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IMPACTS OF CLIMATE CHANGE UPON SUSTAINABLE COOLING (AND HEATING) STRATEGIES FOR OFFICE BUILDINGS IN URBAN AREAS

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Submitted by
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Content

1.1 Abstract

Context
Climate change will negatively impact on thermal comfort of office users by rising indoor temperatures in summer. Productivity of office workers is directly negatively influenced by increased indoor temperatures. Reduced thermal comfort thereby raises work force costs (as salaries make up for the single most important budget point of the majority of enterprises). In order to counteract, it will be necessary to implement mechanical cooling on large scale. Mechanical cooling strongly depends on the availability of electricity at peak hours. Due to expected increased electricity demand this availability of peak power might generally not be guaranteed everywhere at any time in the decades to come. At the same time, any fossil fuel based generation of the required electricity for cooling involves emissions of climate gases which further induce global warming.

Goals
By simulating thermal conditions in nine existing office buildings in Vienna, Austria, this PhD thesis aimed to investigate:

1. the magnitude of cooling demand's increases (and heating demand's decreases) arising in this kind of buildings due to climate change and urban heat island
2. possible measures to minimize energy demand through
   - optimizations of the buildings' envelope
   - optimizations inside the buildings

Methodology
This PhD thesis's methodology employed the well established tool of dynamic thermal simulation in buildings, its novelties lie in the appliance of this tool for the concise assessment of phenomena such as climate change, urban heat island, local wind and microclimate or differences in comfort models. Although these are scientifically acknowledged phenomena, they have hardly been considered in thermal simulation so far, not to speak of practical engineering. First of all this is due to the fact that necessary climate data sets in high temporal resolutions were not yet available. Secondly, there is general uncertainty and debate as to the order of magnitude of such effects and hence whether it is worth the hassle to take them into account in simulation. This is also true for possible approaches of optimization such as natural ventilation and changes in usage profiles. Therefore, establishing viable modes of investigation for crucial developments in the building sector and employing them to the end of concise and quantitative assessment of possible impacts is the scientific effort accomplished by this thesis. The results hence gained allow for a paramount insight as to which challenges in terms of their energy performance office buildings in the metropolitan area of Vienna are really to face within the decades to come and how effective modes of optimization are to be designed.

Results

Future climates yield increasing net cooling demands, while heating demands shrink. Trends for overall final and primary energy demand strongly depend on buildings' properties (and date of construction). The definition of what is regarded as "uncomfortable" according to existing comfort models remarkable differs in quantitative terms and hence impacts upon cooling requirements. The dominance of heating in the overall demand and heating demand's decrease due to climate change leave inner city locations as those with least overall final energy demand.
External thermal insulation of opaque buildings' surfaces results best in terms of reduction of overall final energy demand due to significant reductions in still dominant heating demand. The effects of increased energy efficiency in office equipment are tremendous with respect to cooling demand reductions and range in the order of magnitude of increases due to climate change. Quite simple changes in usage patterns can minimize users' presence during the hottest hours of summer days and hence allow for less cooling efforts. Natural ventilation is shown to hold certain potential for improvements in thermal comfort of free running buildings. Fixed comfort limits, however, may not always be kept.

Conclusion

Overall final and primary energy demand of office buildings will generally not explode due to climate change. This seemingly good news however has to be regarded with high caution: it holds only true due to the fact that existent, especially historic buildings display comparatively high heating demands even today and will profit from reductions in this demand due to global warming. This counteracts considerable increases in cooling efforts. The resulting, overall demand in consequence stagnates – but on a high level, with the respective CO_2-emissions associated!

Discussion

The results gained here clearly show that there is no one-fits-all solution as to how to reduce energy demand of office buildings while safeguarding thermal comfort for office workers. Instead, buildings of different properties and locations ask for different approaches. Thereby, both cooling and heating demands have to be kept in mind in order to avoid rebound effects. This makes detailed simulation indispensable. Differences in comfort models and their demonstrated impacts likewise ask for further discussion and refined definition as to which building type (conditioned/ free running) they are to be employed. Considerable uncertainties prevail regarding future developments in fields such as the energy efficiency of office equipment or software tools for the assessments of local wind and microclimates. Assumptions on possible changes in usage profiles remain highly speculative and while their influence on energy performance is shown to be substantial, they strongly touch non-technical matters which require further discussion in the context of future societies. .

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1.3 Organizational remark

This PhD thesis entirely draws upon the findings of two distinct research projects of the Department for Construction and Environment at Danube University Krems:

- "Offices and Climate Change", funded under the program "Building of Tomorrow" by BMVIT (Austrian Federal Ministry for Transport, Innovation and Technology)[1]

- "Adapting office buildings to climate change", funded by BMLFUW, BMWF, BMWFJ, ÖBF[2]

Both projects were executed under the coordination of the author.
All texts included in this thesis were written by the author except for chapter 3.1 and 3.2, penned by Herbert Formayer and Bernhard Pospischal, Institute of Meteorology, University of Natural Resources and Life Sciences, Vienna, and included here in order to enable sound understanding of the following investigational steps.

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[1] Berger, T.; Fomayer, H. et al (2011)
[2] Berger, T., Pundy, P. (2010)

2 Introduction

2.1 Context

During the past years a general understanding has taken place throughout the scientific community that, besides mitigation measures, additional adaptation will be required to compensate for impacts of global warming that are already inevitable. Regarding the building sector, this primarily means ensuring comfortable indoor conditions during summer despite raising outdoor temperatures without augmenting corresponding energy consumption.

Recently, global climate scenarios have gradually been downscaled to geographic resolutions allowing for more precise forecasts of local climate conditions in the decades to come. Hence, local developments have become predictable.

Urban heat islands are well known to generally display climatic conditions quite distinct from surrounding areas, most pronouncedly detectable in higher ambient temperatures. It is most likely that climatic conditions in urban areas will generally further deteriorate due to climate change. However, software tools for the exact simulation of urban heat islands in distinct cities and locations are not yet available. Hence, the refined prediction of climate change upon urban heat island's development remains impossible.

Offices generally display raised internal loads due to both high rates of occupancy and significant density of technical equipment, both resulting in heat production. At the same time office workers strongly rely on comfortable conditions to be able to perform complex tasks. Offices are especially prone to overheating and consequently they are often equipped with active cooling plants; with increasing outdoor temperatures there is high probability that this trend will continue and aggravate.

Strategies for a reduction in energy demand in buildings generally aim at primarily reducing either heat losses (in winter) or gains (in summer), thereby minimizing efforts for heating and cooling respectively. Only building concepts heeding this principle may successfully harness energy of renewable sources for covering the remaining and, thus reduced, energy demand for both modes of conditioning.

2.2 Current State of Knowledge and Recent Research Findings

The two research projects[3] which form the basis of the present PhD thesis draw upon numerous national and international projects from both meteorology and building physics and extends beyond their findings in ways depicted hereafter:

"reclip:more"[4]:
For the first time, this study on future impacts of climate change in Austria developed locally downscaled scenarios for Austria based on global emissions scenario IS 92a of IPCC. These regionalized climate data still contained substantial uncertainties, which is why they were not employed for data generation here.

SEP[5]
According to investigations done under the Municipal Programme for Energy Efficiency in Vienna sales figures of air conditioning units more than doubled during the extreme temperatures of summer 2003 as compared to the precedent year. Estimations for 2003 suggest that about 37% of commercial technical spaces are already air conditioned and further 32% are equipped with fans. This yields an increase of about 45% compared to the low level of air conditioning in 1987. This clearly indicates that air conditioning, formerly restricted to a few office sky scrapers, is set to become a mass phenomenon.

Investigations on European level likewise show a swift increase since 1990 in office spaces equipped with mechanical cooling[6].

Scrutinizing documented sample buildings revealed how different building designs react to increased indoor temperatures due to climate change[7].

[Holzer and Hammer][8] rendered first estimations for climate change impacts on buildings in Austria.

Austro Clim – guideline for adaptation to climate change[9]
The establishment process for this guideline was funded by the Federal Austrian Ministry for Livelihood and first published by the Institute of Meteorology at University of Natural Resources and Life Sciences, Vienna, in November 2008. It contains a compilation of experts' views on climate change's impact in

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[3] see 1.3 Organizational remark, page 9
[4] Matulla, C., Formayer, H., Haas, P., Kromp-Kolb, H. (2004)
[5] Haas, Reinhard et al, (2004)
[6] Adnot, J., Waide, P.; Armines, France; D.G. (April 2003)
[7] Holmes, Michael J.; Hacker, Jacob N. (2007)
[8] Holzer, Peter; Hammer, Renate (Jänner 2008).
[9] Haas, Willi; Weisz, Ulli; Balas, Maria; McCallum, Sabine; Lexer, Wolfgang; Pazdernik, Katja et al. (November 2008

agriculture, forestry, tourism, water management and power industry as well as the building sector. Further guidelines have since been prepared in cooperation with the Federal Environmental Agency and both analysis and recommendations refined. These efforts form part of broad process to develop a national adaptation strategy. The author of the present PhD thesis has contributed to this process.

StartClim 2006F[10] & „Impacts of climate change in Lower Austria“[11]
Researchers at Wegener centre Graz, Austria, and the University of Natural Resources and Life Sciences, Vienna, studied impacts of climate change on heating and cooling demand in Austria. A regionalized climate data base was linked to data on building stock and current heating and cooling degree days. Relationships of outdoor temperature and energy demand in different sample buildings were analyzed and trends for future population development and legal framework taken into account for assumptions on demands to be expected for energy resources, especially electricity. This investigational approach aims chiefly on macro economics and therefore differs considerable from the investigations within the present PhD thesis. However, the trends for future development of cooling and heating degree days serve as a reference for the climate data sets employed hereafter.

In an international context, research efforts reaching further have already been undertaken with respect to adaptation to climate change;

Building Knowledge for a Changing Climate (BKCC)[12]
The UK climate impact programme initiated extensive studies not only covering technical but also social consequences of climate change for Great Britain. Within this programme, nine distinct research projects were initiated and developed recommendations for adaptive measures on all the relevant stakeholders' side. The exemplary investigation of two urban agglomerations (Greater Manchester and Lewes – a small coastal town in Sussex, population 15,000) rendered findings regarding risks for urban outdoor spaces due to increasingly extreme rains, winds, heat waves. Unlike continental scenarios, climate change in the UK is expected to effectuate foremost in raised amounts and intensity of precipitation – which prevents British adaption strategies from figuring as role model for other European countries.

[Bengtsson et al, 2007][13] published a comparable study for New Zealand.

"Impacts of climate change: buildings and construction in Germany""[14]
This study, commissioned by the German Federal Ministry for traffic, construction and urban development, lists expected macroeconomic impacts of

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[10] Prettenthaler F., Gobiet A., Habsburg-Lothringen C., Steinacker R., Töglhofer C., und Türk A. (2007);
[11] Formayer, Herbert et al (2007);
[12] UK climate impact programme (2007)
[13] Bengtsson Jonas; Bennett, Jessica; McKernon, Stephen; Mullan, Brett; Page, Ian (2007)
[14] Bundesministerium für Verkehr, Bau und Stadtentwicklung (Hg.) (2008a)

climate change in Germany, herein focusing on heat waves, heavy precipitation, and extreme winds and hale. No reference is made to developments of specific building types.

„Strategies for spatial development under the paradigm of climate change“[15]
Likewise commissioned by the German Federal Ministry for traffic, construction and urban development, this study establishes general categories of concernedness for regions in entire Germany and in consequence only touches constructive matters superficially.

„Building when the climate gets warmer“[16]
In 2008 the Federal Swiss Agency for Energy under the research programme “energy in building" published an investigation which comes up with concise results for the Swiss building sector; basics for future normative framework are established and recommendations listed for refurbishments and HVAC equipment. Different building categories are scrutinized as to their vulnerability to climate change. The matrix of relevant parameters employed herein forms a solid point of references for the corresponding situation in Austria which presents the focus of the present PhD thesis.

Keep Cool[17]
Initiated under the „Intelligent Energy Europe“ programme, the EU-project „Keep Cool“ compiled a broad and exhaustive overview on energy efficient cooling methods in 2005. Reference was made to technical information contained herein in “Adapting office buildings to climate change”[18], however, findings are not included in the present PhD thesis but in [Pundy (2010)].

„Future office buildings“[19]
23 German non-residential buildings, optimized in energy performance, have been investigated and monitored during several years by the Frauenhofer Institute for Solar Energy Systems (ISE) and results were compiled in the extensive publication „Future office buildings”. Holistic approaches which take buildings physics into account already in the drafting phase turned out to be crucial for securing summer comfort by means of ambient energy sources only. However, no assumptions were made as to the future impacts of climate change on the implementation and viability of such holistic systems.

Cool San[20]
Funded under the Austrian „Building of Tomorrow“ programme, this project focused on refurbishment strategies for five concise buildings – without, however, taking climate change and urban heat islands into account.

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[15] Bundesministerium für Verkehr, Bau und Stadtentwicklung (Hg.) (2008b)
[16] Brunner, Conrad U.; Steinemann, Urs; Jürg, Nipkow (2008)
[17] Intelligent Energy Europe/ European Agency for Competitiveness and Innovation (Hg.) (2007):
[18] see 1.3 Organizational remark, page 9
[19] Voss, K.; Herkel, S.; Löhnert, G.; Wagner, A. (2005)
[20] Programmlinie Haus der Zukunft (Hg.) (2005)

Master Thesis "Office buildings in an area of conflict between comfort, ecology and climate change"[21]
Two Master Thesis at the Department for Construction and Environment at Danube University Krems, approbated in 2009, dealt with the impacts of climate change on thermal comfort in office blocks during summer. Based on an overview on current normative frameworks and comfort models preliminary investigations were run on concise Viennese office buildings which formed a starting point for the present PhD thesis.

Office 21[22]
Already in 1996 Frauenhofer Institute for Economy and Organisation (IAO) initiated the innovation initiative OFFICE 21® in cooperation with 20 multinational enterprises. In 2003 a book labelled "Increased capacity due to innovative work spaces" presented research findings on influencing factors for productivity and performance of office workers. Therein, thermal comfort appears as but one single contributing factor.

PH Office - Standard for energy efficient office buildings[23]
Funded under the Austrian „Building of Tomorrow" programme, this project focused on defining benchmarks for different categories of energy demand in office blocks as a way to define concisely what passive house standard should be supposed to be like in office buildings. The author of the present PhD thesis contributed to this report and definitions established here with regard to levels of internal loads are employed in the thesis.

2.3 Goals: Theses and Research Questions

This study aimed to investigate impacts of climate change and urban heat island on energy consumption and thermal comfort in office rooms. Conventionally, these two factors are directly linked: Interdependencies between elevated indoor temperatures and reductions in office workers' performance have been accounted for in several investigations[24].

Thermal comfort - herein understood as the compliance with normative indoor temperature limits - is generally safeguarded by means of mechanical cooling. A general rise in outdoor temperature due to global warming thus results in increased energy demand for cooling which induces an increase in CO_2 – emissions for the allocation of energy (if it cannot be provided from non-emitting sources). By this vicious cycle, climate change threatens to be further aggravated.

[21] Pundy, Peter; Retter, Philip (2009)
[22] Frauenhofer Institut für Arbeitswirtschaft und Organisation (IAO) (Hg.). (2003)
[23] Programmlinie Haus der Zukunft (Hg.) (2010)
[24] Seppänen, Olli; Fisk, William; Faulkner, David (2003)

The detailed knowledge of this problem's order of magnitude is an essential basis for the further development of an adaption strategy in the building sector. To provide this basis of knowledge is the current project's mayor goal.

Impacts of climate change

Impact of different climate data sets:

Thesis:

Future climatic conditions due to global warming will generally increase cooling demands, while heating demands can be expected to shrink.

