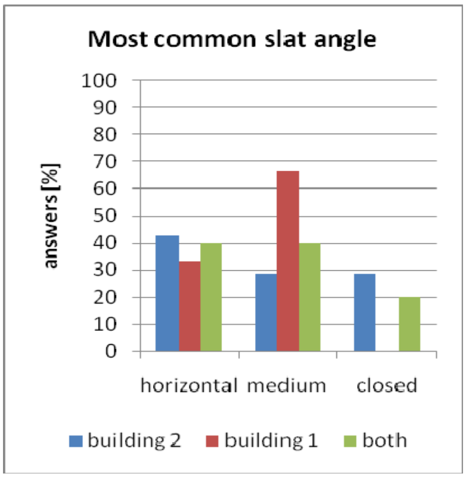


Figure 42: Most common slat angles for venetian blinds

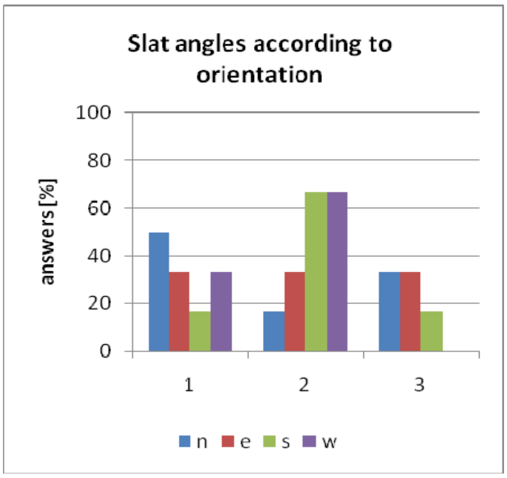


Figure 43: Slat angles according to facade orientation

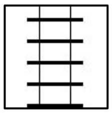


Figure 44:
1= Horizontal slat angle

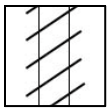
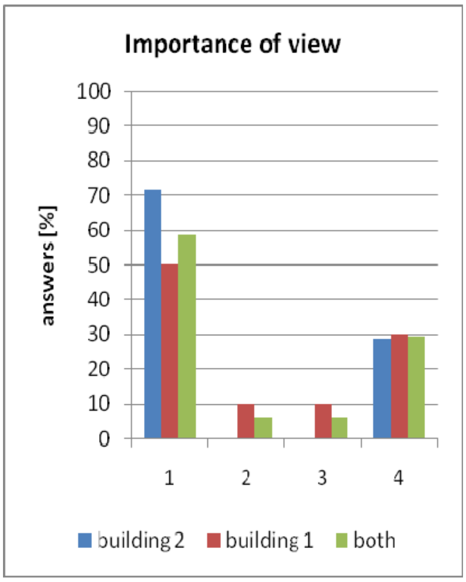


Figure 45:
2= Medium slat angle


Figure 46:
3= Closed slats

Importance of view

Concerning importance of the view, occupants have been asked if they consider the view very important, less important, not important, or if it depends on the quality of the view. The results in both buildings were almost similar: The majority (~60%) of the subjects considered the view very important. However, about 30% of occupants reported that the importance of the view is depending on its quality. Only a minority of subjects reported the view to be “less important” or “not important”. Therefore it can be concluded, that all occupants generally prefer to have a view out of the window. The only limitation seems to occur in case of a poor view.

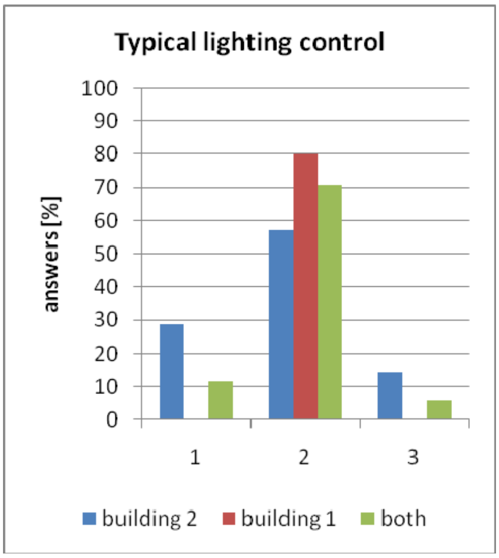


1= Very important
2= Less important
3= Not important
4= Depends on the quality of the view

Figure 47: Importance of view

Lighting control

The operation of the lighting system can have significant influence on thermal comfort. In the field study, occupants have been asked how they operate their lighting system during working hours. In both offices the majority of occupants reported to switch their lighting on and off according to daylight provision. However, in building two it seemed also common to keep the lighting switched on during working hours. In building one in contrast, all occupants reported to switch light on and off according to daylight provision.



1= Lighting is always switched on during working hours
2= Lighting is switched on or off according to daylight provision
3= Lighting is switched on/off AND dimmed according to daylight provision
4= Other, please describe

Figure 48: Typical control of the lighting system

Cooling system: Typical operation period

Concerning the operation period of the cooling system the answers were widely spread. The length of the cooling period varied from the maximum period "April to October" to the minimum period "June – July". However, the variation in building two was broader than in building one. In building 2 the shortest mentioned cooling period was June-July, the longest period May-October and the most common response June-September. In building one in contrast, the shortest periods were July-September/June-August and the longest period April-October. In the latter, the most common periods were June-September and June-August. The most common cooling period in total is June-September.

This variation might be caused by different operation of the cooling system in different rooms, and climate variability from one year to another. Another explanation could be that occupants might be more aware of the exact cooling period if they operate the system themselves compared to central control.

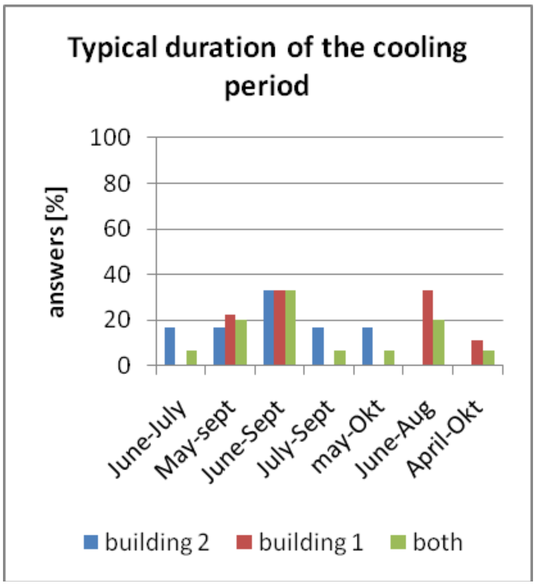


Figure 49: Typical duration of the cooling period

Preferred cooling set points

Asked for their preferred cooling set point, responses in both buildings were different. In building two, the preferred individual cooling set points ranged from 20 to 26°C. Here, no single preferred temperature could be found, but the most mentioned cooling set points were 20, 22 and 25°C (20% each). The average preferred set point here was 22,7°C. In building one in contrast, the reported set points ranged from 22 to 26°C. Additionally a strong preference for the 22°C set point could be found (60%). The average preferred temperature here was 23°C. Overall, preferred temperatures range from 20-26°C, and 22°C is the most favoured cooling set point. The average preferred temperature of all occupants in both buildings is 22,9°C.

Unfortunately, no measurements could be made to verify these answers. It is therefore likely that the answers of occupants refer to the comfort they use to feel when the control panel of the cooling system shows a certain set point. An uncertainty remains, if the room temperature always corresponds exactly with the set point of the cooling device.

Furthermore, there is a significant difference between the lowest preferred set points reported in both buildings. In building two it is 20°C and in building one 22°C. This difference can be explained by the stricter dress code in building two, while there is no dress code in building 1. However, the upper limit of the reported preferred temperature set points was with 26°C similar in both buildings.

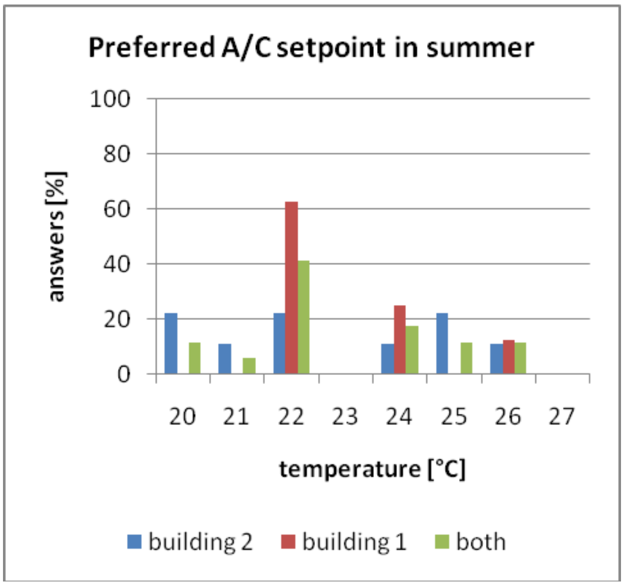


Figure 50: Preferred cooling set points in summer

Maximum acceptable cooling set points

Compared to the preferred temperature for a cooling set point, occupants were also asked about the maximum cooling set point they would still tolerate during summer. In building two, those set points ranged from 24 to 28°C. Additionally, two set points within this ranged seems to be equally preferred, 26 and 28°C. However, the average maximum temperature here was 26,6°C. In building one, maximum acceptable cooling set points had a smaller range from 25 to 26°C. The set point with the most votes for the maximum tolerable temperature in this office is 25°C and the average set point is 25,3°C.

These results have to be evaluated considering the range between the preferred and the maximum acceptable temperatures for each individual. Comparing both buildings, the responses have been different. In building two, the range between preferred and maximum temperatures varied between 1 and 8 K. Here a majority of occupants voted for a difference of 2K. In building one in contrast, the range varied only from 2 to 3 K and the majority of occupants reported a difference of 3K to be acceptable. In total, this results in an acceptable difference of 2-3K.

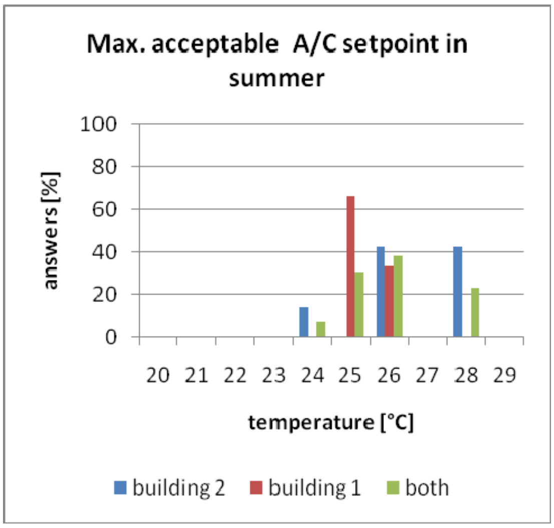


Figure 51: Maximum acceptable cooling set points

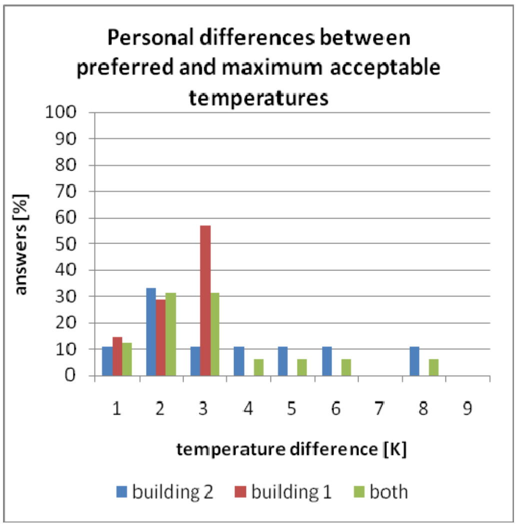


Figure 52: Personal range between preferred and maximum acceptable cooling set points

Occurrence of heat waves

Heat waves are a climate phenomenon, which in the context of climate change is becoming more important. For this reason, occupants have been asked how often perceived heat waves occur. The comparison of results between both buildings showed slight differences. While in building 2 the majority of occupants stated that typically there are 1-3 heat waves per year, in building 1 the majority reported >3 heat waves per year. In total, the majority of subjects reported more than three heat waves per year, followed by 1-3 heat waves.

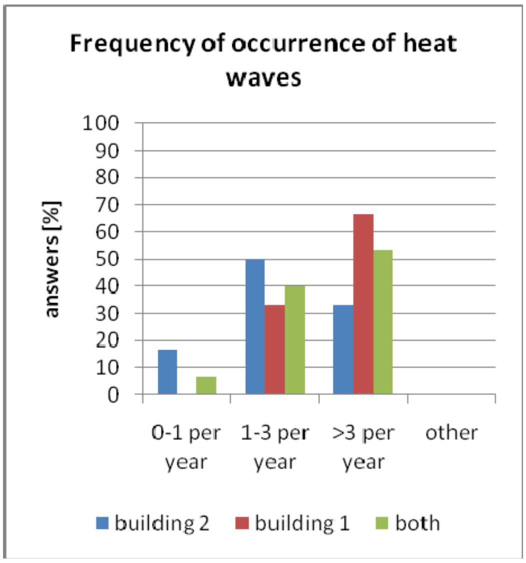


Figure 53: Frequency of occurrence of heat waves

Duration of heat waves

Asked for how long heat waves last, the majority of occupants in both buildings reported a period from 3-5 days to be most common. Only few answers in both buildings voted for shorter periods (1-2 days) or longer periods (6 or 10 days). These relatively consistent answers in both buildings indicated, that the perceived definition for a heat wave by office occupants in Athens might be 3-5 days. This corresponds with the definition for heat waves by the Greek National Meteorological Service.

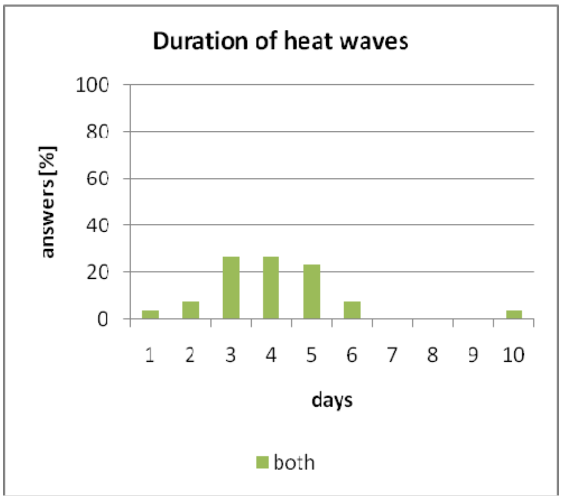


Figure 54: Typical duration of heat waves

Special working conditions during heat waves

Another question aimed to investigate the occupant's attitude towards different opportunities to adapt to heat waves. During heat waves, it is likely, that the effect of passive cooling, even in a building which is designed according to bioclimatic principles and provides adaptive opportunities like window opening, blind switching or clothing adjustment, is limited. This indicates that during heat waves adaptive opportunities of the building might not be sufficient. For this reason, it should be considered to extend the range of adaptive opportunities towards matters of lifestyle and company culture.
Asked if they would accept higher room temperatures in offices during summer/heat waves if they could negotiate with the employer about special working conditions, the vast majority (70%) answered with "yes". Only few occupants said "no" or "I don't know". Additionally, there was no difference between the answers of both buildings.
This indicates that occupants do not generally consider an increase of air conditioning during heat waves as the only possibility to deal with heat. The results of the field study lead to the conclusion that occupants are willing to use different solutions, if they are able to negotiate about it with their employer.

Office occupants have been asked for possibilities, they would like to negotiate about with their employers in order to adapt to heat waves. There were only few answers from building one, therefore it was not possible to distinguish between both offices. The adaptive possibilities to negotiate about which were mentioned most by occupants were "relaxed dress code" and "more flexible working times". Other, less often mentioned aspects were "less work outside the office" and "free cold drinks". This leads to the conclusion, that there are several ways to cope with heat waves. One might be to increase comfort in the office by a more relaxed dress code, cold drinks etc, and another might be to avoid being in the office during extremely hot periods. One person suggested leaving the office from 12am to 4pm during heat waves and returning in the afternoon to work late. However, this option would only be interesting for people to whom an approx. four-hour break in the middle of the day might be useful. Another person suggested using flexible working times differently, arriving at work very early in the morning and leaving already in the afternoon. Generally it can be concluded, that preferences regarding flexible working times might differ significantly among individuals and their lifestyles. Preferences might also depend on the individual task. In the investigated offices dealing with the construction industry, some tasks require presence on construction sites outside the office. During heat waves, working outside the office would result in being strongly exposed to hot temperatures, so for those people the decrease of work outside the office would be a contribution to improving comfort. Those people who spend most of the day inside the office might be more content with negotiating about a more relaxed dress code.

The answers to this question show, that there might be a large potential for comfort improvements beyond the use of additional cooling energy. This potential so far seems to be limited by restrictions of company culture. A more relaxed company culture, allowing occupants to negotiate with their employers about special working conditions during heat waves might not only contribute to decreasing energy consumption. It might also be an improvement to occupant satisfaction with their working environment and thus affect work productivity.

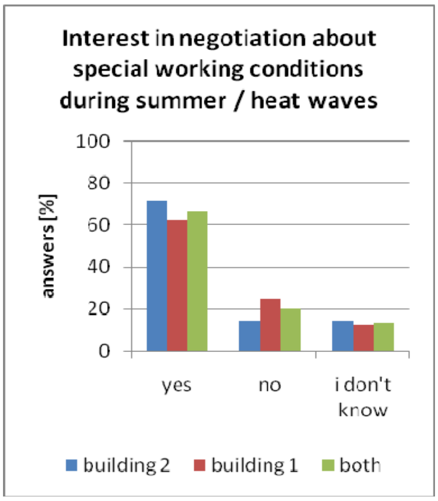


Figure 55: Interest in negotiation about special working conditions during summer / heat waves

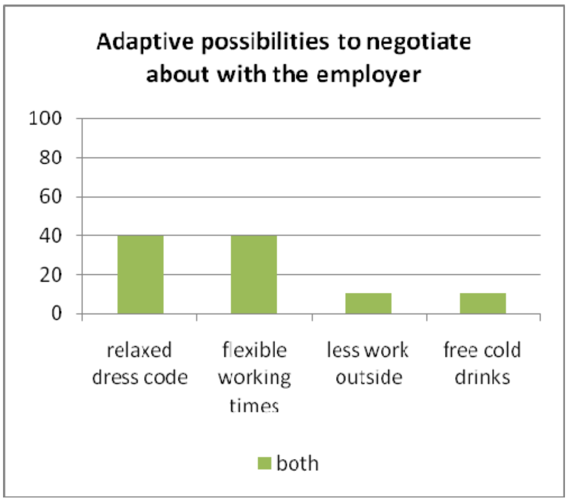


Figure 56: Adaptive possibilities for negotiation during heat waves

Maximum percentage of tolerable heat per day

Asked for the maximum percentage of daily working time occupants would accept to tolerate uncomfortably hot temperatures, in order to reduce air conditioning and help mitigate the climate change, the responses were broadly spread. The variety of answers ranged from 0-5% up to over 30%. While in building two, the majority of occupants voted for 0-5% and 10-20%, the majority of subjects in building one voted for 20-30%, followed by 0-5%. In total, peaks were at 20-30% as well as at 0-5%. The results lead to the conclusion, that there seem to be two types of occupants. One group preferring little or no temperature changes, and another group of people who are willing to accept around 20% of uncomfortably hot temperatures during the working day. No correlation of these differences with façade orientation could be found. Further research would be needed to investigate the reason for these differences.

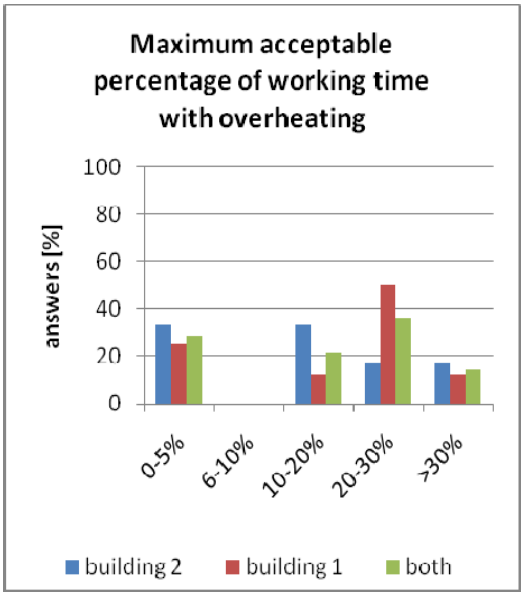


Figure 57: Maximum acceptable percentage
of working time with uncomfortably hot temperatures

Dress code

Another question aimed to find out whether there is a dress code in the office, or not. In building 1 100% of occupants reported „no dress code“. In building two in contrast, the answers were not consistent. The majority of occupants stated that there is a dress code but a significant number of people also said there is no dress code. However, according to the information from a site visit, it can be concluded, that there is a dress code. In addition, apparently this dress code is perceived differently by different occupants. Those occupants who reported a dress code might be considered to feel restricted by it, while those who reported no dress code might not feel any restrictions. This might be caused by different tastes in fashion as well as different clothing standards on different hierarchy levels.

Regarding the use of clothing, occupants were asked how often they adjust their clothing during the day. In building two, the range of clothing adjustments was from “no” to “often”, with a peak at “occasionally”. In building 1, it ranged from “rarely” to “often” with a peak at “often”. These

deviations between both offices can be explained by the stricter dress code in building two, leaving less opportunity for clothing adjustments.
Asked for the reasons for rare or no clothing adjustment, in building 2 the most common answer was „fashion, unofficial dress code with colleagues or clients“, followed by „it is not necessary“. In building one, the only answer was „it is not necessary“. This leads to the conclusion, that clothing adjustment is not only influenced by thermal comfort but also by issues of fashion and unofficial dress codes with colleagues and clients.

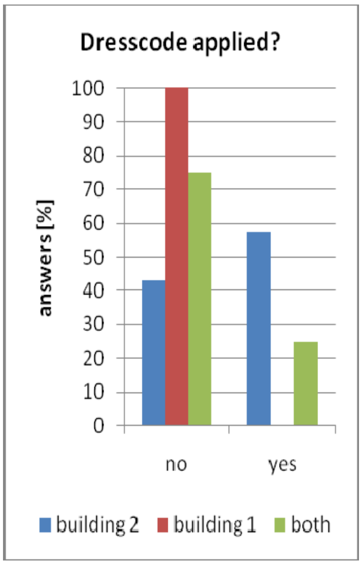


Figure 58: Dress code applied in the office?

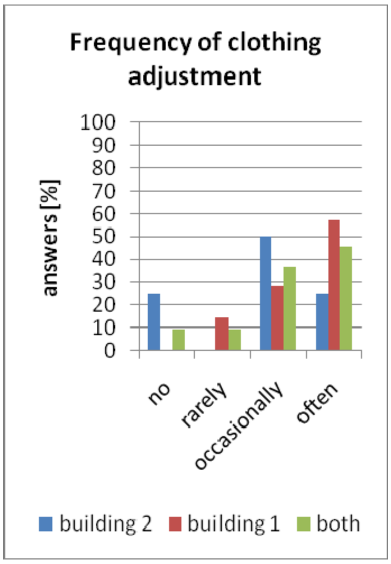


Figure 59: Frequency of clothing adjustment

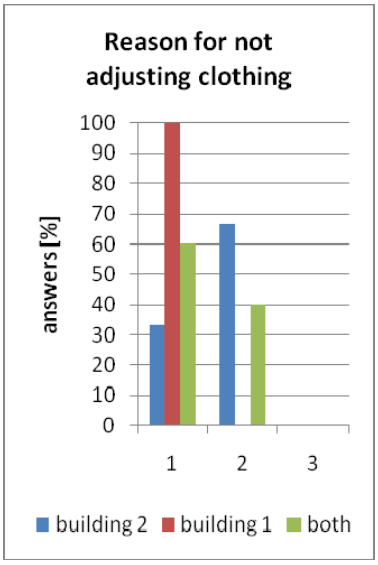


Figure 60: Reasons for not adjusting the clothing

1= It is not necessary
2= Fashion, unofficial dress code with colleagues or clients
3= Other, please describe

Working hours in the office and at the computer

Another important input in building simulation is the working hours. Asked for the hours spent at the desk on a typical day, the answers in building two ranged from eight to 12 hours and in building one from six to 14 hours, the overall range resulting in 6 to 14 hours. Most common in building two were 8 and 10 hours followed by 9 hours. In building 1 9 hours followed by 10h were most common. The same order applies for overall evaluation. A period of 8 to 10 hours or more can therefore be considered typical for the buildings of the field study.
Additionally occupants have been asked how many of their working hours they spend at a computer. In building two subjects reported to spend 7 to 9 hours at the computer with a peak at nine hours. This is consistent with the hours spend at the desk. In building one, occupants reported to spend either one to three or 8 to 11 hours at the computer. Equal peaks were at one, 3 and 10 hours. This might indicate differences in the task, and the management position.

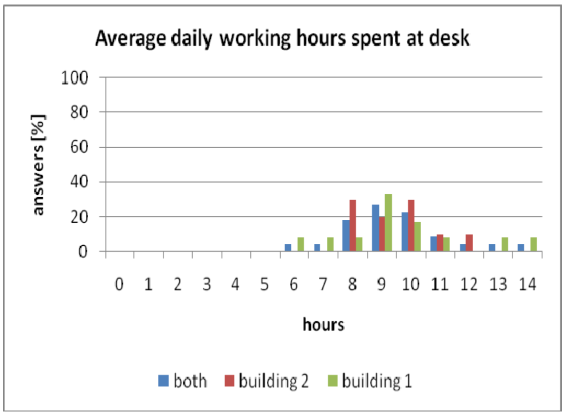


Figure 61: Average daily working hours spent at a desk

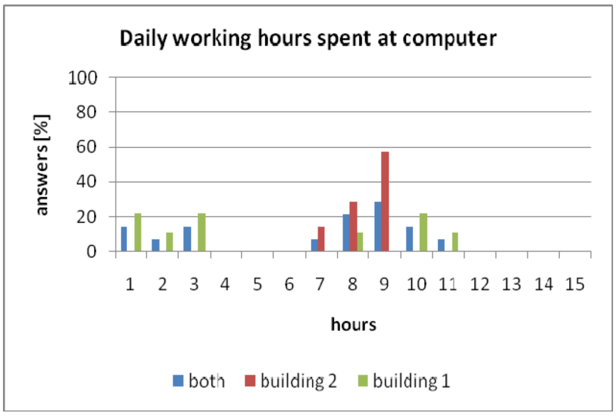


Figure 62: Average daily working hours spent at computer

Conclusions

The results of this field study give an overview about occupant behaviour and preferences in two mixed mode offices in Athens. Due to the small scale of this field study, the results would need further validation. However, they will be compared with results from a literature review in order to derive input data for building simulation focused on the context of Athens, Greece.

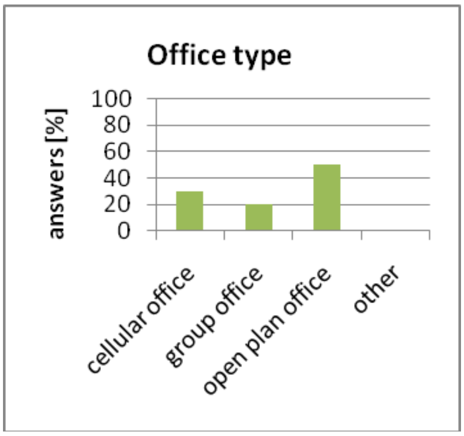
2.1.3 Results from the field study among architects

General remarks

The field study among architects has been conducted to investigate typical building properties and the decision process within the real estate business in Athens. Due to the small number of offices and participating subjects in the survey, the results cannot be considered representative. Further research will be needed to verify the results.

Common office types

According to the responses from Building 1 and 2, the most common office type in Greek office buildings is the open plan office, followed by cellular office and group office.



1= Cellular office
2= Group office
3= Open-plan office
4= Other

Figure 63: Most common office type

Possibility for cross ventilation

Regarding the possibility of cross ventilation, approximately ¾ of responses stated, that cross ventilation is usually possible. ¼ responded it is usually not possible.

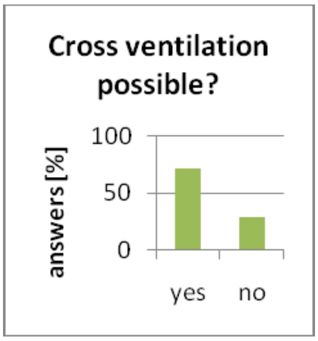


Figure 64: Possibility for cross ventilation?

Obstacles for cross ventilation

There seem to be several typical reasons preventing cross ventilation. Those most mentioned are "too many occupants to decide too few windows" and "floor plan layout does not allow for cross ventilation". The former is mainly caused by occupant density. Especially in group- or open plan offices, it is not very likely, that there are as many openable windows as occupants. Therefore, cross ventilation can only happen if occupants on both sides of the room feel comfortable with opened windows.
The other main reason preventing cross ventilation is floor plan layout. To allow for cross ventilation, there has to be a more or less direct connection for the airflow from one window to the opposite.

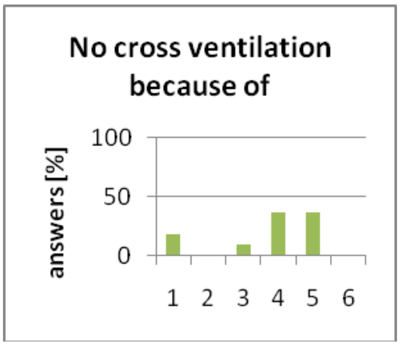
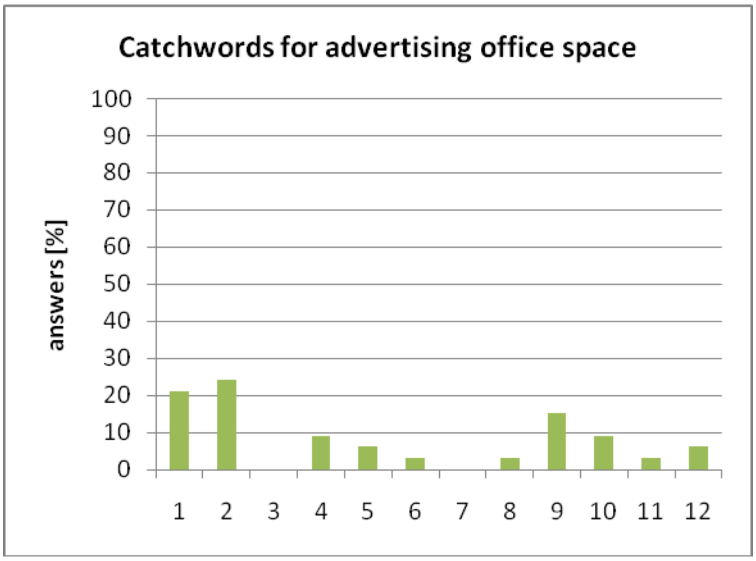


Figure 65: Obstacles for the use of cross ventilation

1= Building too deep
2= Static requires solid core elements in the centre of the building
3= Windows not openable
4= Too many occupants to decide too few windows
5= Floor plan layout does not allow for cross ventilation
6= Other

Catchwords for advertisement of office space

Another question was aiming to find out the most important catchwords to advertise office space for rent. These might indicate in how far „green" aspects are relevant in this context. According to the survey, the most important aspect is the „prestige of the location in the city", followed by the „price for rent" and „quality/luxury level of the building". Less often mentioned reasons were „running costs when in use", „air conditioned" and „design of the building". According to this survey, other aspects like „comfort conditions inside the building", „energy performance", „green building", „security" and „parking facilities" played only a minor role in advertising office space for rent.
These results clearly indicate, that „green" issues and comfort are currently not decisive criteria in the Greek real estate business concerning offices. The predominant aspects are those of prestige, like the location within the city and the quality/luxury level of the building. The location/address of an office building can be considered as a statement of company culture. Distributed on business cards and letters it gives an impression of the company which is in the first place independent from the building itself. However, it is an important part of self-advertising of a company. Customers might expect the headquarters of a bank to be located in a first class inner city location. For a creative business, a location in a less expensive but more artistic quarter would be more convincing for customers. However, the choice of the location for an office building is somehow limited by the price for rent, the second important aspect according to the field study. The quality/luxury level of the building itself, has been reported to be the third important aspect. This is another prestige issue, compared to the location of the building not on urban but on building scale.

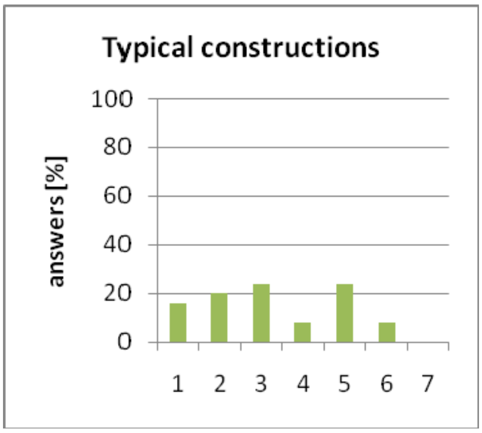


1= Price for rent
2= Prestige of the location within the city
3= View out of the building
4= Running costs when in use
5= Design of the building
6= Comfort conditions inside the building
7= Daylight qualities inside the building
8= Energy performance
9= Quality/luxury level of the building
10= Air-conditioned
11= Green building
12= Other (please describe)

Figure 66: Most important catchwords for advertisement of office space

Typical constructions

The most common constructions in Greek offices, are depending on the combinations, however, solid floor and suspended acoustic ceiling were mentioned most during this survey. Concerning walls, gypsum walls seem more common than solid walls. False floor construction and suspended gypsum ceilings were mentioned less. However, the use of false floor construction was reported to have become increasingly common only during the last five years. According to this study, a concrete ceiling without suspension does not seem to be a typical construction.

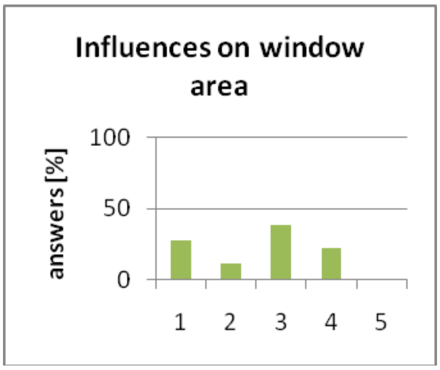


1= Solid walls
2= Gypsum walls
3= Solid floor (slab+ screed)
4= False floor construction
5= Suspended acoustic ceiling
6= Suspended gypsum ceiling
7= Concrete slab ceiling

Figure 67: Typical construction characteristics

Influences on window area

One main influence on thermal and visual comfort in offices is the window area of the room. Therefore it was aimed to find out what influences define the window area for a façade design. The answers clearly indicate that the main decision criterion is architectural fashion. The second important influence according to this study was “client’s wishes (e.g. symbolization of corporate culture etc.)". However, these two influences are closely related to each other and it is likely that client's wishes strongly follow architectural fashions.



1= Client's wishes (e.g. symbolization of corporate culture etc.)
2= References to urban situation
3= Architectural fashions
4= Thermal comfort predictions
5= Other

Figure 68: Parameters influencing window area

Low-e glazing

Regarding the low-e glazing in Greek offices, architects have been asked for the most important reasons for use in offices. The answers show, that the most important reason for the use of low-e glazing are „comfort and energy predictions", followed by client's wishes.
Asked for the most common colour of low-e glazing in Greek offices, a slight majority responded, that these glazings are usually not tinted. Those who considered tinted glazing as more common reported a preference for dark colours. The colour most mentioned was grey, followed by brown. Green and blue were mentioned less.

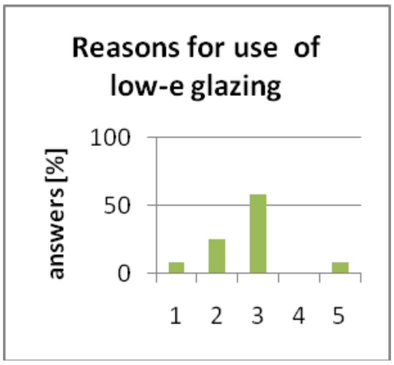


Figure 69: Reasons for use of low-e glazing

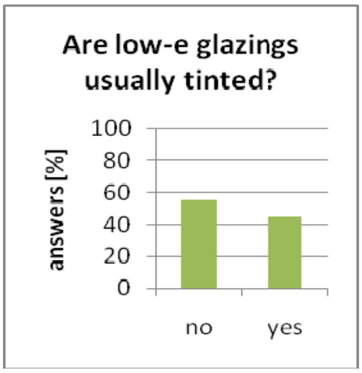
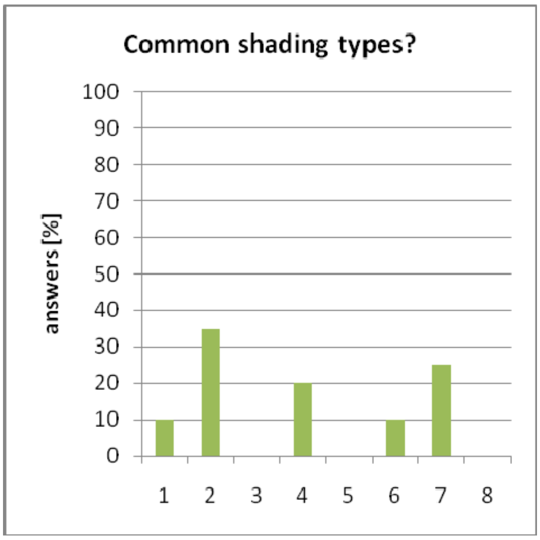


Figure 70: Colour of low-e glazing

1= Legal requirements
2= Client's wishes
3= Comfort or energy predictions
4= Common practice
5= Other (please describe)

Common shading types

Asked for the most common shading types in Greek offices, the majority of subjects reported interior venetian blinds to be most common, followed by overhangs and awnings. Less often mentioned were exterior venetian blinds and horizontal louvers. The use of these shading types has to be considered in combination with window opening types. Since top hung windows are a very common window opening type for offices, this implies that exterior venetian blinds could only be used with a special construction in front of the window, so the blind can be placed vertically even if the window is opened. Interior venetian blinds in contrast do not need any further construction and besides they are cheaper. Interior venetian blinds are often combined with overhangs.