Research Questions:

How will trends for overall final and primary energy demand develop due to these changes? Will demands grow overall?

What will be the distinct effects of climate change upon the performance of different building types within the existent stock dating from different historic epochs?

Impact of different comfort models:

Thesis:

The definition of what is regarded as "uncomfortable" according to the two existing comfort models ("Fanger" and "Addaptive" Model) remarkable differs and hence cooling is regarded to be necessary to differing extents.

Research Questions:

Which quantitative differences can effectively be detected in direct comparison of comfort assessments based on these models?

What are the consequences of these differences in terms of cooling requirements and hence energy demands?

Impact of urban heat island:

Thesis:

Due to warming effects of urban heat islands, locations in CBD[25]s display higher cooling and lower heating demands than outskirts' sites. These effects will be aggravated by global warming.

Research Questions:

What are the measurable impacts of UHI[26] on cooling and heating requirements for distinct locations within the urban region of the city of Vienna?

How will overall final and primary energy demand of different building types within this region develop due to climate changes?

[25] Central Business District

[26] Urban Heat Island

Possible measures for reduction of energy demand
Impact of optimization of buildings' envelopes:
Thesis:
Optimizations in external thermal insulation, glazing and shading are apt to reduce overall energy demands, but their impacts on cooling and heating requirements vary and may even outweigh each other. Therefore, only holistic scrutiny of these measures' impacts under the conditions of climate change can reveal the most suitable approaches.

Research Questions:
Which modifications of buildings' envelops yields most promising results in terms of reduction of overall final and primary energy demand under the conditions of climate change?
Will external insulation become less efficient due to global warming?

Optimizations inside buildings
Internal Loads
Thesis:
Reductions in internal heating loads from IT equipment and artificial lighting impact remarkably upon office buildings' cooling requirements but also potentially increase heating demands.

Research Questions:
To which order of magnitude can increased energy efficiency in office equipment contribute to reducing cooling requirements?
Do such reductions run danger of being outweighed by increased wintry heating demands?

Usage Profiles:
Thesis:
In summer, changes in usage patterns can tend to minimize users' presence in office rooms during the hottest hours of the day and hence reduce cooling demands.

Research Questions:
To which order of magnitude can changes in usage patterns of office rooms contribute to reducing cooling requirements?
Do effective such changes converge with the modalities of modern life?

Natural ventilation
Thesis:
Natural ventilation can contribute to thermal comfort in free running office buildings and holds potential to reduce cooling requirements.

Research Questions:
To which order of magnitude can natural ventilation contribute to increased air change rates in office rooms in specific urban settings?
Are such elevated air change rates sufficient to improve indoor thermal comfort and even reduce cooling requirements in these settings?
Are existent simulation tools able to assess specific microclimates and, in consequence, to render reliable results regarding cooling potential of natural ventilation in specific urban settings?

2.4 Methodology

In this study, thermal building simulation of up to nine representative sample buildings in Vienna, Austria, is employed to assess impacts of climate change, urban heat island, different comfort models and distinct optimization measures on energy demand and thermal comfort.

The framework of this investigation is presented hereafter and comprises indications on both the climate data sets employed and the buildings investigated (construction and conditioning) as well as definitions of simulation variants and assessment parameters.

This PhD thesis's novelties lie in the appliance of the well established tool of dynamic thermal simulation in buildings for the concise assessment of phenomena such as climate change, urban heat island, local wind and microclimate or differences in comfort models. Although these are scientifically acknowledged phenomena, they have hardly been considered in thermal simulation so far, not to speak of practical engineering.

The lack of simulation results in this area is due to the following facts:

- necessary climate data sets for the near and far future were not yet available in high temporal resolutions
- there is general uncertainty and debate as to the order of magnitude of such effects and hence whether, at all, it is worth the hassle to take them into account in simulation

This is also true for possible approaches of optimization such as natural ventilation and changes in usage profiles.

Therefore, establishing viable modes of investigation for crucial developments in the building sector and employing them to the end of concise and quantitative assessment of possible impacts for different building types in Vienna is the scientific effort accomplished by this PhD thesis.

The results hence gained allow for a paramount insight as to which challenges office buildings in the metropolitan area of Vienna are really to face in terms of their energy performance within the decades to come and how effective modes of optimization are to be designed. Interdependencies and possible rebound effects between such measures of optimization are likewise investigated in order to allow for holistic approaches.

2.4.1 Climate data sets[27]

Regarding climatic conditions to be expected for a time frame up to 2050, different localized scenarios have already been developed for Eastern Austria and the Viennese Urban Area; however, no climate data set on an hourly basis had been generated so far.

Therefore, four semi synthetic climate data sets[28] have been generated for the present PhD thesis, based on both collected records and localized scenarios for Vienna's main weather station Hohe Warte (hereafter referred to as "howa"). Therein, future data sets are established on the premises of IPCC's emission scenario A1B.

Thus, either averaged historical weather readings of the following periods or future scenarios were employed to generate semi synthetic climate data sets:

Climate data set denomination		**description**
Temporal resolution	61	Semi synthetic data set of weather observations for the period of 1961 to 1980
	80	Semi synthetic data set of weather observations for the period of 1980 to 2009
	2025	Semi synthetic Scenario for the period of 2025
	2050	Semi synthetic Scenario for the period of 2050
	2003	weather observations from 2003 (extreme summer)
Spatial resolution	howa	Abbr. "Hohe Warte", main weather station
	inne	Abbr. "Innere Stadt", CBD
	dona	Abbr. "Donaustadt", urban location

Table 1: Climate data set description

[27] For detailed information on climate data sets see: 3. Climate data sets, page 24
[28] Krec, K. Halbsynthetische Klimadaten für Wien. Erläuterungen zum Klimadatensatz (2010)

Besides “howa”, two further locations within the city’s boundaries were included in simulations in an effort to assess impacts of the well documented phenomenon of urban heat island. Both “inne” and “dona” are situated closer to the or in the city centre itself and therefore experience more severe impacts of urban heat traps.

Weather observations of the year 2003 which displayed an extremely hot summer are included in the investigations to allow such extremes to be taken into account.

2.4.2 Sample buildings’ construction[29]

Nine Viennese office buildings, fairly representative for the city’s three main construction periods[30], were selected and hence cover the majority of building types to be found in this typical Central European city:

Sample building	Abbreviation	Sample building description
Headquarter National Bank Municipal office block - “ - - “ -	**ONB** **SPZ** **RHS** **SCP**	Built before World War 1
office block National Bank Municipal office block - “ -	**BGN** **FAS** **LES**	Built after World War 2
Multinational Headquarters	**Strabag**	Built 2003, entirely glazed façade
Office block	**SOL 4**	Built 2005, passive house standard

Table 2: Sample building description

- In all these buildings several (two to eight) single office rooms were investigated.
- These rooms were facing South and West, the two orientations most vulnerable to overheating; although each room was simulated and charted individually, overall averages were formed for all buildings.
- Only office rooms housing two work places were selected for simulation. The original size of these rooms was depicted in the computational model in order to account for typological properties of the represented building types.

[29] For detailed information on Sample buildings’ construction see: 4 Sample buildings’ constructive configuration, page 43

[30] Main construction periods are addressed in a quantitative sense: in the present building stock, those constructions dating from the described periods of time make up form the vast majority.

- Only office rooms were investigated, no account was made for further room types frequently encountered in office buildings such as meeting rooms, lounges, cafeterias or server rooms.

2.4.3 Sample buildings' conditioning[31]

The investigations in this PhD thesis aimed to support two distinct ambitions:

- On one hand side findings were requested that would not only be applicable for a specific building but **yield general insights**.
- On the other hand **divergent constructive properties of distinct building** époques should be accounted for as it was to be expected that these properties will cause buildings to react differently to climate change.

These ambitions were incorporated in the design of a simulation mode which hereafter is referred to as "Standard"; in this mode, all sample buildings were run under equal conditions. In consequence, their thermal behaviour can exclusively be attributed to their constructive configuration. This allows for a direct comparison of their constructions' impact on their thermal behaviour.

However, for some steps of the investigation, mode "Standard" turned out not to be applicable. This fact and the reasons therefore are indicated in the concerned modules of investigation. A second simulation mode hereafter referred to as "real" was applied in these modules.
The two different modes of simulation thus can be portrayed as such:

- **Simulation mode "Standard":** in this simulation mode care was taken to maintain comfort conditions acc. Austrian standards[32] in all sample buildings. With comfort conditions equally secured, resulting cooling loads and demands are compared. Conditioning (Lighting, ventilation, cooling and heating regimes) in each building was therefore uniformly modelled regardless of the actual situation in each building. It has to be stressed here, that this simulation mode does not necessarily depict the real situations in the simulated buildings; This is especially true for the passive house building type which loses some of the features integral to the passive house concept (such as mechanical ventilation with heat recovery

[31] For detailed information on Sample buildings' conditioning see: 5 Sample buildings' conditioning, page 55

[32] ÖNORM EN 7730 requires a resultant temperature of 27°C not to be exceeded for more than 5% of working hours per year in the building types in question.

and low levels of internal loads[33]) in order to be comparable to the other buildings.[34]

- **Simulation mode "real":** this simulation mode depicts the real present day situation with hardly any cooling in two of the sample buildings (ONB, BGN). Conditioning in each building under mode "real" was modelled according to the real situation in each building. With energy demand for cooling equally ranging at 0, resulting thermal conditions in the buildings are investigated.

2.4.4 Employed tools of investigation

Dynamic thermal simulation on hourly basis was applied for the close depiction of thermal conditions in single office rooms. This allows for the assessment of impacts of prolonged summer heat waves as well as of increased peak temperatures. The precise depiction of the buildings' respective construction and consequent thermal properties is an indispensable prerequisite for such investigations.

2.4.5 Variants and assessment parameters

Only some of the nine sample buildings were analysed in detail; For in – depth investigations, emphasis was laid on two to four "leading buildings" which represent their respective building epoch in terms of construction. For either all buildings or these leading buildings energy demands under present and future conditions were assessed for cooling, heating and overall final and primary energy. Herein, emphasis was placed upon final rather than primary energy demands; conversion factors for the latter ones are expected to change substantially over the coming decades and hence predictions of future primary energy demands remain highly speculative. Nonetheless, assumptions on primary energy were included because mechanical cooling strongly relies on electricity as an energy resource which in turn is especially intensive in primary energy demand.

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[33] These features are not present in all other buildings in reality, hence to compare these buildings' constructive properties with those of the passive house they had to be omitted.

[34] Additionally, in some cases it turned out to be necessary to closely investigate the buildings' thermal behaviour and its mutual interdependencies with shading, ventilation and cooling regimes by means of the simulation of one single recurring Design Day which was modelled with allusion to the applied climate data sets. Herein, the determinations of the Standard simulation mode were kept (also see chapter 3.5.2 Design Day determination for cooling plant sizing, page 40, and chapter 8.1.6.1 Cooling load under Design Day conditions, page 92).

CO_2 emissions were deduced from these demands. Likewise, demands were simulated for varying locations within the urban fabric to assess urban heat island's impact.

Impacts of improvements in the buildings' outer shell (u-, g-, F_c- values) on the resulting energy demand were calculated.
Furthermore, impacts of improvements in the buildings' interior were investigated: changes in levels of internal loads due to different levels of energy efficiency in office equipment and lighting and different usage profiles as well as applications of natural ventilation strategies.

Except for the comfort model discussion and investigations on natural ventilation, all simulations were done under the assumption of equal indoor conditioning in all sample buildings.

Modular configuration of investigation
These fields of investigation (energy demands, comfort models, urban heat island and optimization in building envelop and interior) were treated independently as separate investigation modules hereafter, while all recurring to either all or selected parts of the presented framework in regards to climate data sets, sample buildings, simulation modes and employed tools.

2.4.6 Results

Impacts of climate change
Impact of different climate data sets: Future climates yield increasing net cooling demands, while heating demands shrink. Trends for overall final and primary energy demand depend on buildings' properties: recently constructed buildings yield higher net cooling than heating demands already today; their overall final energy demand will stagnate or slightly increase over time. Historic buildings will be clearly dominated by high net heating demands even by the year 2050. Hence, overall final energy demand of these buildings decreases over the decades due the decrease in heating requirements. Notwithstanding, these overall demands remain high in absolute terms.

Impact of different comfort models: The definition of what is regarded as "uncomfortable" according to the two existing comfort models ("Fanger" and "Addaptive") remarkable differs in quantitative terms and hence impacts upon cooling requirements. Care has to be take to distinguish between conditioned buildings (which call for the application of the "Fanger" model) and free running buildings (to be assessed according to the "Adaptive" model).

Impact of urban heat island: Locations in CBDs generally display higher cooling and lower heating demands than outskirts' sites. The dominance of heating in the overall demand and heating demand's decrease due to climate change leave inner city locations as those with least overall final energy demand.

Possible measures for reduction of energy demand
Impact of optimization of buildings' envelopes: Even in view of climate change, external thermal insulation of opaque buildings' surfaces results best in terms of overall final energy requirements due to significant reductions in still dominant heating demand.

Optimizations inside buildings
Internal Loads: the effects of increased energy efficiency in office equipment (IT equipment and artificial lighting) are tremendous with respect to cooling demand reductions; Achievable decreases in annual cooling energy demand range in the order of magnitude of increases due to climate change.

In old buildings, however, effects of reduced cooling run danger of being outweighed by increases in heating demand when less internal loads are available in winter. Therefore, better electronic equipment should always run parallel with additional insulation of the external walls.

Usage Profiles: Innovative though quite simple changes in usage pattern can minimize users' presence during the hottest hours of the day and hence allow for less cooling efforts. Impacts of such usage profiles on employees' every day life are considerable and must be discussed beyond purely technical matters.

Natural ventilation is shown to hold certain potential for improvements in thermal comfort of free running buildings. Exact and reliable calculations of achievable air change rates in rooms however require CDF[35] simulations. General potential analysis demonstrates that natural ventilation in urban settings can suffice to improve thermal conditions in sample office rooms to the extent that requirements of an adaptive comfort model are met. Fixed comfort limits, however, may not always be kept.
Natural Ventilation Strategies in historic buildings reveal only restricted effectiveness under the investigated urban conditions.

[35] Computational Fluid Dynamics

3 Climate data sets

3.1 Background[36]

According to IPCC[37] long term climate change scenarios have to be based on the results of coupled global circulation models (GCMs). As the resolution of this type of model is too coarse to resolve regional to local effects, further downscaling of the climate change scenarios is necessary.

One appropriate way is dynamical downscaling with regional climate models (RCMs), as done by the EC- research program ENSEMBLES (Hewitt et al., 2004). In this project several different RCMs, forced with different GCMS have been applied for the whole European domain. All the RCMs have been forced by the A1B emission scenario and was running the whole 21st century. The results of this project would have been suitable for our objectives, but at the beginning of this project only the results of the model runs with 50 km spatial resolution have been available.

As Vienna is located at the easternmost border of the Alps, the spatial resolution of RCM might be crucial for the quality of regional climate change scenarios. Therefore we decided to use the results of the RCM REMO. REMO is the RCM of the Max Planck Institute in Hamburg and this model is also participating in the ENSEMBLES project. On behalf of the German environment agency (UBA), this model made climate change runs for the whole 21st century and the emission scenarios B1, A1B and A2 with 10 km resolution for whole Germany, but including also the largest parts of Swiss and whole Austria. This REMO-UBA (Jacob et al., 2008) model results are the basis for our scenarios for Vienna. We also decided to use the results of the A1B scenario. Till the middle of the 21st century the differences between the emissions scenarios is not very high. Especially the climate change signal of A1B an A2 are quite similar. Only in B1 the climate change signal is a little bit smaller.