1= Exterior venetian blind (retractable)
2= Interior venetian blind (retractable)
3= Screen
4= Awning
5= Vertical louvre
6= Horizontal louvre
7= Overhang
8= Other, please name:

Figure 71: Most common shading types

Common lighting concepts

Regarding common lighting concepts in Greek office buildings, according to the responses in the field study the most typical variation is room related lighting. Task area lighting plays a minor role, as other lighting concepts (ascent lighting).

The decision for a lighting system in office buildings is, according to the results of the field study, mostly influenced by the initial costs. Systems causing lowest initial costs are usually preferred. The second important reason was lowest energy consumption/running costs, followed by the best cost performance ratio. This preference for low initial costs might be typical for the real estate business, where the investor is not at the same time the tenant of the building, and thus does not pay the resulting running costs.

Concerning the lighting design quality, all responses stated that „standard solution, no special design, low price“ is typical for Greek offices. This corresponds to the above-mentioned preference for solutions with lowest initial costs.

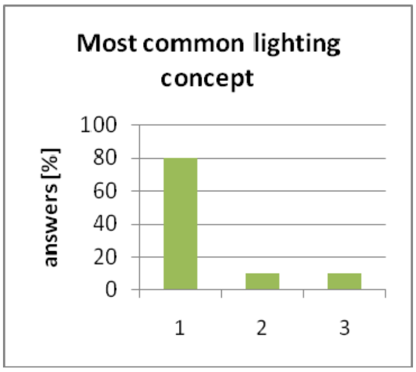


Figure 72: Most common lighting design concepts

1= Room related lighting
2= Task area lighting
3= Other

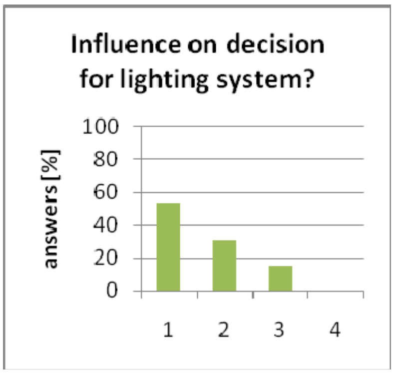


Figure 73: Parameters influencing the decision for a lighting system

1= Lowest initial costs
2= Lowest energy consumption/ running costs
3= Best cost performance ratio
4= Other (please describe)

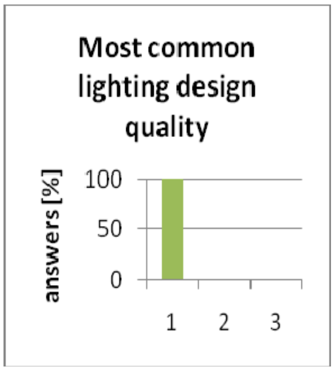
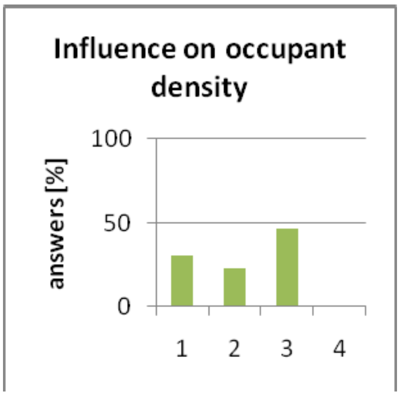


Figure 74: Most common lighting design quality

1= Standard solution, no Special design, low price
2= Sophisticated lighting design, expressing a special prestige or atmosphere desired by the client
3= Other

Occupant density

As far as occupant density is concerned, a question aimed to find out how many people would be working in an office room of 5.4x3.5m (=18,9m²). The answers ranged from two to four persons with a slight majority for three persons. This density of occupants can have significant influence on internal heat loads.
The occupant density in the room is influenced by several parameters. The room size itself, limiting the maximum possible number of occupants. And the company, deciding how many people should work in one room. According to the field study, the most important influence on occupant density is hierarchy, assuming lower densities for senior management positions. The second important influence is the task, i.e. the space needed accordingly and the level of privacy followed by cost effectiveness (= maximum density). Although the latter is in many other building related aspects the predominant decision criteria, regarding occupant density, hierarchies and needs of the task seem to be predominant.



1= Density depending mainly on the task (space needed, privacy)
2= Density depending on cost effectiveness for employer (= maximum density)
3= Density mainly depending on hierarchy (e.g. single occupancy for senior management positions)
4= Other

Figure 75: Parameters influencing occupant density

Floor plan arrangement

Another link between occupant density and comfort is the placement of people/tasks within rooms and the floor plan. For example, a south facing room, occupied by four people will have a stronger risk for overheating than the same room occupied only by one or two persons. Therefore, it can be important to consider according to what criteria the employees are distributed within the office space. Apart from the office space itself, according to the field study two main influences can be considered equally important. The internal company structure (hierarchies) and workflows within the company.

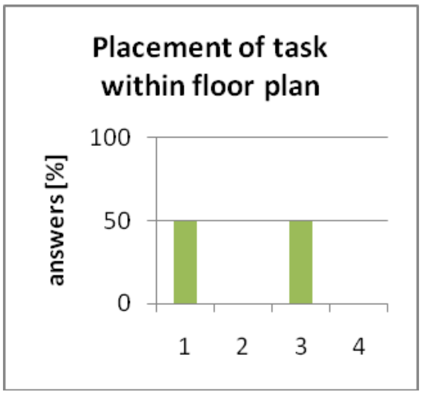


Figure 76: Parameters influencing the internal organisation within floor plan

1= Internal company structure (hierarchies)
2= View out of the window
3= Workflows within the company
4= Other (Please describe)

Client's interest in green buildings

Another question aimed to find out about the most common reasons why clients would be interested in "green" buildings. According to the field study, the most mentioned reasons are "because they are a good advertisement for the client's company" and "because the client wants to save energy costs". Compared to that, the clients care for indoor comfort for the occupants, and the contribution to mitigate the climate change were minor reasons. This clearly indicates that clients are mainly interested in green buildings if they can benefit from it. This benefit can either be reputational, e.g. a "green image", or financial in terms of saving costs.

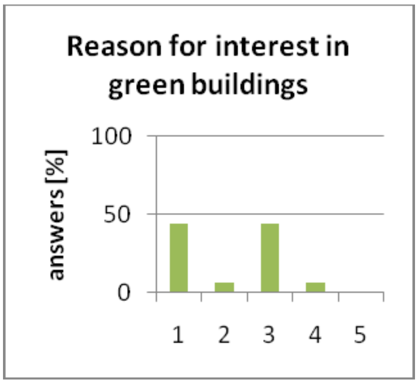


Figure 77: Reason for interest of clients in Green buildings

1= Because they are a good advertisement for the client's company
2= Because the client cares about indoor comfort for the occupants
3= Because the client wants to save energy costs
4= Because the client wants to contribute in mitigating the climate change
5= Other, please describe

Conclusions

The field study among architects gives an overview on typical constructions and architectural designs used for office buildings in the context of Athens, Greece. Thus, input data for building simulation of a typical cellular office can be developed accordingly. Additionally, this field study indicates current trends in office architecture and priorities within the design process of office buildings in Athens. Although due to the small scale of this field study further verification is necessary, the results indicate, that dependencies within the real estate market in Athens are a predominant criteria regarding the design of office buildings. Two main decisive criteria on the Athens real estate market are indicated in this field study. The focus on a maximum rate of return, and architectural fashion. Since the majority of office buildings are built for rent, and the owner is usually not at the same time the tenant, the owner's rate of return can be maximised by reducing the initial costs. This favours cheap solutions, rather than a focus on the resulting energy efficiency, running costs or comfort levels.

Another main influence on design of office buildings is architectural fashion. As the questions on window area indicate, this is not predominantly an influence caused only by architects, but also by the preferences of their clients. However, architectural fashion is also an expression of the lifestyle in a certain era.

2.2. Climate change and weather data

2.2.1 Climate characteristics in Athens

The climate in Athens, Greece can be categorised as temperate, with hot and dry summers [57]. Thus, it belongs to the hottest regions in Europe, with an annual mean global radiation observed in the last decades around 1600 kWh/m² [39]. The main characteristics of the Athens climate vary with season. During winter, the main parameters are sunshine duration, cloudiness, relative humidity, daily temperature range and wind speed. During summer, the typical parameters are cloudiness, humidity, evaporation and wind speed and the daily temperature range [58]. All those parameters directly or indirectly affect thermal comfort, visual comfort and energy performance in office buildings.

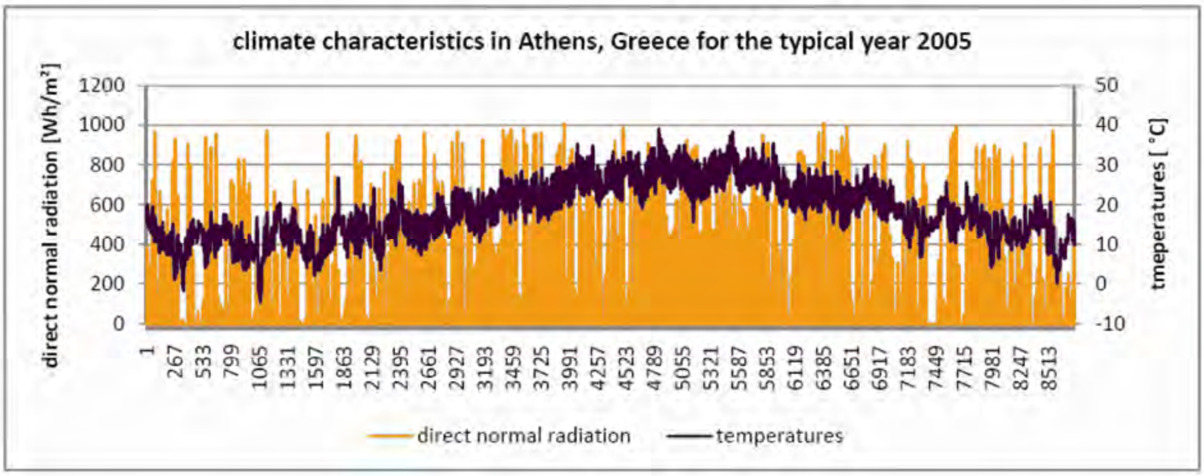


Figure 78: Radiation and temperatures in Athens, Greece, 2005

Due to the increase of greenhouse gas emissions within the last decades, projections of the Intergovernmental Panel on Climate Change [37] for the 21st century predict a global warming of about 0,2°C per decade for the next two decades. For the region of Athens, Greece, an increase of temperatures from 1920 to 1960 and a new increase since the 80s could be observed [59]. This corresponds with findings of Founda et al. [60] who observed an increase in annual temperature by approx. 0,5°C within the last century. Additionally, they predicted a further increase in maximum and minimum daily temperatures (figure 79). They also observed a sudden increase of the frequency of occurrence of particularly hot days as well as the duration of warm episodes in the last decade (figure 80). This indicates that hot periods or heat waves, which are a characteristic of the Greek climate [61], are getting stronger. This corresponds with findings of Meehl and Tebaldi [62], who examined the future behaviour of heat waves for different climate scenarios. They predicted an increase of mean temperatures, and more intense, longer lasting and/or more frequent heat waves.

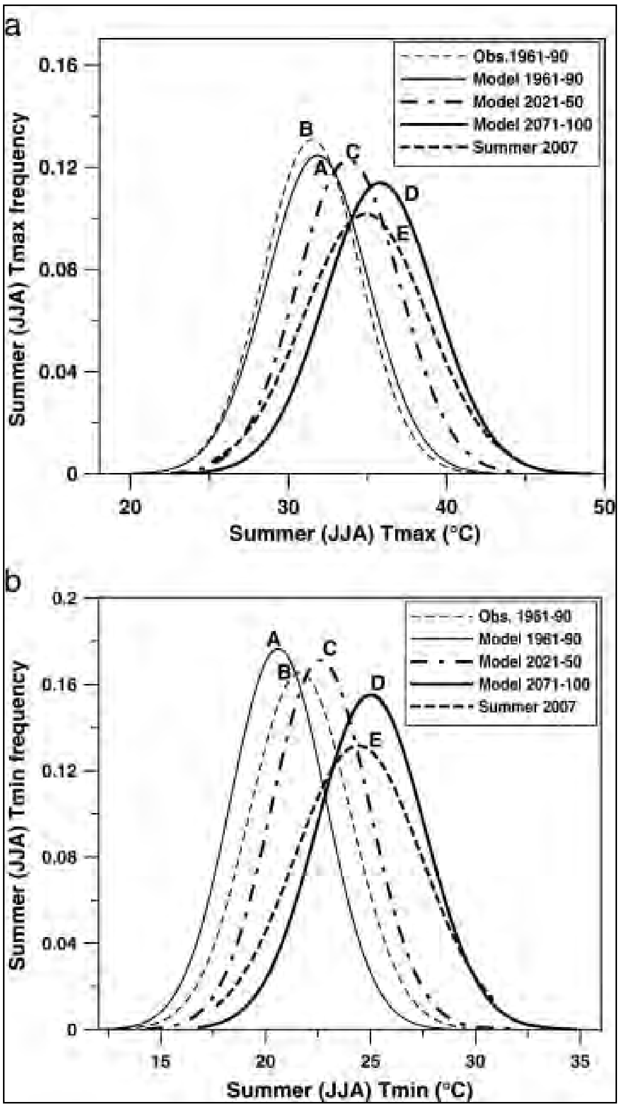


Figure 79: Probability density function (pdf) of Gaussian distributions fitted to JJA maximum (a) and minimum (b) temperature for the following cases: (A) model output for the period 1961-1990 in Athens area, (B) NOA observations for the period 1961-1990, (C) the 2021-2050 model simulations, (D) the 2071-2100 model simulations and (E) summer 2007 (NOA observations), source: Founda and Giannakopoulos [11], figure 10

There is no international definition of a heat wave based on measurable parameters, since perception of heat waves is depending on the local context as well. It can generally be described as unusually high atmosphere-related heat stress, which causes temporary modifications in lifestyle and has notable impacts on health, and human mortality, as well as regional economies, and ecosystems [62, 63, 64]. Following the definition of the Greek National Meteorological Service, a heat wave lasts at least three consecutive days with a maximum daily temperature >37°C [61]. This indicates that although being a meteorological event, it might not be possible to investigate thermal comfort in offices during heat waves without considering the social context.

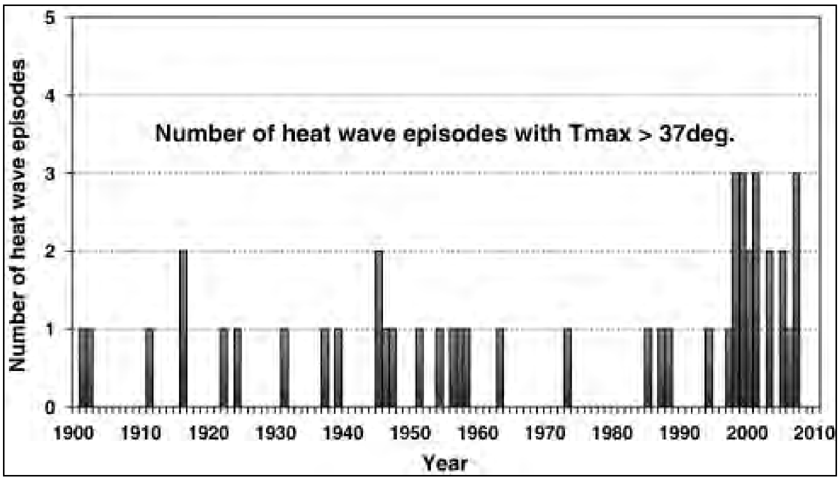


Figure 80: Number of heat wave episodes per summer (JJA) at NOA from 1891-2007. As heat wave episode is considered a sequence of at least 3 consecutive days with Tmax > 37°C, source Founda and Giannakopoulos [11], figure 4

One often reported social impact of heat waves in residential context is the increasing mortality [62, 65], especially during or after the second hot night of heat waves [65]. However, heat related mortality occurs at higher temperatures in hotter regions than in cold regions of Europe and does not account for significantly more deaths in hotter areas [61, 62]. This can be explained by a better protection from heat stress and a better adaptation of people in hot than in cold climates [62]. Additionally, physiological acclimatisation was found to be an important factor limiting heat related mortality in hot regions. From their study, Founda and Giannakopoulos [61] concluded that people would be able to adjust with little increase in heat related mortality to the global warming of approx. 2°C, which is predicted for the next half century. This is due to reduced salt loss in sweat, which is a main cause for deaths in heat waves [61]. However, they further concluded that although this acclimatisation might take place relatively quickly, the required corresponding changes in behaviour and especially changes in buildings and equipment are likely to be much slower.
However, these findings indicate that healthy humans have ability for acclimatization to heat waves. Especially in offices, where relatively healthy occupants can be assumed, these short-term adjustments to hot episodes might be able to influence thermal perception and preference.

One typical reaction in hot climates to the occurrence of heat waves is the increasing use of air-conditioning. However, as observed by de Dear and White [66] for the climate of Sydney, electricity demand peaks during heat waves due to the use of air conditioning. And increasing the grid capacity to meet those peak load demands for cooling would represent an inefficient use of energy resources, since heat waves only occur during very short periods. Demand response strategies can help to reduce peak loads due to air conditioning as demonstrated in a field study in Australia [67]. Possible strategies are variable energy pricing, with increasing tariffs during peak loads, and direct load control, i.e. remote on/off switching of AC compressors according to grid loads. However while the first strategy would lead to an unequal distribution of energy depending on financial possibilities, the second strategy is likely to cause lower comfort and acceptability.
Since comparable solutions require a large technical effort, the above-mentioned findings of Founda and Giannakopoulos [61] could indicate an additional strategy for improving comfort and energy savings. Especially in the working environment of office buildings, occupants are likely to be in a healthy condition to be able to physically acclimatise to heat waves at least to some extent. The

further adaptive opportunities indicated by Founda and Giannakopoulos [61] are behavioural adaptation and changes regarding the building and the equipment. Moreover, while building related adjustments are most likely to be possible concerning the life cycle of the buildings, behavioural adaptation can be possible on a short time scale.

Another climatic phenomenon influencing comfort and energy performance in offices is the heat island effect. Due to reasons of prestige, and/or better connections to public transport, the most attractive locations for offices are usually in the heart of a city, where the heat island effect is strongest. As observed by Hassid et al. [68] the heat island effect can cause a large increase in cooling energy and peak demand up to 100%. They conclude a need to reduce cooling by natural means, and the need to study the yearly variability of the heat island effect. This corresponds with other studies by Mihalakakou et al. [69], and Geros et al [70] who observed, that the intensity of heat islands is not constant. There are periodic and non-periodic fluctuations depending on weather conditions, topographic and topoclimatic complexities and synoptic flow patterns. According to Geros et al. [70], the local microclimate in an urban canyon is strongly related to the form and the geometry of the canyon, its orientation, the heat sources and the construction materials. They observed that in the investigated canyons the daily amplitude of the air temperature was higher outside an urban canyon than inside. This was found to be due to the geometry of the canyons, which reduce the penetration of solar radiation during the daytime period. During the night period, the air temperature outside the canyon was lower than that measured inside. The long wave radiation exchanges during the night between the surfaces of the canyon obstruct the ‘‘release’’ of heat, which is stored in the construction materials in daytime. The resulting average difference between the temperature inside and outside the canyons during the night varied up to 3°C. In the same canyons, the measured wind velocity decreased significantly inside the canyons compared to outside the canyon with variations up to 2.6 m/s and wind direction varying up to opposite direction. As differences between outside and room air temperature as well as wind speed and direction are key drivers for air exchange, the resulting air exchange rates for single sided ventilation varied according to their field study from 0.2 to 10 1/h and from 4 to 69 for a room with cross ventilation [70]. This is illustrated in figure 81 for the different urban canyons in Athens.

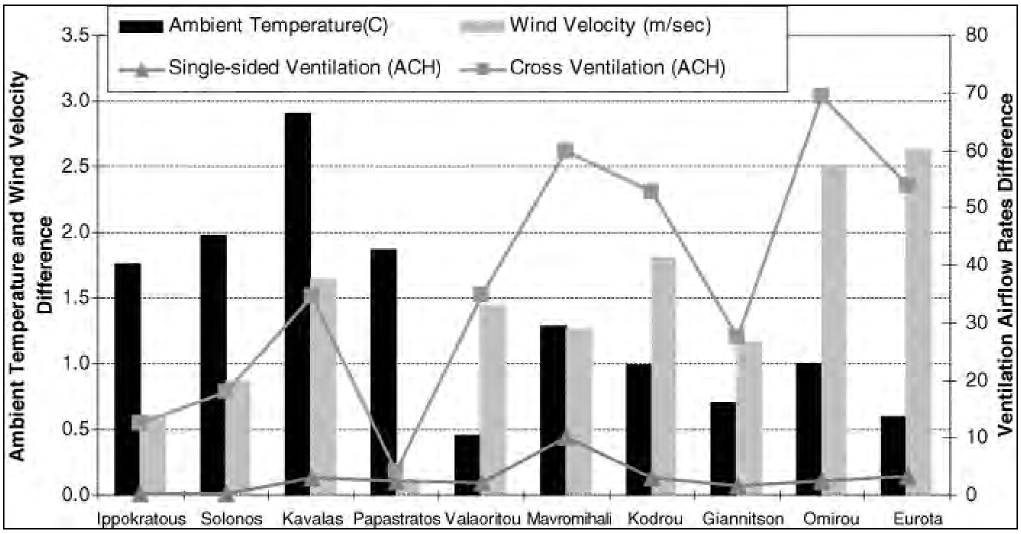


Figure 81: The average difference of the ambient temperature, the wind velocity (horizontal component) and the ventilation airflow rate between the two locations of the typical zone, when ventilation is single-sided and cross, source Geros et al. [70], figure 11

Regarding the reduction of cooling loads by means of natural ventilation the heat island effect should be considered. As recommended by Santamouris et al [71] design of urban buildings should consider the appropriate wind and temperature data instead of routine meteorological observations observed in the open field.

Conclusions

From this literature review it can be concluded, that higher temperatures, heat waves and the heat island effect are important regarding the future characteristics of the Athens climate. However the question occurs, in how far these overheating incidents should be considered in comfort and energy performance evaluation of buildings.
In Greece, HVAC systems are usually dimensioned according to the worst-case scenario from a climatic file, i.e. a reference year that is created based on average measured climate data from the past. Following this approach, the use of climate files including heat waves and future climate change scenarios would lead to an increase in installed HVAC power.
Future comfort evaluation therefore has to face two seemingly contradictory influences. Increasing temperatures due to the climate change and heat waves, which cannot be ignored in order to maintain satisfactory comfort conditions in buildings. And at the same time the need to reduce energy consumption and CO_2 emissions.
For this reason, in terms of thermal comfort evaluation and legislation an increasing focus on non-technical solutions like behavioural adaptation, the reduction of internal heat gains and the improvement of natural ventilation might be useful. Adaptive thermal comfort models already provide a method to consider these influences, but they are currently only applied in naturally ventilated buildings.
Additionally, the common definition of heat waves „causing temporary modifications in lifestyle" might raise the question in how far current comfort models are applicable during heat waves anyway. Since current comfort models seem to reflect the lifestyle-based expectations of occupants in naturally (adaptive models) or mechanically (static models) ventilated buildings, the adaptive potential of changing lifestyle and expectations during heat waves should be further investigated.

2.2.2 Weather data sets used this study

The in the preceding paragraph mentioned findings regarding the influence of local climate characteristics on comfort and energy performance correspond with observations of Pültz and Hoffmann [36]. They investigated different commonly used weather data sets regarding their validity for the prediction of overheating in summer when using building simulation. The results showed that test reference years (TRY), average Meteonorm data and IWEC data lead to an underestimation of overheating. As such, these data do not seem suitable to predict thermal comfort and energy performance in offices in a future warmer climate as well. This supports findings of Kalz et al. [72] indicating that thermal comfort in a building should be classified with reference to a year with typical weather conditions for the location concerned.

A commonly used weather data set for Athens, for use in dynamic building simulation is the IWEC data set available from the energyplus website [73]. The IWEC data files are 'typical' weather files derived from up to 18 years of hourly-observed weather data. As such they are based on data from the past and do not consider recent or future observations in climate change.
However, building simulation is usually supposed to predict the thermal behaviour of buildings for almost its life cycle, typically for a period of approx. 15 to 20 years ahead. As predicted by Cartalis et al. [74] when evaluating the influence of climate change scenarios on heating and cooling degree-days, significant increases in energy demand for cooling are expected for the coming years during spring and summer.

Thus, the question arises how future climatic events like heat waves and the heat island effect should be reflected in weather data sets today. Since studies observed a significant increase in temperatures during approximately the last decade [61], and predicted a further increase for the future [62], measured weather data sets [38] for the last decade in the region of Athens, Greece have been analysed for this study. However, these weather data were measured at airports, which are usually located outside of the city. As such, they do consider heat waves, but they are not likely to consider the urban heat island effect. Additionally, these data sets usually have smaller or larger gaps, they do not contain information on all parameters needed for input in building simulation, and they are not provided in a file format usable for building simulation. Therefore, the data sets can be used for comparison, but the final data set has to be generated. For this study, the comparison has been based only on temperatures, since they are the commonly used parameter and they were found to be the most consistent of the available data.
Figure 82 shows a histogram of outside air temperatures of different years, measured at Elefsis airport approx. 25km northwest of the city of Athens. It has to be considered that most data sets have larger gaps also in summer, so the amount of hours with high temperatures is likely to be even higher than shown in the figure. However, generally a large variability of temperatures in different years can be observed, with the standard weather data set [35] providing the lowest number of hours with temperatures above 30°C. This distribution supports the above-mentioned findings that standard weather data sets are likely to underestimate overheating hours in offices.

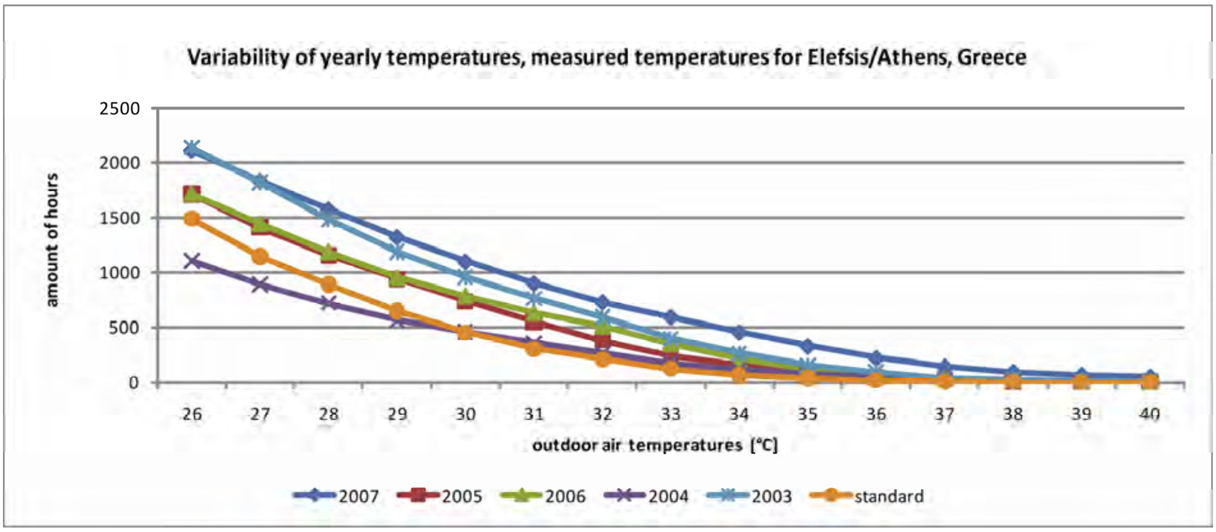


Figure 82: Distribution of measured outside air temperatures for different years at Elefsis airport near Athens, Greece, compared with the energyplus standard weather data set.

In order to evaluate the influence of climate variability on comfort and energy performance in offices, two different weather data sets have been chosen for comparison. Year 2007 as the hottest year during the last decade, and year 2005 as a year with typical average temperatures during the last decade. Both measured data sets do not have significant gaps during summer so they can be used for comparison. Figure 83 shows the temperature distribution for both data sets over the year. While in 2005 temperature distribution is relatively consistent, in 2007 three heat waves can be observed. Following the definition of the Greek National Meteorological Service, a heat wave lasts at least three consecutive days with a maximum daily temperature >37°C.

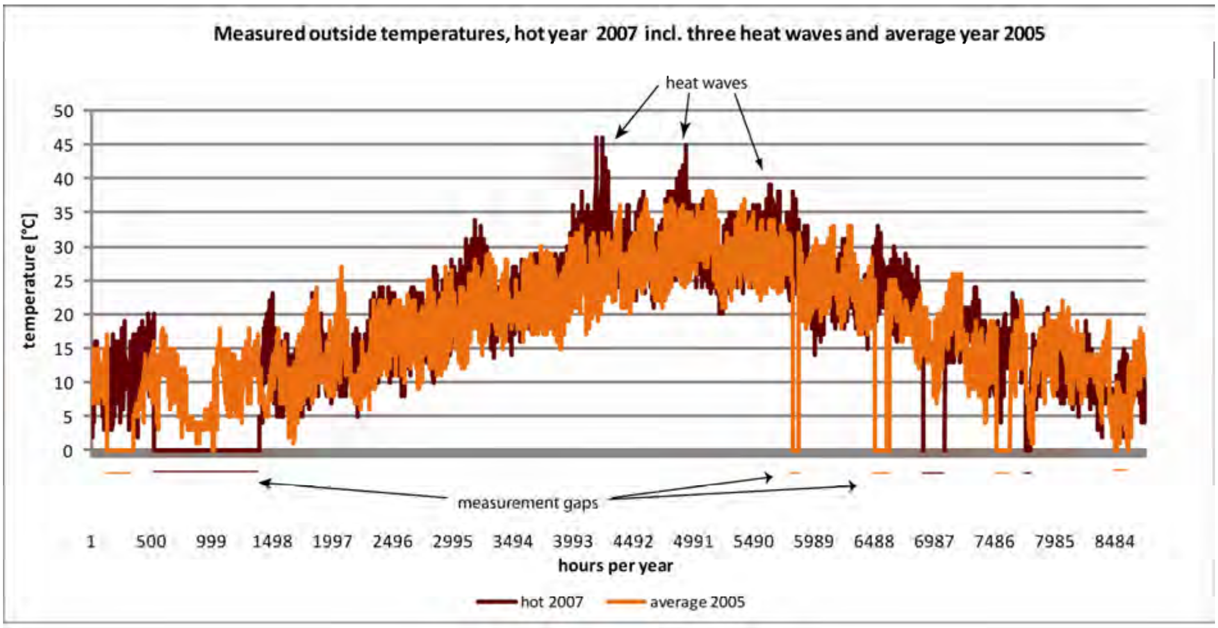


Figure 83: Comparison of measured outside air temperatures for year 2007 (incl. three heat waves) and year 2005

Figures 84 - 86 compare the temperatures during the heat waves in 2007 with those of 2005 at the same period. From these graphs, it can be observed that heat waves usually lasted for no more than 5 days, so in total heat waves accounted for around 15 days in 2007. Based on 260 working days per year, heat waves in the hot year of 2007 occurred throughout 5,7% of the working time, and even less in all other years. In naturally ventilated buildings however, it might be likely that EN 15251 adaptive thermal comfort requirements, allowing for a maximum of 5% exceeding hours, are not met during heat waves. In addition, in mixed mode and air conditioned buildings, cooling loads are likely to increase with the above-mentioned effects on peak loads and grid capacities. However, even considering the predicted increase in frequency and magnitude of heat waves, they will account for only a small percentage of the annual working time during the next decades. This supports the conclusions drawn above, that during these short periods behavioural adaptation might be an effective means to improve comfort and energy performance in offices. It would not require large technical effort and could be implemented in a short time scale.

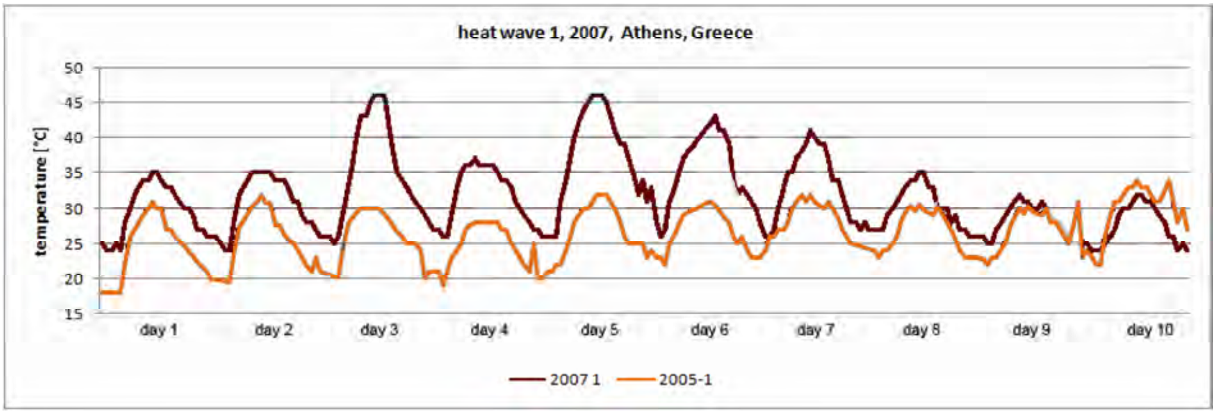


Figure 84: Comparison of measured outside air temperatures for year 2005 and 2007 during the period of the first heat wave in 2007

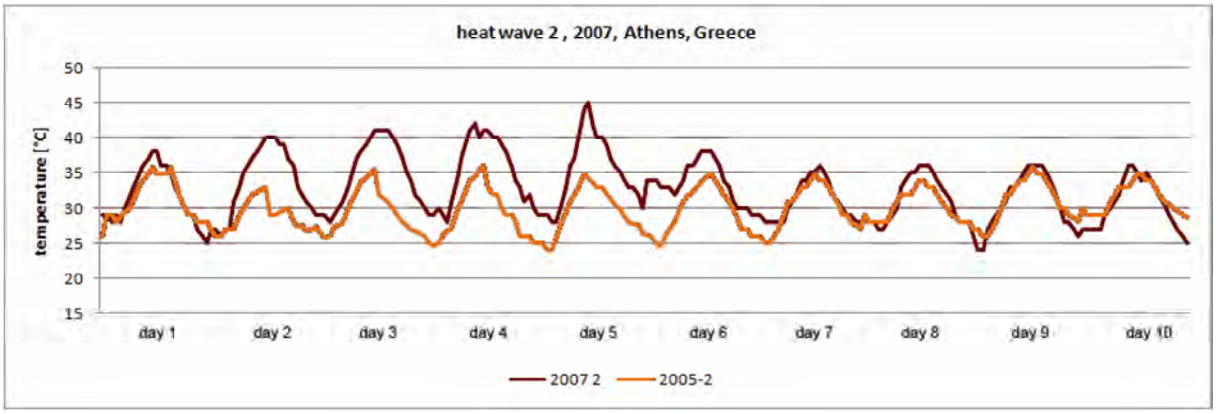


Figure 85: Comparison of measured outside air temperatures for year 2005 and 2007 during the period of the second heat wave in 2007

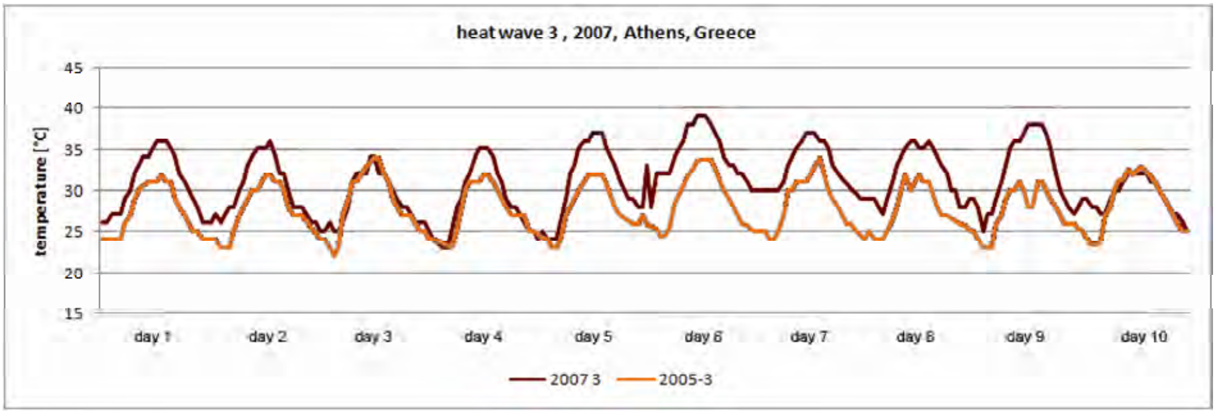


Figure 86: Comparison of measured outside air temperatures for year 2005 and 2007 during the period of the third heat wave in 2007

In order to be used in building simulation, weather data sets have been generated for this study using the software Meteonorm 6.0 [39]. This software allows for adjustments on the data set for a specific location. The time period for the data source can be chosen, and it is possible to choose whether extreme or standard values should be taken into account for outside air temperatures as well as solar radiation. Thus, it is possible to produce a variety of data sets for one location, for comparison with characteristics of measured data. Using these adjustment possibilities, a weather data set could be generated with a comparable temperature distribution as in 2005 (figure 87).

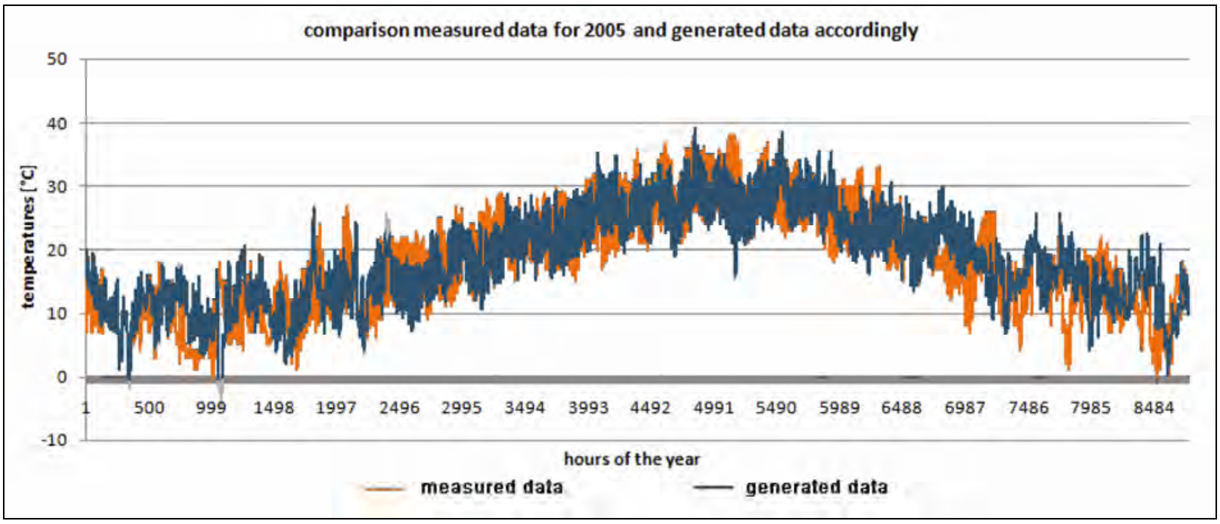


Figure 87: Comparison of measured and generated weather data for year 2005

Using the software Meteonorm, it was not possible to generate a weather data set for Athens reflecting the heat waves of the year 2007. However, in order to consider the influence of heat waves in this study, a simplified method has been used to obtain a weather data set accordingly.
The generated data set for a hot year, comparable of the year 2007, has been modified for this study. For the limited periods during heat waves, the generated data for outside air temperatures have been replaced with the measured data from 2007. This methodology has been approved by Meteonorm [75], however the results should be considered only as approximations and further validation would be needed. The resulting data set is therefore based on generated data by Meteonorm 6, and includes measured heat wave characteristics for outside air temperatures for the year 2007 (figure 88).

These two weather data sets are used in this case study, to illustrate the range of influence, local climate variability can have on the thermal- and energy performance in offices.

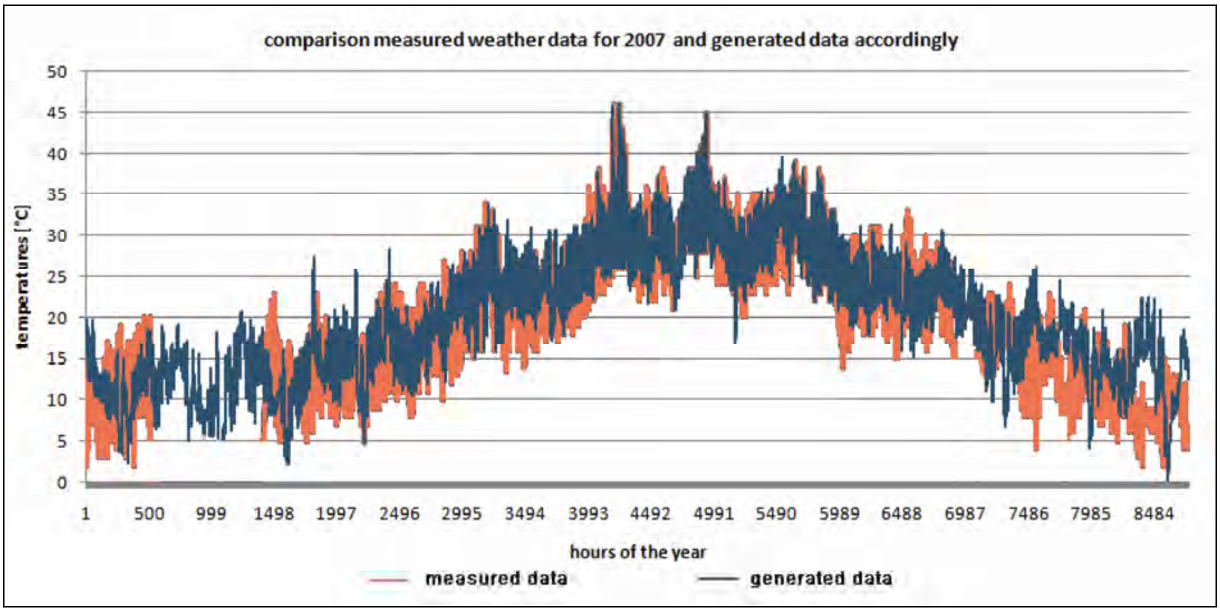


Figure 88: Comparison of measured and generated weather data for year 2007

2.3 Building parameters

2.3.1 Room geometry

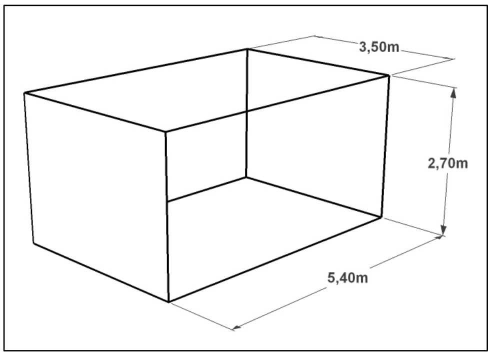


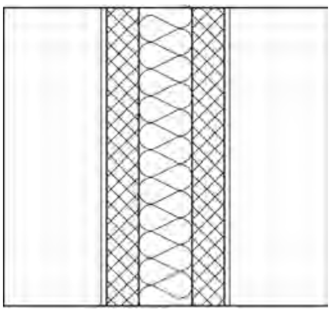
Figure 89: Cellular office room used for the parametric study in Athens

The investigated office room is a typical cellular office with a room depth of 5,4m, a facade width of 3,5m and a room height of 2,7m.

2.3.2 Construction and thermal mass

The constructions used in building simulation for this study have been derived from the results of the field study among architects in Athens. The u-values are typical for the Athens climate.

Exterior wall, heavy



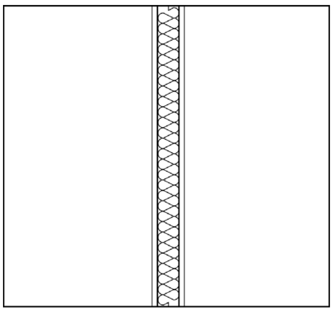
U=0,5W/m²K

Layers from outside to inside:

Exterior finish	=1,5 cm
Brick	=9,0 cm
Rigid foam	=5,0 cm
Brick	=9,0 cm
Interior finish	=1,5 cm

Figure 90: construction of Exterior wall, heavy

Exterior wall light



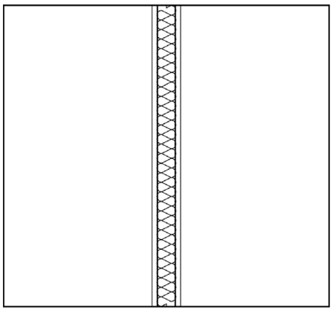
U= 0.58W/m²K

Layers from outside to inside:

Exterior finish	= 1,5 cm
Rigid foam	= 6,0 cm
Interior finish	= 1,5 cm

Figure 91: construction of exterior wall, light

Internal wall light



Layers:

Gypsum board	=1,5 cm
Insulation	=5,0 cm
Gypsum board	=1,5 cm

Figure 92: construction of Interior wall, light

Internal wall heavy

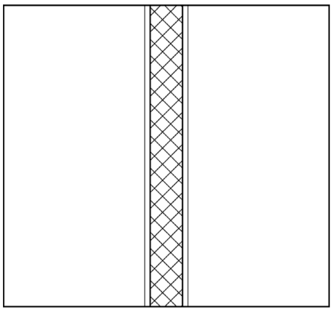
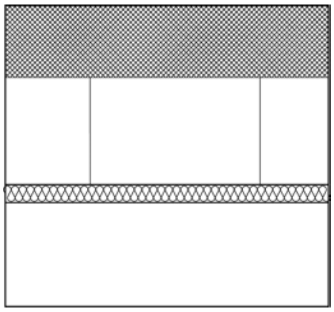


Figure 93: construction of Interior wall, heavy

Layers:

Interior finish	=1,5 cm
Clay bricks	=9,0 cm
Interior finish	=1,5 cm

Suspended acoustic ceiling

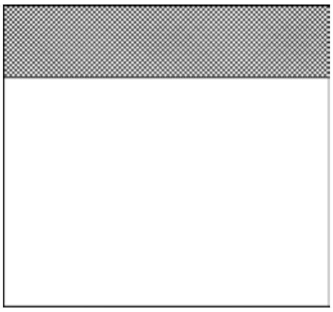


Layers:

Concrete slab	=25 cm
Airspace	=40 cm
Acoustic ceiling panels	=5,0 cm

Figure 94: suspended acoustic Ceiling

Concrete ceiling

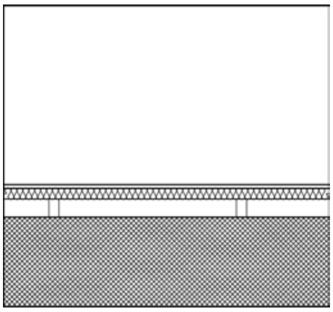


Layer:

Concrete slab	=25cm

Figure 95: concrete ceiling, without covering

False floor

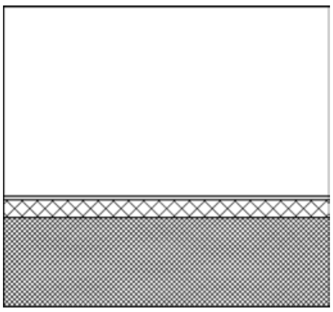


Layers:

Carpet	=1,0 cm
Insulation	=3,0 cm
Airspace	=15 cm
Concrete slab	=25 cm

Figure 96: false floor

Cement Floor- concrete ceiling



Layers:

Carpet	=1,0 cm
Cement floor	=5,0 cm
Concrete slab	=25 cm

Figure 97: cement floor
on concrete slab

2.3.3 Window and glazing

The room is ventilated by a steplessly opening top hung window (1,50m x 1,26m), with a typical max. opening angle of 20°, placed in the middle of the facade (figure 98), above a sill height of 80cm.

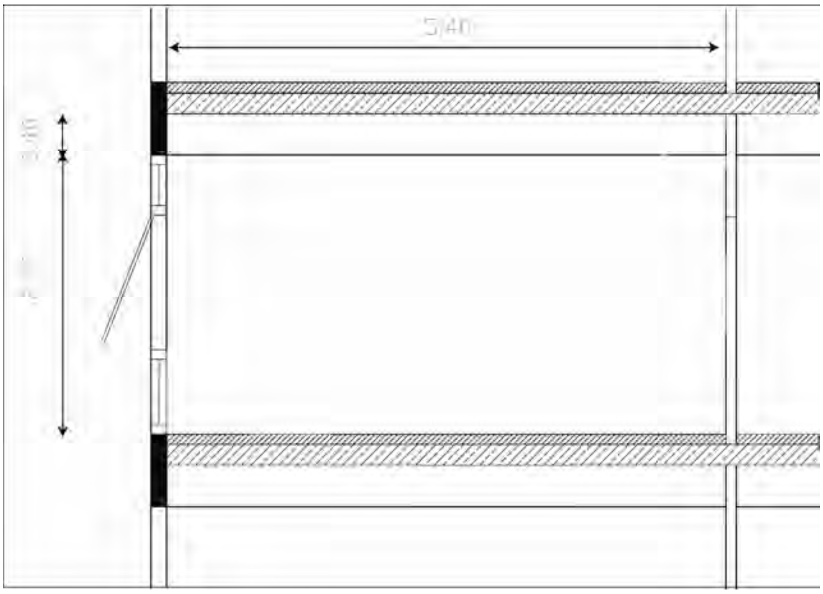


Figure 98: section of cellular office

As shown in figure 99 and 100, this window configuration can be used for different window areas of the facade.

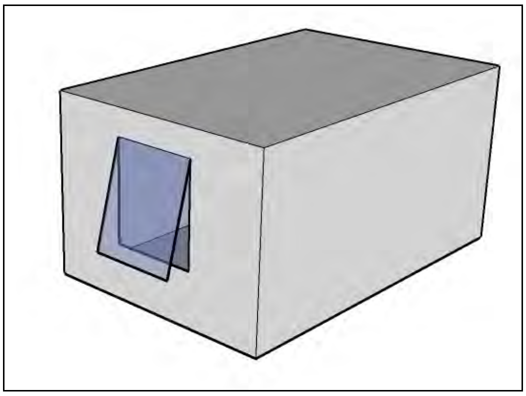


Figure 99: Window area= 10% of floor area

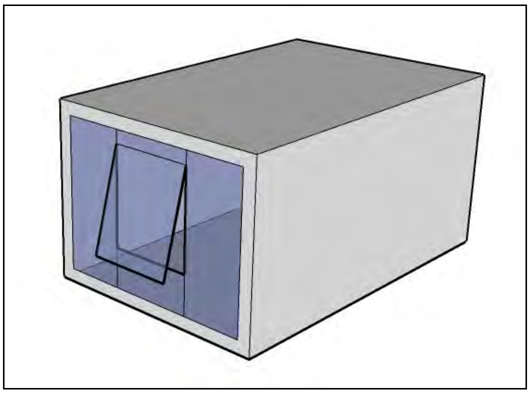


Figure 100: fully glazed facade

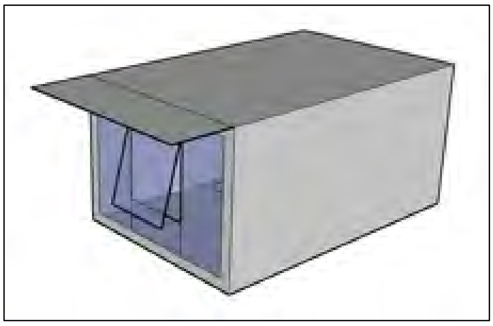
The top hung window is modelled according to the method described by Coley [76], using a discharge coefficient of 0,65 [77].
Two different glazing types, typical for the Greek climate have been used. A standard double-glazing and a low-e glazing with the properties presented in table 9.

Name	Structure	u-value	g-value	t-vis
Standard	6/12/6	2,7	0.76	0.81
Low-e	6/12/6	1,6	0,46	0,73

Table 9: Glazing properties

2.3.4 Shading

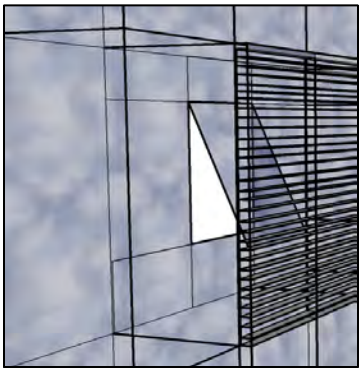
Overhang



In case of an overhang, the width is adjusted according to window width, placed directly above window, depth of overhang =1m

Figure 101: overhang

Exterior venetian blind



Slat width = 10 cm
Slat distance = 10 cm
Slat angles= 10° = closed, 45° = medium
Colour = RAL 9006 = white aluminium

The exterior venetian blind is mounted on an additional construction 0,7m in front of the façade in order to enable opening of the top hung window.

Figure 102: exterior venetian Blind

Interior venetian blind

The blind is exactly covering the window, without gap between the blind and the window frame.
Since the activated internal venetian blind used in this study has significant influence on the effectiveness of natural ventilation, correction factors for discharge coefficients according to Tsangrassoulis [78] have been applied.

Slat width = 2,5cm
Slat separation = 2,5cm
Slat angles 10° = closed, 30° = medium

Figure 103: interior venetian blind

2.3.5 Artificial lighting systems

Concerning artificial lighting, the chosen system in offices is in the first place depending on the specific office task, the budget and the question in how far the lighting concept is supposed to be decorative (e.g. high prestige offices) or purely functional. Regarding the installed lighting power, it is a question of the combination of luminaire, lamp and ballast, and therefore there is a broad variety of possibilities, each resulting in different energy consumption.
To show the range of influence the artificial lighting design has on comfort and energy performance, two different variations for the investigated room have been derived from the field study among architects and developed using the light design software “Relux” [52], each fulfilling the requirements of DIN EN 12464-1 [53]. They are shown in table 10.

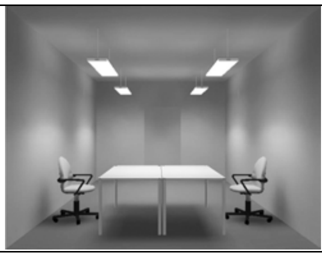
Lighting systems		
design	“standard”	“optimized”
visualisation		
specifications	Surface mounted luminaires with specular louvers, installed lighting power per room = 21,3W/m²	Pendant luminaires with micro-prismatic light redirection, installed lighting power per room =13,1W/m²

Table 10: Lighting design variations for the cellular office room

2.3.6. Building design configurations used in this study

The constructions used in this case study are supposed to represent different configurations of thermal mass, in order to evaluate the resulting effect on thermal comfort. At the same time, they are supposed to reflect typical constructions for office buildings in Athens, assuming different priorities regarding the building design.
“Light” thermal mass is based on a curtain wall façade, false floor construction and gypsum walls for more flexibility regarding changes in the floor plan and furnishing, and a suspended acoustic ceiling. Medium thermal mass is comparable to the light variation, but with a less expensive screed floor instead of false floor and a solid façade instead of the curtain wall. Heavy thermal mass assumes solid façade, screed floor, solid internal walls and no suspended ceiling. This offers maximum thermal mass to evaluate its impact on comfort and energy consumption. However, this configuration is not very typical for office buildings in recent years, since it offers less flexibility regarding changes of floor plan or installations.

Based on these results from the field study in Athens, different configurations for the simulation model regarding construction, windows, lighting and shading have been developed. They are aimed to cover a broad range of possible design and construction variations, and to reflect different priorities within the design process as derived from the field study. Variation 1, “prestige” is assumed to represent a high quality office, with light constructions permitting reversibility of the floor plan, a fully glazed façade (low-e glazing) reflecting current architectural fashion, and a higher quality lighting system. The second variation is supposed to reflect a variation causing lowest initial costs, with a solid façade and solid floor, smaller window area and a standard glazing- as well as lighting system. The third variation is assumed to represent a "green" building which is supposed to provide maximum comfort and low energy consumption. It is assumed to have heavy thermal mass, exterior shading, medium window size and an energy efficient lighting system. The configurations used in this study are presented in table 11.

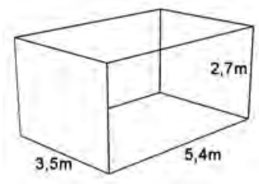
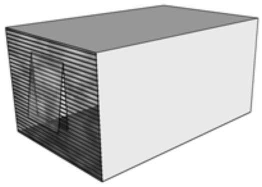
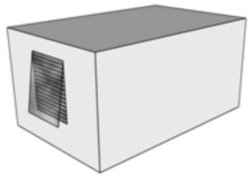
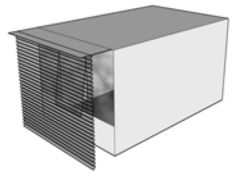
Building configurations			
configuration	1, "prestige"	2, "low initial costs"	3, "green"
			
Thermal mass	Light	Medium	heavy
Window area	100%	20%	70%
Glazing	Low-e	Standard	Low-e
shading	internal venetian blind	Interior venetian blind	Exterior venetian blind
overhang	no	no	1m
Lighting system	optimised	standard	optimised

Table 11: Design configurations for the cellular office room according to different priorities in early design stages

2.4 Occupant behaviour and internal heat loads

2.4.1 Introduction

Concerning comfort, energy consumption and CO_2 emissions in offices, the building cannot be evaluated independent from the use by its occupants. While the building is mainly influenced by architects, engineers and their clients, the use of the building is influenced by its occupants on a company as well as on an individual level. However, the use of office equipment, lighting systems and building controls is difficult to predict. It depends on tasks, level of prestige, financial budgets, consciousness for green issues and individual preferences. Therefore, it is likely to vary from one company to another and among different tenants and individuals in one building. On a company level, building use mainly refers to the use of office equipment and lighting systems and the possibility for ventilation outside office hours. The following paragraphs examine occupant behaviour and the use of office equipment and lighting systems as derived from literature and the field study in Athens.

2.4.2 Occupancy

The office is considered to be occupied by two persons, with a typical furnishing and resulting reference point for daylighting in the middle of the work plane (figure 104). Occupancy of these two persons is simulated according to the profile in figure 105.

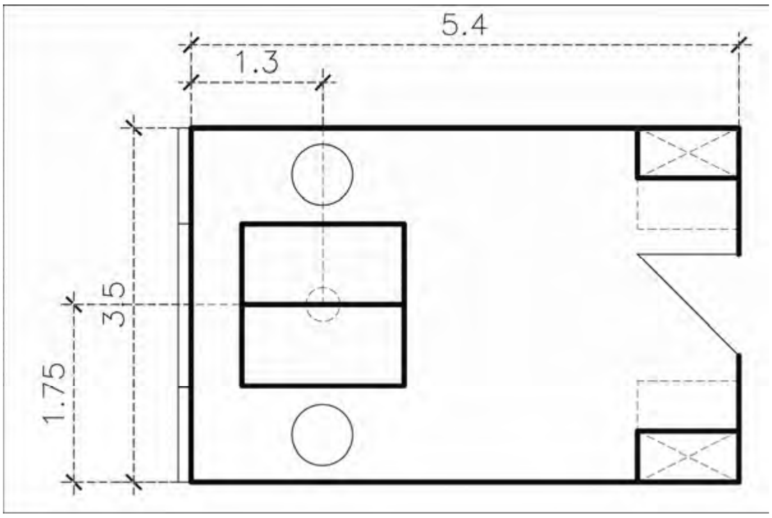


Figure 104: Office room with typical furnishing and resulting daylight reference point

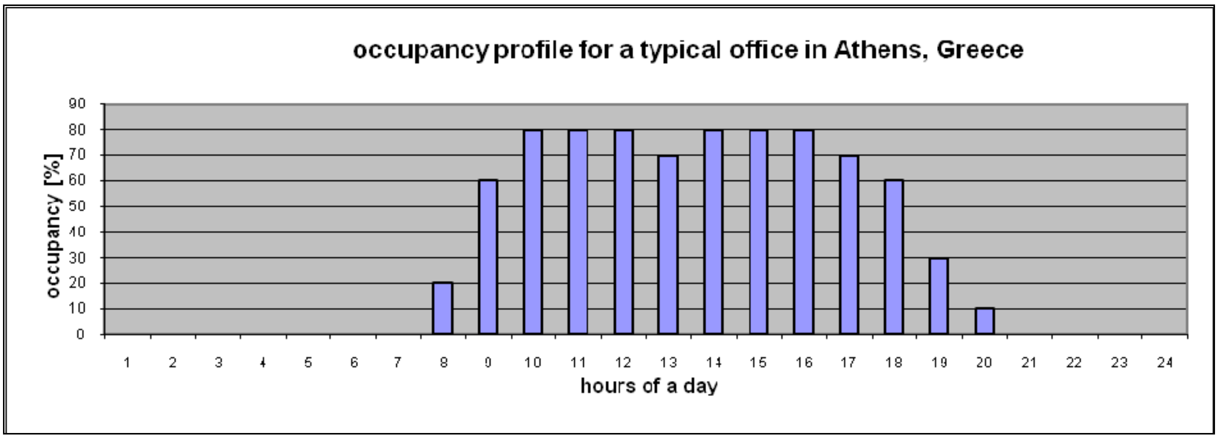


Figure 105: occupancy profile for a cellular office room

2.4.3 Internal heat loads due to office equipment

Internal heat loads can be approached by the task and a related typical set of office equipment as well as by the intensity of use. Tables 12 - 14 show the different energy consumption for three different office tasks as taken from the energy star database [54], representing a state of the art level of energy consumption:

- Processing task, using a standard PC, a phone and an inkjet printer resulting in lower energy consumption.
- Secretary's task, using a more powerful computer, a laser instead of an inkjet printer and an additional fax machine, resulting in medium energy consumption.
- Advertising agency or architectural office, using a powerful computer, 2 screens, a colour laser printer and a scanner, resulting in a high-energy consumption.

Comparing these different configurations indicates that energy consumption of office equipment is strongly depending on the task especially when desktop computers are used. The use of notebooks in contrast reduces the energy consumption significantly.

advertising agency / architectural office (high energy consumption)	on [W/person]	standby [W/person]	Off [W/person]*
workstation	250	20	10
1x system 17" CRT (73W) or 2x value 22"LCD (2x37=74W)	74	2	2
Phone with answering machine	2	2	2
Colour laser multi function device 6-12ppm	15	15	15
Value A4 scanner	11	11	11
total	**352**	**50**	**40 / 0***
Total with workstation and one LCD replaced by notebook * off-mode: connected / disconnected from power supply	**82**	**15**	**13 / 0***

Table 12: Technical characteristics for a high energy consuming office equipment configuration, suitable for a secretary task, based on data from energy star [54]

secretary task (medium energy consumption)	on [W/person]	standby [W/person]	Off [W/person]*
multimedia PC	146	10	5
Value 19" LCD monitor	38	1,5	1,2
Phone with answering machine	2	2	2
Value Laser printer (20ppm)	7	7	7
Fax (fast >10ppm)	12	12	12
total	**205**	**32,5**	**27,2 /0***
Total with workstation and one LCD replaced by notebook * off-mode: connected / disconnected from power supply	**57**	**26**	**24 / 0***

Table 13: Technical characteristics for a medium energy consuming office equipment configuration, suitable for a secretary task, based on data from energy star [54]

processing task (low energy consumption)	on [W/person]	standby [W/person]	Off [W/person]*
Value PC	100	10	5
Value 19" LCD monitor	38	1,5	1,2
Phone with answering machine	2	2	2
Ink jet colour printer	1	1	1
total	**141**	**14,5**	**9,2 / 0***
Total with workstation and one LCD replaced by notebook * off-mode: connected / disconnected from power supply	**25**	**14**	**6 / 0***

Table 14: Technical characteristics for a low energy consuming office equipment configuration, suitable for a secretary task, based on data from energy star [54]

Another influence on the energy consumption caused by office equipment is the amount of time the devices are in "on", "standby" or "off" mode. Regarding the latter is it important, whether the devices are still connected to power supply or not, i.e. when using an "off"- switch at the sockets. Different intensities for use of office equipment, as taken from the energy star database [54] are presented in table 6.

2.4.4 Occupant controlled natural ventilation

Regarding window opening behaviour of occupants, a literature review indicates a large individual spread and a large variety of influences. The main influences as derived from the literature review are described below.

Geometry

One influence observed in field studies is the type of the window, and the related opening percentage or angle [47, 50, 79, 80]. As observed by Richter et al. [47], air exchange rates can multiply according to window opening type, opening angle as well as size and placement within the

façade. This is likely to affect the behaviour of occupants, who are also observed to not only open or close the window, but in case the window type allows, also adjust the opening percentage or angle accordingly [81,82].
Additionally it could be observed, that the operation of windows was different for small clerestory windows compared to larger windows, regarding the frequency and the duration of openings [83].

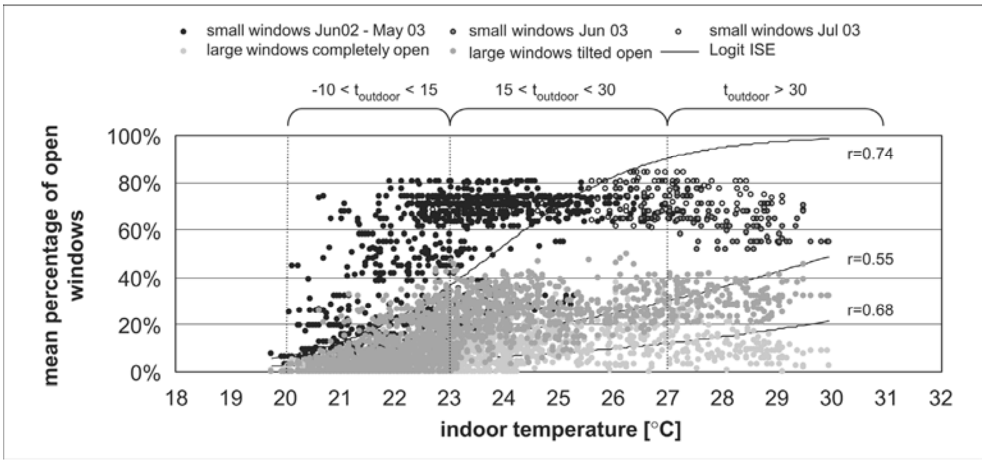


Figure 106: Correlation of the mean percentage of open windows to the indoor temperature over the period of 13 months (July 2002–July 2003). Hourly mean values. Data evaluation of working hours (weekdays, 8 am–6pm CET). Source: Herkel et al. [83], figure 6.

This corresponds with findings reporting a dependency of window opening with weather conditions, especially wind and resulting perception of draft in the office [50, 84, 85]. Another influence affecting the effectiveness of natural ventilation is the use of blinds [86], obstructing the air exchange.

Temperatures

Apart from those more geometrical influences on the use of windows, environmental parameters were observed to be important as well.
Among those, a main influence on window operation as reported in the literature is room temperature [7, 82, 87, 88, 89, 90]. In contrast to outside air temperature, it considers the effect of varying internal heat loads and solar heat gains (façade orientation) in different offices. Nevertheless, outdoor temperature was observed to be an important key driver as well [7, 81, 83, 87, 88, 90, 91].
These field studies lead to the conclusion that the influence of outside air temperature is varying according to season. Rijal et al. [88] concluded that indoor temperature might be the key driver for window opening, in order to limit the rise of room air temperature. However, the question how long the window would remain open would be likely to depend on outdoor temperature. From a field study in Pakistan, they also concluded that the proportion of windows open continues to increase in higher indoor temperatures but it decreases in highest outdoor temperatures in order to prevent the hot air entering [88].
During winter, several field studies [81, 83, 89, 90] observed either no significant correlation between window switching and room temperature or that the correlation with outdoor temperature was stronger, which might be explained by a constant room temperature due to heating.

This assumption correlates with Fritsch et al [81] who assumed that in summer people open the windows in attempt to cool the rooms, while during mid season windows might act as a more convenient heater control than thermostatic valves.

Previous window state

Another parameter influencing the window opening behaviour of occupants as observed by field studies [81, 89, 90, 92] is the previous window state. This parameter was found especially important in the context of night ventilation. If night ventilation is not possible, the previous window state at arrival of occupants in the morning is 'closed'. This means that in summer during the night, the room temperature might have increased and the indoor air quality decreased which could be an explanation for the observation that the frequency of window opening events increased with higher indoor temperatures on arrival [82, 89].

Window operation models

Based on these findings a variety of window opening models has been developed. They are based on different parameters according to the focus and the climate zone of the study. Fritsch developed a model for the Swiss climate, based on opening angle, time of the day, outdoor temperature, and preceding window angle [81]. Nicol [91] developed an algorithm depending on outdoor temperature based on data from UK, Pakistan and throughout Europe. Rijal et al [87, 88] developed an algorithm depending on indoor and outdoor temperature, based on a field study in UK. Haldi and Robinson [90] developed a model based on a field study in Switzerland referring to indoor temperature, pollution, outdoor temperature, noise, wind and rain, which was further developed into a model based on occupancy, time of the day, window status, outside- and indoor temperature [92]. Yun and Steemers developed an algorithm depending on indoor temperature, time of the day and window state [89], based on observation in UK. Herkel et al [83] developed a window-opening model based on time of the day and outdoor temperature, based on a field study in Germany. For the climate of Pakistan Rijal et al [88] developed a model based on outside and inside temperature and the preceding window status. Page [93] developed a model based on indoor pollution and indoor and outside temperature, based on a study in Switzerland.
Despite considering a variety of different influences according to the focus of the study, all these models are based on temperatures, outside, either inside or both. Thus, it can be concluded that temperatures or the temperature difference between outside and inside are the most important influence on window opening by occupants in all investigated climates.

2.4.5 Night ventilation

Based on the field study in mixed mode offices, the possibility for night ventilation has been investigated for the context of Athens. The majority of occupants reported that night ventilation is not possible. Security issues were mentioned as the predominant reason by about 80% of the subjects. Further, but minor important reasons were the interference of night ventilation with a running cooling system and weather protection.

This supports findings of Yun et al. [82] who also observed a strong dependency of night ventilation on façade design and security issues. It can be concluded that the possibility for ventilation outside office hours is mainly a decision on a company level. Due to perceived security at the location, the floor level, the window size, prescriptions of insurance companies and weather protection, the question whether or not night ventilation is allowed, is often an issue of company policy rather than a decision of individual occupants (figure 107).

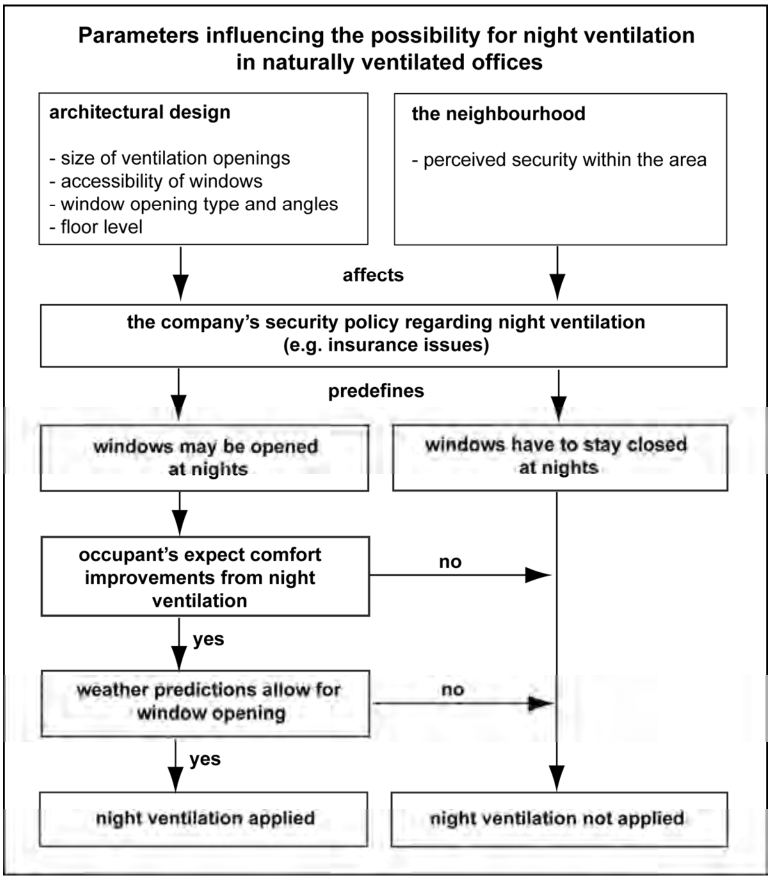


Figure 107: Parameters influencing the possibility for night ventilation in naturally ventilated offices

Apart from this predominant influence, field studies identified indoor temperature [89, 85] outdoor temperature [85, 88] as well as window state before departure [82, 89] as parameters influencing the use of night ventilation on an individual level.