In graph 1 the transient development of the summer (blue) and winter (red) temperature anomaly relative to the period 1961-1990 for Vienna is shown. The thin line show the values of single years and the bold lines a 20 year Gauss filter is shown. Both seasons show a more or less linear increase of the temperature starting around the year 2010. The increase reaches in both seasons the order of 5 degrees till the end of the 21st century. It can also be seen, that this linear trend is modified by decadal fluctuation of the model with the magnitude of ± 0.5 degrees. This is important for the construction of climate change signals for

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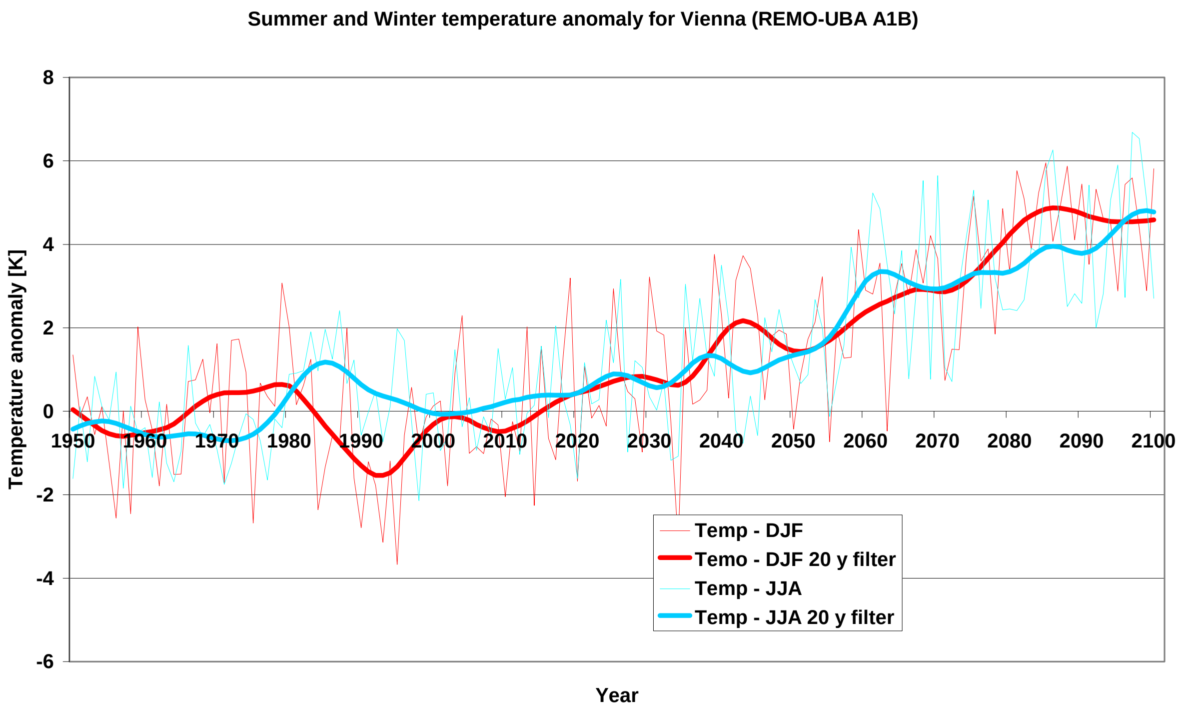
[36] This section was contributed by Formayer and Pospischal; see 1.3 Organizational remark, page 9
[37] IPCC (2007)

specific time periods. When we look on the climate change signal for 2025 or 2050 we always take a 30 year time frame around this dates (2011-2040 for 2025 and 2036-2065 for 2050) to smooth out the decadal fluctuations.



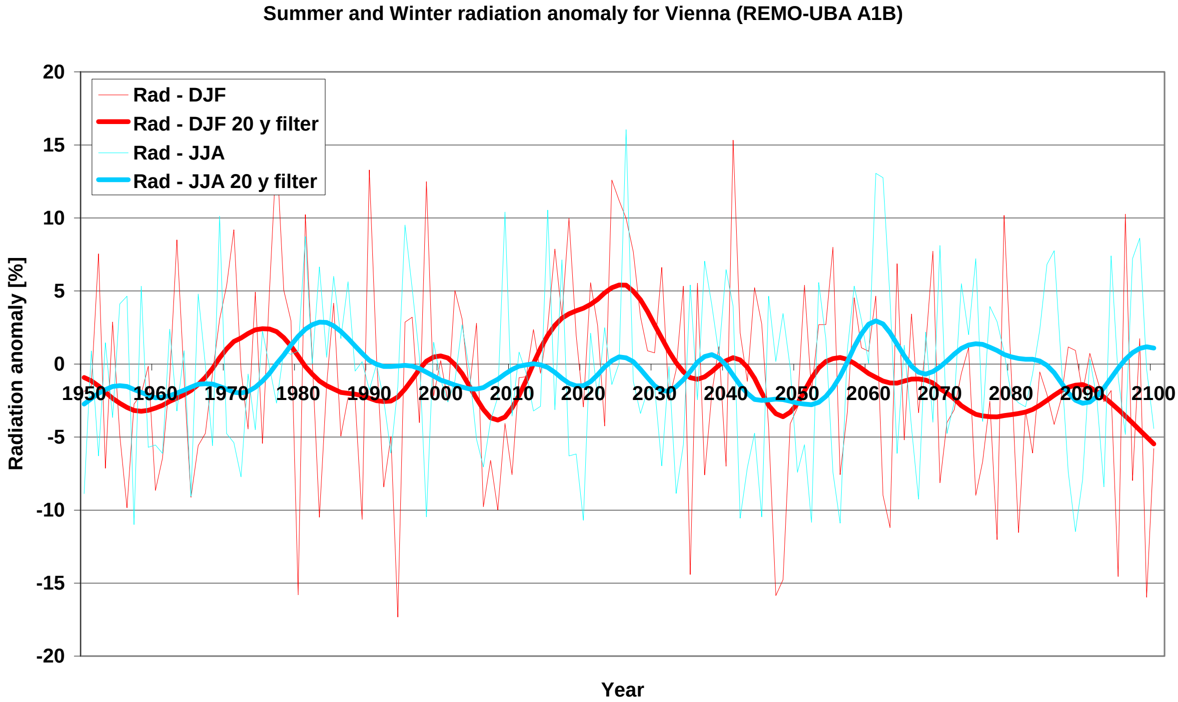
Graph 1: Temperature scenario (JJA = summer, DJF = winter) for Vienna derived from the regional climate model REMO-UBA forced with the emission scenario A1B.

For this study additional to temperature we also need the parameter relative humidity, wind speed, global radiation and diffuse radiation. All these variables showed now significant trend in the REMO-UBA A1B scenario for the 21st century in Vienna. In graph 2 as an example the development of the global radiation in Vienna is shown for the summer (blue) and winter (red) season. Both season show realistic fluctuation of 15 % from year to year and even the smoothed time series with 20 year Gauss filter show fluctuations in the order of up to 5 % in winter and ~ 3 % in summer. But in both seasons no trend can be seen.

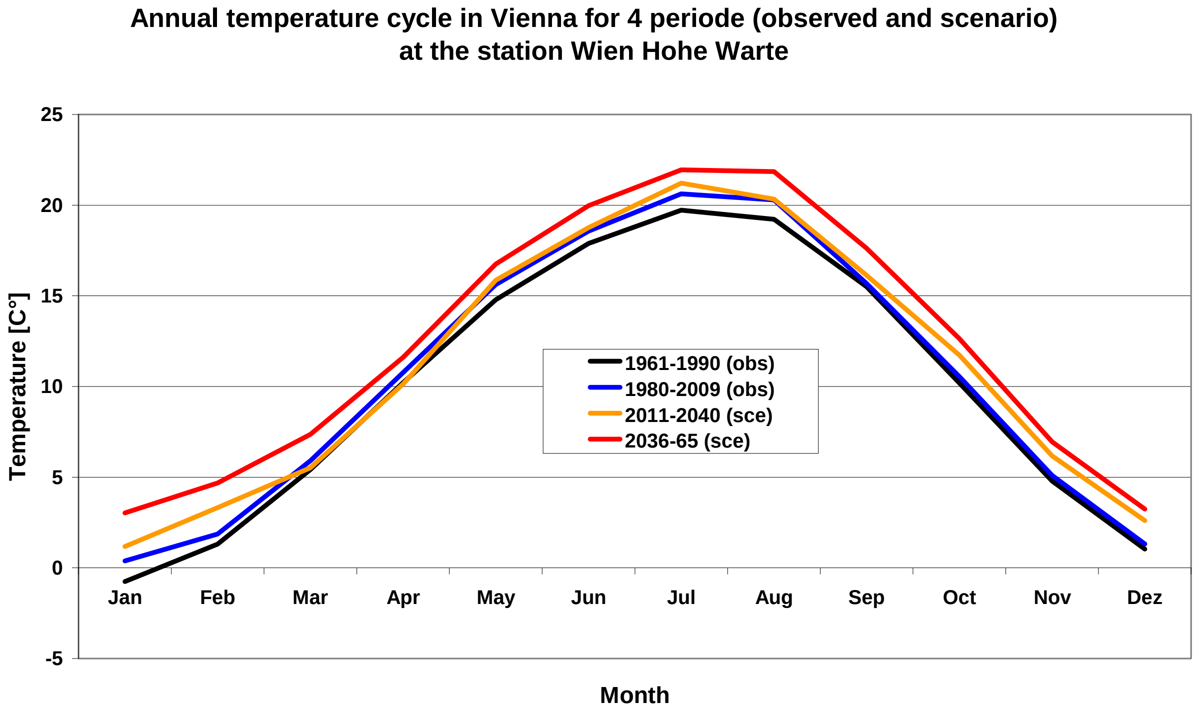
As the decadal variability of the REMO-UBA results are not in phase with the natural decadal variability, the climate change signal of these variables is random and includes no additional information. Therefore only for temperature the climate change signal has been quantified for the two scenario periods 2025 and 2050. I

In graph 3 the average annual cycle of the monthly mean temperature for the two observational periods (1961-1990 and 1980-2008) and the scenario periods (2011-2040 and 2036-2065) is shown for the weather station Wien Hohe Warte. The high temperature increase within the last decades can be seen in the difference between the black line (1961-1990) and the blue line (1980-2009). Temperature increase was most pronounced in January and February and from

May to August. No warming was observed in autumn within the last decades. The warming in the last decades was that high, that especially in spring and summer is no difference between the last observation period (1980-2011) and the first scenario period (2011-2040) for temperature. Between the first and the second scenario period (from 2025 to 2050) a further continuous warming appears, with maximum warming from January to April. The average warming from the first observational period (1961-1990) till the second scenario period (2036-2065) is 2.35 degree with increased warming in winter and spring and slightly lower warming in spring and autumn.



Graph 2: Solar radiation scenario (JJA = summer, DJF = winter) for Vienna derived from the regional climate model REMO-UBA forced with the emission scenario A1B.



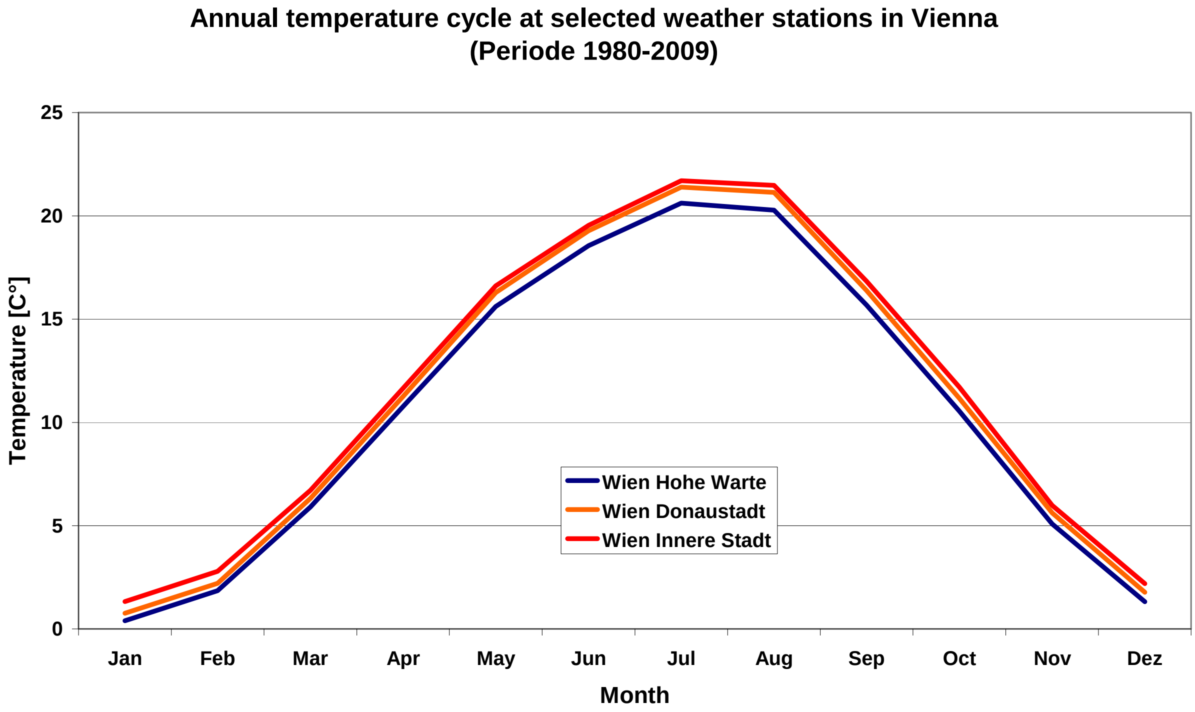
Graph 3: Annual cycle of the monthly mean temperature for four different periods (observations and scenarios) in Vienna at the weather station Wien Hohe Warte

Do represent the spatial diversity of the meteorological situation within a large city like Vienna we choose three weather stations. The main weather station is Wien Hohe Warte. This station is located at the Austrian weather service (ZAMG) and is operating on the same place since 1872 and has hourly observations since 1950. This station is located on the border of Vienna on the hills of the Vienna Woods at an altitude of 198 m.

The representative of downtown Vienna is Wien Innere Stadt. This station is located in the centre of town at an altitude of 171 m. This station is oberating since 1984.

The third station is called Wien Donaufeld. This station in at the border of the centre of Vienna close to the Danube. The altitude of the station is 161 m at it is operating since 1996.

In graph 4 annual cycle of the mean monthly temperature is shown of the three stations. Innere Stadt is the warmest station in all months. This shows, that the head island effect of Vienna is most pronounced at this station. In terms of monthly means Donaufeld lays between Innere Stadt and Hohe Warte , closer to Innere Stadt from March to August and closer to Hohe Warte in the rest of the year.



Graph 4: Annual cycle of the monthly mead temperature at three selected weather stations in Vienna for the period 1980 – 2009.