2.4.6 Occupant controlled blind switching

Several field studies have been conducted to investigate the reasons for blind switching, and they discovered, that blinds are mainly used to protect from glare followed by overheating [94, 44, 95]. Inkarojrit [95] identified the following window blind closing reasons, ordered according to percentage of responses: 1. to reduce the direct or reflected glare on the computer screen 2. To reduce the brightness of workspace surfaces, 3. To reduce the direct glare from sunlight, 4. To reduce heat from the sun, 5. To increase visual privacy or for security reasons, 6. Other.

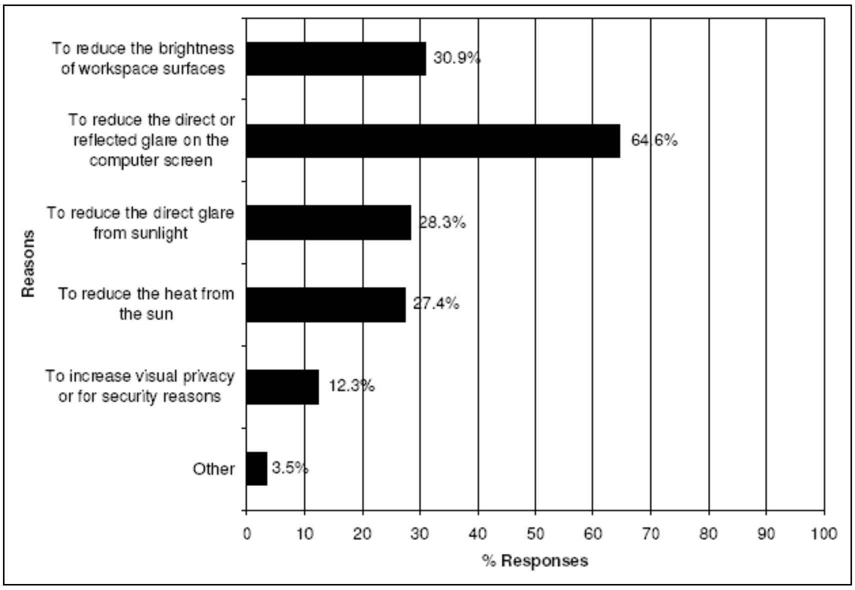


Figure 108: Window blind closing reasons, source Inkarojrit [95], figure 4.2

The following paragraphs examine the most important parameters influencing occupant controlled blind switching as derived from the literature.

Orientation and sky condition

Significant variations were observed in window blind occlusion for the different orientations, with higher occlusion values for south facing facades compared to north, east or west facades [42, 95, 96, 97]. As observed by Inkarojrit [95], occupants in north- and east facing offices use windows preliminary to control the brightness of workspace surfaces, especially window brightness, and rarely closed window blinds to reduce heat from the sun. Users in north facing rooms seemed to use window blinds to avoid the low sun angle in early morning or late afternoon. In rooms with south and west facing facades in contrast, the main reason to use window blinds was found to be control of heat from the sun, more than brightness control.

Another correlation for blind switching was observed with sky condition, resulting in a larger proportion of window occlusion on clear days than on cloudy days [42, 95, 41]. This parameter is also closely related to the occurrence of glare.

Protection from glare

There are two different “qualities” of glare commonly used in literature. Sutter et al. [46], described discomfort glare as a non-instantaneous sensation, which does not necessarily reduce visibility and might remain unnoticed by occupants, but can cause headaches or eyestrains on the long term. And disability glare, as an instantaneous physiological phenomenon, causing a reduction of visual performance. Most field surveys observed large individual differences in the tolerance of glare [41, 44, 45, 98], and as mentioned by Tuaycharoen and Tregenza [45], discomfort glare cannot be predicted from physical variables alone. It also depends on the context and the focus of the user’s attention. Therefore, it may be assumed that while disability glare might cause closing of blinds for the majority of occupants, blind switching as a reaction to discomfort glare might show larger individual differences. Despite these differences, some main influences on the perception of glare could be derived from the literature review:

- Generally, many field investigations reported a correlation of blind switching with penetration of direct sunlight in the room [42, 44, 95, 99, 100, 101]. However, as observed by Bülow-Hübe [44], glare discomfort can arise even on overcast days, from direct view of the sky when illuminance of the sky is several times higher than that of interior walls.
- Another important influence on the perception of glare is the window area of the façade [44, 96, 98, 100]. Generally, higher degrees of perceived glare with larger window sizes could be observed [98, 102]. Partly contradictory, perceived glare was also reported to be high for medium window sizes due to the high contrast between the glaring source (window) and the surrounding adjacent wall and lower for larger and smaller window sizes [100].
- Additionally Osterhaus [98] investigated the influence of different window arrangements on perceived glare. The results indicate, that facade design, i.e. the placement of windows within the facade, has influence on the perception of glare as well.
- Several field studies also identified the location of the workplace and the screen in relation to the window as strongly influencing the perception of glare and the resulting use of blinds [44, 46, 95, 96, 100, 101]. Newsham [101] reported that blind use falls rapidly with distance from the window, as the probability of direct sunshine falling on the occupant decreases. The occupants closest to the windows had a substantial effect on blind switching, while the effect of those further from the windows could be considered minimal. This suggests that the furnishing of the office has some potential to influence glare perception in offices.
- Sutter et al. [46] also reported a dependency of occupant's tolerance of glare due to the quality of the screen. This indicates that technical office equipment, too, indirectly provides optimization potential for visual comfort improvements [96].
- Observations of Galasiu and Veitch [41] indicated a dependency of tolerated glare on the specific task. Occupants spending less time working at a computer have been observed to be more tolerant of glare, than users spending more time working at a computer.
- An additional influence on glare in offices, reported by Boubekri and Boyer [100], refers to other visual and aesthetic factors such as the appearance of the window as well as the visual and aesthetic interior qualities of the room, e.g. the degree of specular reflections from interior surfaces (walls and ceiling) and the wall area surrounding the window.
- Another influence on perception of glare and related blind switching behaviour is the view out of the window [41, 44, 45, 100]. As observed by Bülow-Hübe [44] occupants sometimes make a compromise between glare and the possibility to see out. Tuaycharoen and Tregenza [45] investigated the dependency of discomfort glare from the quality of view. They found, that glare discomfort decreased as interest of the view increased, and concluded that the effect of a subjects interest in the view has a greater effect on comfort, than the relative brightness range. Additionally, they reported that images of natural scenes were associated with less discomfort glare than those of urban scenes, and three layer views were less glaring than one-layer views. Regarding the luminance, a view with a wide luminance range was found likely to be more glaring than one of the same luminance but with less variation.

Overheating protection

Although, according to literature, glare control seems to be the most important reason to close blinds in offices, overheating control is an important influence as well [41, 42, 46, 90, 95, 101]. Nevertheless blind switching for overheating protection plays a larger role in naturally ventilated, compared to air-conditioned buildings [95].
Sutter et al [46] showed a dependency of blind switching with indoor temperature and found more blinds closed, when the room temperature was above 26°C. Haldi and Robinson [90] reported a correlation of blind switching with both, indoor and outdoor temperature, but considered room temperature to have slightly higher predictive power.

Privacy

Another reason to close blinds in an office is the occupant's desire for privacy. As Foster and Oreszczyn [96] reported, certain blinds might always be closed for this reason throughout the day. Additionally Inkarojrit [95] observed that many occupants closed their window blinds to increase visual privacy or security at the end of the day. This control characteristic was supposed to be driven by internal psychological reasons rather than measurable physical factors (i.e. for the feeling of security rather than decreasing light and/or temperature).
It can be concluded, that although privacy might not be a blind closing reason as important as glare or overheating protection in offices, it might become predominant in certain situations.

Blind opening

Unlike reasons for closing blinds, the literature review provides less information regarding reasons to open blinds again. Inkarojrit [95] observed in a field study in several private offices in Berkeley that the main reason for opening the blinds was to increase the level of light in the workspace, followed by the wish to maintain visual contact to the outside. Other reasons e.g. to feel the warmth of the sun or to increase the spaciousness of the room were significantly less important.
Additionally Sutter et al. reported a correlation between indoor temperature and the proportion of raised window blinds, and Galasiu and Veitch [41] observed a dependency of the likelihood of shading opening from the quality of view.
Generally, it can be concluded, that blind closing is likely to be a reaction to a concurrent feeling of discomfort or disability, directly affecting the work productivity. Blind opening in contrast, does not directly diminish a discomfort or disability affecting the ability to work as long as enough daylight or artificial lighting is available. As reported by Boubekri and Boyer [100], it might be more likely to be affected by psychological effects, such as cheering up the atmosphere in a room by increasing the level day- and or sunlight. For this reason, it might be concluded, that closing of blinds might be more or less similar for active and passive subjects. Differences are more likely to appear regarding the opening of blinds. Passive occupants are likely not to make any changes for the rest of the day, once the blinds are closed. Active subjects are more likely to open the blinds when the reason for closing has disappeared.

Daily patterns

Observations from field studies provide evidence that daily blind switching patterns vary significantly from one person to another. Additionally, many occupants used the same blind control strategy throughout large periods of the year. Regarding dependencies between blind switching and time of the day, the following correlations can be derived from literature review:

- Several field studies observed, that occupants tend to open blinds at the beginning of the day [41, 95, 97, 103]. Only in north and east facing rooms, this effect was found to be less significant due to low sun angles in early morning and possible sensations of glare.
- Throughout the day it could be observed, that users made little attempt to change the blinds [41, 42, 46], and chose a blind position preliminary based on long-term experiences and resulting expectations. Galasiu and Veitch [41] also reported that occupant's likelihood to adjust blinds according to sunlight increases, when the sun has been shining for at least one hour. These findings suggest that office occupants prefer to switch blinds as little as possible during the day. This effect might be even stronger, when there are more occupants than operable blinds, or if the blind controls are not easily accessible e.g. due to furnishing of the room. The blind position is therefore likely to be a compromise between glare and overheating prevention, daylighting, view and preferences of colleagues.
- At the end of the day, several field studies observed increased switching of blinds again [41, 95, 97]. Several reasons were reported. For northern room orientations, blind closing was reported to be caused by low sun angles in the evening [95, 97]. Inkarojrit [95] reported visual privacy or security to be further reasons to close blinds at the end of the day. And Galasiu et al. [41] also observed an increased tendency to open the blinds at the end of the day.

Window coverage of activated blinds

The closing percentage is largely depending on the shading system. However, this study is focused on the use of venetian blinds. As described by Bülow-Hübe [44] the coverage of a window by a venetian blind is depending on the distance of the bottom slat to the top of the window and the slat angle.
Several field studies investigated the blind closing percentages with contradictory results: Some field studies observed that if closed, blinds are mainly closed completely, covering 100% of the window [46, 95, 101]. However, there were also observations that subjects prefer to choose an intermediate blind position, not covering 100% of the window [44, 95, 96]. These deviations can be explained by findings of Inkarojrit [95], who reported a dependency of closing percentage from the reason causing the blind switching. If the blinds were closed to increase visual privacy, security or to reduce heat from direct solar penetration, they tend to be closed completely. However, if the blinds were closed to reduce brightness and glare, the majority of blinds were not fully closed. In this case, it can be assumed that occupants only close the blinds to a percentage eliminating the present discomfort or disability of glare, but try to maintain visual contact to the outside environment.

Slat angles for venetian blinds

Apart from the coverage of the window, the slat angle of venetian blinds is another important influence for daylighting and view. The slat angle is influenced by a variety of parameters like sky condition, sun position, task and location of the working place in the room [41].
Field studies generally revealed, that slats typically have a positive tilt towards the external ground [44, 46, 103]. Negative tilts were very rarely chosen [44, 46]. As reported by Bülow-Hübe [44], most occupants seemed to prefer a slat angle of 30° (to horizontal) or larger. Additionally Sutter et al. [46] observed a dependency of slat angles from room temperature in the office, and observed that slats were tilted 10° more towards the ground (more closed) when the room temperature was above 26°C.
Inkarojrit [95] investigated the adjustment of window blind slats per day, and found out that the majority of occupants adjusted the blinds less than once per day.

Manual control

Manual controls are typically located directly at the window. This is likely to affect blind switching in shared offices, depending on the accessibility of controls and the preferences of colleagues [96].
The operation of those controls, i.e. adjustment of blind height and slat angle is depending on the system. Several field studies reported ergonomic difficulties of occupants to operate the blinds [44, 96]. As concluded by Foster and Oreszczyn [96], subjects might only alter them when exposed to extreme environmental discomfort. Additionally, as observed by Bülow-Hübe [44], the combined function of adjusting the slat angle and the blind height at the same time was found to be complicated to use.
Another common parameter derived from the literature [95, 99] is the difference between active and passive users. Passive users are assumed to keep the blinds closed throughout the working day, while active users open the blinds again when no more protection due to glare heat or privacy is necessary.

Automatic control

Automatic control of switchable shading systems is often connected with low acceptability of occupants [41, 95, 99]. Especially photo-controlled systems are often considered disturbing, and acceptance is higher if there is an option for manual override [41].
It was observed in field studies, that while automatic opening of the blinds was usually accepted, automatic closing had a low acceptance and blinds were usually re-opened manually [41, 99]. For this reason, Reinhart and Voss [99] concluded, that there are different thresholds for closing and opening of blinds. Additionally they observed, that an automatic blind control system triggered occupants to adjust their blinds often. In addition, it remained unclear if these reactions would have been the same for a manually controlled blind, or if they were mainly a reaction to unsatisfactory settings of the automated control.
In another field study [95], occupants were asked for features an ideal automated/intelligent window blind system should have. The answers indicated that such a system should mainly reduce glare while maintaining access to natural light and view. Additionally it should be easily usable and have a user-override and a programmable feature.

2.4.7 Occupant controlled light switching

Introduction

In general, office occupants prefer daylight to artificial lighting in workplaces, supported by the belief that daylight supports better health [41]. However, artificial lighting is needed, and as observed by Nicol [104] it is controlled in a way to adapt the environment in a way to improve comfort. This user controlled light switching has significant impact on annual electric lighting energy use [99]. The following paragraphs present the results of a literature review on parameters influencing the use of artificial lighting.

Lighting system

As observed in field studies, the use of artificial lighting is depending on the chosen lighting system [41, 44, 99]. A lighting system offering adjustment of different lighting levels for the room as well as the task area is usually preferred by office occupants. In these cases, occupants prefer lower lighting levels in the room suitable for computer tasks, and higher lighting levels for paper tasks by individual luminaires at the individual desks [41, 44]. However, the use of individual work place luminaires was also depending on how pleasant the light was perceived to be [41]. Additionally, switching can be different for direct and indirect or dimmed lighting, since with the latter occupants are likely to fail to notice that the lighting is switched on, resulting in lower switch-off probabilities [99, 103].

Control systems

As observed by Galasiu and Veitch [41], automatic control of artificial lighting is more likely to meet the requirements for workplace illuminance and luminance ratios, but higher occupant satisfaction is reached with user-controlled lighting even when required values are not met. Additionally, it was observed that occupants prefer control systems, which are easy to use [41, 105]. Complicated systems were often observed to be switched off completely. Otherwise, they were operated in the easiest available mode, independent of the resulting lighting effect. Personal programming of light switching schedules was observed not to be used by occupants, and coupled automatic light and blind switching was only found acceptable in case of a possibility to manually override the settings [41].

As observed by Reinhart and Voss [99] dimmed and daylight linked photo controlled lighting systems can increase energy savings up to 60%. On the other hand, occupant acceptance for photo controlled lighting was observed to be low [41, 106, 107] and difficult to maintain, with higher satisfaction in case of possibility to manually override the settings. As observed by Doulos et al [107] the performance of the lighting system and the related energy savings are strongly depending on the photo sensor's spatial and spectral response. In case of fluctuating daylight levels, rapid switching of lights on and off can annoy occupants and reduce the lamp life, so the control algorithm plays an important role as well [107].

When using automatic on/off lighting control, Tzempelikos and Athienitis [108] reported a 77% reduction in electricity demand for lighting and 16% reduction in annual cooling demand, for 30% window-to wall ratio. This control strategy was found to have a relatively high user satisfaction [106]. Especially upon departure in the evening or when leaving the workplace for temporary departure, occupants were observed not to switch off the lighting system, so an automatic intelligent switch-off at the end of the day or an occupancy sensor were found to be useful [103, 106].

Influences on light switching

The most common correlation of light switching with physical measurable parameters in offices is a dependency with illuminance on the work plane. Observed thresholds of work plane illuminance below which an increasing probability for switching on the lighting was observed were 280lux [99], 200lux [109], or 100 lux [*97*]. However, many field studies also observed a large individual variability concerning related thresholds [41, 44, 99, 103, 104, 106, 109].
Reported reasons for the variability were tasks [41, 94], the amount of persons in the room [41], distance from windows [41], lighting concepts [99], location of the light switch [43, 110] age, degree of fatigue and cultural background, the atmosphere of the room regarding the interior design [41], and the external daylight conditions at the arrival at the office [106]. However, an influence on light switching independent from the illuminance was observed as well, since an activated lighting can be interpreted as a signal to be at work [99].
Additionally, Nicol [104] observed a tendency of occupants to switch the lighting, in order to maintain a certain common internal illuminance. Moore [106] observed the preferred lighting levels to alter with season, since artificial lighting did not increase for the darker winter month compared to the rest of the year. Galasiu [41] also observed a difference in preferred colour temperature depending on the amount of available daylight and a tendency of occupants to add 150 to 400lux artificial lighting in addition to daylight. Bülow-Hübe [44] reported a stronger relationship between the use of artificial lighting and illuminance levels at lower daylight levels in the evening, than for normal daylight conditions during the day.

Switching patterns

Regarding daily switching patterns, a strong coincidence with switch on events for lighting could be observed at the occupant’s arrival at the workplace [99, 103, 106]. During the day, intermediate switch-on events were found to be less frequent [99, 106]. Additionally, Nicol observed a stronger adjustment of artificial lighting from one day to another than within one working day [104]. Additionally the likelihood for switching the lighting off was found to be correlated with the duration of the absence [97, 109], with an increasing likelihood at durations for one hour or more.

Another common observation for occupant controlled light switching was the differentiation between active and passive users [99, 101, 103, 104]. Active users were observed to adjust indoor illuminance levels according to daylight provision, and passive users were found to keep the lighting switched on throughout the whole working day, independent of prevailing daylight levels. Additionally, Moore [106] observed a more passive use of lighting controls with an increasing number of occupants in the room.

Light switching models

Newsham [101] proposed a light switching model considering two different control strategies, assuming passive users to keep lights on for all occupied hours and active users to manually control lighting level approached by an algorithm, depending on occupant presence and illuminance on the work plane.

Reinhart [43] proposed an integrated model for light switching in cellular offices based on occupancy, light status in the previous time step, blind settings, and the presence and delay time of an occupancy sensor.

2.4.8 An ideal and worst case scenario for use in building simulation

Introduction

The literature review as well as the results from the field study in mixed mode buildings in Athens indicate, that in real buildings there might be large variations regarding the use of office equipment and user behaviour concerning the control of blinds, lights and windows. Therefore, a precise modelling seems very difficult, especially without detailed knowledge of the building and its environment, and the particular building users.
For this reason, an ideal and worst-case scenario has been used in this study, differing between parameters on a company and an individual level. The former refers to parameters, which are usually predefined by the company and valid for all individual occupants. The latter refers to parameters, which can be used differently by individual occupants within the company. The ideal scenario represents from comfort and energy point of view the optimum (commercially available or comfort influencing) use, the worst-case scenario the least optimized use. These extreme case scenarios aim to illustrate the range of influence of building use on comfort and energy performance in offices. They are developed for use in building simulation, and thus they can only rely on physical measurable variables. However, in real buildings, the influences on building use are much more diverse, including social aspects, the environment of the specific buildings, the usability of building controls and individual preferences. For this reason real building use can be expected somewhere in between these extreme cases and the extreme case scenarios are not aimed to represent real building use in practice. Nevertheless, they can help to demonstrate the range of influence, different building use has on comfort and energy performance in offices.

Office equipment

The use of office equipment is strongly depending on the tasks. Thus, it is likely to vary from one building or room to another.
The office task assumed in this study is based on a configuration for an advertising agency or an architectural office with a high (busy) intensity of use. Assuming a high energy-consuming task implies, that tasks requiring less energy consuming equipment would perform even better and comfort evaluation results are not limited to specific tasks.

However the related energy consumption differs significantly regarding the chosen devices, i.e. the use of desktop computers or notebooks and regarding the question whether the equipment is still consuming energy in "off"-mode or not. The office for the worst-case scenario is therefore assumed to be equipped with desktop computers, which are consuming energy in "off"-mode. For the ideal scenario, the use of notebooks instead of desktop computers is assumed, with the devices being disconnected from power supply outside office hours by using switchable plug connectors.

Ventilation

Regarding ventilation, literature review and the field study in mixed mode buildings in Athens indicate, that the main reason to operate windows is for control of thermal comfort and room air quality. And the predominant influences on occupant controlled natural ventilation are outside and indoor temperatures, and particularly the difference between them both.

Since windows were observed to be kept closed at very low exterior temperatures and when outside temperature exceeds indoor temperature, it can be concluded that there is an upper and a lower threshold for temperature differences for the use of natural ventilation.

For this study a top hung window sized 20% of the facade area, with a maximum opening angle of 20° is assumed. As a lower threshold, the window is closed when outside temperature exceeds the room temperature. Following the adaptive principle "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort" (Humphreys and Nicol) [30], in this case study, occupants are considered to operate the windows, and adjust the opening angle in order to optimise thermal comfort in their office. Thus, the upper threshold, when the window is closed for protection from cold air entering the room, is varying from one building configuration to another due to different internal and solar heat gains. The same applies for the intermediate threshold, defining up to what temperature difference the window is opened at maximum opening angle. Additionally windows are assumed to be closed due to draft when the wind force is 6 Beaufort (11-14m/s) or higher, which corresponds with findings of Haldi and Robinson [92]. Since there was no strong difference observed in field studies, no division into active or passive users or regarding the worst case and the ideal scenario has been made for this case study.

Regarding night ventilation however, different user behaviour could be observed in field studies. It was predominantly based on the respective night ventilation policy of the company. For this reason, the ideal scenario assumes night ventilation to be possible and the worst-case scenario assumes no possibility for night ventilation.

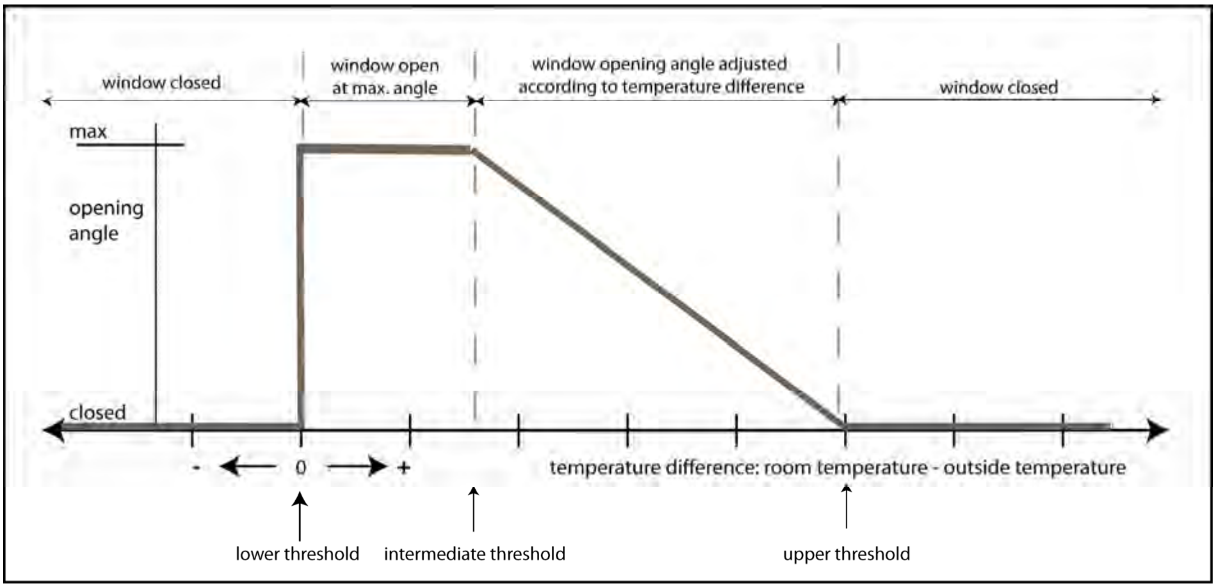


Figure 109: Window opening scheme as modelled in the parametric study

Use of blinds

The literature review indicates, that manually controlled blind switching is strongly varying from one person to another, and thus very difficult to predict. However, three main reasons could be derived, causing the activation of blinds: protection from glare, prevention from overheating and wish for privacy. Another main influence is the difference between active and passive users.

In this study, the following blind switching characteristics are assumed: Passive occupants are assumed to keep the blinds closed throughout the working day, with blinds completely covering the window at a slat angle of 10°. Since this configuration does not allow for a view, it could also represent blind closing due to privacy. Active occupants in contrast, are assumed to open or close the blinds according to the occurrence of glare and/or overheating. The criteria for glare is a discomfort glare index > 22, and the criteria for heat is a temperature > 26°C according to the findings of Sutter et al [46].The corresponding set points, slat angles and the resulting view quantity are described in table 15.

User type	Set points	Fixed slat angle / quantity of view
passive	Blinds always closed (24h per day)	10° / no view
active	blinds are closed during working hours if discomfort glare index > 22 and/or if room temperature > 26°C and at the same time solar radiation on the façade >= 200W/m²	45° / limited view

Table 15: Blind switching criteria

Use of artificial lighting

The literature on occupant controlled light switching indicates, that the whole variety of individual influences is very difficult to be reflected in building simulation, since the parameters are limited to physically measurable variables. However real occupant behaviour can be approached, by considering at least the strongest correlations observed in the literature. Lighting control is assumed to be operated manually, since this is the most common control strategy with the highest user acceptance. Additionally, occupants are considered either passive or active. In this case study, passive users are assumed to keep the lighting on throughout the working day. Active users are assumed to switch the lights on and off according to the daylight illuminance on the work plane. Although lower thresholds have been reported in the literature for computer tasks, the common set point of 500lux from EN 12464-1 [53] has been used in this case study. Due to the room related lighting system this higher threshold seems more suitable in order to provide satisfying lighting conditions for paperwork as well.

Ideal and worst case scenario

Table 16 presents a summary of the parameters used to define the worst case and the ideal scenario for this case study. These scenarios have been developed for use in building simulation, and are thus limited to calculable parameters, excluding social variables. As such, these scenarios do not aim to model occupant behaviour precisely. However, they are a means to reflect the range and the variability of occupant behaviour, and the resulting impact on comfort and energy performance in real buildings.

Worst case and ideal scenarios for use of office equipment, ventilation, blinds, and lights			
Influenced on	parameter	worst case scenario	ideal scenario
company level	Office equipment	- With desktop computers (352W) - no possibility to disconnect office equipment from power supply outside office hours (40W)	- With notebooks (82W) - possibility to disconnect office equipment from power supply outside office hours (0W)
	ventilation	- no night ventilation possible	- night ventilation possible
Level of individual occupants	Use of blinds	- blinds closed all day (passive user) - slat angle 10° (no view)	- blinds opened + closed according to glare or heat protection (active user) - slat angle 45° (limited view)
	Use of lights	- light on during working hours (passive user)	- light on/off according to daylight (active user)

Table 16: Worst case and ideal scenario for the use of office equipment, ventilation, blinds and lights

CHAPTER 3, COMFORT AND ENERGY PERFORMANCE EVALUATION

3.1 Energy consumption

End energy consumption is calculated for heating, cooling, lighting and office equipment, since they all affect thermal comfort, and contribute to the running costs to be paid for by tenants of the building. Consumption for lighting and office equipment is based on the configuration of the chosen system/devices and the intensity of use. Energy consumption for heating is based on a typical system operated by natural gas. The cooling system is an electric room air conditioning system [111]. The performance of those two systems is described in table 17.

System	Primary energy source	Coefficient of performance (COP) / energy efficiency ratio' (EER)
heating	Natural gas	0,85
cooling	electricity	3,06

Table 17: Coefficients of performance for heating and cooling [source 111]

The corresponding greenhouse gas emissions are calculated based on primary energy factors for Greece (table 18).

Energy source	CO_2 [g/MJ]	SO2 [g/MJ]	NOX [g/MJ]
natural gas	54,53	0	42,22
electricity (mainland)	236,11	4,31	0,33

Table 18: Primary energy factors for Greece, source: Hellenic Ministry of Development, "Measures for reducing buildings' energy consumption and other regulations", Law 3661/08, 19.05.2008, Appendix 1, opuscule A, table 2.2 (in Greek)

3.2 Thermal comfort

Thermal comfort in this work is evaluated according to the adaptive thermal comfort model of EN 15251-2007 (Annex A2) [5], the valid regulation for Greece. This standard provides a static model for mechanically ventilated-, and an adaptive thermal comfort model for naturally ventilated buildings.
In the adaptive model, operative room temperatures are plotted against the exponentially weighted running mean of the outdoor temperature, and a range of comfortable conditions is defined by upper and lower temperature limits (figure 110).

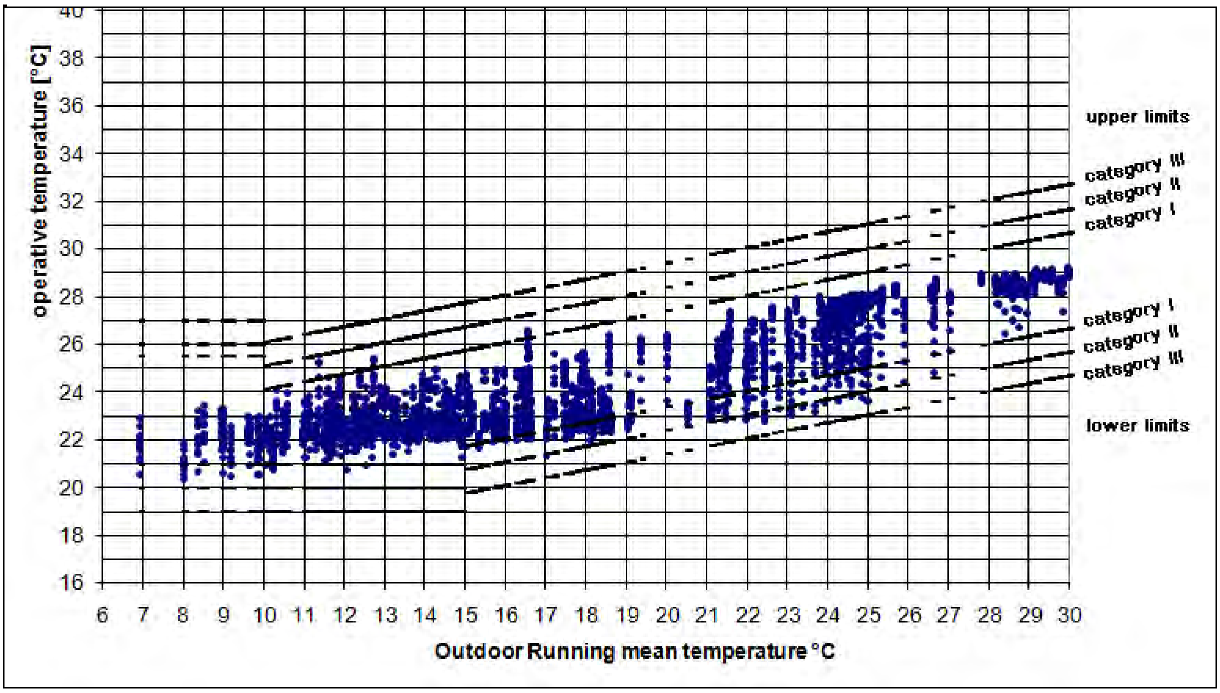


Figure 110: Operative temperatures plotted against the outdoor running mean temperature according to the adaptive thermal comfort model of EN 15251-2007 [5]

The adaptive thermal comfort model of EN 15251 [5] classifies three different comfort categories. Category I for a high level of expectation, targeted at very sensitive and fragile persons, like sick people, elderly or young children. Category II is recommended for a normal level of expectation, for new buildings and renovations, and category III is targeted at existing buildings for a moderate level of expectation. Values outside these categories (=category IV) should only be accepted for a limited part of the year.

The categorisation allows for a maximum of 3 or 5% of occupied time per day, week, month and year outside the limits of the category. For an 8h working day, this allows for 24 minutes per day, 2 hours per week, 9 hours per month and 108 hours per year outside the comfort limits. However, this criterion is designed not only for thermal comfort but also applicable for other parameters of discomfort. EN 15251-2007 (Annex G2) [5] mentions in this context especially the example of short time increased air velocity or noise when opening windows. However, thermal comfort and indoor temperatures cannot be adjusted as directly as noise or draft, by opening or closing a window. Therefore the shorter the investigated period (e.g. day, week, and month), the more it might be difficult to meet the exceeding criteria in terms of room temperatures. Since in this work EN 15251 is only applied for evaluation of thermal comfort, and noise, draft and indoor air quality are not considered, the exceeding criteria is only applied on a yearly basis.

For the adaptive model to be applicable, the investigated room should have no mechanical cooling, and opening or closing of windows by occupants shall be the primary means of regulating thermal conditions. The model is designed for spaces where occupants are involved in sedentary physical activities with metabolic rates from 1,0 -1,3 and where occupants may freely adapt their clothing insulation.

However, in Mediterranean climates like Greece the majority of office buildings are operated in mixed mode, using a cooling system only for a limited part of the year while the rest is naturally ventilated. According to EN15251, these buildings have to be evaluated according to the static model (Annex A1) [5].

3.3. Daylighting

Daylight has a range of influences on humans. Before the use of artificial lighting, periods of rest or activity were largely controlled by the rising and setting of the sun. Boyce and Rea [112] described three ways how visible light affects people; the visual system, the circadian photo biological system and the perceptual system.
Regarding visual performance, relevant parameters are the amount of light, the spectrum of the light and the distribution of the light on and around the object [113]. Concerning the circadian system, daylight has implications for sleep/wake states, alertness, human physiology, mood and behaviour and it influences daily patterns of hormone secretion and body temperature cycles [56]. Regarding the perceptual system, (day-) lighting is a statement about the designers or owners attitude towards daylight and the location, which is interpreted differently by individual occupants according to their own culture and expectations [113]. This statement affecting the observer's mood and motivation can even override physical visual discomfort [113].
In terms of physically measurable variables, daylight is similar to artificial light sources in terms of being electromagnetic radiation in the wavelengths, which can be absorbed by the photoreceptors of the human eye [114]. However, the eye is also the portal by which light enters the body for non-visual effects [56]. One important non-visual effect of daylight observed in offices, is the positive effect of daylight illumination on performance of occupants [115]. Additionally the presence of sunlight in offices was found to correlate with job satisfaction and general well-being [41, 105, 116], as to some extent the variability of illuminance and luminance [117].
One main characteristic of daylight is its inconsistency, since solar radiation varies with latitude, season, time of the day and weather. Daylight in interior spaces often reaches considerably greater light levels than recommended for artificial lighting, which is perceived to be more pleasant [55]. Artificial lighting designed to optimise the visual effect of a space based on minimum comfort requirements does not take account of these non-visual effects [56].
Therefore, optimising daylighting in buildings can result in health benefits as well as increased safety and productivity, and it provides a potential for energy saving, if artificial lighting is switched off when there is sufficient daylight.

However, preferred illuminance thresholds are very individual and several field studies reported a large range of different thresholds for switching on the artificial lighting system [41, 104, 105, 118, 119, 120, 121, 122]. Ranges of preferred indoor illuminance were observed from 100-600lux [105], 150-500 lux [123], 100-500lux [122], 0-2500lux [104]. This indicates a minimum preferred illuminance value to be around 100lux, which corresponds with observed maximum probabilities for light switching [105, 119, 121, 122, 123]. Typical preferred thresholds were observed to be less consistent. However, the majority of field studies observed typical thresholds between 300 and 600 lux [104, 105, 118, 119, 122, 124], with a tendency towards 500 lux for reading and writing and towards 300 lux and lower for VDU work [105, 124]. The maximum preferred threshold for indoor illuminance observed in a field study was 930lux [104]. Generally, a tendency of increased satisfaction with higher illuminance levels can be detected [124]. However with decreasing daylight, people tend to adapt to low levels of illuminance by natural light and prefer working in less bright environment, rather than switching on the artificial lighting [104].

Daylighting in this work is evaluated based on daylight autonomy. In case of the ideal building use scenario, artificial lighting is switched on as soon as daylight illuminance is below 500lux, and off again when illuminance exceeds this threshold. For the worst-case scenario, no threshold applies and lighting is switched on throughout working hours.