3.2 Generation of climate data sets[38]

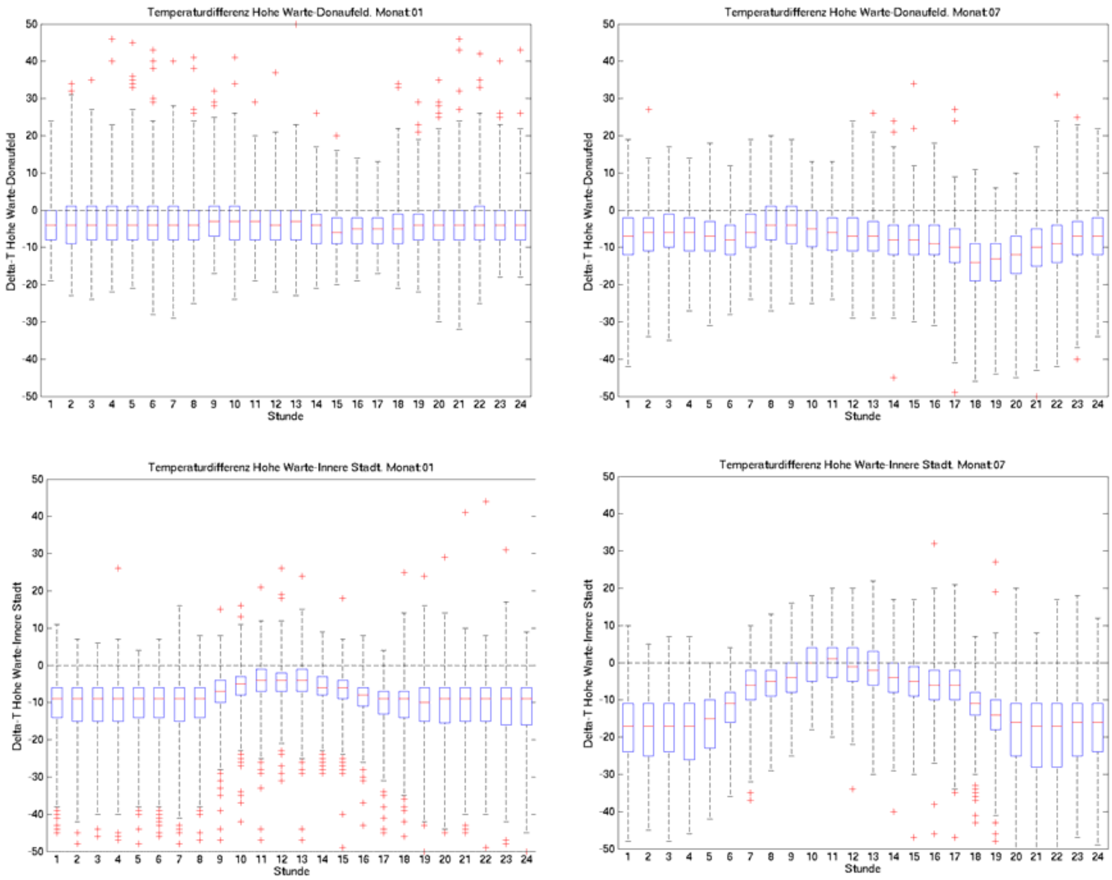
Bases for the construction of the synthetic climate data sets are the hourly observations of the three meteorological stations Hohe Warte, Donaufeld and Innere Stadt. The synthetic climate data sets should be able to represent the observed climate change in Vienna, as well as further scenarios. So we decided to use the WMO – standard period 1961-1990 and the last available observational thirty years 1980-2009 for the observations. For the scenarios we use two period not too far in the future, 2011-2040 for the near future and 2036-2065 for mid century.

As only the station Hohe Warte has hourly measurements of the parameter temperature, relative humidity , wind speed, global radiation and diffuse radiation for the whole period 1961-1990, we estimated the missing values for the station Innere Stadt and Donaufeld from the measurements at Hohe Warte.

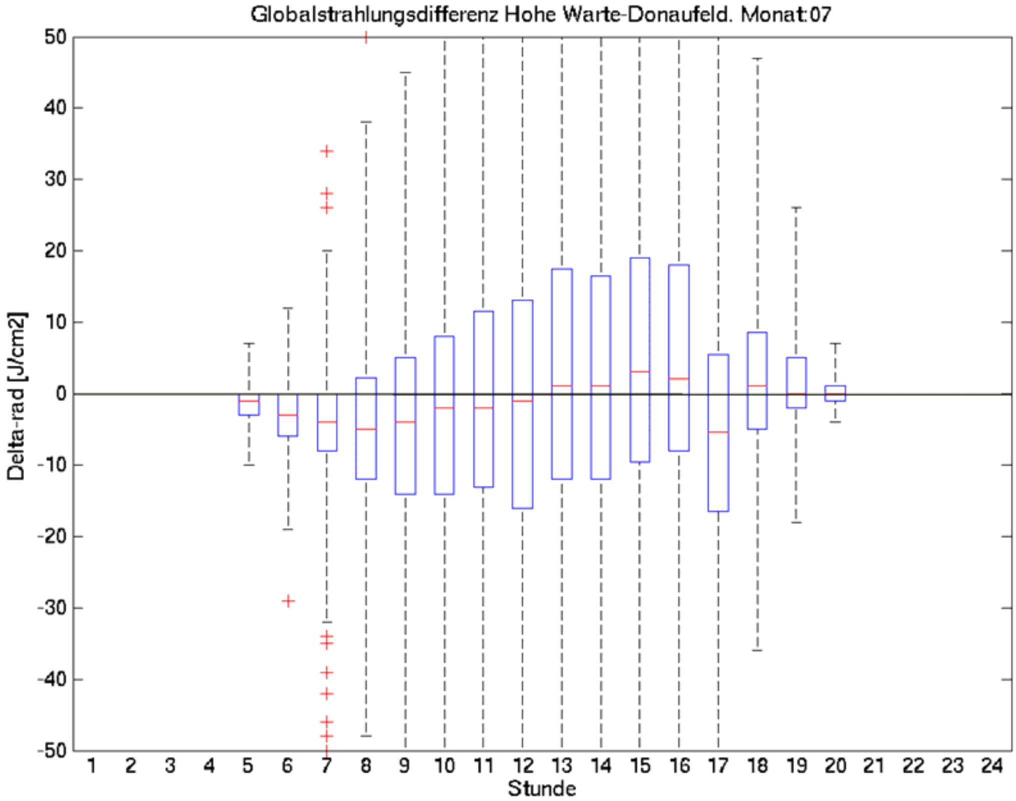
For this, an analyses of the differences of the hourly values within month was applied. In graph 5 the distribution of the hourly differences between Hohe Warte and Donaufeld (upper panel) and Innere Stadt (lower panel) for the month January (left) and July (right) is shown. In January Donaufeld (upper left) is constant 1 degree warmer than Hohe Warte. Innere Stadt however shows a slight diurnal range. Arround noon (9 am to 3 pm) Innere Stadt is only half a

[38] This section was contributed by Formayer and Pospischal; see 1.3 Organizational remark, page 9

degree warmer than Hohe Warte, the rest of the day also 1 degree. In July both stations show a diurnal range in temperature differences. In Innere Stadt the warming is most pronounced during night time with temperature 2 degree higher than Hohe Warte. During daytime the differences decreases and vanish totally during noon. This is in good agreement with the urban head island effect. In Donaufeld the situation is not so clear. The station is general half a degree warmer than Hohe Warte and the difference is most pronounced from 5 to 8 pm. This seems to be related different insolation around 5 pm (see gaph 6) and in general different temperature conversion of the solar radiation in the surrounding of the weather station and this part of town.



Graph 5: Temperature differences (1/10 degree) between the weather stations" Wien Hohe Warte" and "Wien Donaufeld" (upper panel) and "Wien Innere Stadt (lower panel) for January (left) and July (right)



Graph 6: Radiation differences between the weather stations" Wien39 Hohe Warte" and "Wien Donaufeld

39 Wien: German for Vienna

3.3 Description of climate data sets

For the modelling of climatic conditions semi synthetic data sets[40] were used which comprise hourly values for external temperature, relative humidity, global and diffuse radiation and wind speed. For all these parameter the semi synthetic data sets comply with average monthly values of weather observations during specified long term periods of time. Hence, on the basis of weather observations these data sets depict characteristic weather situations including extreme winter and summer conditions.

Such data sets have been generated for four time periods and three distinct Viennese locations. Hence the following data sets were employed:

- "howa 61": semi synthetic data set covering the observation period 1961 – 1980 for the location of Vienna's main weather station
- "howa 80": semi synthetic data set covering the observation period 1980 – 2009 for the location of Vienna's main weather station
- "howa 2025": semi synthetic data set depicting future climate conditions in 2025, for the location of Vienna's main weather station; based on localized climate scenarios
- "howa 2050": semi synthetic data set depicting future climate conditions in 2050, for the location of Vienna's main weather station; based on localized climate scenarios

- "Inne 61": semi synthetic data set covering the observation period 1961 – 1980 for Vienna's CBD
- "Inne 80": semi synthetic data set covering the observation period 1980 – 2009 for Vienna's CBD
- "Inne 2025": semi synthetic data set depicting future climate conditions in 2025, for Vienna's CBD, based on localized climate scenarios
- "inne 2050": semi synthetic data set depicting future climate conditions in 2050, for Vienna's CBD, based on localized climate scenarios

- "dona 61": semi synthetic data set covering the observation period 1961 – 1980 for an urban location within Vienna
- "dona 80": semi synthetic data set covering the observation period 1980 – 2009 for an urban location within Vienna
- "dona 2025": semi synthetic data set depicting future climate conditions in 2025, for an urban location within Vienna
- "dona 2050": semi synthetic data set depicting future climate conditions in 2050, for an urban location within Vienna; based on localized climate scenarios

[40] Heindl W., Kornicki T., Sigmund A. (1990)

3.4 Key figures for analysis of climate data sets

The described data sets have been analysed by in terms of parameters, which are expected to influence the thermal behaviour of the investigated sample buildings.

- Average external temperature (year, summer):

[C°]
Yearly or summer average of external temperatures (including all hours of day) provide a first insight into overall climatic conditions contained in a data set and allow for the general comparison of data sets across different time periods and locations. Additional information is rendered by appraisal of an average summer temperature which indicates whether a data set displays especially hot summer months (June – August).

- Average hourly irradiation (year, summer):

[W/m^2]
For office buildings, which in general are characterized by significant internal loads, the incidence of high amounts of solar gain through glazed building envelopes is of crucial influence for thermal behaviour and comfort. Thus, average hourly irradiation rates, especially for summer conditions, allow for insights on thermal stress placed upon these building types. The proportions of diffuse irradiation therein reveal how much direct sunlight complementarily is expected to reach a horizontal plain.

- Cooling degree days:

[CDD]
Degree days, too, are essentially a simplified representation of outside air temperature data. They are a measure of how much and for how long outside air temperature is higher than a specific base temperature – internationally this base temperature is most frequently set at 18.3°C (65°F).

- Heating degree days:

[HDD]
Although winter conditions are not a focus in this study, all year round assessment parameters are nonetheless charted in order to check possible interdependencies. Therefore, the applied climate data sets are likewise analysed as to their respective heating degree days. Analogue to cooling degree days, these indicate by how much and for how long outside air temperature is lower than a specific "base temperature" – according to national standards this base temperature was set at 12°C (unlike internationally common figures of 15,5°C or 18,3°C). In contrast to cooling degree days, heating degree days are calculated regarding the difference between the average daily outside temperature and an aspired indoor temperature of 20°C for the period of time during which outside temperature falls below the base temperature.

- Comfort limit temperatures acc. EN 15251 (adaptive comfort model):

The assessment of indoor comfort conditions inevitably leads to the discussion of different comfort models. The applied climate data sets are likewise assessed according to these models here. The adaptive comfort model draws from the calculation of a rolling mean of outdoor temperatures which takes into account that people adapt their habits and thermal expectations in accordance with prevailing weather conditions. Comfort limits in turn are determined on basis of this rolling mean, graded for different types of buildings requiring different levels of comfort.[41] Therefore, the yearly swing of the external temperature rolling mean was depicted.

- Cumulative amount of hours surpassing temperature limits (summer):

[C°]
Amount of hours surpassing continuous temperature limits; this gives hint at which data sets generally range higher or lower in the frequency of either low or high temperatures.

[41] For limitations of the adaptive comfort model acc. to EN 15251 see chapter 8.2 Module 2: Discussion of comfort models, page 98

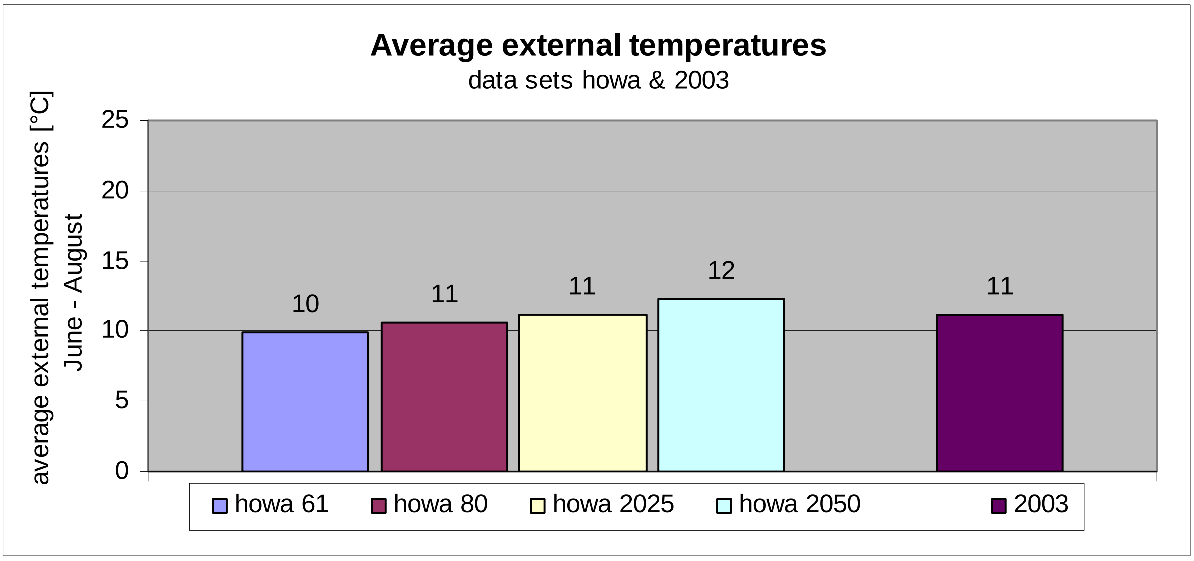
3.5 Results of analysis of climate data sets

3.5.1 Average external air temperature

The comparison of air temperatures of the employed data sets displays a difference in mean monthly temperatures between data sets 61 and 2050 respectively of nearly 3K on a yearly basis. A distinct difference is already discernable between "howa 61" and "howa 80": the former one is roughly representing the immediate past, while the latter one can be regarded as representing today's situation; between the two, an overall increase in average temperature of more than 1 K has in fact already been recorded. This is a bigger difference than is to be expected for the time lap between "howa 80" and "howa 2025".