3.4 Windows and view

Windows are the link between the room and the outside environment, and their function in offices relates to daylighting, the provision of sunlight, ventilation and view. However, regarding comfort and well-being these functions can also be contradictory in terms of glare and privacy. As indicated by Tuaycharoen and Tregenza [45], visual comfort cannot only be defined by physical variables, but aesthetic values have to be considered as well. In addition, view, task, sunlight and atmosphere seem to be more important than external and internal illumination [41]. Additionally field studies indicated that a view could positively influence performance and productivity of office workers [104, 115].

However, the view is influenced by a variety of parameters, like window size, shape, the observer's position, the view content and issues of glare.
Several studies investigated the user satisfaction with window size, and a window size 10% of facade area or smaller was found to be unsatisfactory [41, 125]. Additionally the minimum window size was found to be independent of sun position, time of the day, season and weather [126]. For window sizes of more than 10% of façade area, the user satisfaction increases with window size, but decreases with the amount of mullions [41]. Highest user satisfaction is reached between 30 and 60% of façade area [41, 125, 126]. However, preferred window size was also found to be depending on the view content. When a view provides attractive features like open space, greenery and information content, bigger windows are preferred than with a view of buildings [127]. For a monotonous view like a close building façade or sky without a skyline, the preferred window size is smaller, compared to complex views [127].

Concerning the preferred shape of a window in terms of view, horizontal windows were preferred to vertical arrangements of the same size [41, 125]. Additionally a relationship between skyline height and window height and width was observed [125]. Another dependency of window shape was reported to depend on the observer's position. If the desk was placed near the facade, windows were preferred wider, than when the desk was placed far from the windows [41]. Regarding window height, sill heights tend to be preferred below seated eye level, head heights above standing eye level [125]. However, for ground floor views, slightly lower windowsills seem to be preferred than for views on higher levels. This might be due to an increasing need for security on higher levels. On ground floors, the preferred lower windowsill conflicts partly with a need of privacy [125].

The observer's position in relation to the window was found to be another parameter influencing the view. Generally, a preference of occupants to sit near the window could be observed, unaffected by the visual field [128]. For angular views of the facade below 60° it was observed, that the preferred minimum window width is additive, i.e. it can be divided into several parts and yet provide subjective satisfaction [126]. For angular views of the facade above 60°, the observer does not see simultaneously the centrally viewed windows within the 60° and those beyond this limit. Therefore, subjective judgement is then based on single windows, and assessed to the full minimum acceptable size. In larger rooms, any additional window beyond a viewing angle of 60° will not be evaluated [126].

Another important parameter concerning the view is the view content. It was observed, that people tend to prefer views of natural scenes to urban places [127]. Additionally people prefer scenes extending from nearby to distant elements (foreground, middle distance, far distance and sky, complex, varying in colour and materials), to those of limited range (middle distance, e.g. view of a concrete wall with little colour variation) [45]. This corresponds with other observations that a predominantly horizontal view of landscape or the city provides maximum amount of information about the inanimate or non- human environment [125, 128]. Least favoured views observed in field studies were those fully obstructed by other buildings [125]. Additionally, a significant difference between occupants on the lower floors, who have a stronger preference for a view of the ground, and those on the upper floors could be observed. [128]

The view out of a window is also affected by glare. Discomfort glare is the sensation of distraction and annoyance. It is produced by the large contrast between the light source and its surrounding area and by the saturation effect due to the intensity of the brightness of the source. Glare from windows was found to be associated with reduced office worker performance [115].
The assessment of glare from windows refers to several variables including window size, quality of view, the degree of specular reflections from interior surfaces, and the wall area surrounding the window, as well as other visual and aesthetic factors, such as the quality of the view, the appearance of the window as well as the visual and aesthetic interior qualities of the room [100].
Discomfort glare is a result of the contrast between the window and the adjacent walls and ceiling [100]. A view of wide luminance range is likely to be more glaring than one of the same mean luminance but with less variation [45]. Due to the contrast between the window as a glaring source and the surrounding adjacent walls, this indicates also a dependency of glare from window size [100, 44]. Additionally the position of the observer in relation to the windows has some influence as well, since the closest window is likely to have strongest influence on daylighting, but the window facing the occupant might have strongest impact on the perception of glare [128].

Regarding the view, for this study only the quantity is evaluated. This refers to the percentage of working time will full view (blinds open), limited view (blinds closed, but slat angle allows for a limited view), or no view (Blinds closed, slat angle not permitting a view). However this evaluation method is only a prototype, and these percentages have to be evaluated considering the given window size, since the quality and the quantity of view are different for 20, 70 or 100% window area. Corresponding visualizations are shown in table 19.

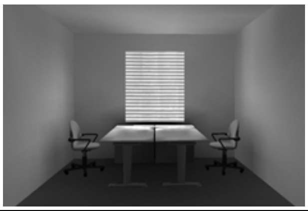
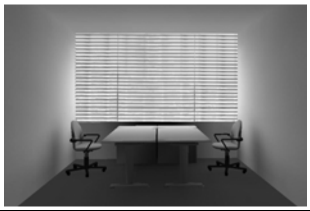
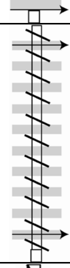
Use scenario	**1, “prestige”**	**2, “low-cost”**	**3, “green”**	**Slat angle**
Full view				
Limited view				
No view				

Table 19: Visualisations of view quantity

CHAPTER 4, SIMULATION RESULTS FOR ATHENS

4.1. Naturally ventilated offices

Regarding thermal comfort evaluation, Greek building regulation refers to EN 15251. This norm introduces an adaptive thermal comfort model for naturally ventilated and a static model for mechanically ventilated buildings. An initial study for Hamburg, Germany, indicated, that the requirements according to this model are difficult to meet even in a moderate climate for South facing rooms with high internal heat loads. This study therefore investigates, in how far naturally ventilated offices in Athens, Greece can meet the requirements according to this model.

4.1.1 Simulation results

To investigate the influence of weather data, internal heat loads and occupant behaviour in different building configurations in Athens, Greece, different configurations have been simulated based on input data in chapter 2. All configurations are naturally ventilated and if not described otherwise facing south. Energy performance and comfort are evaluated according to the methods described in chapter 3. Thermal comfort is evaluated according to the adaptive thermal comfort model of EN 15251 [5].

Building configurations and weather data sets

Table 20 shows the influence of weather data, internal heat loads and occupant behaviour for the "prestige" building configuration, based on a light construction without thermal mass, 100% window area and internal venetian blinds.
Regarding the influence of the weather data, the results show a decrease in the percentage of hours meeting the criteria for the three thermal comfort categories for the hot data set. Additionally the hot weather data set leads to slightly lower energy consumption and CO_2 emissions. For the worst-case scenario of occupant behaviour, this is due to a decrease in heating energy, for the ideal scenario it is due to a decrease in lighting energy. For the ideal scenario, the hot data set leads to a slightly lower percentage of working time with deactivated blinds (=full view), but at the same time a higher daylight autonomy, due to higher solar radiation.
Comparing the ideal and worst case scenario of internal heat loads and occupant behaviour, the ideal scenario results in a significant increase in the percentage of hours meeting the criteria for the categorisation according to EN 15251. At the same time, energy consumption and CO_2 emissions are reduced by about 75%. However, none of the configurations meets the thermal comfort criteria of EN 15251, leading to a categorisation into category IV.

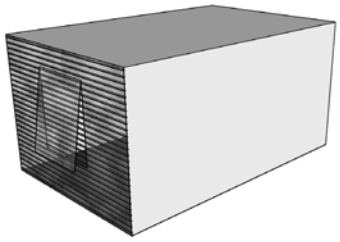
	“Prestige” configuration: Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Thermal comfort category according to EN 15251	IV	IV	IV	IV
Category I hours [%]	25	20	40	39
Category II hours [%]	35	27	54	51
Category III hours [%]	44	36	64	60
End energy total [kWh/m²a]	148	148	40,8	39,6
CO_2 emissions total [t/a]	2.37	2.36	0.61	0.58
Full view [%]	0	0	29	28
Daylight autonomy [%]	0	0	60	63

Table 20: Building configuration “prestige”, comfort and energy performance for different scenarios of internal heat loads, user behaviour and weather data sets.

Table 21 shows the influence of weather data, internal heat loads and occupant behaviour for the “low-cost” building configuration, based on medium thermal mass, 20% window area and internal venetian blinds.

Regarding the influence of the weather data, for this configuration as well, the results show a decrease in the percentage of hours meeting the criteria for the three thermal comfort categories for the hot data set. The hot weather data set leads to slightly lower energy consumption and CO_2 emissions for the ideal scenario of building use. This is due to a decrease in lighting energy. For the ideal scenario, the hot data set leads to slightly higher daylight autonomy, due to higher solar radiation.

Comparing the ideal and worst case scenario of internal heat loads and occupant behaviour, the ideal scenario results in a significant increase in percentage of hours meeting the criteria for the categorisation according to EN 15251. At the same time, energy consumption and CO_2 emissions are reduced by about 50%. This effect is not as strong as for the “prestige” building configuration, because due to the smaller window area and the resulting lower daylight autonomy the potential for energy savings for lighting energy is limited.

As for the “prestige” configuration, none of the variations meets the thermal comfort criteria of EN 15251. Although the percentage of hours meeting the comfort criteria is higher, compared to the “prestige” configuration, the resulting categorisation is category IV.

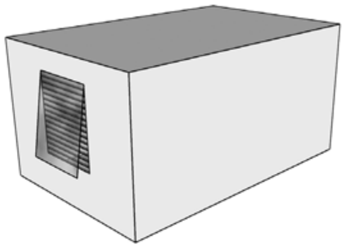
	"Low-cost" configuration: Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Thermal comfort category according to EN 15251	IV	IV	IV	IV
Category I hours [%]	38	31	62	56
Category II hours [%]	47	38	72	65
Category III hours [%]	52	45	79	72
End energy total [kWh/m²a]	175	175	77	76
CO_2 emissions total [t/a]	2.81	2.81	1.27	1.22
Full view [%]	0	0	34	34
Daylight autonomy [%]	0	0	17	22

Table 21: Building configuration "low cost", comfort and energy performance for different scenarios of internal heat loads, user behaviour and weather data sets.

Table 22 shows the influence of weather data, internal heat loads and occupant behaviour for the "green" building configuration, based on high thermal mass, 70% window area and external venetian blinds.
As for the "prestige" and the "low-cost" configuration, regarding the influence of the weather data, the results show a decrease in percentage of hours meeting the criteria for the three thermal comfort categories for the hot data set. The hot weather data set leads to slightly lower energy consumption and CO_2 emissions for the ideal scenario of building use. This is due to a decrease in lighting energy. For the ideal scenario, the hot data set leads to slightly higher daylight autonomy, due to higher solar radiation.
Comparing the ideal and worst case scenario of internal heat loads and occupant behaviour, the ideal scenario results in a significant increase in percentage of hours meeting the criteria for the categorisation according to EN 15251 [5]. At the same time, energy consumption and CO_2 emissions are reduced by about 75%. This effect is as strong as for the "prestige" building configuration, due to similar effective (above desk height) window areas and resulting potential for savings in lighting energy.
Only for the ideal scenario of building use, with the average weather data set, the thermal comfort criteria according to EN 15251 are met, and comfort category III is achieved. For all other variations, the resulting comfort category is IV.

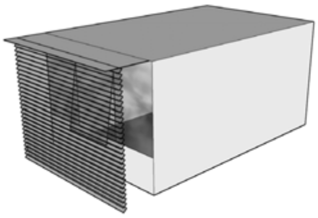
	“Green” configuration: Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Thermal comfort category according to EN 15251	IV	IV	III	IV
Category I hours [%]	72	65	78	72
Category II hours [%]	82	75	92	83
Category III hours [%]	88	81	99	90
End energy total [kWh/m²a]	147	147	39	37
CO_2 emissions total [t/a]	2.36	2.36	0.63	0.59
Full view [%]	0	0	30	29
Daylight autonomy [%]	0	0	55	60

Table 22: Building configuration “green”, comfort and energy performance for different scenarios of internal heat loads user behaviour and weather data sets.

Slat angle of blinds

Figure 23 shows the influence of different slat angles for the exterior venetian blind, based on the “green” building configuration and ideal use of internal heat loads and occupant behaviour. The investigated slat angles are 80° (to horizontal = closed blinds) providing no view, 30° providing an obstructed but still perceivable view and 0° (horizontal slats) providing a disturbed but in terms of view content almost full view. The results show almost similar percentages of hours meeting the criteria for the different comfort categories, and the resulting thermal comfort category for all configurations is III. However, regarding energy consumption and CO_2 emissions, both parameters decrease the more opened the slat angle is set. This is due to a decreasing consumption of energy for lighting, due to the higher daylight autonomy for opened slat angles.

In terms of lighting energy savings, it can be concluded, that blinds should be kept as opened as the protection from glare or overheating allows. The results show highest CO2 emissions for the variation with closed blinds, and lowest for the variation with horizontal blinds. Since all configurations still meet the criteria for thermal comfort category III, according to EN 15251 [5], the additional solar heat gains due to the open slat angle can be compensated by the robustness of the building. The differences regarding the percentage of occupied hours where thermal comfort criteria are met are almost negligible for this building configuration. For less robust variations, the impact on thermal comfort might be stronger. However keeping the slat angle of venetian blinds as opened as possible is an effective means to improve visual comfort, energy consumption and CO_2 emissions in offices. Nevertheless, it has to be balanced with possible negative side effect on thermal comfort.

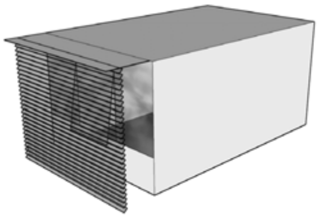
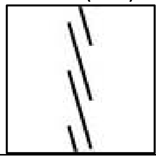
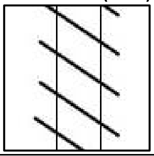
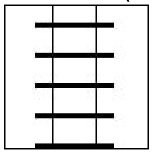
	“Green” configuration : Internal heat loads and user behaviour: ideal scenario Climate: average		
	Slat angle		
	Closed (80°) 	Medium (30°) 	Horizontal (0°) 
Thermal comfort category according to EN 15251	III	III	III
Category I hours [%]	74	78	79
Category II hours [%]	94	92	94
Category III hours [%]	100	99	100
End energy total [kWh/m²a]	45	39	33
CO_2 emissions total [t/a]	0.72	0.63	0.53
Full view [%]	29	30	32
Daylight autonomy [%]	42	55	68

Table 23: Comfort and energy performance for different slat angles of a venetian blind, “green” building configuration

Facade orientation

Table 24 presents a comparison of the “prestige” building configuration, based on the ideal building use scenario and average climate for different facade orientations. Regarding the percentage of working time meeting the thermal comfort criteria according to EN 15251, the results show highest percentages for the north side, followed by the west, the east and the south side. However, differences are strongest on the north side, while east, south and west lead to relatively similar percentages. Nevertheless all variations have to be categorised in category IV. Concerning energy consumption and CO_2 emissions, the effect is almost opposite. Lowest values can be observed for the south side, followed by the east, the west and the north side. This is due to a decrease of heating loads in winter and an even stronger decrease in lighting energy consumption, from the south to the north side. The latter can be explained by the higher daylight autonomy inside the office for facade orientations exposed to direct solar radiation, even with activated blinds.
A strong correlation can be observed between daylight autonomy and CO2 emissions. Due to the higher illuminance in rooms with facade orientations exposed to the sun, less artificial lighting is needed, and the resulting CO2 emissions are reduced. However, the corresponding influence on adaptive thermal comfort, i.e. the percentage of working hours in category III according to EN 15251 [5] is inverse.
It can be concluded, that facade orientation has a different impact on thermal comfort, than on visual comfort, energy consumption and CO_2 emissions. Optimisation strategies should therefore consider the interactions of thermal and visual comfort and the resulting impact on running costs and the environment.

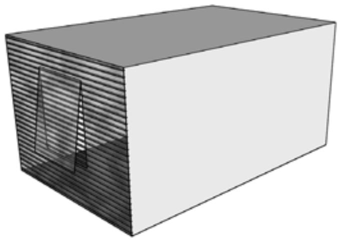
	"Prestige" configuration: Internal heat loads and user behaviour: ideal scenario Climate: average			
	orientation			
	North	East	South	west
Thermal comfort category according to EN 15251	IV	IV	IV	IV
Category I hours	53	45	40	45
Category II hours	67	58	54	59
Category III hours	78	67	64	69
End energy total [kWh/m²a]	53	44	40,8	46
CO_2 emissions total [t/a]	0.79	0.64	0.61	0.67
Full view [%]	30	31	29	26
Daylight autonomy [%]	37	56	60	51

Table 24: Building configuration "prestige", comfort and energy performance for different orientations.

Influence of single parameters

Based on the "low cost" building configuration and the worst-case scenario of internal heat loads and user behaviour, the impact of single parameters has been investigated as shown in table 25. The comparison is based on the worst-case scenario for internal heat loads and occupant behaviour, and only one parameter at a time has been optimised.
Concerning thermal comfort, the most effective means for improvement is the use of night ventilation, closely followed by the replacement of desktop computers by notebooks, the replacement of the standard by an optimised lighting system, the disconnection of desktop computers from power supply outside office hours, and the active switching of lights and blinds. However, none of the variations meets the comfort criteria according to EN 15251 [5]. Regarding energy consumption and CO_2 emissions, the results are different. The most effective reduction method here is the replacement of desktop computers by notebooks. Further methods, although not as effective, are the use of an optimised instead of a standard lighting system, the disconnection of desktop computers from power supply outside office hours, and active switching of blinds and lights. However the use of night ventilation, although improving thermal comfort does not contribute directly to energy- and CO_2 emission savings in naturally ventilated buildings. Night ventilation provides an effective method to maintain thermal comfort without using a cooling system, and thus can contribute indirectly to energy and CO_2 emission savings.
Regarding the percentage of working time with full view or daylight autonomy, the only possibility for improvement as observed in this study is the active use of blinds and lights by office occupants.

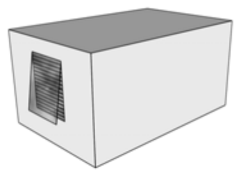
	Low-cost: Internal heat loads and user behaviour Climate average Worst case scenario of building use with single parameters changed					
	worst case scenario	Office equipment disconnected outside office hours	Notebook instead of desktop computer	Optimized lighting system	Night ventilation	Active switching of blinds and lights
Thermal comfort category according to EN 15251	IV	IV	IV	IV	IV	IV
Category I hours	38	42	51	46	51	41
Category II hours	47	49	58	52	60	48
Category III hours	52	56	65	58	67	54
End energy total [kWh/m²a]	175	152	102	147	175	162
CO_2 emissions total [t/a]	2.81	2.44	1.64	2.36	2.81	2.61
Full view [%]	0	0	0	0	0	34
Daylight autonomy [%]	0	0	0	0	0	17

Table 25: Variation of comfort and energy performance when varying single parameters, “low cost” building configuration

4.1.2 Discussion

The use of weather data sets

In order to evaluate the impact of different weather data on thermal comfort, the percentage of working time meeting the criteria for comfort category III have been compared for the hot and the average weather data set. Figure 111 shows the difference in percent of the working time fulfilling the criteria for comfort category III for the average subtracted by those of the hot data set for different building configurations.
The strongest impact of varying weather data can be observed for the prestige configuration in combination with the worst-case scenario, followed by the low-cost configuration with the same scenario. Thus it can be concluded, that the higher solar and internal gains and the less robust the building can balance these loads, the more a hot weather data set will reduce the percentage of comfortable hours in the office. However, the impact of the weather data set seems to depend more strongly on the scenario of building use than on the building configuration. Configurations including the worst-case scenario tend to be more strongly affected by the hot weather data set, than configurations with the ideal scenario for building use. Only in case of the green building configuration, the impact of the building use scenario is less influential.
Additionally it can be observed that the use of the hot weather data set slightly increases the daylight autonomy due to higher direct radiation. Moreover, this slightly affects the energy consumption and CO_2 emissions due to energy savings for lighting in case of an ideal scenario (= active use of lights and blinds).

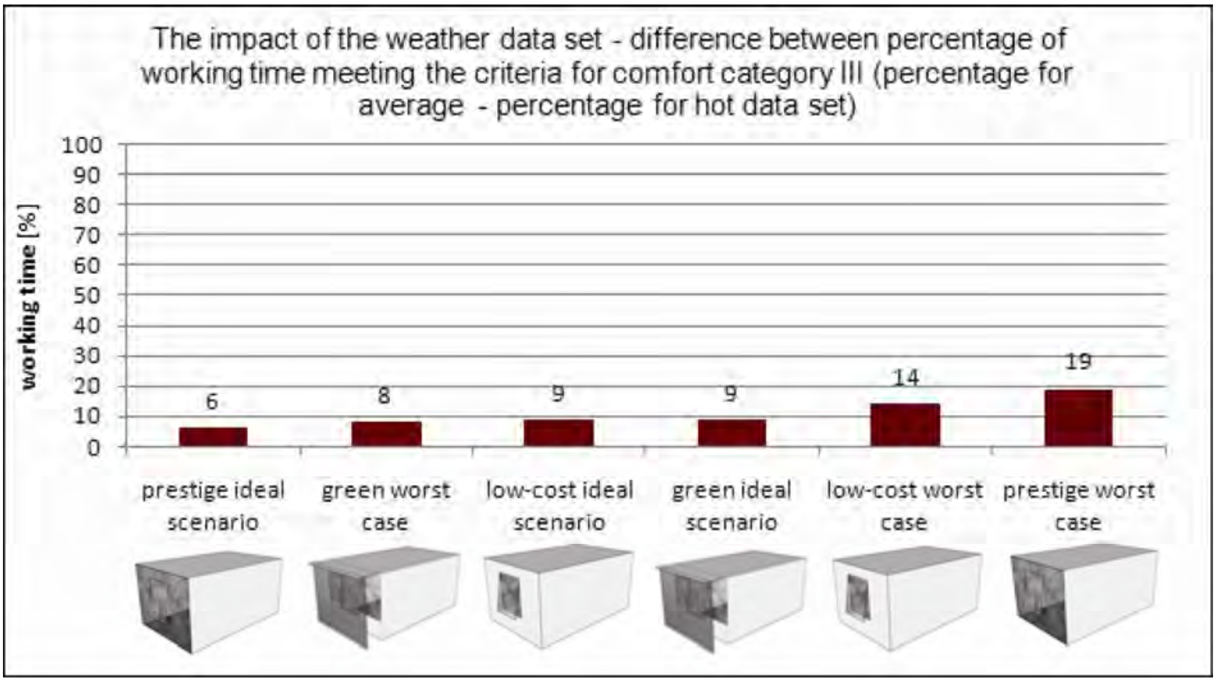


Figure 111: Difference in percentage of working time meeting the criteria for adaptive comfort category III according to EN 15251 [5] due to the use of different weather data sets

Thermal comfort

Figure 112 compares the impact of different configurations of the building and user scenarios on the percentage of working time, when temperatures meet the criteria of the adaptive model of EN 15251 [5] for category III. For all configurations, the average weather data has been used. The results indicate, that in a green building, which is well protected against solar heat gains by an external shading system, robust regarding the balance of heat loads due to high thermal mass, and allows for a high daylight autonomy due to large window areas, the percentage of working time when thermal comfort category III is met is highest. Even in case of worst-case internal heat loads and occupant behaviour, the robustness of the building provides potential to balance thermal comfort.

Compared to the green building configuration, the low-cost variation leads to a significantly lower percentage of hours within comfort category III, even though thermal comfort with the ideal scenario of building use is much better than for the worst-case scenario. The lowest percentage of working hours within comfort category III can be found for the prestige building configuration. This variation provides lowest robustness to balance solar and internal heat gains, so even in case of ideal building use, the percentage of working time within the thermal comfort levels tends to be low.

It can be concluded, that the robustness of the building to balance solar and internal heat loads is crucial for the achievement of adaptive thermal comfort according to EN 15251 in naturally ventilated offices in the Athens climate.

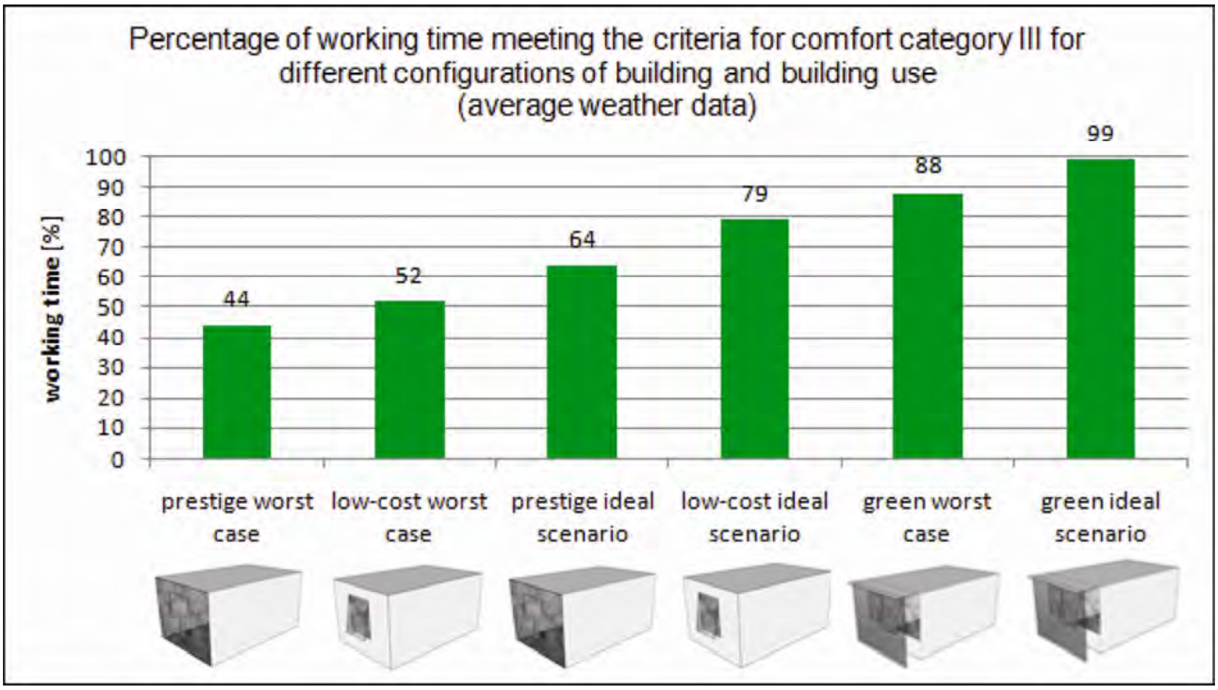


Figure 112: Percentage of working time meeting the criteria for adaptive comfort category III according to EN 15251 [5] for different configurations of building design, occupant behaviour and internal heat loads

CO_2 emissions

Figure 113 shows a comparison of CO_2 emissions caused by the different configurations of the building, internal heat loads and occupant behaviour. The results indicate, that in terms of CO2 emissions, the predominant influence is not the building configuration, but the use of internal heat loads and the occupant behaviour. Lowest CO_2 emissions are caused by the prestige configuration, with only little difference to the green building configuration, both in combination with the ideal scenario. They are followed by the low-cost building configuration in combination with the ideal scenario. However, CO_2 emissions for this configuration are about twice as high compared to the former mentioned variations. Configurations including the worst-case scenario are causing highest CO_2 emissions, lowest of which are caused by the green building, closely followed by the prestige configuration. The low-cost configuration causes the highest CO_2 emissions. Generally, the CO2 emissions caused by the configurations including the worst-case scenario are approximately 2-4 times higher, than those based on the ideal scenario of building use. The higher values for the low-cost variations are caused by the less efficient lighting system. The magnitude of difference between the configurations with ideal and worst case scenario is predominantly caused by the replacement of desktop computers by notebooks for the ideal scenario. However, another contributing parameter is energy savings due to active light switching of office occupants.

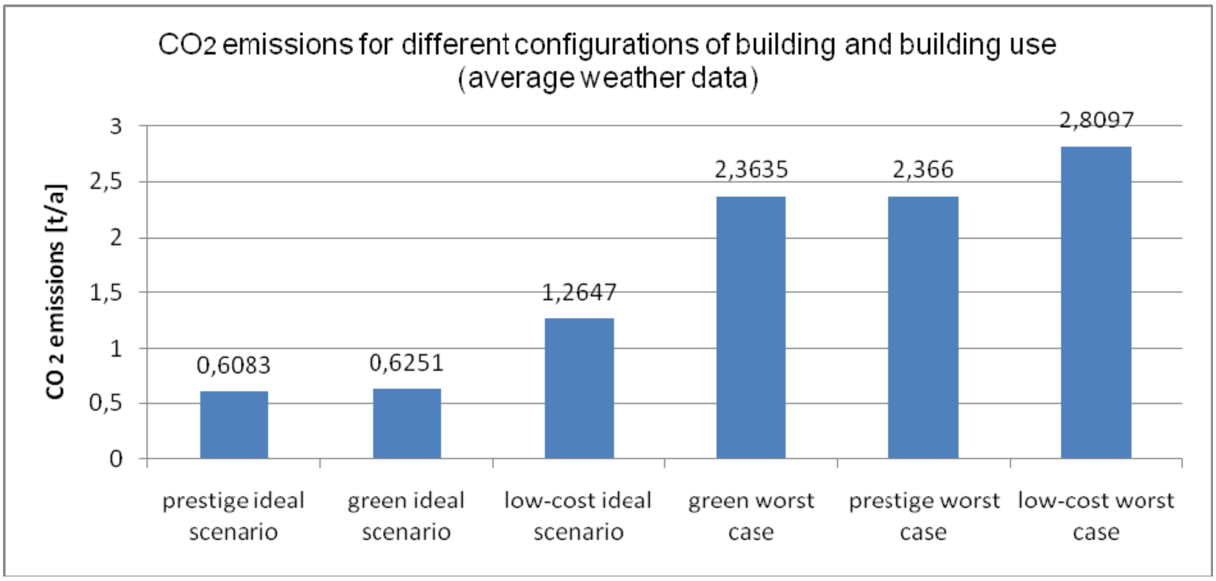


Figure 113: Comparison of CO_2 emissions for different configurations of building design, internal heat loads and occupant behaviour.

Daylight autonomy

Figure 114 shows a comparison of the different building configurations regarding their impact on daylight autonomy. Since for the worst-case scenario, blinds are assumed to be closed completely throughout working time, only the variations based on the ideal scenario have been considered in this comparison. The results show a strong correlation with the window area. Lowest daylight autonomy (17%) can be observed for the low-cost configuration, which has a minimum window area of 20%. In this configuration, it is equivalent to 10% of the floor area, which is the required minimum according to Greek legislation. Significantly higher percentages of daylight autonomy can be observed for the green building (55%) and the prestige configuration (60%). This shows that the window area above the height of the work plane is crucial for the evaluation of daylight autonomy. Although this value is similar for the green and the prestige configuration, the lower value for the green building can be explained by the additional overhang and the exterior location of the shading.

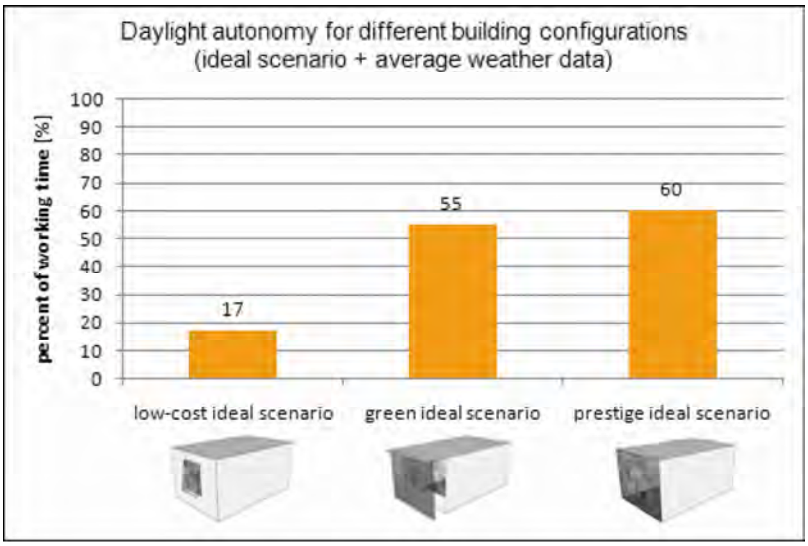


Figure 114: Daylight autonomy according to building design

View

Regarding the evaluation of the impact on view, a comparison is shown in figure 115. Like for daylight autonomy, only the variations based on the ideal scenario have been compared. For all three configurations the percentage of working time with full view = deactivated blinds is around 30%. The prestige configuration shows the lowest value (29%), followed by the green building (30%) and the low-cost variation (34%). The lowest value for the prestige configuration can be explained by a higher likelihood of blind closing for overheating protection, since this configuration is the least robust regarding the balance of solar and internal heat gains. The highest value for the low cost configuration can be explained by a lower likelihood of blind closing due to glare, because of the small window size. Thus, it can be concluded that the robustness of the building in terms of balancing solar and internal heat gains as well as the window size, influence the percentage of working time with full view.
However, it should be considered, that this study evaluates only the quantity of full view for the given window size. The influence of window size on the quantity and the quality of view is not considered in this study.

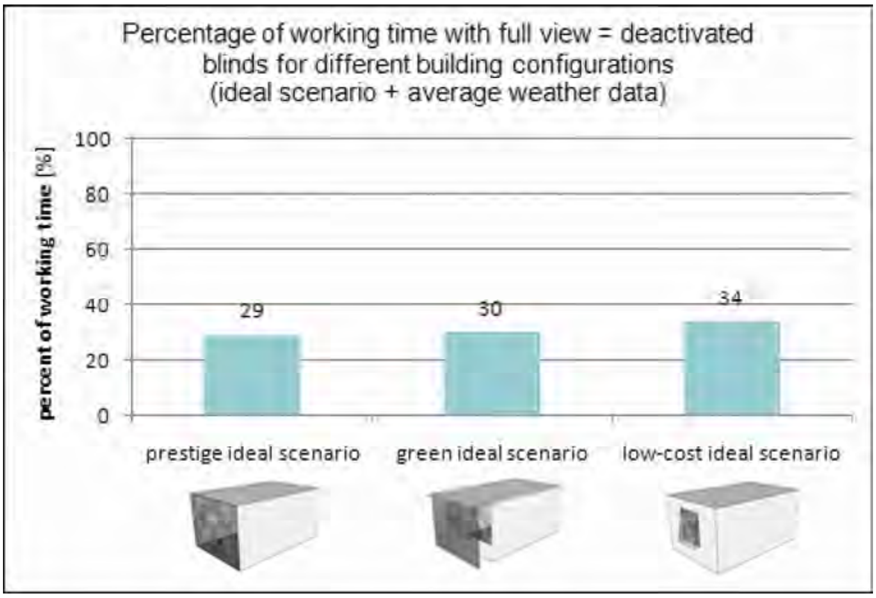


Figure 115: Percentage of working time with full view for different building configurations

Distribution of comfort and room temperatures

Chapter 4.1 indicated, that it was very difficult to meet the requirements for thermal comfort category III for naturally ventilated buildings in the climate of Athens, Greece. Among the three investigated building configurations in combination with either the worst case or the ideal scenario of internal heat loads and occupant behaviour, only for the green building configuration in combination with the ideal scenario and the average weather data set it was possible to achieve thermal comfort category III. This leads to the conclusion, that it might be even more difficult if not impossible to achieve thermal comfort category II or I. The green building configuration for this study has been designed in order to show the optimisation potential of an optimised office building. However, it cannot be considered a representative configuration for the Athens office building stock, and thus it

is likely that currently the majority of naturally ventilated office buildings in Athens do not meet the requirements of the adaptive model of EN 15251 [5]. This leads to the question, if thermal comfort in naturally ventilated offices in Athens is lower than in moderate climates, or if Athens office occupants are more tolerant regarding higher temperatures. Further field research would be needed, which could not be conducted within this study.
However, the magnitude of exceeding hours compared to the comfort limits as well as their distribution over the year can be interesting in this context.

Figure 116 shows the distribution of room- and operative temperatures for the prestige building configuration in combination with the worst case or ideal scenario without any heating or cooling based on the average weather data set. In both cases, room temperatures during summer months significantly exceed the comfort limits, with temperatures reaching and exceeding 40°C. For the worst case scenario the magnitude is even stronger, so even minimum temperatures during working times in summer are above the comfort limits. During winter however, the variation based on the ideal scenario leads to a significant percentage of working time when room temperatures exceed the lower comfort limits, and heating would be needed. For the worst-case scenario in contrast, due to higher internal heat loads, room temperatures are less exceeding the lower comfort limits. While during summer, room temperatures are exceeding comfort temperatures during a continuous period, during winter exceeding hours can be more typically characterised by single temperature peaks. In any case, the amount of room temperatures exceeding the upper comfort limits is significantly exceeding the maximum of 5% allowed in EN 15251 [5].

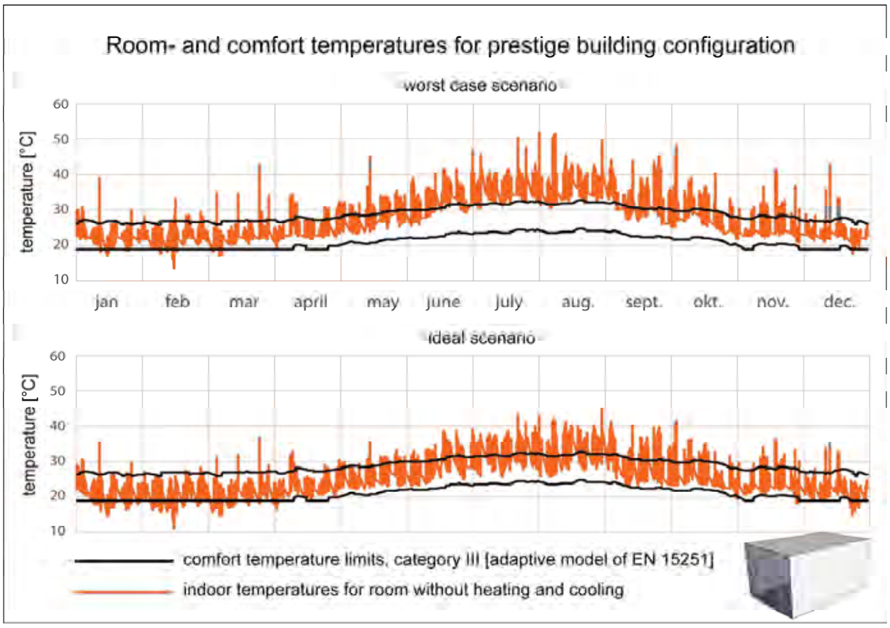


Figure 116: Prestige building configuration, room and comfort temperatures for the ideal and worst case scenario of occupant behaviour and internal heat loads, without heating and cooling

Figure 117 shows the distribution of room and operative temperatures for the low-cost building configuration in combination with the worst case or ideal scenario without any heating or cooling based on the average weather data set.
In combination with the worst-case scenario, even lowest room temperatures during summer exceed the upper comfort limits for category III. In winter, however the majority of working hours has room

temperatures within the comfort limits, except for some occasional temperature peaks. In combination with the ideal scenario, lower temperatures during summer are within the comfort limits while higher temperatures exceed the upper limits. During winter, most working hours are within the comfort limits, except for some occasional peaks, which are only slightly exceeding the limits. As for the prestige configuration, during summer, temperatures are exceeding the comfort limits for a continuous period, while exceeding peaks occur predominantly in winter.
For all these configurations as well, the amount of room temperatures exceeding the upper comfort limits is significantly exceeding the maximum of 5% allowed in EN 15251 [5].

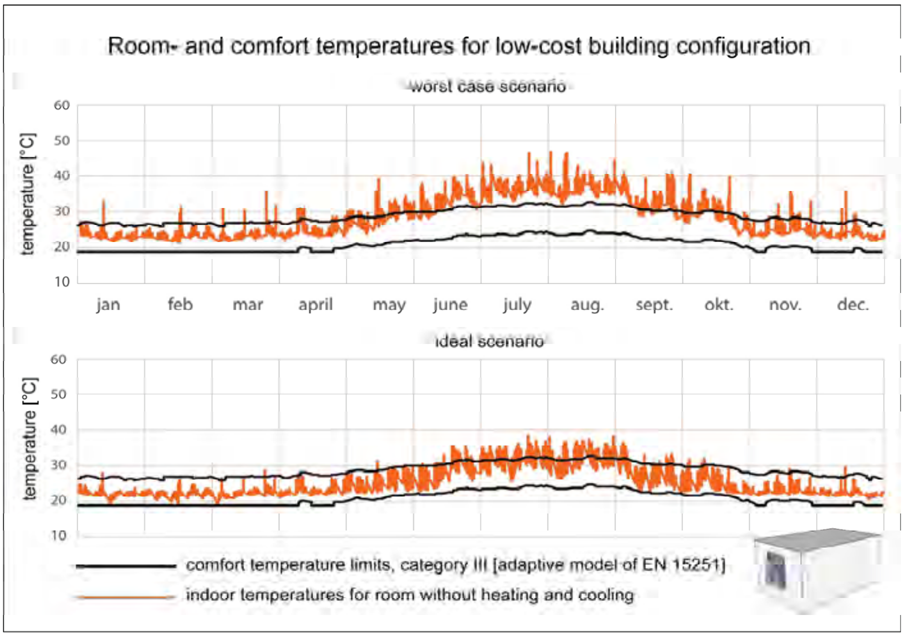


Figure 117: Low-cost building configuration, room and comfort temperatures for the ideal and worst case scenario of occupant behaviour and internal heat loads, without heating and cooling

Figure 118 shows the distribution of room and operative temperatures for the green building configuration in combination with the worst case or ideal scenario without any heating or cooling based on the average weather data set.
In combination with the worst-case scenario, even lower room temperatures during summer are exceeding the comfort limits, while during winter room temperatures during working hours are almost completely within the comfort limits. In combination with the ideal scenario, room temperatures in summer are rarely exceeding the comfort limits, and during winter, they almost completely meet the comfort criteria for category III.
For the green building configuration, the same characteristics regarding the exceeding hours in summer and winter can be observed. During summer, exceeding hours occur within a more or less continuous period, while during winter occasional temperature peaks occur. However, the magnitude of these temperature peaks in winter is small, so comfort limits are not exceeded. For the ideal scenario of building use, room temperatures during summer are rather low, so the 5% exceeding criteria of EN 15251 [5] is met on a yearly basis. In combination with the worst-case scenario, the amount of exceeding hours significantly exceeds 5%.

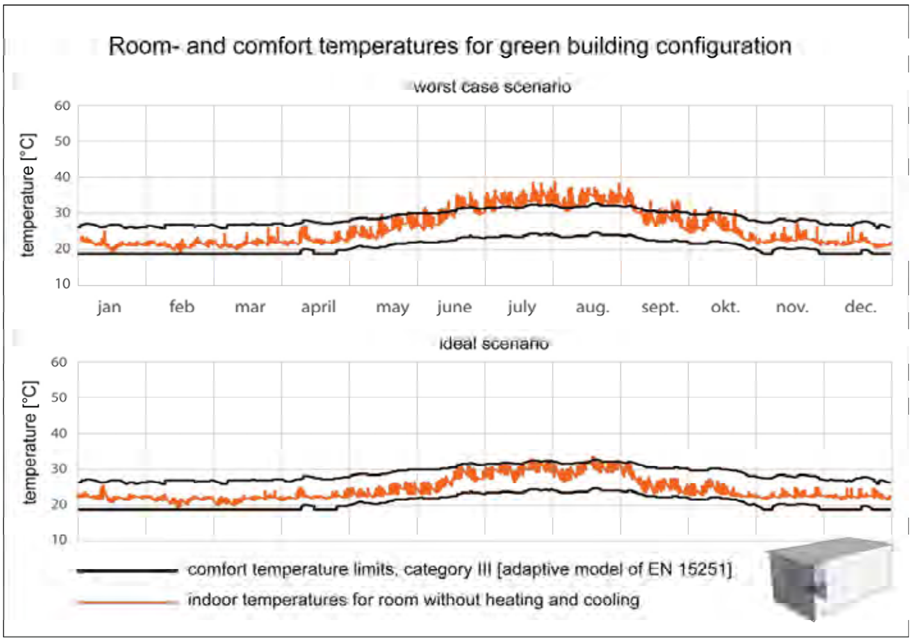


Figure 118: Green building configuration, room and comfort temperatures for the ideal and worst case scenario of occupant behaviour and internal heat loads, without heating and cooling

From the distribution of room- in relation to comfort temperatures, it can be observed, that for the climate of Athens in any configuration of the building and its use, magnitude and distribution of exceeding hours varies significantly between summer and winter. While during summer exceeding hours occur during a rather continuous period, exceeding hours during winter are more typically characterised by occasional temperature peaks. The magnitude of these exceeding hours however, is predominantly influenced by the building configuration. Highest exceeding temperatures occur for the prestige configuration, medium for the low cost variation and lowest for the green building. This is due to their different ability to balance solar and internal heat gains.
It can be concluded that the general characteristics regarding the distribution of room temperatures in summer and winter seem to be predefined by the climate. In addition, it should be further investigated in how far office occupants are accustomed to these characteristics.

Main results

- The investigation on the use of different weather data sets for building simulation shows, that local climate variability (i.e. average or hot weather data) can have significant impact on comfort, energy performance and CO2 emissions in offices. The magnitude of this impact is depending more strongly on the use of office equipment, lighting systems and occupant behaviour, than on the properties of the building. However robust buildings which are well protected from solar heat gains, and providing a high thermal mass, are less likely to be affected by local climate variability than less robust buildings. In any case, in terms of energy or comfort evaluation, the weather data set should be carefully chosen according to the focus of the study.
- Concerning the provision of adaptive thermal comfort according to EN 15251 [5], the robustness of the building is the crucial parameter. As for the climate variability robust buildings which are well protected from solar heat gains, and providing a high thermal mass

are most likely to provide satisfying thermal comfort conditions for occupants, without the need for a cooling system.

- Unlike for the provision of thermal comfort, regarding the reduction of energy consumption and CO2 emissions, the crucial parameter is not the robustness of the building, but the use of office equipment, lighting systems and occupant behaviour. The worst-case scenario used in this study causes 2-4x higher energy consumption and CO2 emissions than the ideal scenario for internal heat loads and occupant behaviour. Among the related parameters, the replacement of desktop computers by notebooks and the replacement of a standard by an optimised lighting system provide the largest reduction potential for energy consumption and CO_2 emissions.
- Concerning the optimisation of daylighting, the size of the window area above the work plane is the crucial parameter. Daylight autonomy is strongly correlated with window area, even though in the climate of Athens, Greece, blinds are usually activated for a large percentage of the working time. However, a large window area can help to maintain daylight autonomy when blinds are activated, if the slats are not completely closed. In addition, it can help to maintain daylight autonomy when shading is not needed. However, in case of manual control, active switching of blinds by occupants is required.
- Concerning the view this study shows, that in the climate of Athens, Greece, blinds are likely to be activated for around 70% of the working time. This percentage is similar for all investigated building configurations and only very slightly varying with window size. The quantity of view is therefore apart from the window size, predominantly influenced by the slat angle of activated blinds chosen by the occupants.
- In this study, the adaptive thermal comfort model of EN 15251 [5] has been applied for different configurations of the building, internal heat loads and occupant behaviour. Additionally the influence of an average and a hot weather data set has been compared. The results show, that only in case of an very optimised building and the average weather data set, with at the same time reduced internal heat loads and ideal occupant behaviour, it was possible to meet the criteria of the adaptive thermal comfort model in EN 15251. However, this configuration is not the most likely variation in office context. This raises the question, in how far the use of air conditioning can be reduced in the Athens climate, if at the same time it seems almost impossible to achieve even thermal comfort category III by using naturally ventilated buildings. However, as mentioned in EN 15251, the comfort limits above a running mean outdoor temperature are based on a limited database. Further research would be needed to find out if occupants in naturally ventilated buildings in Athens are more tolerant towards hot temperatures than assumed in EN 15251.
- The general characteristics regarding the distribution of thermal comfort exceeding hours seem to be predefined by the climate. The magnitude as well as the amplitude of the room temperatures over the year are predominantly influenced by the configuration of building and use scenario. Further research would be needed to investigate in how far office occupants in a certain climate are accustomed to certain characteristics of room temperature changes within a day as well as within a year. In that case, the definition of allowed exceeding hours should consider their amount as well as the magnitude. Since this is also affected by national building regulations and traditions, this could lead to different exceeding criteria definitions for each country. Further research would be needed.

4.2 Mixed mode offices

The study in chapter 4.1 investigated the comfort and energy performance of offices in the climate of Athens, based on naturally ventilated buildings. Concerning thermal comfort, the results show that for the majority of investigated configurations, it was not possible to achieve even thermal comfort category III, by using only natural ventilation.

However, the majority of office buildings in Athens are operated in mixed mode, using natural ventilation for a part of the year and cooling only throughout hot periods. For mixed mode buildings, EN 15251 recommends to use the static thermal comfort model (Annex A1), which is based on and recommended for air-conditioned buildings. This model correlates thermal comfort with thermal neutrality, since occupants in field studies preferred constant temperatures in cooled buildings. However, according to IPCC [37], the largest use of energy in commercial buildings in hot climates is air conditioning, and in order to mitigate the climate change this consumption should be reduced.

Since occupants in naturally ventilated buildings prefer temperatures reflecting the variability of the outside climate, but occupants in air-conditioned buildings prefer constant temperatures, the question about the preferences of occupants in mixed mode buildings arises. Further research would be needed to investigate in how far thermal preferences of office occupants, who are used to natural ventilation for a part of the year change, once the cooling system is switched on. However, literature [3, 4, 5] indicates, that occupant's preferences in mixed mode buildings might be similar to those observed in naturally ventilated buildings. Additionally, the field study (chapter 2.1) in two mixed mode office buildings in Athens also indicated a larger range of tolerance towards temperatures than assumed in the static thermal comfort model. Although further research on the occupant acceptance would be needed, this part of the study aims to investigate the applicability and the potential for energy and CO_2 emission savings, if the adaptive thermal comfort model of EN 15251 [5] would be used for thermal comfort evaluation in mixed mode buildings as well.

Figure 119 shows the distribution of room temperatures for a typical office room using a 23°C cooling set point, which is common for air-conditioned buildings in Athens, plotted into the adaptive thermal comfort model according to EN 15251. The graph shows, that for a large quantity of office hours, operative temperatures even exceed the lower comfort limits of the model, while the upper limits are almost never reached.

The following study is based on the same configurations of building, internal heat loads and occupant behaviour as investigated in chapter 4.1. If not mentioned otherwise, the rooms are facing south. Since the majority of these configurations did not meet the criteria of thermal comfort category III, in this part of the study a cooling system has been added. The cooling periods and set points have been adjusted in order to meet the criteria for adaptive thermal comfort category III according to the adaptive thermal comfort model of EN 15251. The resulting impact on energy consumption, CO_2 emissions and visual comfort has been investigated.

The differences between the cooling set points within one configuration are because cooling set points affect the air temperature, but thermal comfort is evaluated based on the operative temperature.

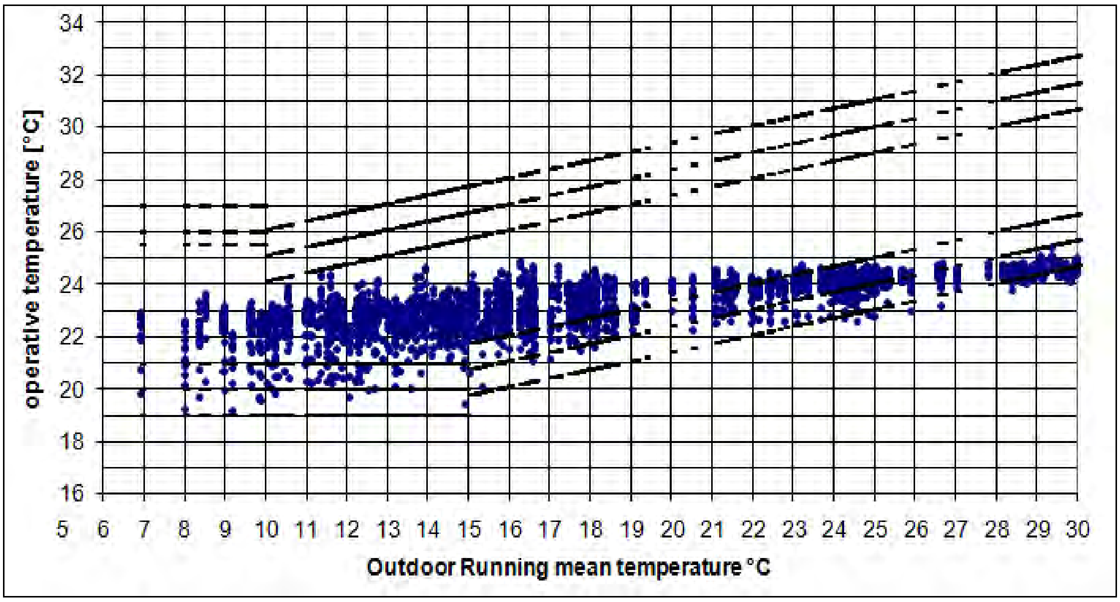


Figure 119: Operative temperatures in a mixed mode building using a fixed cooling set point of 23°C plotted against adaptive thermal comfort limits of EN 15251-2007 [5]

4.2.1 Simulation results

Building configurations and weather data

Table 26 investigates the influence of weather data, internal heat loads and occupant behaviour for the "prestige" building configuration, based on a light construction without thermal mass, 100% window area and internal venetian blinds.

Regarding the influence of the weather data, higher peak cooling loads and longer cooling periods are needed for the hot weather data set, whereas the maximum possible cooling set point to reach thermal comfort category III is not affected.

Additionally the hot weather data set significantly increases energy consumption and CO_2 emissions. In all cases this due to increased energy consumption for cooling.

For the ideal scenario, the hot data set leads to an almost similar percentage of working time with deactivated blinds (=full view), but at the same time a higher daylight autonomy, due to higher solar radiation.

Comparing the ideal and worst case scenario of internal heat loads and occupant behaviour, the ideal scenario leads to shorter cooling periods and lower peak cooling loads. At the same time, it reduces energy consumption and CO_2 emissions to about 1/3 of the values for the worst-case scenario.

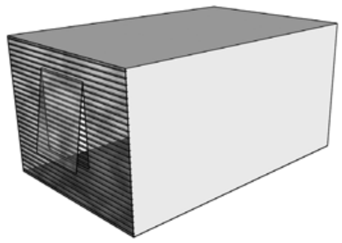
	“Prestige” configuration: Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Max. cooling set point to reach comfort category III	26	26	28	28
Peak cooling load [W]	2958	3058	2330	2596
Potential for overheating	April-November	February-December	May- November	May - January
End energy total [kWh/m²a]	200	220	60	74
CO_2 emissions total [t/a]	3.18	3.53	0.91	1.15
Full view [%]	0	0	29	28
Daylight autonomy [%]	0	0	60	64

Table 26: Building configuration “prestige”, comfort, energy performance and resulting cooling set points for different scenarios of internal heat loads, user behaviour and weather data sets, when the adaptive model according to EN 15251 [5] is applied to adjust cooling set points in a mixed mode office

In comparison with table 26, table 27 shows peak cooling loads, energy consumption, CO_2 emissions, daylighting and view for the prestige configuration, when cooling set points are constantly set at 22°C. In the field study (chapter 2.1) this was reported the most common cooling set point in Athens. For this comparison, the cooling period is assumed similar to that needed in order to meet the comfort criteria for the adaptive thermal comfort model.

The results show, that for the worst-case scenario of internal heat loads and occupant behaviour, the resulting energy consumption and CO2 emissions change only very slightly, and peak cooling loads remain the same. For the ideal scenario of internal heat loads and occupant behaviour, peak cooling loads, energy consumption and CO_2 emissions increase significantly when using constant cooling set points. However, daylight autonomy and view are not affected.

“Prestige” configuration:	Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Peak cooling load [W]	2958	3058	2463	2596
End energy total [kWh/m²a]	203	224	72	81
CO_2 emissions total [t/a]	3.25	3.59	1.10	1.27
Full view [%]	0	0	29	28
Daylight autonomy [%]	0	0	60	64

Table 27: Building configuration “prestige”, comfort and energy performance for different scenarios of internal heat loads, user behaviour and weather data sets, when using a fixed cooling set point (22°C) in a mixed mode office

Table 28 investigates the influence of weather data, internal heat loads and occupant behaviour for the “low-cost” building configuration, based on medium thermal mass, 20% window area and internal venetian blinds.

Regarding the influence of the weather data, for this configuration as well, the hot data set leads to higher peak cooling loads and longer cooling periods. Additionally the hot weather data set significantly

increases energy consumption and CO_2 emissions for all configurations, due to an increase in cooling loads.
For the ideal scenario, the hot data set slightly increases daylight autonomy, due to higher solar radiation, however the percentage of working hours with deactivated blinds is not affected.
Comparing the ideal and worst case scenario of internal heat loads and occupant behaviour, the ideal scenario decreases energy consumption and CO_2 emissions by 50% and more.
This effect is not as strong as for the "prestige" building configuration, because due to the smaller window area and the resulting lower daylight autonomy, the potential for energy savings for lighting energy is limited.

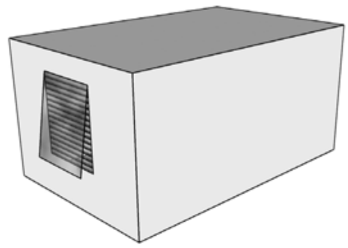
	"Low-cost" configuration: Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Max. cooling set point to reach comfort category III	28	26	28	26
Peak cooling load [W]	1910	2212	1090	1290
Potential for overheating	May - November	February-December	June- august	February - December
End energy total [kWh/m²a]	206	240	86	110
CO_2 emissions total [t/a]	3.31	3.84	1.38	1.77
Full view [%]	0	0	34	34
Daylight autonomy [%]	0	0	17	22

Table 28: Building configuration "low-cost", comfort, energy performance and resulting cooling set points for different scenarios of internal heat loads, user behaviour and weather data sets, when the adaptive model according to EN 15251 [5] is applied to adjust cooling set points in a mixed mode office

In comparison with table 28, table 29 shows peak cooling loads, energy consumption, CO_2 emissions, daylighting and view for the low-cost configuration, when cooling set points are constantly set at the common set point of 22°C. Like for the prestige configuration, the cooling period is assumed similar to that needed in order to meet the comfort criteria for the adaptive thermal comfort model.
The constant cooling set point leads to higher energy consumption and CO_2 emissions; however, this influence is significantly stronger for the average weather data set, than for the hot weather data set. Peak cooling loads increase significantly for all variations, except for the worst-case scenario in combination with the hot weather data set. Here the higher value for the variation following the adaptive model is due to an increase in cooling loads caused by the peak load occurring at a changing set point. Considering this effect, the peak loads for this configuration can be considered almost equal. Like for the prestige configuration, daylight autonomy and view are not affected.

“Low-cost” configuration	Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Peak cooling load [W]	2083	2106	1523	1589
End energy total [kWh/m²a]	219	241	91	113
CO_2 emissions total [t/a]	3.51	3.87	1.47	1.82
Full view [%]	0	0	34	34
Daylight autonomy [%]	0	0	17	22

Table 29: Building configuration “low-cost”, comfort and energy performance for different scenarios of internal heat loads, user behaviour and weather data sets, when using a fixed cooling set point (22°C) in a mixed mode office

Table 30 investigates the influence of weather data, internal heat loads and occupant behaviour for the “green” building configuration, based on high thermal mass, 70% window area and external venetian blinds.

Regarding the influence of the weather data, the results show a slight increase in peak cooling loads for the hot weather data set and the worst-case scenario of internal heat loads and occupant behaviour, while the length of the cooling period is not affected. For the ideal scenario in combination with the average weather data set, no cooling is needed, while the hot data set requires cooling for one month.

The resulting differences in energy consumption and CO_2 emissions are small or not significant and varying according to increased cooling- and decreased lighting energy consumption for the hot weather data set.

For the ideal scenario, the hot data set leads to slightly higher daylight autonomy, due to higher solar radiation.

Comparing the ideal and worst case scenario of internal heat loads and occupant behaviour, the ideal scenarios results in a significant reduction of energy consumption and CO_2 emissions to about ¼ of the values for the worst case scenario.

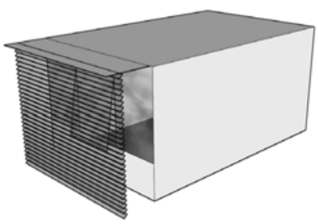
	“Green” configuration: Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Max. cooling set point to reach comfort category III	28	28	-	28
Peak cooling load [W]	1155	1180	-	726
Potential for overheating	June - august	June - august	-	July
End energy total [kWh/m²a]	160	165	39	39
CO_2 emissions total [t/a]	2.54	2.55	0.63	0.62
Full view [%]	0	0	30	29
Daylight autonomy [%]	0	0	55	60

Table 30: Building configuration “green”, comfort, energy performance and resulting cooling set points for different scenarios of internal heat loads, user behaviour and weather data sets, when the adaptive model according to EN 15251 [5] is applied to adjust cooling set points in a mixed mode office

In comparison with table 30, table 31 shows peak cooling loads, energy consumption, CO_2 emissions, daylighting and view for the green configuration, when cooling set points are constantly set at the common set point of 22°C. Again, the cooling period is assumed similar to that needed in order to meet the comfort criteria for the adaptive thermal comfort model.

For the green building configuration, the constant cooling set point causes only slight increases in energy consumption and CO_2 emissions for all variations. However, the effect on peak cooling loads is relatively strong for all configurations, but especially for the ideal scenario of building use peak cooling loads more than double. Like for the other building configuration, daylight autonomy and view are not affected.

"Green" configuration	Internal heat loads and user behaviour			
	worst case scenario		ideal scenario	
Weather data set	Average	hot	Average	hot
Peak cooling load [W]	1478	1625	-	1889
End energy total [kWh/m²a]	161	164	39	41
CO_2 emissions total [t/a]	2.59	2.63	0.63	0.65
Full view [%]	0	0	30	29
Daylight autonomy [%]	0	0	55	60

Table 31: Building configuration "green", comfort and energy performance for different scenarios of internal heat loads, user behaviour and weather data sets, when using a fixed cooling set point (22°C) in a mixed mode office

Slat angle of blinds

Figure 32 compares the influence of different slat angles for the exterior venetian blind based on the "green" building configuration and ideal use of office equipment and lighting systems as well as ideal occupant behaviour. The investigated slat angles are 80° (to horizontal = closed blinds) providing no view, 30° providing an obstructed but still perceivable view, and 0° (horizontal slats) providing a disturbed but in terms of view content almost full view.

The results show no need for cooling for the variation with the medium slat angle, and slightly lower peak cooling loads and shorter cooling periods for the variation with the closed slat angle than for the one with horizontal slats.

However, regarding total energy consumption and CO_2 emissions, both parameters decrease the more opened the slat angle is adjusted. Although cooling energy consumption slightly increases with opened slat angles, this is due to a decreasing consumption of energy for lighting, due to the higher daylight autonomy for opened slat angles.

In terms of energy savings, it can be concluded, that blinds should be kept as opened as the protection from glare or overheating allows, and a slight increase in cooling energy can be compensated by an even stronger decrease in energy for artificial lighting. The magnitude of this effect however is affected by the coefficient of performance (COP) for the cooling system, and stronger the better the COP.

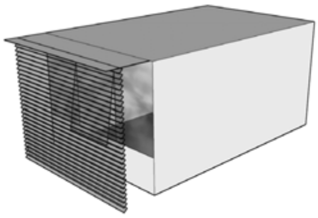
	"Green" configuration: Internal heat loads and user behaviour: ideal scenario, climate: average		
	Slat angle		
	Closed (80°)	Medium (30°)	Horizontal (0°)
Max. cooling set point to reach comfort category III	30	-	30
Peak cooling load [W]	510	-	542
Potential for overheating	June- august	-	June- august + December
End energy total [kWh/m²a]	49	39	38
CO_2 emissions total [t/a]	0.79	0.63	0.60
Full view [%]	29	30	31
Daylight autonomy [%]	41	55	68

Table 32: Building configuration "green", comfort, energy performance and resulting cooling set points for different slat angles of venetian blinds, when the adaptive model according to EN 15251 [5] is applied to adjust cooling set points in a mixed mode office

Orientation

Table 33 presents a comparison of the "prestige" building configuration, based on the ideal building use scenario and average climate with the room facing different orientations.
Regarding the peak cooling loads, the results show highest values for the south side, followed by the west, the east and the north side. However the potential for overheating, i.e. the length of the cooling period as well as the cooling set points to achieve thermal comfort category III are relatively constant.
Concerning energy consumption and CO_2 emissions, the effect is almost opposite. Lowest values can be observed for the south side, followed by the east, the north and the west facade. This order is due to the lower energy consumption for lighting on the facades exposed to the sun and the balance with additional cooling energy. In most cases, the magnitude of lighting energy savings significantly exceeds the magnitude of increase in cooling energy due to the better COP of the cooling system. The latter can be explained by the higher daylight autonomy inside the office, for facade orientations exposed to direct solar radiation, even with activated blinds.
It can be concluded, that facade orientation has a different impact on cooling energy consumption, than on visual comfort, and total energy consumption and CO_2 emissions. Optimisation strategies should therefore consider the interactions of thermal and visual comfort and the resulting impact on running costs and the environment.

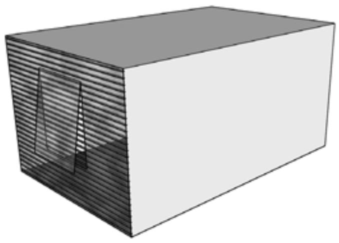
	"Prestige" configuration: Internal heat loads and user behaviour: ideal scenario, climate: average			
	orientation			
	North	East	South	west
Max. cooling set point to reach comfort category III	28	28	28	28
Peak cooling load [W]	1053	2140	2330	2220
Potential for overheating	May-November	May-November	May- November	April - November
End energy total [kWh/m²a]	65	63	60	67
CO_2 emissions total [t/a]	0.97	0.94	0.91	1.01
Full view [%]	30	31	29	26
Daylight autonomy [%]	37	56	60	51

Table 33: Building configuration "prestige", comfort, energy performance and resulting cooling set points for different facade orientations, when the adaptive model according to EN 15251 [5] is applied to adjust cooling set points in a mixed mode office

Influence of single parameters

Based on the "low cost" building configuration and the worst-case scenario of internal heat loads and user behaviour, the impact of single parameters has been investigated as shown in table 34. The comparison is based on the worst-case scenario for internal heat loads and occupant behaviour, and only one parameter at a time has been optimised.

Concerning the reduction of peak cooling loads, the most effective means for improvement is the replacement of desktop computers by notebooks, followed by night ventilation, the disconnection of desktop computers from power supply outside office hours, the replacement of the standard by an optimised lighting system, and the active switching of lights and blinds. A similar effect can be observed for the potential for overheating, i.e. the length of the cooling periods. The maximum cooling set point to achieve thermal comfort category III, however is constant.

Regarding total energy consumption and CO_2 emissions the results are slightly different. The most effective reduction method is the replacement of desktop computers by notebooks, followed by the use of an optimised instead of a standard lighting system, the disconnection of desktop computers from power supply outside office hours, and active switching of blinds and lights. However, the use of night ventilation, does not contribute significantly to energy- and CO_2 emission savings in mixed mode offices, since the room temperatures during the day in mixed mode buildings are already reduced by the cooling system.

Regarding the percentage of working time with full view or daylight autonomy, the only possibility for improvement as observed in this study is the active use of blinds and lights by office occupants.

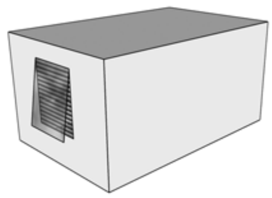
	“Low cost” configuration: Internal heat loads and user behaviour, climate average, worst case scenario of building use, single parameters changed					
	Worst case scenario	Office equipment disconnect ed outside office hours	Notebook instead of desktop computer	Optimized lighting system	Night ventilation	Active switching of blinds and lights
Max. cooling set point to reach comfort category III	28	28	28	28	28	28
Peak cooling load [W]	1910	1770	1460	1780	1540	1865
Potential for overheating	May - November	May - November	June-October	May-October	May-October	May - November
End energy total [kWh/m²a]	206	182	119	174	197	196
CO_2 emissions total [t/a]	3.31	2.93	1.91	2.80	3.16	3.15
Full view [%]	0	0	0	0	0	34
Daylight autonomy [%]	0	0	0	0	0	17

Table 34: Building configuration “low-cost”, influence of single parameters on comfort, energy performance and resulting cooling set points, when the adaptive model according to EN 15251 [5] is applied to adjust cooling set points in a mixed mode office

4.2.2. Discussion

The results of chapter 4.1 indicated, that for the three chosen naturally ventilated building configurations, it was very difficult to achieve even thermal comfort category III according to EN 15251 [5]. Although further verification regarding the occupant acceptance would be needed, this part of the study aimed to investigate the magnitude of possible energy savings when the adaptive model of EN 15251 would be applied in mixed mode buildings (during naturally ventilated as well as cooling periods) as well.

Influence of weather data sets

When the adaptive thermal comfort model of EN 15251 is applied in mixed mode buildings for the adjustment of cooling set points as well, the use of the hot instead of the average weather data set leads to an increase of peak cooling loads, longer cooling periods, and consequently also to higher energy consumption and CO_2 emissions. This effect is especially obvious for the prestige and the low cost variation. For the green building configuration only for the worst-case scenario in combination with the hot weather data set, a slight increase in peak cooling loads could be observed. However, the length of the cooling periods is not affected for the green building, and the resulting impact on energy consumption and CO_2 emissions is small.
For all configurations, the impact on visual comfort is similar like in naturally ventilated buildings, with higher daylight autonomy for the hot data set, due to higher intensity of solar radiation; however, the impact on the percentage of full view is the same.

Figure 120 shows a comparison of the use of the hot instead of the average weather data set for a naturally ventilated compared to a mixed mode building, when applying the adaptive thermal comfort

model of EN 15251. The results show strong differences between the naturally ventilated and the mixed mode building. In the naturally ventilated building configurations, in combination with the worst-case scenario for internal heat loads and occupant behaviour, CO_2 emissions are not affected by the hot weather data set. Since no cooling is used, the effect of the hot weather data set is not significant compared to the magnitude of internal heat loads. In combination with the ideal scenario however, CO_2 emissions decrease by 4-6 % due to decreasing energy consumption for lighting caused by a higher daylight autonomy / higher solar radiation.
When the adaptive thermal comfort model is applied in mixed mode buildings, energy consumption and CO_2 emissions increase significantly for the prestige and the low-cost configuration, when the hot weather data set is used due to increased cooling loads. Only for the green building, the impact is not significant. While for the naturally ventilated variations, the impact on CO_2 emissions depends mainly on the scenario of building use, rather than the building itself, for the mixed mode building, it is different. Here the building as well as the building use has strong influence. For the green building configuration, the use of the hot instead of the average weather data set does not have significant impact on CO_2 emissions. For the prestige and the low-cost configuration however, it ranges from around 10-30 %, and the impact on variations with the ideal scenario of building use is much stronger than for the worst-case scenario. This stronger impact for the ideal scenario has to be evaluated considering the absolute magnitude of CO_2 emissions, which are significantly lower than for the worst-case scenario. This can be explained by lower internal heat loads, in relation to which the impact of the climate becomes more obvious.

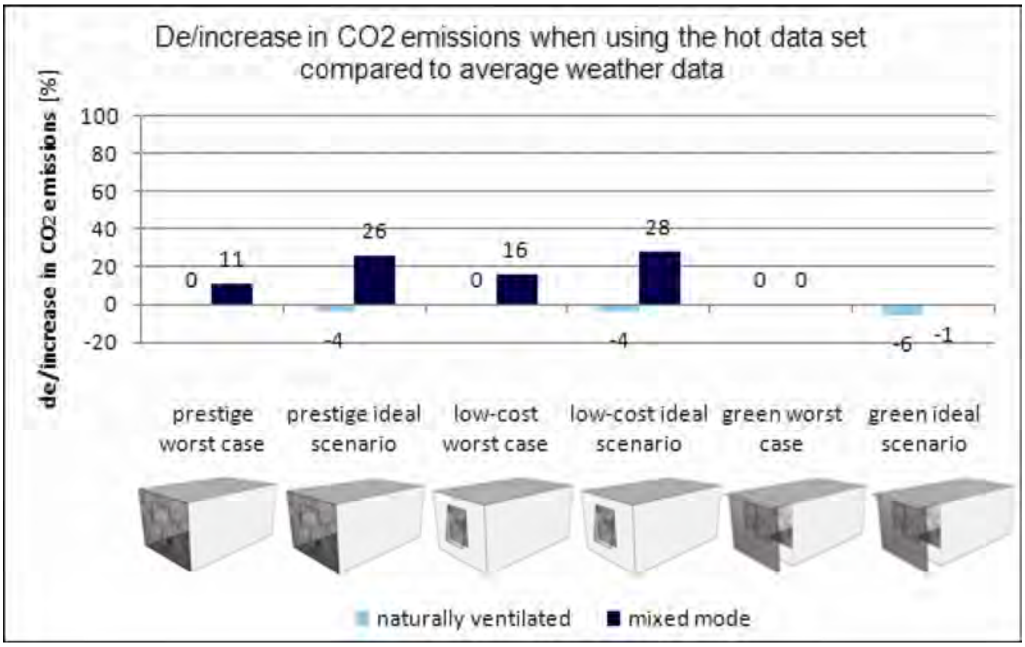


Figure 120: Influence of different weather data sets on CO_2 emissions, when applying the adaptive thermal comfort model according to EN 15251 for naturally ventilated compared to mixed mode buildings

Influence of adaptive cooling set points on peak cooling loads

Figure 121 compares either the resulting peak cooling loads for the room variations using cooling set points according to the adaptive model of EN 15251 [5], or a fixed cooling set point of 22°C during the same period. The results show, that the use of cooling set points according to the adaptive thermal comfort model can reduce peak cooling loads. However, the magnitude of this reduction varies according to the building configuration and the scenario of building use. For the prestige configuration in combination with the worst-case scenario, as well as for the green building in combination with the ideal scenario, the difference in cooling set points has no impact on peak cooling loads. For all other configurations, the use of cooling set points according to the adaptive model reduces cooling loads. The reduction potential however, is not constant for all configurations, but the larger the more optimised the combination of building and building use is. In these configurations, internal heat loads and peak cooling loads are already reduced, so the use of adaptive cooling set points has a more obvious effect.