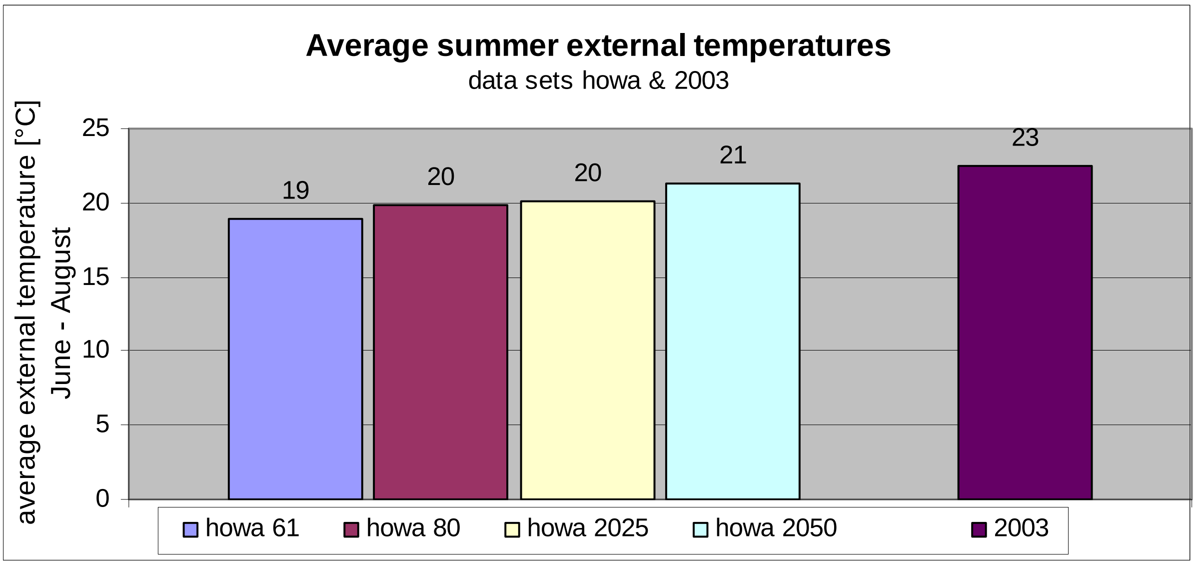
It has to be kept in mind that various climate data sets frequently in use today in thermal simulations for sizing of cooling and heating plants in newly to be built office blocks roughly date to the period of "howa 61". Herein lies a considerable danger: while energy requirements under the use of such climate data sets tend to be overestimated in the case of heating, they run risk of underestimating the cooling demand and they may even result in too low maximum cooling loads that are too low and consequently in non satisfying comfort conditions, e.g. frequent overheating in rooms of these new buildings.

In the overall comparison of climate data sets the observations from 2003 portray this particular year as having been hot throughout, but not even as hot as has to be expected on average for the period of 2050.



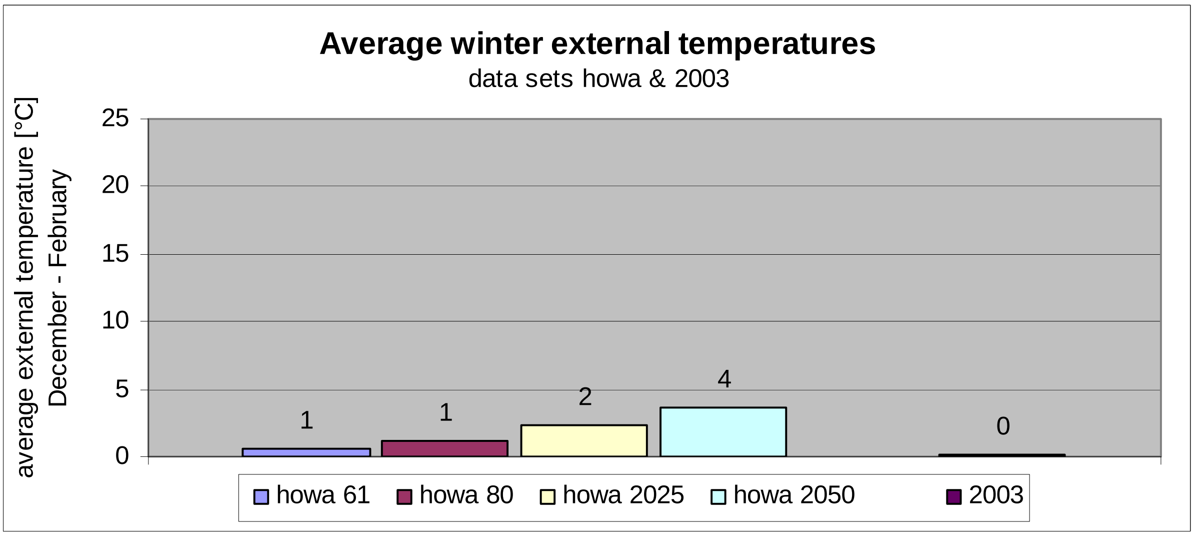
Graph 7: Average annual external temperatures for different temporal resolution of howa

However, when the comparison is restricted to external temperatures during the summer months of June to August, it turns out that 2003 was even hotter than summers are to be expected on average for the period around 2050. While the relation between average temperatures of the “howa” data sets remains generally unchanged as compared to the average annual means, the summer mean of 2003 clearly exceeds all others. This demonstrates that the summer of 2003 by all means was an extreme event; a scenario, however, that is expected to recur more often under the premises of climate change.



Graph 8: Average summer external temperatures for different temporal resolution of howa

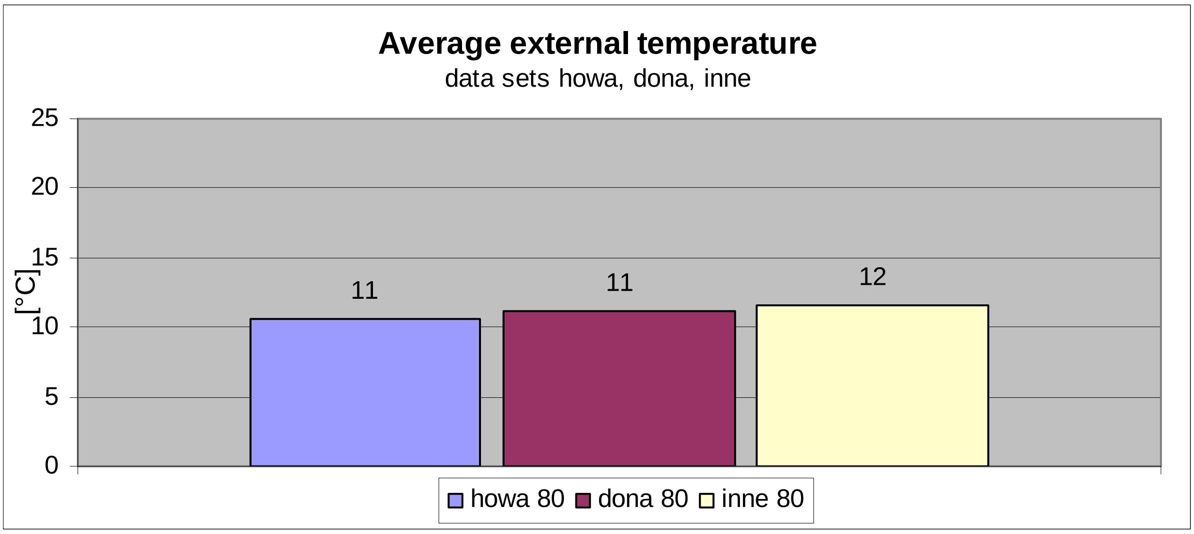
Winter average temperatures reveal that hot summers like those of 2003 are not necessarily linked to warm winters: that year’s winter mean ranges below those of all long–lived averages of the “howa” data sets.



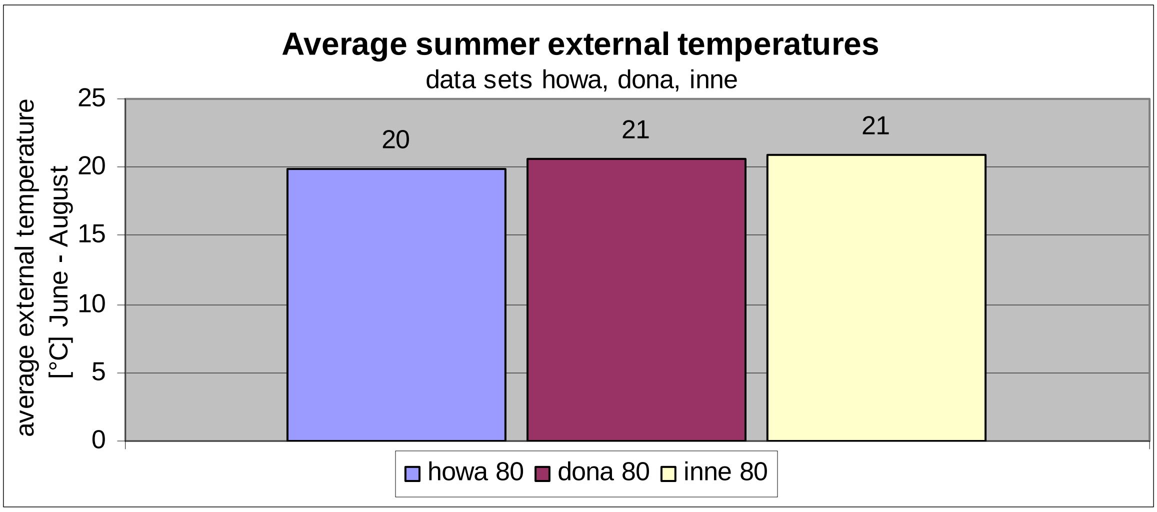
Graph 9: Average winter eternal temperatures for different temporal resolutions of howa

Spatial resolution of climatic conditions within the city area of Vienna is exemplarily displayed here for the temporal setting of “80”: while annual temperature average scores lowest for “howa” in the green city outskirts, the highest value is obtained for the location “inne”, even though differences are minor. This goes in line with general literature indications[42] that Vienna is a well ventilated city and in consequence does not display harsh urban heat island intensity.

This proposition holds true even for summer months; calm nights which elsewhere favour the build-up of consistent temperature differences between core cities and cooler surroundings are seldom here.



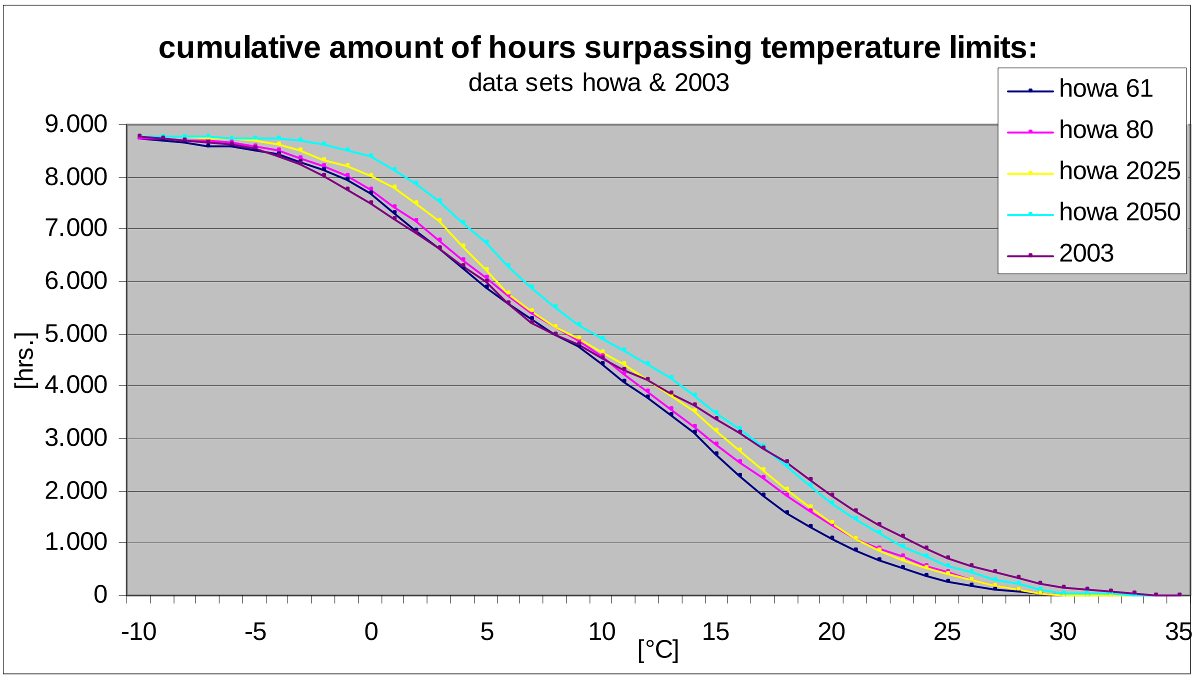
Graph 10: Average external temperatures for different spatial resolution



Graph 11: Average Summer external temperatures for different spatial resolutions

42 Mursch-Radlgruber, Erich; Trimmel, Heideline (2009)

The following graph shows during how many hours of the year temperatures of all the applied climate data sets of “howa” range above a specific value. Some relations can be derived from this graphic representation:
For low winter temperatures, ”howa 80” ranges slightly above “howa 61”. While the difference is more distinct for medium temperatures up to approximately 20°C, the data sets tend to converge again for elevated summer temperatures.
2003 displays the highest amount of hours with low temperatures, ranges in the middle for medium temperatures and highest for high temperatures.
“howa 2025” runs in between “howa 80” and “howa 2050” for winter temperatures, but approximates values of “howa 80” for summer times.

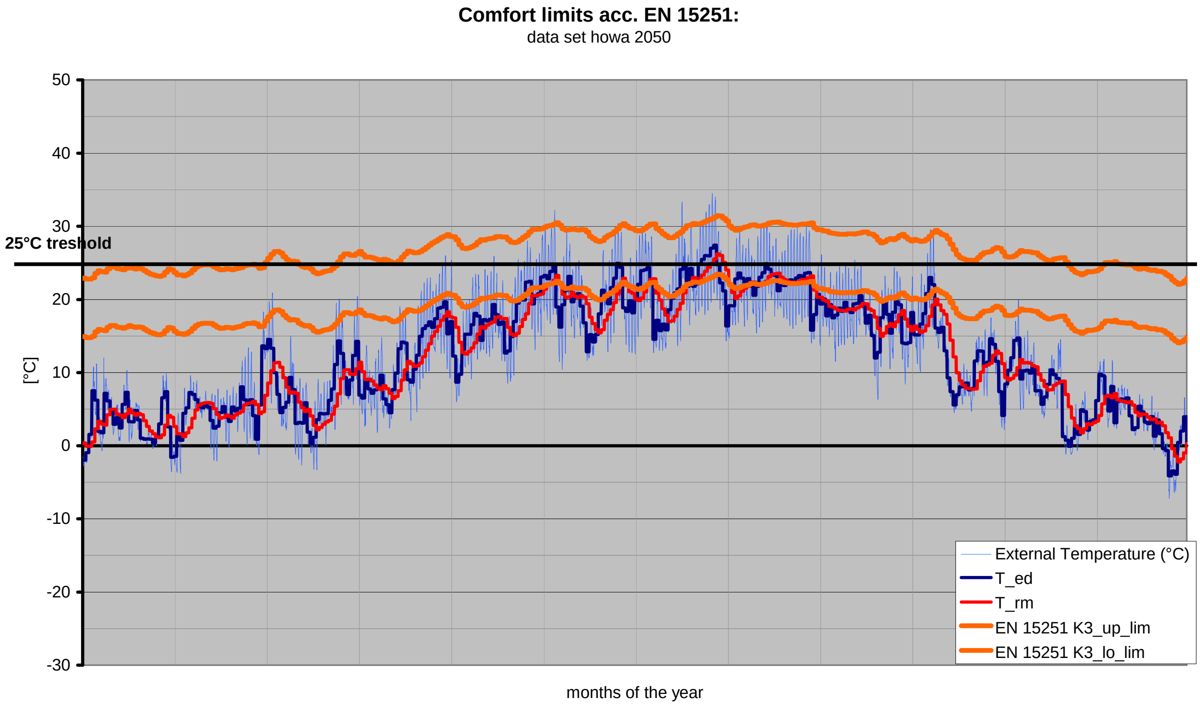


Graph 12: Amount of hours surpassing continuous temperature limits for different temporal resolutions of howa

<u>Comfort limit temperatures acc. EN 15251 (adaptive comfort model):</u>

The comfort temperature belt established on the base of rolling mean outdoor temperature[43] closely follows the swing of outdoor temperatures during summer months (winter comfort conditions are not investigated here). The highest acceptable temperatures reach values well beyond 30°C for data set “howa 2050”.