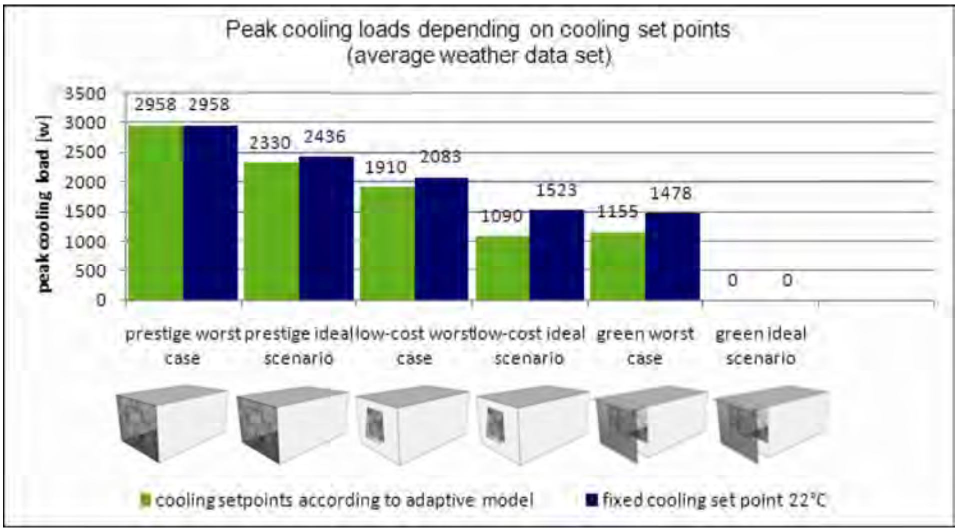


Figure 121: Peak cooling loads when adjusting the cooling set points in a mixed mode office according to the adaptive thermal comfort model of EN 15251, compared to the use of a fixed cooling set point 22°C

Influence of adaptive cooling set points on CO_2 emissions

Figure 122 shows a comparison of CO_2 emissions for different building and use configurations when using either a fixed cooling set point of 22°C, or cooling set points according to the adaptive thermal comfort model of EN 15251 [5]. For all configurations, CO_2 emissions increase for the variation using fixed cooling set points, due to an increase in cooling energy. CO2 emissions for the green building in combination with the ideal scenario remain constant since no cooling is needed. The largest difference in CO_2 emissions between fixed and adaptive cooling set points can be observed for the low-cost building configuration in combination with the worst-case scenario for building use. This can be explained by the highest facade u value for this configuration, due to lower window area. Since for the worst-case scenario no night ventilation is possible, during the night, heat accumulated by internal heat loads cannot leave the room as easily as for the configurations with higher window area, and increases cooling loads during office hours.
It can be concluded, that the use of an adaptive thermal comfort model in mixed mode buildings can contribute to the reduction of CO_2 emissions caused by offices.

However, considering the absolute magnitude of CO_2 emissions, the results show that the reduction of internal heat loads as well as active switching of blinds and lights by office occupants reduces CO_2 emissions by a larger magnitude than the use of an adaptive model for cooling set points.

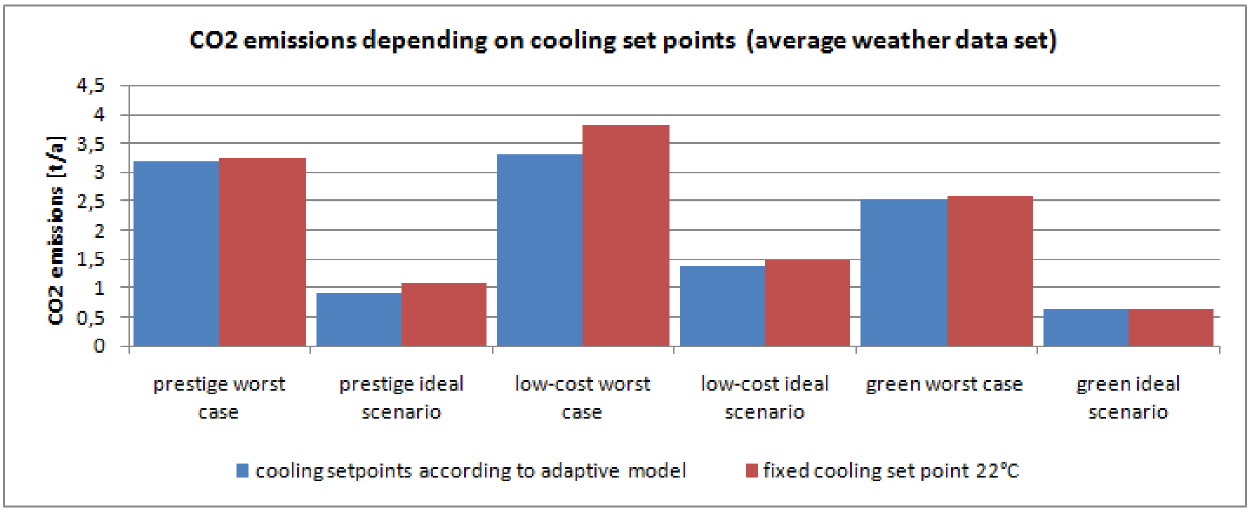


Figure 122: CO_2 emissions when adjusting the cooling set points in a mixed mode office according to the adaptive thermal comfort model of EN 15251, compared to the use of a fixed cooling set point 22°C

Distribution of cooling loads and room temperatures over the year

In this study, the adaptive model of EN 15251 [5] has been applied for mixed mode context, since currently there is no adaptive model targeted at mixed mode buildings available. Although this model was designed for naturally ventilated buildings, the distribution of cooling loads and comfort temperatures has been examined in order to draw some conclusions regarding the applicability of the model in mixed mode context.

Figures 123 - 125 show the distribution of cooling loads for the prestige, the low-cost and the green building configuration over the year. Cooling set points have been adjusted on a monthly basis, in order to meet the requirements of the adaptive thermal comfort model of EN 15251, based on exceeding criteria of 5% per year.

It can be observed, that the magnitude of cooling loads differs significantly between the different configurations. Highest cooling loads occur in the prestige configuration, which is due to the internal shading in combination with a large window area strongly exposed to solar heat gains. Medium cooling loads occur in the low-cost configuration, due to a high u-value of the glazing despite the small window area. Lowest or no cooling loads occur in the green building, which is best protected from solar heat gains. Thus it can be concluded, that the general magnitude of cooling loads, as well as the length of cooling periods in mixed mode buildings is correlated to the level of protection from solar heat gains.

Additionally, although the general magnitude of cooling loads is predefined by the building, significant differences occur for the worst case and the ideal scenario of internal heat loads and occupant behaviour. The use of an ideal instead of the worst-case scenario has two effects. It reduces the magnitude of cooling loads and additionally it shortens the length of cooling periods.

Regarding the peak cooling loads, it can be observed, that their occurrence within the year differs significantly for the three investigated building configurations. While for the green building configuration, they occur in summer, for the prestige configuration they occur in winter and for the low cost building in summer or autumn depending on the scenario of use. However, typically peak cooling loads are expected in summer and especially during heat waves. This is only the case for the green building configuration. For the prestige and low-cost configurations, solar heat gains are constantly higher throughout the year so the additional cooling load needed to meet the lower comfort limits in winter exceeds the magnitude of additional cooling loads needed in summer during heat waves for higher comfort limits.

Concerning the influence of different weather data sets, the results show, that the use of a hot instead of the average weather data set, significantly extends the cooling periods needed to meet the requirements of adaptive thermal comfort category III.

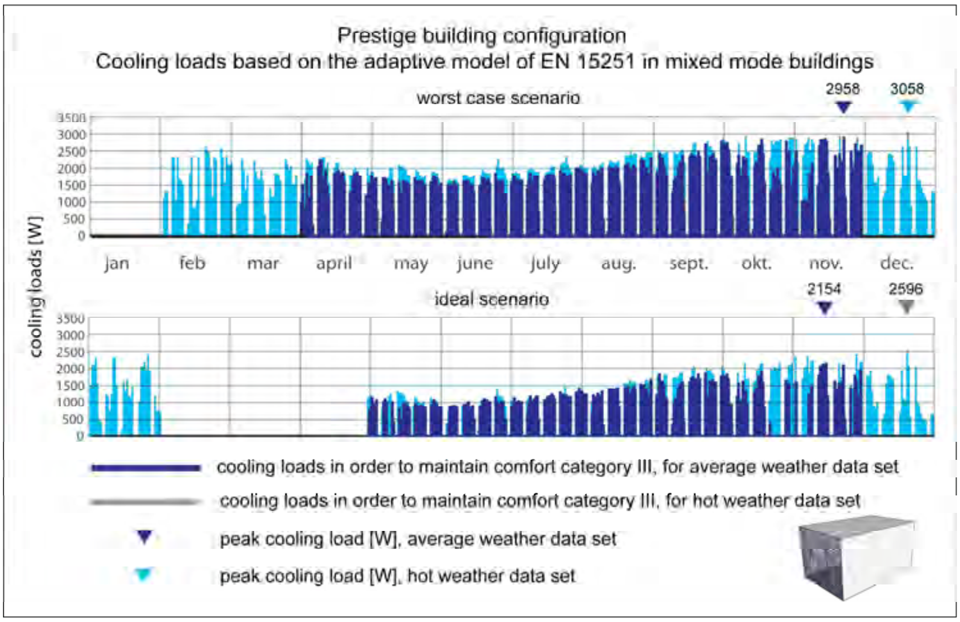


Figure 123: “Prestige” building configuration, distribution of cooling loads for the ideal and worst-case scenario of occupant behaviour and internal heat loads, when adjusting the cooling set points according to the adaptive thermal comfort model of EN 15251

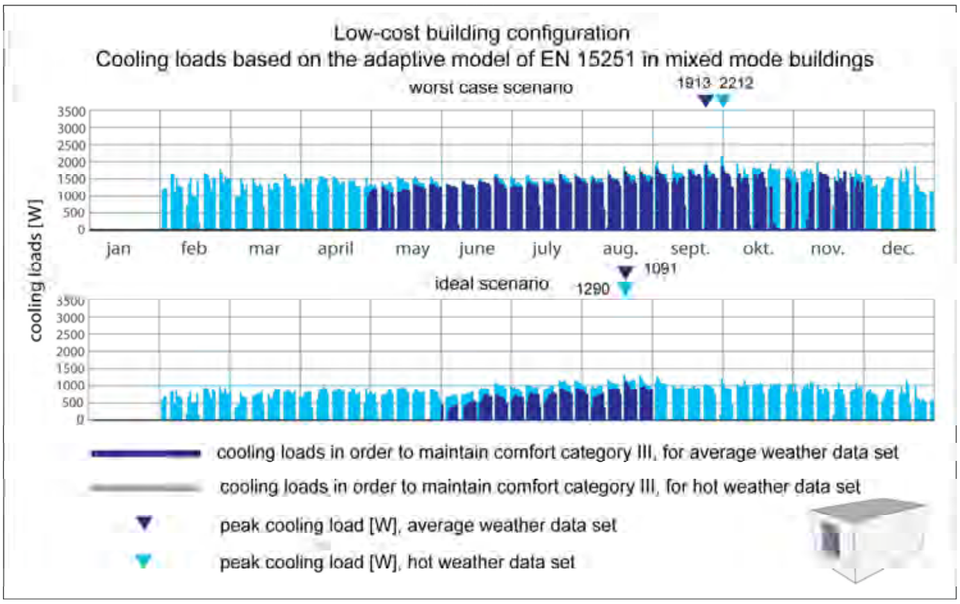


Figure 124: “Low-cost” building configuration, distribution of cooling loads for the ideal and worst-case scenario of occupant behaviour and internal heat loads, when adjusting the cooling set points according to the adaptive thermal comfort model of EN 15251

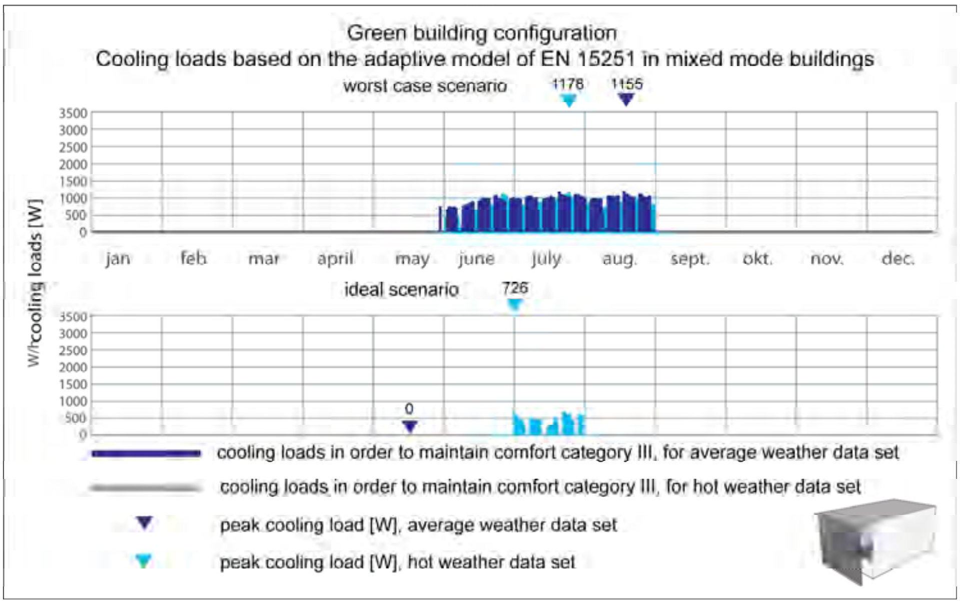


Figure 125: "Green" building configuration, distribution of cooling loads for the ideal and worst-case scenario of occupant behaviour and internal heat loads, when adjusting the cooling set points according to the adaptive thermal comfort model of EN 15251

Comparing the length of the cooling periods with the cooling periods reported by office occupants in the field study (chapter 2.1.5), shows a correlation in case of the average weather data set. The reported cooling periods in the field study ranged maximum from April to October, minimum from June to July and in average from June to September. For the prestige configuration as well as for the low-cost configuration in combination with the worst case scenario, the cooling periods are longer than reported in the field study, but it has to be considered that the modelled rooms are not similar to the offices in the field study. Therefore, it might be concluded that in combination with the average weather data set, the application of the adaptive thermal comfort model of EN 15251 [5] in mixed mode buildings could lead to realistic results regarding the length of cooling periods. However, in combination with the hot weather data set including heat waves, the results are different. For the green building configuration, the use of the hot weather data set leads to smaller changes in magnitude and length of cooling periods, since the building properties are robust against thermal influences. For the prestige and the low-cost building scenario in contrast, cooling periods are extended to almost the full year. Although the hot weather data set includes heat waves in summer, the differences compared to the average weather data set occur in winter.

This effect is further examined in figures 126 - 128, where room air and outside air temperatures are plotted against comfort temperatures for the average weather data set. The same characteristics like for the naturally ventilated configuration (chapter 4.1) can be observed, with an occasionally large temperature amplitude within a short time scale during winter. Since this characteristic is similar for all configurations, although with a different magnitude, it can be concluded, that it is caused by the interaction of the outside climate and the u-value of the facade. However, the modelled facade constructions are typical for the Athens climate. A lower u-value in winter could reduce the magnitude of the temperature amplitude, but it would reduce the opportunity for night cooling during summer in configurations where no night ventilation in possible.
Generally, the results show, that only for the green building configuration, room temperatures are not or only rarely exceeding the comfort limits in winter. For the low-cost and the prestige configuration, which are more common in the Athens context, they are occasionally but significantly exceeding the

limits. As soon as these exceeding hours sum up to 5%, cooling is needed for the rest of the year in order to maintain adaptive thermal comfort according to EN 15251 [5]. For the hot weather data set, these exceeding hours occur more frequently, so longer cooling periods are be necessary to meet the comfort limits.

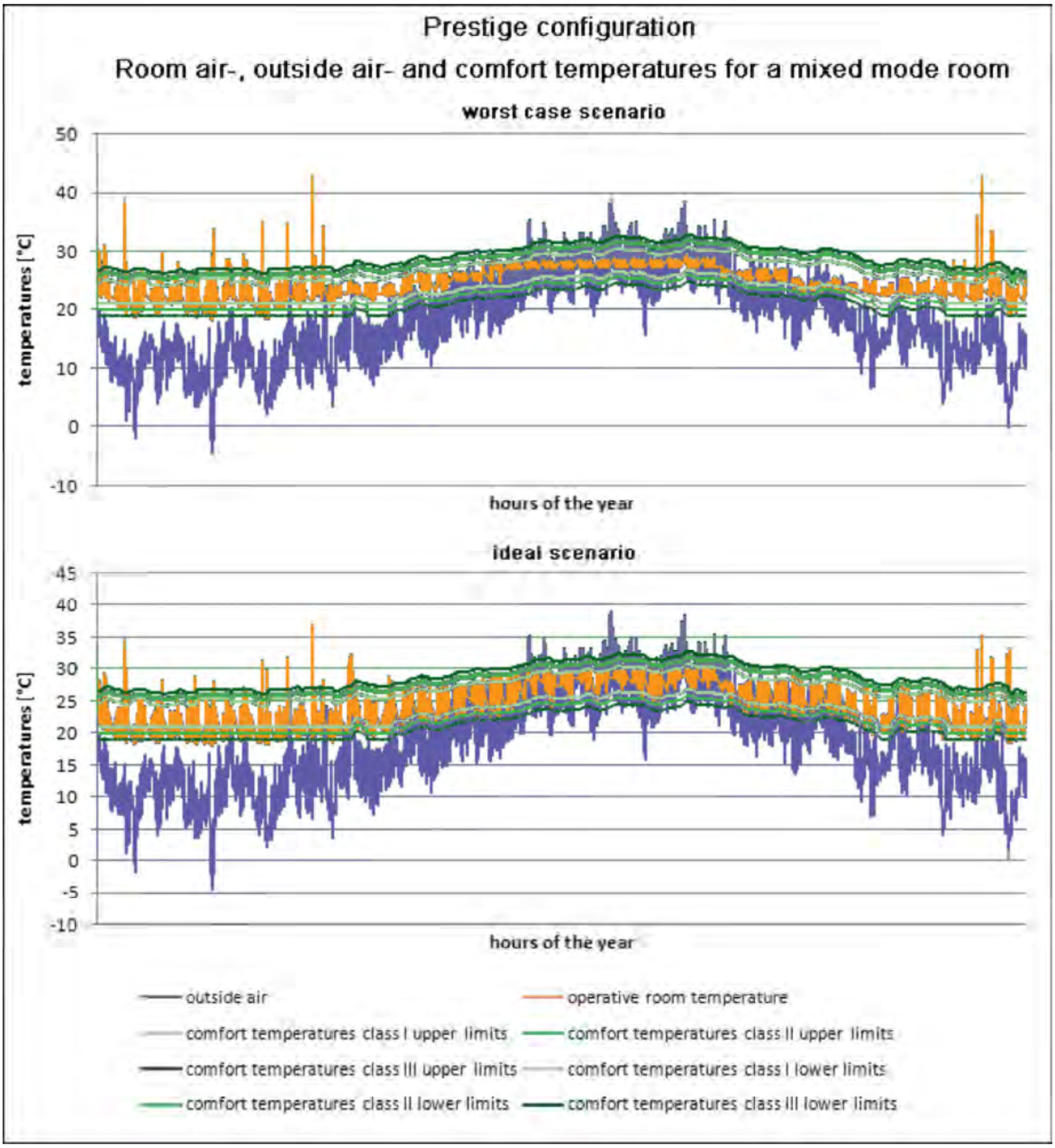


Figure 126: Prestige building configuration, average weather data set, room- and outside air temperatures, when adjusting the cooling set points in a mixed mode office according to the comfort limits of the adaptive model according to EN 15251

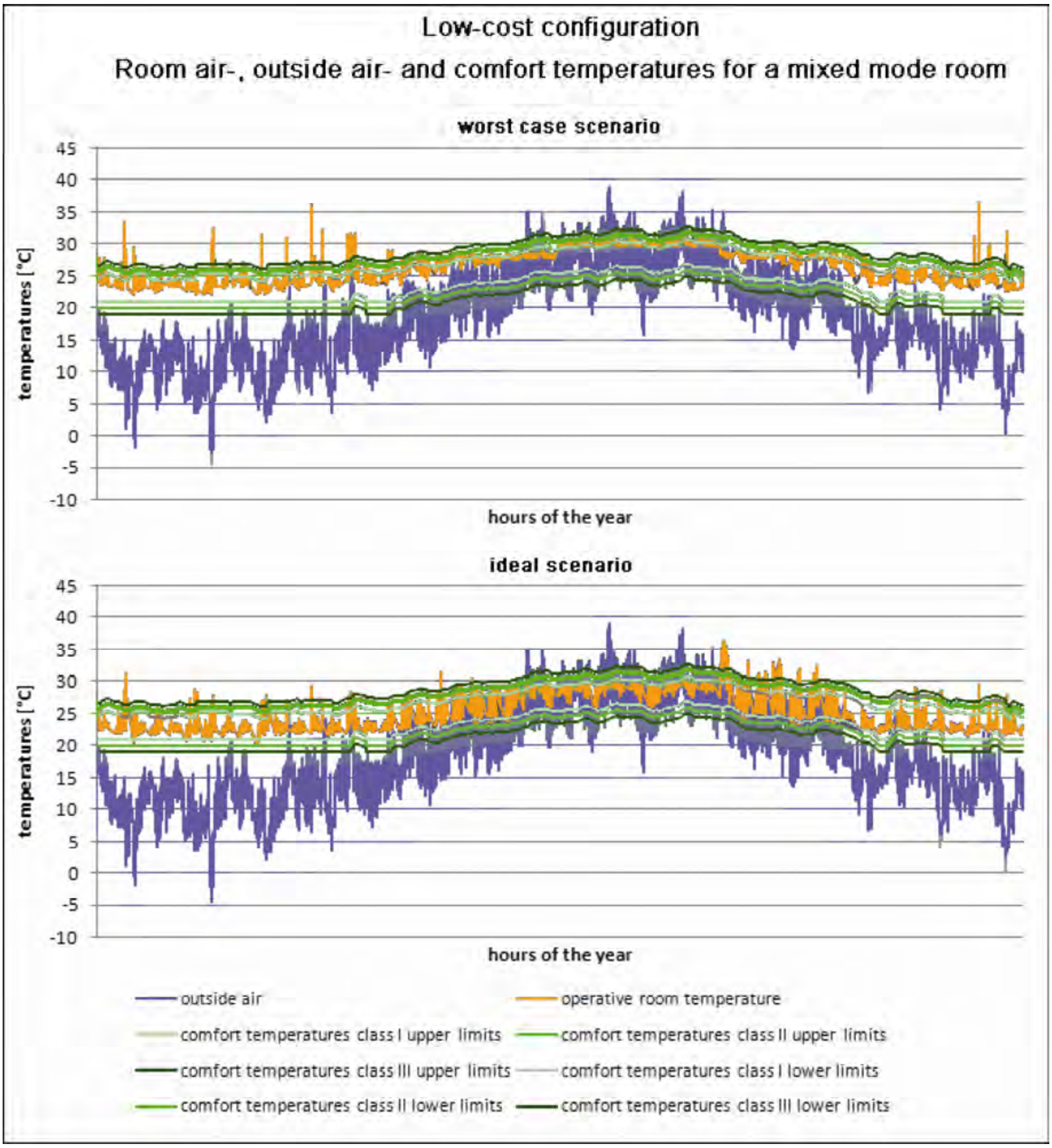


Figure 127: Low-cost building configuration, average weather data set, room- and outside air temperatures, when adjusting the cooling set points in a mixed mode office according to the comfort limits of the adaptive model according to EN 15251

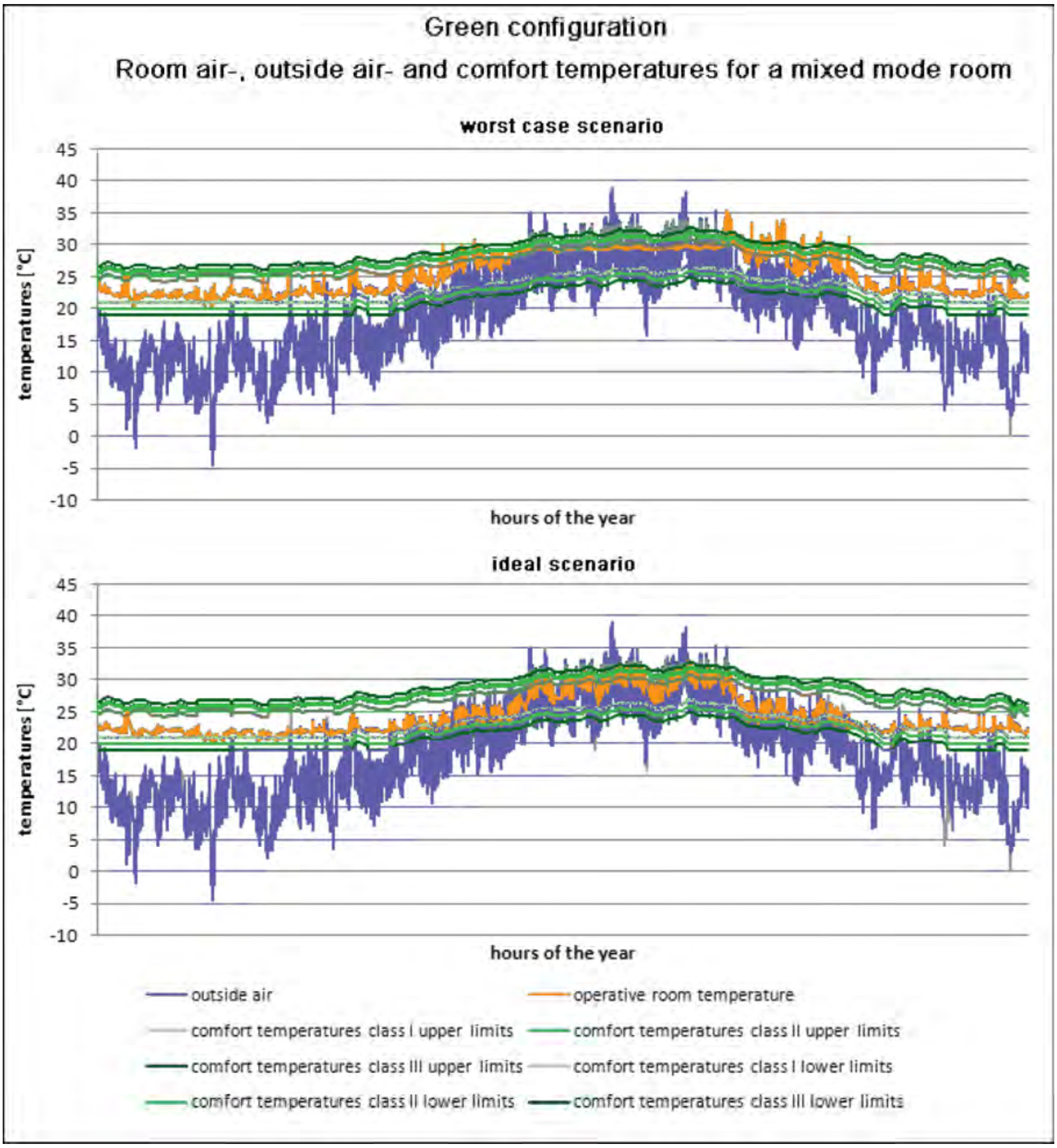


Figure 128: Green building configuration, average weather data set, room- and outside air temperatures, when adjusting the cooling set points in a mixed mode office according to the comfort limits of the adaptive model according to EN 15251

Comfort limits

Following the requirements of Greek regulations, this study is focused on maintaining thermal comfort according to comfort category III of EN 15251-2007 [5]. However the cooling set points needed to meet the requirements of comfort category II and I have been tested as well.

The results show that using monthly-adjusted cooling set points for several configurations of building and scenarios of use in this case study it was very difficult to meet the requirements of thermal comfort category I.

This is due to the comfort temperature limits in spring and autumn. In case of less optimized configurations with higher internal heat loads, and without night ventilation the upper limits are exceeded (figure 129).

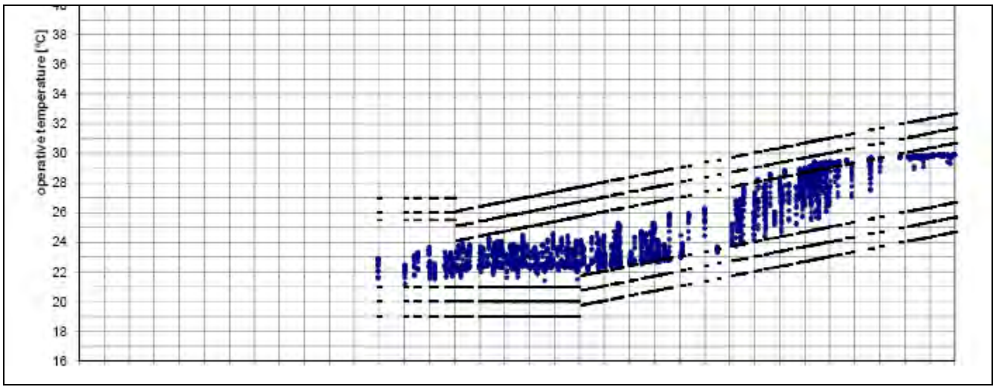


Figure 129: Optimised building configuration without night ventilation, the operative temperatures exceed the upper comfort limits

And in case of an optimized configuration with low internal heat loads using night ventilation, the lower comfort limits are exceeded (figure 130). This characteristic can be observed for comfort category II and III as well, although with a lower magnitude. Since it could penalize optimized internal heat loads and the use of night ventilation, this could indicate that the comfort limits during spring and autumn are relatively tight for the climate of Athens. Further research would be needed to investigate in how far occupants prefer temperatures below the current comfort limits in the first morning hours, in order to reduce peak temperatures during the day.

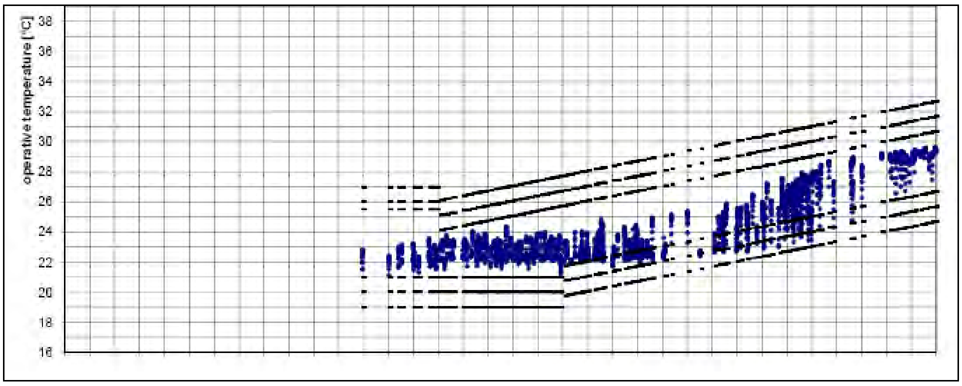


Figure 130: Same configuration as in figure 129 but using night ventilation, the operative temperatures exceed the lower comfort limits

Additionally concerning comfort limits, the influence of a hot weather data set including heat waves has been compared with the standard weather data set. Figure 131 shows the comfort limits for category III for the average and the hot weather data set, as well as maximum day and the minimum night temperatures for each data set.

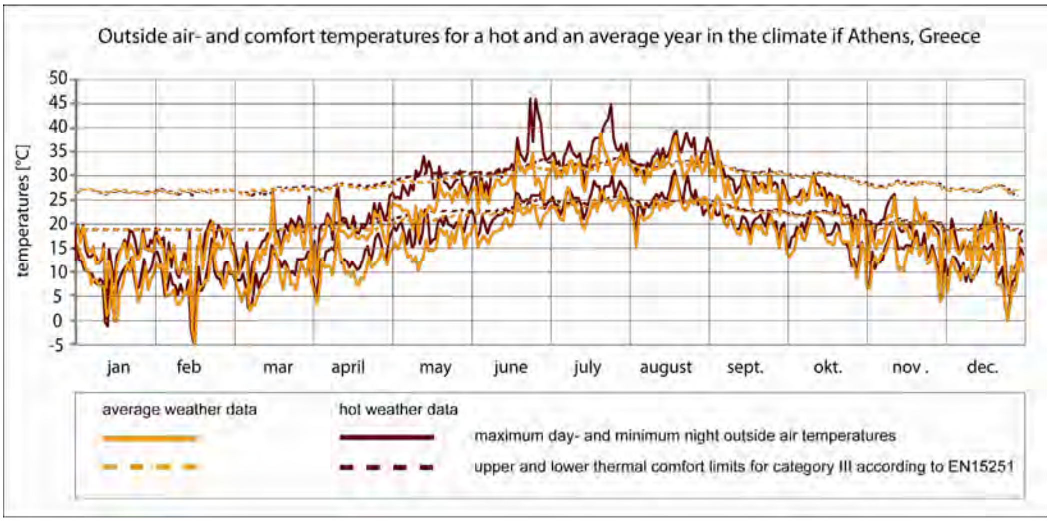


Figure 131: Comfort temperatures according to the adaptive model of EN 15251, for an average compared to a hot weather data set including heat waves for Athens, Greece

The distribution of comfort temperatures shows, that for the hot year, the distribution of comfort temperatures is almost similar to the average year. Only during heat waves, comfort temperatures show slightly stronger „peaks“, compared to the average year. Additionally a deviation of time between the peak temperatures of heat waves and the peaks of comfort temperatures can be observed. Comfort temperature peaks delay approximately 1 - 2 days, so for the hot data set it peaks when the heat wave is already ending. This corresponds with findings of de Dear [129] who investigated different calculation methods for comfort temperatures and reported a time lag when comfort is calculated based only on preceding days excluding „today“. According to EN 15251-2007 [5], the running mean temperature for a day is also based on mean temperatures for the day before and preceding days, excluding the present day. This exclusion considers the fact that for the integration in building management systems, temperatures for the current day cannot be known in advance. However for use in building simulation, complete data sets are available and „today‘s“ temperatures could be considered. Further research would be needed, to investigate in how far heat waves can or should be considered in comfort temperature limits.

Conclusions regarding adaptive thermal comfort models

According to EN15251, comfort category I is targeted at “spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons“. These persons are not typical occupants in offices. Additionally, according to Arens et al. [130], comfort category I does not lead to higher acceptability of comfort than category II and III. As demonstrated above it was very difficult to maintain comfort category II and I in the climate of Athens, even by using adaptive cooling set points. For several configurations, comfort temperatures exceeded not only the upper, but also the lower comfort limits, especially in morning and evening hours during spring and autumn. This is caused by the facade u-value and the resulting heat loss during colder outside temperatures. However, these facade constructions are typical in Athens. This leads to the question, whether comfort in Athens offices is lower than in moderate climates, or if office occupants in Athens are more tolerant regarding the temperature amplitude in their office. Further field research would be needed. Nevertheless, the results from the field study in mixed mode Athens offices indicate, that office occupants in Athens might be more tolerant regarding varying indoor temperatures. This could indicate that in the context of Athens, just one comfort category, category III might be sufficient. The requirements of this category could be met in this study using cooling set points within the acceptable range reported in the field study (chapter 2.1).

However, the 5% thermal comfort exceeding criteria implemented in EN 15251 might not be directly applicable in mixed mode context in Athens. It has been designed for naturally ventilated buildings, where exceeding hours can occur at a high magnitude predominantly during summer. In mixed mode buildings during summer the cooling system will be switched on and maintain the comfort limits, so exceeding hours can only be expected outside cooling period in spring autumn and winter. In the climate of Athens, exceeding characteristics are different during summer and during winter. During summer continuous exceeding hours throughout a longer period are likely, during winter they occur only occasionally for a very short period. This indicates that exceeding criteria should differ for naturally ventilated and mixed mode buildings, as well as for winter and summer. This corresponds with Kalz et al. [72] who proposed comfort evaluation related to season. Since the 5% criteria even on a yearly basis is very sensitive towards different weather data sets, it can be concluded, that a more flexible exceeding criteria, considering the length as well as the magnitude of overheating, might be more suitable in the context of Athens. Further research would be needed.