[43] For a detailed description of the adaptive comfort model and the notion of rolling mean outdoor temperature refer to chapter 8.2 Module 2: Discussion of comfort models, page 97



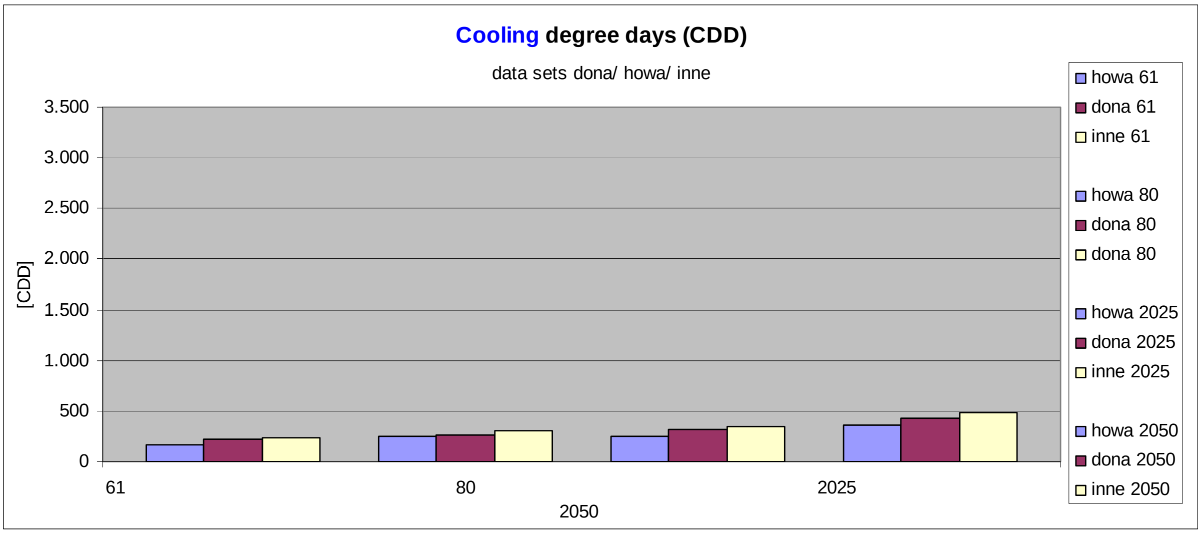
Graph 13: Annual swing of upper and lower comfort limit for climate data set "howa 2050" acc. EN 15251[44]

T_{ed} depicts daily means while T_{rm} constitutes the rolling mean external temperature. The limit temperatures "EN 15251 K3_up_lim" and "EN 15251 K3_lo_lim" border the comfort temperature belt according to the adaptive comfort model for building category 3 (existing buildings with reduced expectations on users' side regarding thermal comfort) acc. EN 15251. The horizontal line marks the 25°C threshold above which the determination of the comfort limit temperature only relies on restricted amount of data.

Cooling Degree Days

Nearly as striking as the differences between different temporal resolutions are the differences between the locations howa, dona and inne in terms of Cooling Degree Days (CDD): the difference is at approximately 50 CDD between the "80" data sets and increases to almost 200 CDD between the "2050" data sets portraying the location "inne" as clearly more prone to overheating than the main weather station "howa".

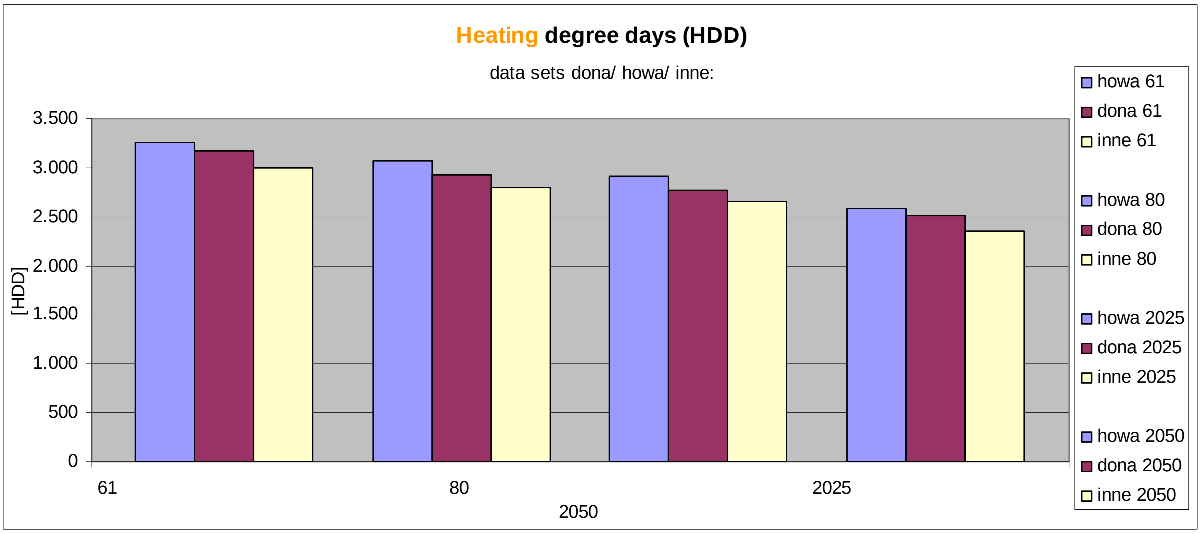
[44] adapted with thankful acknowledgement from: Holzer, P.: climate data wien.xls



Graph 14: Cooling degree days for different temporal and spatial resolution

Heating Degree Days

An almost mirror inverted situation is found for heating degree days, although on a higher level; data set "howa" displays highest values in heating degree days for all temporal resolutions.



Graph 15: Heating degree days for different temporal and spatial resolution

3.5.2 Design Day determination for cooling plant sizing[45]

For the sizing of cooling plants, climate engineeres simulate indoor conditions of the building in question by useing Design Days. In this concept, the building is exposed to the continuous (at least: 15fold) repetition of a specific single day's data set. By this, heat wave conditions are modelled and in consequence sizing figures are achieved which can be expected to fall on the safe side under all conditions.

The corresponding Austrian technical norm ÖNORM B 8110-3 (1999)[46] describes the compilation of Design Day climate data sets as follows: it takes local conditions into account and asks for a 24 hours' set of outdoor air temperatures which is not surpassed on more than 13 days in long-term mean.

For all climate data sets investigated here ("howa 61" to "howa 2050") those days where selected which display outdoor temperatures not found more often than 13 times throughout the year. The temperature courses of these days together with the associated irradiation values were utilized as Design Days which represent the corresponding climate data set.

However, the Design Days thus compiled are not necessarily fully representative for the corresponding climate data set: they do not depict differences in both temperature and irradiation between the climate data sets themselves as the single days chosen cannot be expected to run completely parallel to the characteristics of the annual data sets they were taken from. Hence it is barely possible to depict differing conditions of the annual climate data sets "howa 61" to "howa 2050" in their respective Design Days.

3.5.3 Average hourly irradiation

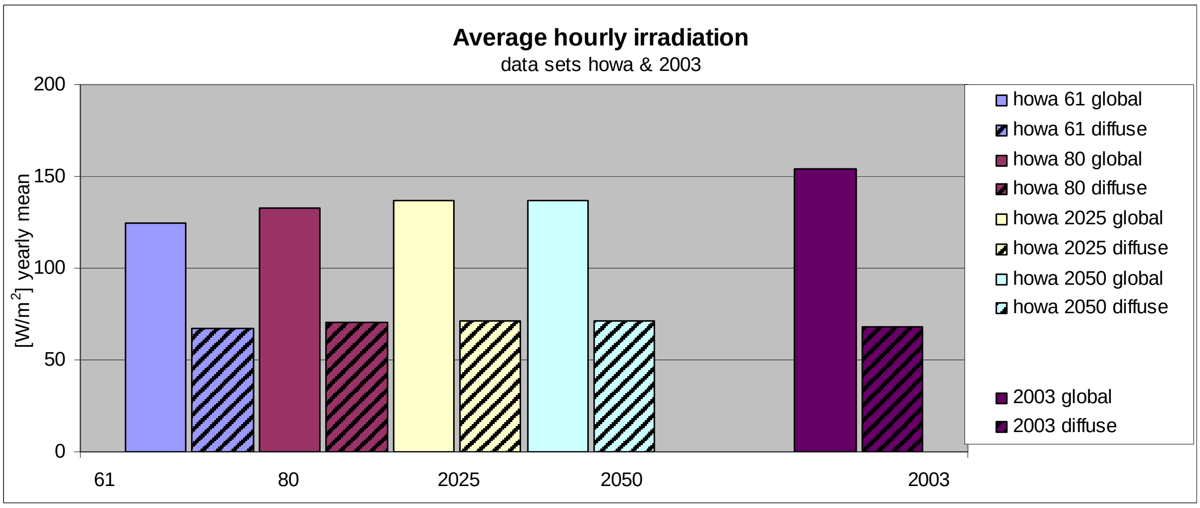
Solar gains through transparent building parts strongly influence indoor temperatures; hence, the importance of external irradiation for indoor comfort and conditioning energy demand is obvious.

Average hourly irradiation rates of both global and diffuse fraction for the applied climate data sets demonstrate a consistent trend: global irradiation constantly increases between "howa 61" and "howa 2050" and reaches a pronounced peak in data of 2003. At the same time the diffuse fraction of this global irradiation remains virtually unchanged, which implicates that direct irradiation in turn increases over all data sets. This astonishing effect is well known from cities within the Western industrialized countries; it is generally attributed to anti

[45] See also: 8.1.6.1 Cooling load under Design Day conditions, page 92
[46] ÖNORM B 8110-3 (1999): chapter 7, page 8

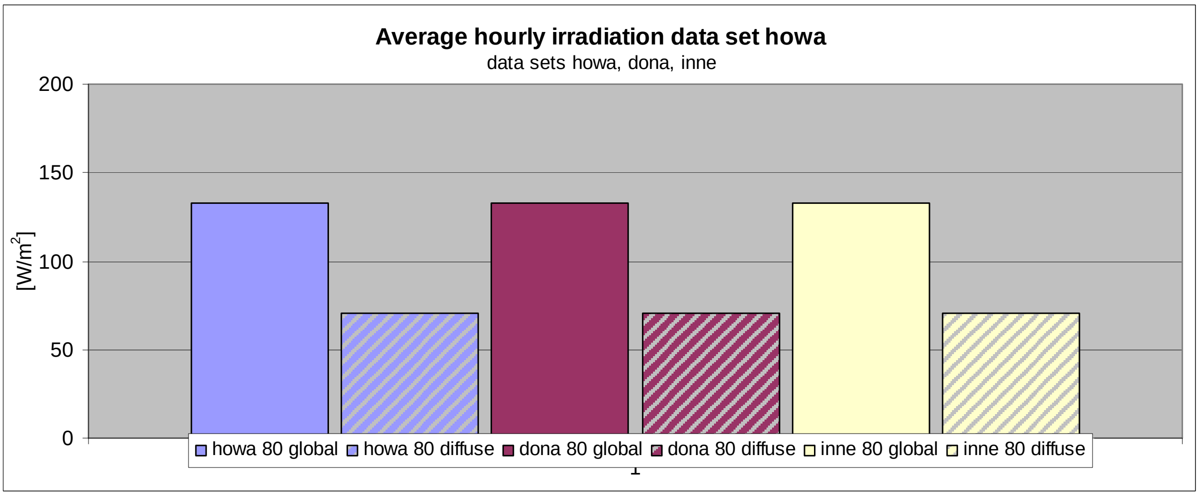
air pollution measures undertaken throughout the last two decades in an attempt to counteract Global Dimming.

Global Dimming was widely observed in the 1970ies and 1980ies and found to be caused by massive air pollution. Aerosols of various consistencies and anthropogenic origin caused a clearly measureable, increasing blocking of solar irradiation. Consecutive efforts to counteract by the appliance of appropriate filtering technology are by now yielding success in terms of less blocking so that raised levels of irradiation are reaching the atmosphere again. The future scenarios "howa 2025" and "howa 2050" foresee remaining potential for this process while data of 2003 depicts an exceptionally hot summer rich in solar irradiation.



Graph 16: Average hourly irradiation for different temporal resolution of howa & 2003

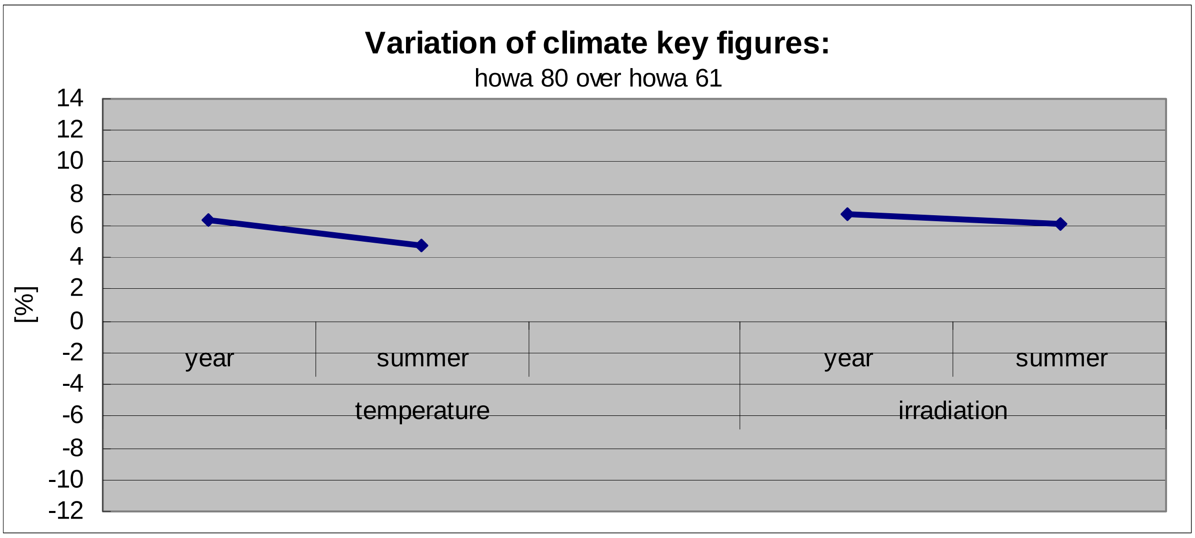
Regarding spatial resolution, however, no difference can be detected between the different Viennese locations in terms of solar irradiation.



Graph 17: Average hourly irradiation for different spatial resolution

Comparison of climate data sets

Analytic effort was undertaken to compare the applied climate data sets over the course of time: the following graph exemplarily describes the relative increases in external temperature and solar irradiation displayed by data set “howa 80” as compared to “howa 61”, both for the entire year in general and the summer months in particular.



Graph 18: Comparison of data sets howa 61 and howa 80

Remarks on humidity and wind

As relative outdoor air humidity displays no significant changes in the more recent readings from 1980 to 2009 as compared to those of 1961 to 1990 do not detect clear signals in this respect either, future data sets “howa 2050” and “inne 2050” remain generally unchanged in terms of humidity. Similarly, values for both wind speed and direction experience no significant alternation.

4 Sample buildings' constructive configuration

This study investigates up to nine sample buildings' thermal behaviour due to their particular constructive properties incorporated in their constructions, which in turn are strongly determined by their respective building epoch (room layout, storey height and the like). This is to stress that their constructive configuration is what differentiates the sample buildings from each other, whereas the conditioning of their indoor climate, as diverse as it might be in reality, is assumed to be uniform in the simulation runs in order to make the results comparable. Hence, these results exclusively display the constructions' and the design's influence upon the thermal behaviour under the applied climate data sets and optimization strategies.

4.1 Description of sample buildings

Close inquiry about available sources of information revealed, that hardly any consistent statistics are available as for the determination of "typical" office buildings in the city of Vienna. Unlike data for residential buildings, the central Austrian bureau for statistics does not separately register data on office buildings neither in general nor for the capital city of Vienna in particular. Hence, informal information from holders of large real estate portfolios, developers of business locations and leading real estate broking consultants form the only available sources of information.

These bits of information, however, do not build up to a consistent picture but rather spotlight the respective holder's insight to the overall office market. The Municipality of Vienna's proper building stock in terms of offices barely displays any building dating from after the 1960ies. With the City authorities being a stakeholder in this present project, emphasis was hence laid on buildings originating from these times.

Having said that, leading real estate broking consultants do not normally deal with buildings built earlier than 1990, and they affirm, that office buildings from earlier decades are nonmarketable. In general, such buildings constitute company head quarters in the companies' proper holdings (whereas nowadays such head quarters are normally leased from a provider or developer). In consequence, information on offices built between 1960 and 1980 is especially scattered and hard to come by.

It turned out to be nearly impossible to assess a statistically founded typology of Viennese office buildings. As an alternative, the generally most common division of building epochs in the country was applied, which in turn is determined by

20th century's history; the chosen sample buildings therefore represent three main building epochs:

- built before World War1 (WW1),
- built after World War 2 (WW2),
- built after 1990 and
- the comparatively new passive house building standard.

4.1.1 Leading and additional buildings

For all epochs involved at least one sample was chosen. For the period “before WW1” and “after WW2” additional buildings were added to the sample in order to broaden the statistical basis. However, only for four sample buildings the available data on constructive configuration was sufficient for in – depth investigation. This is why detailed analysis is mainly focuses on these four buildings, hereafter referred to as “leading buildings”.

If no detailed information was available on the additional buildings' constructive configuration, reference was made to the construction of the leading building of the respective building epoch. General assumptions on the construction of post WW2 buildings proved to be difficult; This epoch already displays a considerable wider ranger of different constructions than the precedent phase from before WW1 (which essentially relayed on plastered full brick only). In consequence, post WW2 buildings also cover a considerable range of different thermal properties. The present investigation strives to highlight the margin of possible values by a worst-case approach: for both cooling and heating requirements, reference was made to the sample building of this group which displays highest demands in the respective field.

The following Table 3 portrays these four edifices and Table 4 lists the additional buildings (including abbreviation and address) registered in the respective building epoch. In all these buildings several (two to eight) single office rooms were investigated. These rooms cover the two orientations most prone to overheating, namely south and west - although each room was simulated and charted individually. Overall averages were formed for these two orientations. Only office rooms housing two work places were selected for simulation. The original size (area and room height) of these rooms was depicted in the computational model in order to account for typological properties of the represented building type.

Only office rooms were investigated no account was made for other room types frequently encountered in office buildings such as meeting rooms, lounges, cafeterias or server rooms. These types of rooms experience such a broad range of possible variations that generally applicable statements regarding their thermal behaviour can't be seriously given here. However, as the double office room forms the single most frequent room type in most medium to large office buildings in Vienna, the simulation results allow for a bottom up assemblage which in turn facilitates first insights into the expected thermal behaviour of the overall complex[47].

[47] It goes without saying that the prevalence of different spatial concepts such as the typical North American cubicles require other approaches in simulation.

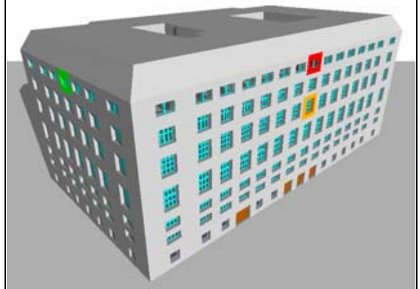
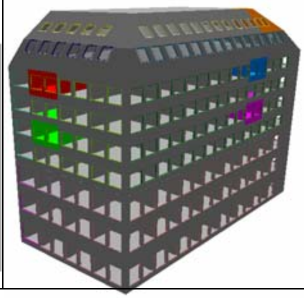
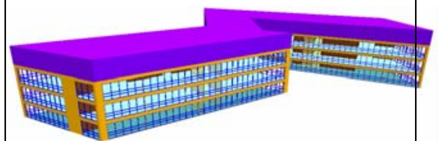
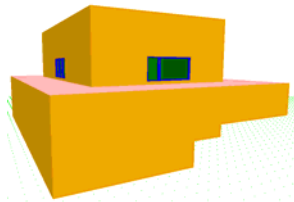
				
Denomination	**ONB**	**BNG**	**Strabag**	**SOL 4**
Address Period of construction	9., Otto-Wagner-Platz 3 1913 – 1925	9., Otto-Wagner-Platz 3 1950 – 1956	22., Donau-City-Straße 9 2001 - 2003	Guntramsdorferstr.30, Mödling 2005
Nr. of storeys	10	9	13	4
Net office area	43.255 m^2	8.107 m^2	28.000 m^2	2.221 m^2
Description	Headquarter of the Austrian National Bank	Office Unit of the Austrian National Bank	Headquarter of an Austrian Construction Group	Individually inhabited office units, Passive house standard
Orientation of sample rooms	5^{th} floor: S, N, E 7^{th} floor: S, W, E	4^{th} floor: S, W, N 6^{th} floor: S, W, N 8^{th} floor: S, SW	5^{th} floor: N, S, NE, SW, W	2^{nd} floor: S, W
Model Sample rooms colored resp. equipped with windows				

Table 3: General description of leading sample buildings, including representation of the applied geometric model

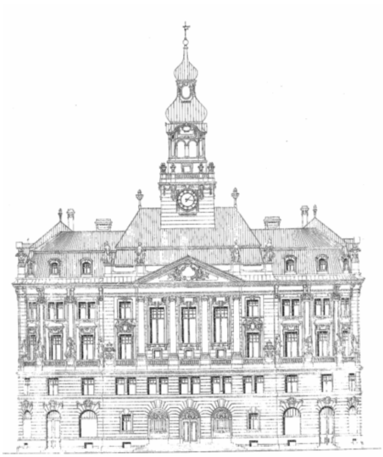
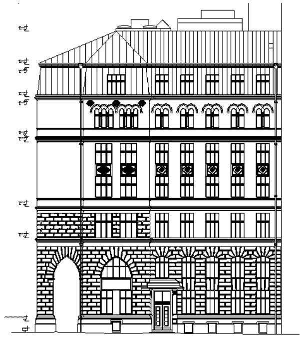
Additional Buildings			
Built before WW1	**SPZ** (20., Am Spitz Nr.1) 	**RHS** (1., Rathausstrasse 14–16) 	**SCP** (8., Schlesinger Platz 2 – 6) 
Built after WW2	 **FAS** (10., Favoritenstrasse 18)	**LES** (8., Lerchenfelderstrasse 4) 	

Table 4: Additional sample buildings' representation

4.2 Key figures for analysis

The buildings' constructive configurations were analysed in terms of their disposition to summer overheating. The following key figures play a role herein:

Occupancy
[m2/pers.]; only net area of the investigated office rooms was taken into account; all sample rooms are occupied by two workers;
In thermal terms occupants represent heat sources and the more persons reside within the same area, the more heat is generated. Depending on the buildings' time of construction, they display different room layouts resulting in different occupation densities.

Glazing fraction
[%]; only net window pane area of the investigated office rooms was taken into account;
The proportion of glazed surface contained within the overall exterior envelope of the sample rooms strongly influences the amount of solar gain, which contributes to the room's heating up.

g-Value
[-] acc. EN 410
The quality of the glazed parts of the exterior wall in terms of transmission of solar irradiation likewise determines which amount of the striking irradiation is effectively received and absorbed inside. This ability of the glass panes is characterized by their g – value: the higher the g – value the more irradiation is admitted.

Fc-Value
[-] acc. ÖNORM B 8110-3
Shading can counteract heat penetration to a significant extent, strongly depending, however, on the shade's position in respect to the glass pane: Exterior shades are generally more effective in keeping irradiation out than those between or behind the panes. This interdependency is depicted in the applied Fc – value of the respective shading device; the higher this value the more irradiation is admitted.

U-Value
[W/m2K] acc. EN 673
Heat transmission between indoors and outside both via opaque and glazed parts of the exterior wall may occur in either direction, depending on which side the temperature is higher. During winter, it will always be colder outside than inside, but the situation may vary during the summer months, when cooling occurs during relatively cold nights and heating up during hot days. In any case, the

overall U-value of an entire wall construction reveals its ability to withhold heat transmission: the lower the value the better the walls' insulation.

Mass
[kg] acc. ÖNORM B 8110-3
The thermal mass of the enclosing wall and ceiling elements characterizes a room's thermal inertia. The occurring heat is stored in this mass thereby dampening/ postponing heat peaks. This ability to store heat is limited though to the uppermost centimetres of the construction's layers.

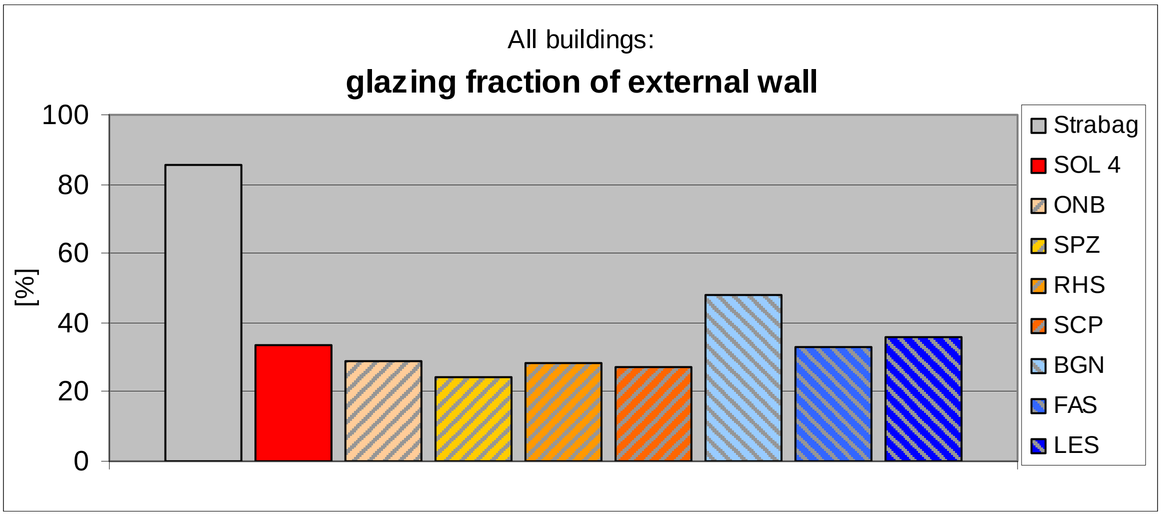
4.3 *Results of comparative building analysis*

Graph 19 gives an overview of the buildings' thermal properties in absolute values. This graph also indicates the colour code used for the different buildings hereafter: Buildings from before WW1 are displayed in orange shades while those from after WW2 are marked by shades of blue. Strabag is always displayed in grey and SOL 4 in red.

		temperature		irradiation							
		U - value		g - value	Fc - valu	g*F_c - val	glaz	glaz		occupna	mass
		[-]		[-]	[-]	[-]	[%]	[m^2/m^3]		[m^2/pers.	[kg/m^2]
Strabag		1,24		0,36	0,58	0,2	85,27	0,15		11,15	246,32
ONB		0,99		0,62	0,19	0,1	28,80	0,05		14,05	284,78
SOL 4		0,34		0,52	0,15	0,1	33,37	0,06		12,42	561,15
SPZ		1,36		0,71	0,21	0,1	24,49	0,05		15,83	296,56
RHS		1,79		0,66	0,22	0,1	28,20	0,05		15,10	439,86
SCP		1,80		0,66	0,21	0,1	27,30	0,05		14,79	321,36
BGN		0,92		0,62	0,36	0,2	48,02	0,12		11,97	684,30
FAS		1,75		0,67	0,35	0,2	32,87	0,07		17,22	475,12
LES		1,56		0,66	0,21	0,1	35,96	0,07		16,09	292,92

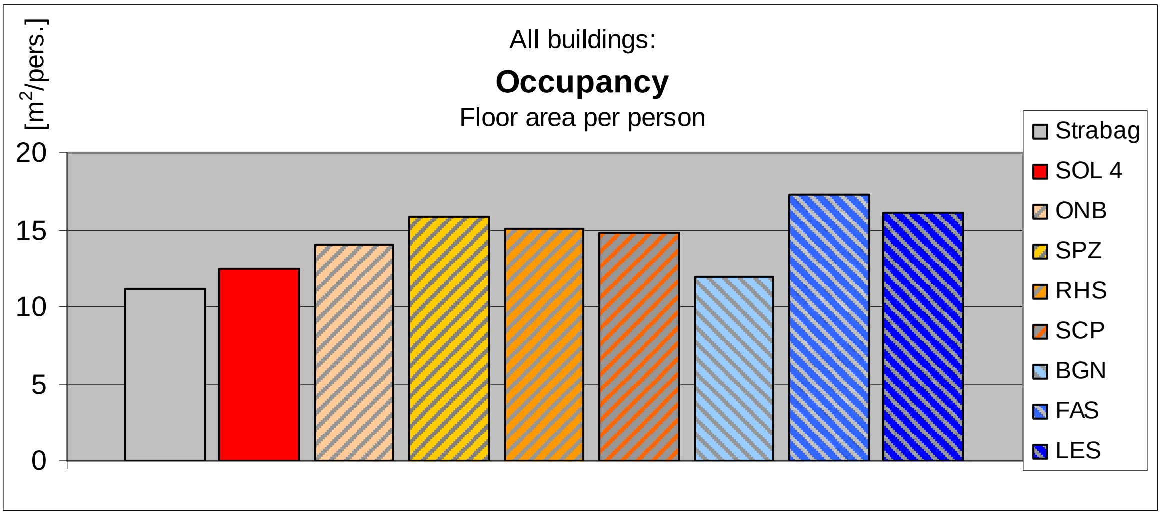
Graph 19: Overview buildings' properties

Glazing fraction is by far highest in the fully glazed Strabag building which only misses 100% glazing due to frame fractions in the exterior wall. Buildings built before WW1 display low glazing fractions while buildings from after WW2 range somewhat in between. Passive house SOL4 is tuned to harness winter sun for heating purpose and likewise displays medium glazing fraction.



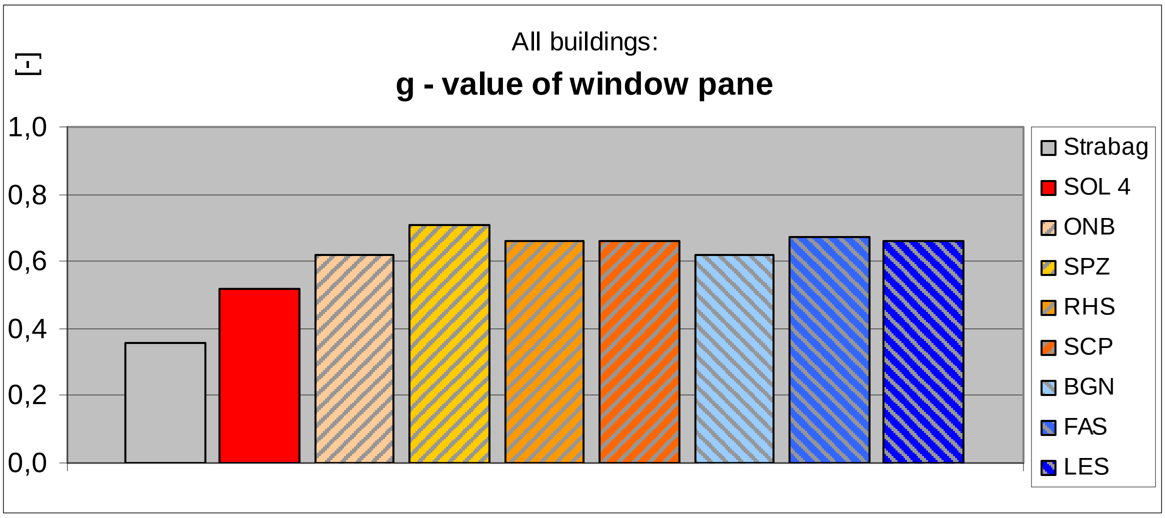
Graph 20: Glazing fraction of all buildings

Modern buildings such as Strabag and SOL 4 tend to optimized floor ratio and show rather high occupancy rates resulting in limited floor area per employee. The situation is quiet different for historical buildings from before WW1 which offer considerable more space per person. For buildings from the age of a developing service industry right after WW2 the situation is less uniform and considerable differences are found within this sample.