Additionally, results of the field study (chapter 2.1) indicate that there seem to be different levels of thermal comfort expectations among office occupants. In order to mitigate the climate change, one group of occupants would accept a maximum of 5% exceeding hours and a second group up to 20% and more. This variations show, that temperature preferences are more likely to be expressions of habits rather than thermal necessities. However, habits alter with lifestyle, and the habit of being used to low cooling temperatures, or a fixed cooling set point of 22°C might be changeable towards higher set points in the context of a green lifestyle.
Another influence, which, according to the field study, would cause a higher acceptability for higher room temperatures, is a more relaxed company policy, especially in terms of flexible working times and dress code. However, as indicated in the literature [33, 131, 132, 133], psychological parameters, like the satisfaction with the task and the social working environment might play an important role as well. Further research would be needed. However, this might indicate, that a further categorisation of comfort levels could be based on just one set of temperature limits, but with adjustable exceeding criteria according to the context of the building and its occupants.

Another influence reported in the field study was the occupant’s tolerance between the preferred and maximum acceptable cooling set point of 2-3K. This might indicate, that typical cooling set points of 22°C, which were reported as the preferred cooling temperature, are more an expression of a habit, than thermal needs. Assuming that this habit developed at the beginning of air conditioning as an expression of a certain lifestyle, it could be interesting in how far lifestyle would have to change towards a more relaxed attitude on comfort temperatures and exceeding criteria.

A future thermal comfort standard for mixed mode as well as naturally ventilated office buildings in the context of Athens could be based on one set of comfort limits, but with an adjustable classification in terms of exceeding criteria. This criterion could consider thermal behaviour of buildings according to local climate characteristics, the influence of internal heat loads and occupant behaviour, levels of expectations of occupants, and social parameters like the strictness of company policy. Further research would be needed.

CHAPTER 5, CONCLUSIONS

5.1. Conclusions

Aim of this work was to evaluate the range of influence of building design, occupants and heat waves on thermal comfort, visual comfort and greenhouse gas emissions in offices in the Mediterranean climate of Athens, Greece. The potentials and limits for optimisation of these parameters have been investigated in the context of naturally ventilated and mixed mode offices.

An ideal and worst case scenario for occupant's influences

The variability of occupant behaviour has been approached by exploring the range of influence, rather than predicting specific occupant behaviour precisely. An ideal and worst case scenario has been developed for this work to reflect his range. By using these scenarios, it is possible to demonstrate the variability of occupant's influences on comfort and greenhouse gas emissions in offices. Additionally it allows for a comparison of the magnitude of occupant's influence with that of the building design and the climate.

Thermal comfort

The results indicate that for naturally ventilated, as well as for mixed mode offices, the predominant influence on thermal and visual comfort is building design. For the three investigated configurations, the percentage of working time fulfilling the criterion according to EN 15251, category III varies from around 50 to almost 100%. A green or robust building, well protected against solar heat gains but allowing for high daylight levels, and well balancing thermal loads, contributes significantly to the provision of thermal and visual comfort. Green buildings are also least affected by the varying influences of occupants. Table 35 illustrates the influence of building design on adaptive thermal comfort according to EN 15251 for naturally ventilated buildings, and the sensitivity to different occupant scenarios.

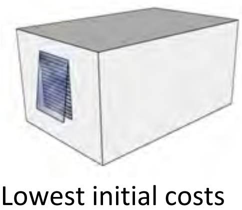
Influence of building design on EN 15251 adaptive thermal comfort in naturally ventilated offices in Athens, Greece			
Building design variation	 Prestige	 Lowest initial costs	 green
% of working time fulfilling EN 15251 adaptive thermal comfort model, category III, for average influence of occupants	54%	66%	94%
Variability due to occupant influences (worst / ideal scenario)	+/- 10%	+ / - 15%	+ / - 5%

Table 35: Influence of building design on EN 15251 adaptive thermal comfort in naturally ventilated offices in Athens, Greece

In mixed mode offices, where summer thermal comfort is maintained by the cooling system, building design also predefines the magnitude of peak cooling loads (table 36), and thus influences the dimensioning of the cooling system. Peak cooling loads for the green configuration are less than 1/3 of those for the prestige configuration. The influence of occupants seems strongest for the green configuration. However, it has to be considered that here the occupant's influence is least superposed by solar heat gains, and absolute peak cooling loads are still lower than for the other configurations.

Influence of building design on peak cooling loads in mixed mode offices in Athens, Greece			
Building design variation	 Prestige	 Lowest initial costs	 green
Peak cooling loads [W] for a fixed cooling set point 22°C	2710	1800	740
Variability due to occupant influences (worst / ideal scenario)	+/- 10%	+ / - 15%	+ / - 100%

Table 36: Influence of building design on peak cooling loads in mixed mode offices in Athens, Greece

CO2 emissions

Unlike for thermal comfort, the predominant influence on greenhouse gas emissions and running costs to be paid by the tenant, is the use of the building by its occupants. The use of energy saving office equipment, i.e. notebooks and LCD screens instead of desktop computers and CRT screens significantly reduces internal heat loads and CO2 emissions. Additionally, an energy efficient lighting system and active use of blinds and lights by occupants reduces the resulting energy consumption for lighting. The three investigated configurations show a strong correlation of total CO2 emissions with daylight provision. This leads to highest values for greenhouse gas emissions and lowest occupant influence for active shading control for the "low-cost" variation with the smallest window area.
Table 37 shows the resulting CO2 emissions for the three configurations of naturally ventilated offices in Athens, and their variability due to varying occupant scenarios.

CO_2 emissions for different naturally ventilated offices in Athens, Greece, and the variability due to occupant's influences			
Building design variation	 Prestige	 Lowest initial costs	 green
CO_2 emissions [t/a], with average influence of occupants	1,49	2,04	1,49
Variability due to different occupant influences (worst / ideal scenario)	+ / - 60%	+ / - 40%	+ / - 60%

Table 37: CO_2 emissions for different naturally ventilated offices in Athens, Greece, and the variability due to occupant's influences

Concerning greenhouse gas emissions caused by mixed mode offices in the climate of Athens, the Coefficient of Performance (COP) of the cooling system is another crucial parameter. The comparison between the prestige and the low-cost variation shows, that in case of an energy-efficient cooling system, it can be more effective in terms of CO_2 emissions, to decrease artificial lighting by increasing daylighting, even though additional cooling might be needed to maintain thermal comfort. However, a large window area above the work plane, a shading system allowing for daylighting even in activated condition, and active use of blinds and lights by occupants are required.
Table 38 shows the resulting CO_2 emissions for the three configurations of mixed mode offices in Athens, and their variability due to varying occupant scenarios.

CO_2 emissions for different mixed mode offices in Athens, Greece, and the variability due to occupant's influences			
Building design variation	 Prestige	 Lowest initial costs	 green
CO_2 emissions [t/a], with average influence of occupants, and fixed cooling set point 22°C	2,18	2,49	1,61
Variability due to different occupant influences (worst / ideal scenario)	+ / - 50%	+ / - 40%	+ / - 60%

Table 38: CO_2 emissions for different mixed mode offices in Athens, Greece, and the variability due to occupant's influences

Heat waves and weather data sets

An exceptionally hot summer like in Athens in 2007, which as a first approximation could reflect characteristics of a future climate, is likely to reduce adaptive thermal comfort in naturally ventilated offices by around 10% for all investigated configurations. For the prestige configuration, this impact on thermal comfort is also strongly affected by the influence of occupants, whereas this effect is almost negligible for the green configuration. It can be concluded that green buildings, are least affected by a hot summer like in 2007 and by different occupant scenarios. Table 39 shows the influence of a hot summer like in 2007 on thermal comfort according to EN 15251 in comparison to an average summer like in 2005.

Influence of a hot summer with heat waves on EN 15251 adaptive thermal comfort in naturally ventilated offices in Athens. The data are based on a comparison of the hot summer 2007 and the average summer 2005.			
Building design variation	 Prestige	 Lowest initial costs	 green
Reduction in % of working time meeting the EN 15251 adaptive thermal comfort criteria for category III, for average occupant's influence	-13%	-12%	-9%
Variability due to different occupant influences (worst / ideal scenario)	+ / - 7%	+ / - 3%	+ / - 1%

Table 39: Influence of a hot summer with heat waves on EN 15251 adaptive thermal comfort in naturally ventilated offices in Athens. The data are based on a comparison of the hot summer 2007 and the average summer 2005.

In case of mixed mode buildings, thermal comfort in summer is maintained by the cooling system. Additional cooling is therefore directly affecting the CO2 emissions for cooling. This effect varies from 2% for the green configuration to 14% for the low cost variation (table 40). The concurrent relative influence of occupants is largest for the green configuration and smallest for the low cost variation.

Influence of a hot summer with heat waves on CO2 emissions in mixed mode offices in Athens. The data are based on a comparison of the hot summer 2007 and the average summer 2005.			
Building design variation	 Prestige	 Lowest initial costs	 green
Increase in CO2 emissions, fixed cooling set point 22°C	+12%	+14%	+2%
Variability due to different occupant influences (worst / ideal scenario)	+ / - 48%	+ / - 36%	+ / - 60%

Table 40: Influence of a hot summer with heat waves on CO2 emissions in mixed mode offices in Athens. The data are based on a comparison of the hot summer 2007 and the average summer 2005.

These results show, that an exceptionally hot summer like in Athens in 2007, significantly influences thermal comfort in naturally ventilated- and CO2 emissions in mixed mode offices. The main difference between the summer of 2005 and 2007 was the occurrence of heat waves in 2007, which accounted for approximately 5% of the working time. Due to the extreme temperature characteristics of heat waves, in hot summers like in 2007, offices are likely not to meet the exceeding criterion for thermal comfort according to EN 15251. Consequently, additional cooling would be needed, and thermal comfort would have to be evaluated according to the static model. Accounting for heat waves in the context of EN 15251 is therefore likely to encourage the preventative installation of cooling systems.
However, as observed in the field study in Athens conducted for this work, a large majority of occupants would accept higher temperatures in their offices if they would be able to negotiate with their employers about special working conditions during summer / heat waves. The most mentioned issues to negotiate about were flexible working times and a relaxed dress code. Additionally, the field study showed a large variability in the range of tolerance regarding overheating hours for different occupants. These observations support the importance of contextual and psychosocial variables in comfort evaluation as stated in literature [13, 33, 133, 134]. Although further research would be needed, they indicate a potential to relax the exceeding criteria of the EN 15251 adaptive thermal comfort standard, by considering contextual and psychosocial parameters.

From the comparison of two different weather data sets for the climate of Athens, Greece, it can be concluded, that weather data sets for use in building simulation should be carefully chosen according to the focus of the study. The comparison of a building's performance, based on different climate scenarios, can help building designers and their clients to define the desired comfort levels. If applied in early design stages, it can also help to balance comfort expectations and greenhouse gas emissions, in order to encourage sustainable solutions.

EN 15251 adaptive thermal comfort model in a Mediterranean climate

The initial study for the climate of Hamburg, Germany, indicated difficulties to meet the requirements according to the EN 15251 adaptive thermal comfort model for south oriented rooms with high internal heat loads. This led to the question in how far it is possible to meet these requirements in a Mediterranean climate like Athens, Greece. From the building design configurations investigated in this work, only the green building with an ideal user scenario and only in case of the average weather data set for the year 2005, could meet the requirements for category III according to EN 15251. Following this norm, all other configurations would need additional cooling to provide sufficient comfort. As such, they would have to be evaluated according to the static comfort model, and in the context of climate change, this would lead to increasing CO_2 emissions for cooling. However, according to EN 15251, adaptive comfort limits above 25°C running mean outdoor temperature are based on a limited database. Since there are naturally ventilated buildings in Athens, further research would be needed, to investigate if occupants in these buildings are generally uncomfortable, or if they are more tolerant towards hot temperatures than assumed in EN 15251.

Additionally, the categorisation according to EN 15251 is designed for different kinds of buildings. In office context, it might not be necessary to meet the requirements for category I, targeted at fragile or sick persons. Comfort evaluation in this work has been based on category III, which is recommended for Greek public buildings. However, the distribution and magnitude of exceeding hours shows, that if the comfort limits of category III are exceeded, those of categories II and I are usually exceeded as well. Different building design and occupants, influence room temperatures by a magnitude, strongly exceeding the difference between the comfort limits of the three comfort categories according to EN 15251. This observation indicates, that in office context in a Mediterranean climate, just one comfort category might be sufficient. Further differentiation could then be provided by different exceeding criteria. Further research would be needed.

Savings potential of adaptive cooling set points

The majority of office buildings in Mediterranean climates are operated in mixed mode, using a cooling system only during the hottest period of the year and otherwise they are naturally ventilated. According to EN 15251, these buildings should be evaluated according to the static model, based on constant comfort temperatures. However, literature indicates, that occupant's preferences in mixed mode buildings might be more relaxed [5] or comparable to those in naturally ventilated buildings [4]. In this work, the savings potential for greenhouse gas emissions for the hypothetical application of the EN 15251 adaptive thermal comfort model on cooling set points in mixed mode offices has been evaluated. The results show, that adaptive cooling set points according to the comfort limits of EN 15251 can reduce CO_2 emissions in mixed mode offices up to 6%. However, at the same time the variability due to occupants is predominating, ranging from +/-40 to +/-60% (table 41).

Influence of adaptive cooling set points according to the EN 15251 adaptive model on CO_2 emissions, compared to fixed cooling set point 22°C			
Building design variation	 Prestige	 Lowest initial costs	 green
Reduction in CO_2 emissions when using adaptive cooling set points according to EN 15251 instead of the fixed set point 22°C	-6%	-6%	-2%
Variability due to different occupant influences (worst / ideal scenario)	+ / - 50%	+ / - 40%	+ / - 60%

Table 41: Influence of adaptive cooling set points according to the EN 15251 adaptive model on CO_2 emissions, compared to fixed cooling set point 22°C

Table 42 shows the influence of adaptive instead of fixed cooling set points on peak cooling loads, also influencing the dimensioning of the cooling system. Adaptive cooling set points can reduce peak cooling loads by around 20% for the green and the low cost configuration, while the influence on the prestige variation is rather small. This influence can be superposed by varying occupant's influence ranging from approx. 10% for the prestige variation to 100% for the green variation.

Influence of adaptive cooling set points according to the EN 15251 adaptive model on peak cooling loads, compared to fixed cooling set point 22°C			
Building design variation	 Prestige	 Lowest initial costs	 green
Reduction in peak cooling loads when using adaptive cooling set points according to EN 15251 instead of the fixed set point 22°C	-3%	-17%	-22%
Variability due to different occupant influences (worst / ideal scenario)	+ / - 9%	+ / - 16%	+ / - 100%

Table 42: Influence of adaptive cooling set points according to the EN 15251 adaptive model on peak cooling loads, compared to fixed cooling set point 22°C

Daylighting and view

This work demonstrates, that in case of active use of blinds and lights by occupants, the improvement of daylighting can significantly contribute to a reduction of greenhouse gas emissions in offices. As can be observed from the simulations, in the climate of Athens, venetian blinds are activated for approximately 70% of the working time of the year, either due to glare, overheating protection or both. This value differs only slightly with window size or facade orientation. An unobstructed view is therefore only available for 30% of the annual working time. Due to the high external illuminance in the Athens climate however, it is still possible to achieve daylight autonomy even with activated blinds, as long as the slats are not closed. Daylight autonomy increases, with window area above the work plane and the more opened the slat angle is adjusted. It also varies with orientation, with highest values on the south side, followed by east, west and north.
For naturally ventilated as well as mixed mode offices, it can be observed, that in case of active control of lights and blinds, total CO2 emissions caused by the office decrease, the more opened the slat angle is adjusted. For naturally ventilated offices, this potential has to be balanced with glare and overheating protection. In mixed mode offices, as long as permitted for glare protection, it can be beneficial in terms of CO2 emission savings, to increase daylighting to the disadvantage of thermal comfort, as long as the coefficient of performance of the cooling system is better than that of the lighting system. It can be concluded, that large window areas are not necessarily a disadvantage in a Mediterranean climate, as long as an effective shading system is used. Additionally, the choice of the shading system is crucial, and solutions should be preferred, which allow for high daylight levels and view quantity in activated mode.

Conclusions regarding building practice and comfort policy

In the context of climate change, the construction of green buildings should be encouraged and facilitated. As indicated by the field survey, especially for office buildings, mechanisms of the real estate market play an important role. Office buildings are often built by an investor, for rent to a tenant. Since running costs for comfort (heating and cooling) are paid by the tenant, the investor's return rate is increased by minimising the initial costs of the building. This encourages conventional solutions, and more expensive energy saving alternatives are only likely to be considered if they also increase the return rate. Further research would be needed, to investigate in how far the attractiveness of green buildings on the real estate market can be increased.

Concerning the reduction of greenhouse gas emissions, the influence of occupant behaviour, energy efficient lighting systems as well as office equipment is crucial, and in office context predominating the influence of building design. In contrast to building design, which is most likely to be altered in early design stages or in case of refurbishment, occupant behaviour and occupant's use of office equipment can be influenced on a short time scale. Further research would be necessary, to investigate, how the awareness of occupants for their range of influence on a company as well as on individual level can be increased, and energy efficiency encouraged.

In the context of exceptionally hot summers like in Athens in 2007, which might be a first approximation to a future climate, it will be very difficult to maintain adaptive thermal comfort in naturally ventilated offices in a Mediterranean climate. Already today, the most common solution to guarantee a certain comfort level in offices, refers to the dimensioning of the cooling system. In order to reduce the related energy consumption for cooling, this work indicates a climate change mitigation potential, by increasing the flexibility in the adaptive thermal comfort standard according to EN 15251 for offices. Although further research and validation would be necessary, indications derived from this work refer to:

- the consideration of the variability of the influence of occupants in offices, e.g. by a simplified comfort categorisation based on only one category, while further differentiation can be implemented in the exceeding criterion
- the consideration of local climate characteristics like heat waves in the definition of the exceeding criterion
- the extension of the adaptive thermal comfort model towards more contextual and psychosocial parameters

It can be concluded, that in order to increase sustainability of office buildings, the right balance between building design, occupants and their comfort expectations, and the local climate characteristics is crucial. The comparison of building simulation results based on weather files reflecting different climate change characteristics, can give useful information regarding the thermal and energy performance throughout the building's life cycle.

Optimisation strategies will be most successful considering the context of a specific building and focusing on the balance of all influencing parameters, rather than on optimisation of single parameters separately.

5.2. Suggestions for further research

This work revealed several research fields, which would be worth further investigation. Corresponding research ideas derived from this study are listed below.

- This work demonstrates, that green buildings can contribute significantly to the provision of satisfying comfort and the reduction of greenhouse gas emissions in offices. However, the field study among architects in Athens indicated, that mechanisms of the real estate market are the main obstacle for the development of green buildings. Further research will be needed, to investigate how green office buildings can be promoted on the real estate market.

- In terms of greenhouse gas emissions in office buildings, the influence of occupants is predominant. This refers especially to active use of blinds and lights as well as to the choice of office equipment. Green occupants are a benefit for green buildings, but also in case of refurbishment, where the optimisation potential of the building can be limited, green occupants can significantly contribute to a reduction of CO2 emissions. Further research would be needed, to investigate how the awareness of occupants for their influence on climate change mitigation can be encouraged, and how the occupant's influence on greenhouse gas emissions can be better considered in building codes.

- This work shows, that the weather data set for use in building simulation should be carefully chosen according to the focus of the study. Common standard weather data are not likely to be useful to predict the thermal performance of a building in a future climate. However, weather data sets including climate change scenarios and heat island effects are often not available in a file format suitable for building simulation. Further development of suitable weather data sets would be necessary.

- This study indicated that effectiveness of natural ventilation and the possibility for night ventilation are related to window size, type and placement within the facade, and the usability and accessibility of window controls. Further investigation on window- or facade configurations offering maximum flexibility to adjust openings according to occupant's preferences could be useful.

- As indicated by this work, an energy efficient cooling system can contribute significantly to a reduction of greenhouse gas emissions in mixed mode or air-conditioned buildings. Further research will be needed, to improve the coefficient of performance of cooling systems.

- In naturally ventilated buildings in the Mediterranean climate of Athens, it is difficult to meet the criteria of the adaptive thermal comfort model according to EN 15251. Further research would be needed to investigate, if comfort levels in naturally ventilated offices in Athens are lower than in moderate climates, or if occupants are more tolerant regarding room temperatures, than their counterparts in a moderate climate are.

- In this work, the hypothetical application of comfort limits according to the EN 15251 adaptive thermal comfort model on cooling set points in mixed mode offices has been investigated. Although the range of influence of occupants is predominant, the results indicate a potential for greenhouse gas emission savings, when cooling is controlled according to an adaptive model instead of fixed cooling set points. Further research would be needed to validate the applicability of adaptive cooling set points in field studies in mixed mode buildings.

- Considering the history of thermal comfort evaluation and office building design, it can be observed, that comfort models so far always followed the lifestyle of an era, mainly influenced by technological and social trends. The availability of air conditioning strongly affected thermal comfort expectations and lifestyle of office occupants and lead to and increasing use of energy due to cooling. However, the field study in Athens indicates, that the implementation of more behavioural and psychosocial parameters in adaptive thermal comfort standards might lead to more relaxed comfort expectations in offices. Further research would be needed.

- In the Mediterranean climate of Athens, it is difficult to meet the requirements even of category III according to the EN 15251 adaptive thermal comfort model. Additionally the variability of room temperatures due to different building design and occupant's influences, strongly exceeds the difference in comfort temperatures for the three comfort categories according to EN 15251. This indicates, that in office context in a Mediterranean climate just one comfort category might be sufficient to predict thermal comfort. A more flexible exceeding criterion provides potential for further differentiation. This refers especially to the consideration of national climate characteristics like heat waves, and to the extension of the adaptive model towards more parameters of behavioural and psychosocial adaptation. Further research would be needed.

APPENDIXES

A1. Questionnaire targeted at occupants

By answering this questionnaire, you are helping to collect information to be used within a PhD thesis based at University of Thessaly, Greece and HafenCity University Hamburg, Germany. All answers contained in this questionnaire will remain strictly confidential. Please read each question carefully before answering.

Please name the building and town your office is located in:

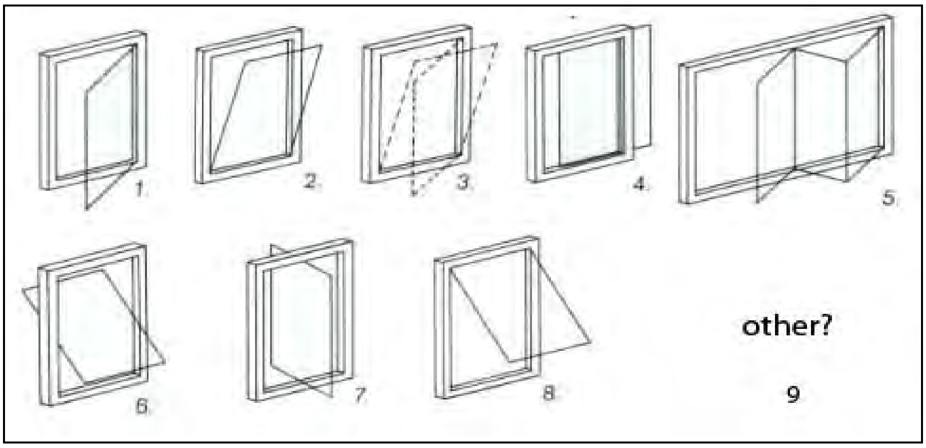
*Building*____
___

*Town*____
___

1. Window opening behavior:

1.1 How does your window open? Please insert the number according to the picture below and a typical opening angle/percentage

Opening type Nr._____ opening percentage_____ (or) opening angle________



1.2 **How many people are working in your office?** Please insert number: ______

1.3 How many openable windows do you have in your office? Please insert number: _______

1.4 What is the most important reason for you to open the window in your office during summer? Please mark with a cross:

[ ] Room temperatures are uncomfortably hot and I want to avoid further increase
[ ] Room temperatures are not yet uncomfortably hot but I want to avoid overheating
[ ] I want to improve the room air quality (e.g. smell)
[ ] I want acoustic contact with the outside environment
[ ] Other (please describe):____

1.5 If you share window control with colleagues, what is the most important influence on the decision to open a window in summer? Please mark with a cross:

[ ] Windows are opened as soon as somebody in the room desires cooling
[ ] Windows are opened as soon as somebody in the room desires a better room air quality
[ ] Windows are opened as soon as somebody in the room desires contact to the outside environment
[ ] We try to make a compromise / democratic decisions
[ ] The person in senior management position usually decides
[ ] Other (please describe):____

1.6. What is the most important reason for you to close the window in your office during summer? Please mark with a cross:

[ ] The air entering the room is too hot
[ ] The air entering the room is too cold
[ ] The air entering the room is polluted (smog, dust,…)
[ ] Protection from noise outside
[ ] Protection from draft
[ ] Other (please describe):____

1.7. If you share window control with colleagues, what is the most important influence on the decision to close a window in summer? Please mark with a cross:

[ ] Windows stay closed as long as somebody wants to prevent cooling
[ ] Windows stay closed as long as somebody wants to prevent overheating
[ ] Windows stay closed as long as somebody wants protection from noise outside
[ ] Windows stay closed as long as somebody wants to prevent draft
[ ] We try to make a compromise / democratic decisions
[ ] The person in senior management position usually decides
[ ] Other (please describe):____

1.8 Can you leave the windows open at nights and on weekends?

[ ] Yes [ ] No

1.9 If you answered question 1.8. with “no”, why not?

Please describe: ____

2 Shading control:

4.2 What kind of shading do you have in your office? Please mark with a cross:

[ ] exterior venetian blind (retractable)
[ ] interior venetian blind (retractable)
[ ] screen
[ ] awning
[ ] vertical louvre
[ ] horizontal louvre
[ ] overhang
[ ] other, please name: ____________________________________

4.3 Which direction is your office window facing to? Please mark with a cross:

[ ] North	[ ] east	[ ] south	[ ] west
[ ] Northeast	[ ] southeast	[ ] southwest	[ ] northwest

2.3 If adjustable, what is the most important reason to close the shading in your office during summer? Please mark with a cross:

[ ] Room temperatures are uncomfortably hot and I want to avoid further increase
[ ] Room temperatures are <u>not yet</u> uncomfortably hot but I want to avoid overheating
[ ] protection against glare, caused by the sun shining in the office
[ ] Protection against glare, caused by overcast sky, sun is <u>not</u> shining in the office
[ ] Wish for privacy
[ ] I never close my shadings
[ ] I always keep shadings closed
[ ] Other (please describe):____

2.4 If you share shading control with colleagues, what is the most important influence on the decision to close the shading in summer? Please mark with a cross:

[ ] shadings are closed as soon as somebody complains about heat
[ ] shadings are closed as soon as somebody wants to prevent overheating in advance
[ ] shadings are closed as soon as somebody complains about glare from the sun
[ ] shadings are closed as soon as somebody complains about glare from sky (without sun)
[ ] shadings are closed as soon as somebody wishes privacy
[ ] shadings are never closed
[ ] shadings are always closed
[ ] Other (please describe):____

2.5 If adjustable, what is the most important reason to open the shading in your office during summer? Please mark with a cross:

[ ] To increase daylighting
[ ] To have a better view out of the window
[ ] Both, daylighting and view
[ ] to feel the warmth of the sun
[ ] I want to improve ventilation
[ ] I never open my shading
[ ] Other (please describe):____

2.6 If you share shading control with colleagues, what is the most important influence on the decision to open the shading in summer? Please mark with a cross:

[ ] shadings are opened as soon as somebody wants to increase daylighting
[ ] shadings are opened as soon as somebody wants to increase the view
[ ] shadings are opened as soon as somebody wants to increase both daylighting and view
[ ] shadings are opened as soon as somebody wants to feel the warmth of the sun
[ ] shadings are opened as soon as somebody wants to improve ventilation
[ ] shadings are never opened
[ ] shadings are opened as soon as the sun is not shining on the façade any more
[ ] Other (please describe):____

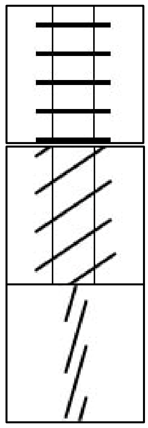
2.7 In case of venetian blinds, how often do you adjust the slat angle per day? Please mark with a cross:

[ ] rarely 0-1x per day [ ] 2-5x per working day [ ] >5x per working day

2.8 In case of venetian blinds, what percentage of the window do they usually cover when activated?

[ ] 25% [ ] 50% [ ] 75% [ ] 100%

2.9 In case of a venetian blind, what is the most common slat angle used for your office? Please mark with a cross:



[ ] more or less horizontal slats, **providing a (good) view**

[ ] medium angle, **view is limited, but possible**

[ ] slats more or less vertical, **no view**

2.10 **How important is it for you to have a view out of your window? Please mark:**

[ ] Very important [ ] less important [ ] not important
[ ] Depends on the quality of the view

3 Lighting control:

3.4 How do you usually operate your lighting system during working hours? Please mark with a cross:

[ ] Lighting is always switched on during working hours
[ ] Lighting is switched on or off according to daylight provision
[ ] Lighting is switched on/off AND dimmed according to daylight provision
[ ] other, please describe: ____

4 Control of air conditioning

4.4 Do you have air conditioning available in your office?

[ ] yes [ ] no

4.5 During which months of the year do you usually use air conditioning? Please insert months:

From ___________________________to___________________________

4.6 What is the preferred temperature you like to use as an air-conditioning set point during summer? Please insert temperature: _________°C

4.7 What would be the maximum temperature you would tolerate as air conditioning set point during summer in order to save energy? Please insert temperature: _________°C

5 Lifestyle and heat waves:

5.1 How often do heat waves typically occur in your city?

[ ] 0-1 per year [ ] 1-3 per year [ ] > 3 per year [ ] other: ________________

5.2 How long does a heat wave last? Please insert approximate number of days:

____

5.3 Would you accept higher room temperatures in offices during summer/heat waves, if you could negotiate with your employer about special working conditions during these periods? E.g. free cold drinks, longer lunch breaks, more flexible working times, relaxed dress code,…? Please mark with a cross:

[ ] Yes [ ] No [ ] I don't know

5.4 Referring to question 5.3, what possibilities could you imagine negotiating about with your employer? Please describe:

____

____

____

5.5 What maximum percentage of your daily working time could you imagine to tolerate uncomfortably hot temperatures in order to reduce air conditioning and help mitigate the climate change? Please mark with a cross:

[ ] 0-5% [ ] 6-10% [ ] 10-20% [ ] 20-30% [ ]>30%

5.6. Is there an official dress code in your office? [ ] No [ ] Yes

If YES, please give details. ____

5.7. If there is no dress code in your office, do you adjust your clothing during the day to increase thermal comfort?

[ ] No [ ] yes, rarely [ ] yes, occasionally [ ] yes, often

5.8. If your answer to 5.7 was "no" or "rarely", what is the most important reason?

[ ] it is not necessary

[ ] fashion, unofficial dress code with colleagues or clients

[ ] other, please describe: ____

5.9 During a typical day, how many hours do you spend at your desk?

.... hours

5.10 During a typical day, how many hours do you spend at a computer?

.... hours

6 Concluding comments

Please add any comments you wish to make about anything discussed thus far in the questionnaire, or about anything, which you think, may affect your internal environment

____

____

____

____

____

**** THANK YOU FOR YOUR CO-OPERATION AND TIME IN COMPLETING THIS QUESTIONNAIRE ****

A2. Questionnaire targeted at architects

By answering this questionnaire, you are helping to collect information to be used within a PhD thesis based at University of Thessaly, Greece and HafenCity University Hamburg, Germany. All answers contained in this questionnaire will remain strictly confidential.
Please read each question carefully before answering.
*Please name the office/company you are working for:*_________________________________

1.1 What is the most common office type in Greece? Please mark:

[ ] Cellular office
[ ] Group office
[ ] Open-plan office
[ ] other

1.2 Is cross ventilation usually possible in Greek offices?

[ ] yes
[ ] no

1.3 If cross ventilation is not possible why not?

[ ] building too deep
[ ] static requires solid core elements in the centre of the building
[ ] windows not openable
[ ] too many occupants to decide too few windows
[ ] floor plan layout does not allow for cross ventilation
[ ] other: ____

1.4 What catchwords are currently most important when advertising office space for rent?
Please mark the three most important:

[ ] price for rent
[ ] prestige of the location within the city
[ ] view out of the building
[ ] running costs when in use
[ ] design of the building
[ ] comfort conditions inside the building
[ ] daylight qualities inside the building
[ ] energy performance
[ ] quality/luxury level of the building
[ ] air-conditioned
[ ] green building
[ ] other: ___________________________

1.5 Regarding thermal mass, what constructions are most typical for Greek office buildings?

[ ] solid walls
[ ] gypsum walls
[ ] solid floor (slab+ screed)
[ ] false floor construction
[ ] suspended acoustic ceiling
[ ] suspended gypsum ceiling
[ ] concrete slab ceiling

1.6 What are the three most important influences on window area in office buildings?

[ ] client's wishes (e.g. symbolization of corporate culture etc.)
[ ] references to urban situation
[ ] architectural fashions
[ ] thermal comfort predictions
[ ] other: ____
[ ] other: ____

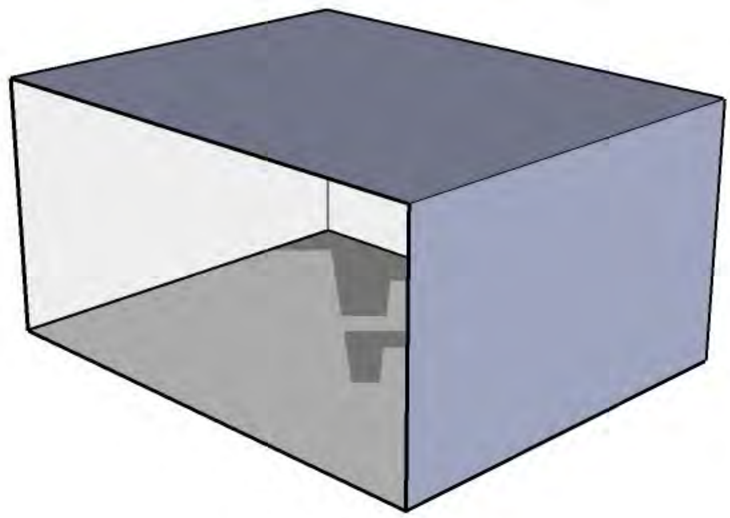
1.7 What is the most important reason to use low-e glazing in office buildings?

[ ] legal requirements
[ ] client's wishes
[ ] comfort or energy predictions
[ ] common practice
[ ] other: ____

1.8 Is low-e glazing usually tinted in Greek office buildings?

[ ] No
[ ] Yes, colour: ____________________________________

1.9 The drawing below shows the façade of an office room with the dimensions 3.5x2.7m and 100% window area. Please draw a typical placement of openable windows within this façade.



1.10 What types of shading systems are most common in Greece?

[ ] exterior venetian blind (retractable)
[ ] interior venetian blind (retractable)
[ ] screen
[ ] awning
[ ] vertical louvre
[ ] horizontal louvre
[ ] overhang
[ ] other, please name: ___________________________

1.11 What lighting concept is most common in Greek office buildings?

[ ] room related lighting
[ ] task area lighting
[ ] other: ____________________________

1.12 What aspect is the most important influence on the decision for a lighting system in office buildings?

[ ] lowest initial costs
[ ] lowest energy consumption/running costs
[ ] best cost performance ratio
[ ] other: ___________________________________

1.13 What lighting design quality is most common in Greek office buildings?

[ ] standard solution, no special design, low price
[ ] sophisticated lighting design, expressing a special prestige or atmosphere desired by the client
[ ] other: ___________________________________

1.14 How many persons are typically working in a cellular office room, area 5.4x3.5m?

____persons

1.15 What is the most common influence on occupant density in the above mentioned office room?

[ ] density depending mainly on the task (space needed, privacy)
[ ] density depending on cost effectiveness for employer (= maximum density)
[ ] density mainly depending on hierarchy (e.g. single occupancy for senior management positions)
[ ] other: ____

1.16 What is the most dominant aspect to decide the placement of a task within the floor plan?

[ ] internal company structure (hierarchies)
[ ] view out of the window
[ ] workflows within the company
[ ] other: ________________________________

1.17 What is the most common reason for clients to be interested in 'green buildings'?

[ ] because they are a good advertisement for the client's company
[ ] because the client cares about indoor comfort for the occupants
[ ] because the client wants to save energy costs
[ ] because the client wants to contribute in mitigating the climate change
[ ] other, please describe: ____

1.18 Concluding comments:

Please add any comments you wish to make about anything discussed thus far in the questionnaire, or about anything, which you think, may affect your internal environment

____

____

____

____

**** THANK YOU FOR YOUR CO-OPERATION AND TIME IN COMPLETING THIS QUESTIONNAIRE ****

A3. Related publications

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A5. List of figures

A6. List of tables