Graph 21: Occupancy rate of office rooms in sample buildings

The comparison of transition limiting qualities of window panes clearly reflects the development made in glazing technology throughout the last century: while window panes in old buildings did not receive any treatment in order to limit solar transmission, modern buildings are equipped with selective, sun protective glazing and its associated, low g-values.

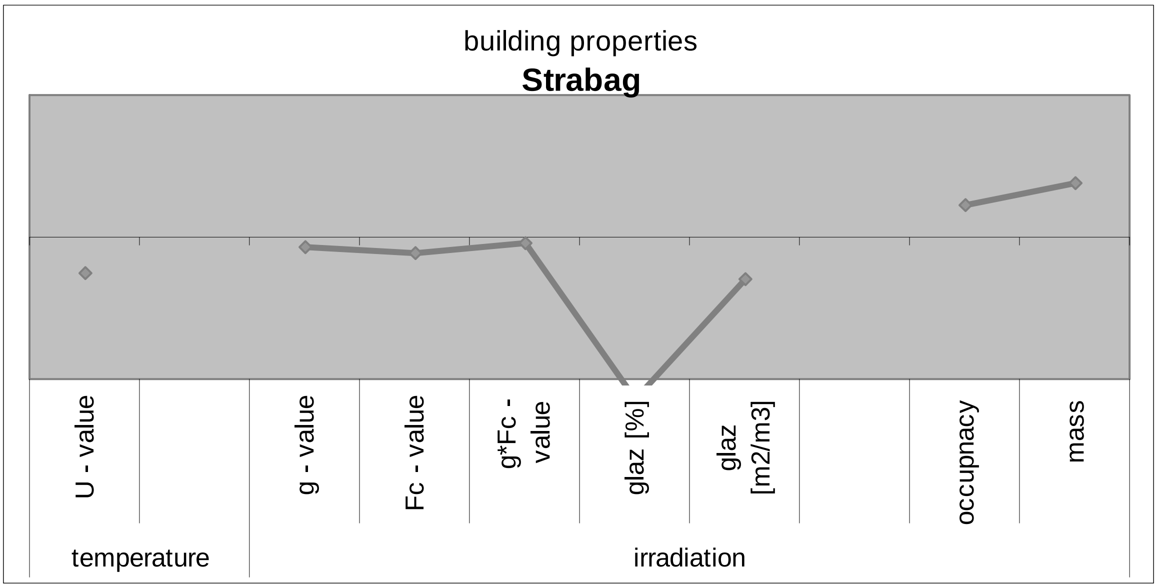


Graph 22: g – value of window panes in all sample buildings

4.3.1 Simplified graphical method for portraying of buildings based on their thermal properties

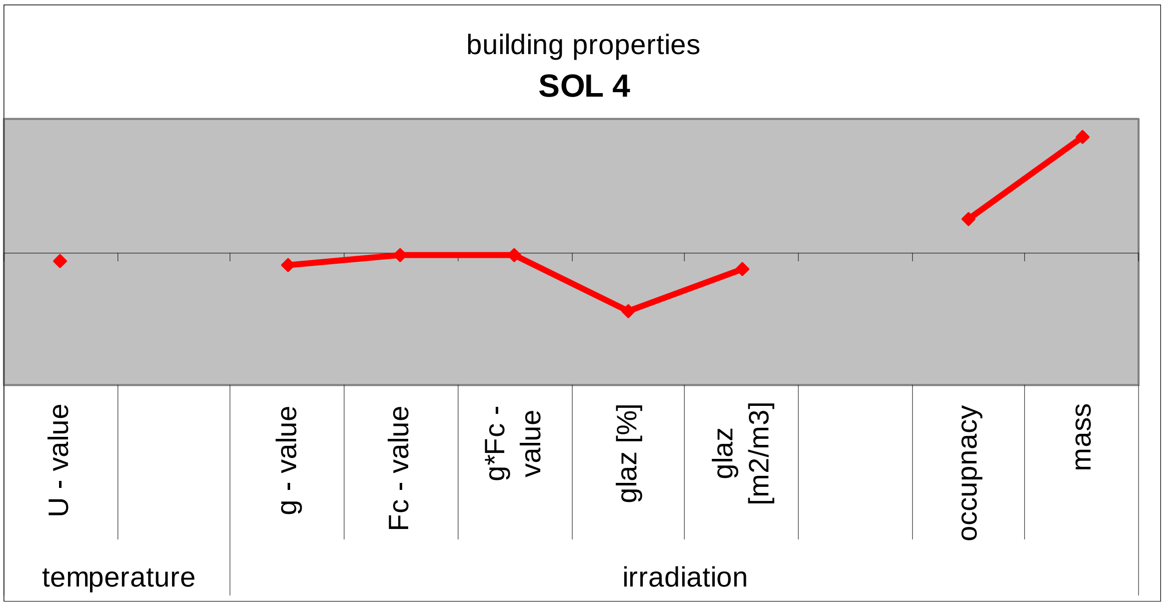
Having compared single properties over all sample buildings, it appeared likewise advisable to compare several thermal properties of single leading sample buildings. Therefore, a graphical method was applied which definitely did not strive to reflect these properties in correct relationship to one another. Rather, the goal was to forward a simplified, one glance portrait of the respective building which gives a qualitative rather than purely quantitative indication of the properties in question. The sequence of these properties is basically arbitrary but equal for all buildings, a division is only made between those properties influencing the building's reaction to temperature and to irradiation, respectively. The graphical linking of (basically not related) values by a line only serves to improve readability in the sense of drawing a profile for each building.

Low values far from the middle line represent properties which tend to render a building prone to overheating, while high values reflect certain robustness. Due to the depiction of values of different nature in one graph, the middle line functions as a tool of orientation only: while values such as u-, g-, and F_c-value have their theoretical maximum at 0, others such as mass only start here.



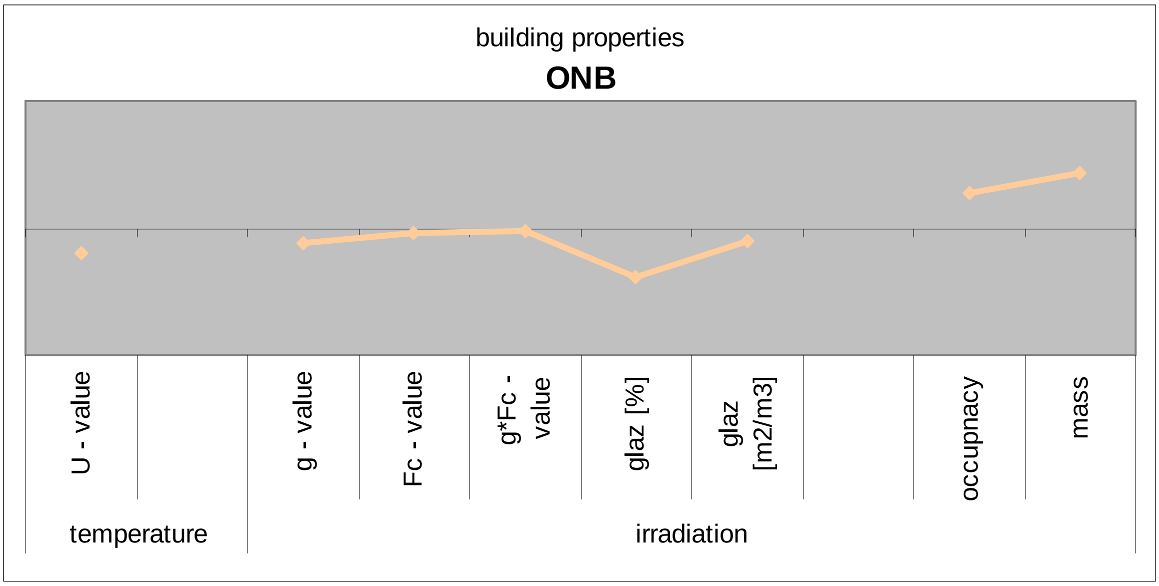
Graph 23: Strabag's building properties Fehler! Verweisquelle konnte nicht gefunden werden.

Strabag's most distinct feature is its high glazing fraction which negatively impacts on the building's ability to withstand external heat. Modern sun protective glazing is in place, but shading can only be placed between the window panes due to wind force considerations.



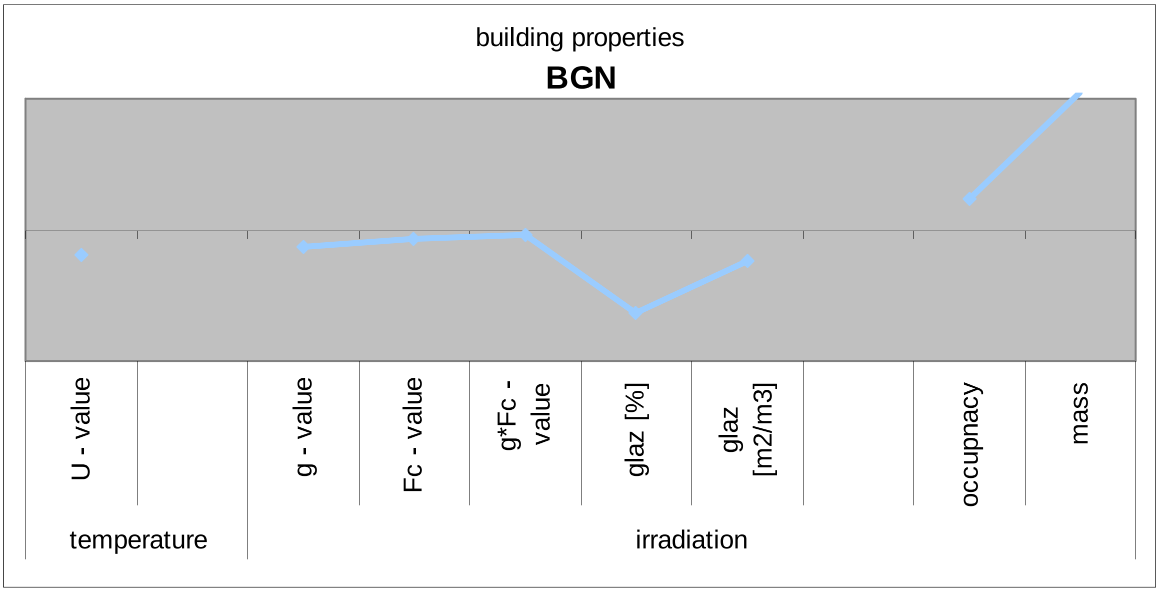
Graph 24: SOL 4's building properties

SOL 4 is characterized by its u-value that is extremely close to zero. Sun protective properties of glazing and sun shading are very effective too; thermal mass of exposed concrete ceilings is harnessed.



Graph 25: ONB's building properties

ONB displays a very small glazing fraction of its exterior walls. Occupancy is low and exterior sun shading effective.



Graph 26: BGN's building properties

BGN's glazing fraction of the exterior wall is remarkably high, its F_c-value moderate due to placement between window panes. Occupancy is high and so is mass.

5 Sample buildings' conditioning

This study investigated nine sample buildings' thermal behaviour, which reflects their particular constructive properties. This is to stress that the conditioning of their indoor climate, divers as it might be in reality, was assumed to be uniform in the simulation runs in order to make the results comparable.

These results generally refer to energy demand taking equal thermal comfort as baseline assumption and hence display the constructions' thermal behaviour under the applied climate data sets. The simulation mode operating on this basis is thus denominated as "Standard".

In some cases, nevertheless, it seemed advisable to also implement "real" conditioning in the simulation of some sample buildings meaning that the actual present-day thermal situation in the particular building was depicted and used as a baseline scenario for the assessment of thermal comfort conditions.

5.1 Description of simulation modes

The following list provides a more detailed description of the simulation modes mentioned above for the sample buildings' conditioning.

Simulation Mode "Standard"

- This simulation mode aims to obtain information on the sample buildings' performance in terms of energy demand due to their type of constructive configuration only.
- For the obtained results to be comparable between sample buildings all buildings were simulated under equal framework conditions. These conditions and the thermal conditioning applied in the simulation may therefore not match real conditions; the choice of the building technology applied may even be unusual for the respective sample buildings. These anomalies were accepted for the sake of comparison of distinct buildings.
- Several double office rooms of a specific size in a sample building were simulated under documented standardized parameters regarding ventilation, shading, cooling and internal loads;
- Hence, obtained results reveal the building's performance due to it's constructive configuration only; However, it has to be kept in mind, that these results are valid for the single rooms investigated and are therefore not scalable to the entire building's performance since other types of rooms (meeting rooms, lounges, cafeteria, server rooms and the like) are not taken into consideration. This, however, is no contradiction to the fact that the obtained results are proportionally valid for an abitrary amount of office places.

Simulation Mode "real"

- Several sample buildings, dating back to periods before World War One and shortly after World War Two, (partly) lack cooling devices in the actual present situation and already display precarious comfort conditions today. These comfort deficits are not displayed in the simulation mode "Standard", which operates under documented standardized parameters regarding ventilation, shading, cooling and internal loads.
- Simulation mode "real" therefore separately addresses existing comfort conditions in theses sample buildings by applying existing ventilation, shading, Cooling (if available at all) and internal loads.
- Simulation results are therefore analyzed in terms of hours surpassing temperature limits
- Energy demand is not analyzed under simulation mode "real"

Simulation Mode "Design Day"

At some points, selective investigations were run to gain a more precise insight into a particular building's behaviour; these were generated under the recurring appliance of a single Design Day. This kind of steady state is generally used for the sizing of heating and cooling plants[48]. The applied Design Day was generated on basis of the climate data sets portrayed above and referring to Austrian technical norm ÖNORM B 8110-3 (1999) for configuration[49].

[48] See VDI 2078

[49] see chapter 8.1.6.1 Cooling load under Design Day conditions, page 92

5.2 *Key figures for conditioning*

5.2.1 Ventilation

Ventilation is assumed to be provided both manually and mechanically; during office hours for outside temperatures ranging between 18 and 26°C windows are assumed to be opened by building users.
Mechanical ventilation is applied to the simulated office rooms in order to safeguard desirable levels of fresh air according to the following regime:

Ventilation			
air change rate	in office hrs.		2 / h *)
	outside office hrs.		0 / h
office hrs.		6:00 – 19:00	
heat recovery		none	
*) acc. ÖNORM 8110-5			

Graph 27: Ventilation régime simulation mode Standard

5.2.2 Shading

Shading can be effectuated by different shading devices as described in chapter 4.3 Results of comparative building analysis, page 50, Shading is uniformly effectuated in all sample buildings according to the following regime:

Shading			
working days			
Upper Limit	180	W/m2	*)
Schedule	9:00 - 19:00		
Weekends			
Upper Limit	180	W/m2	*)
Schedule	9:00 - 19:00		
*) irradiation level on vertical surface at which shading is activated			

Graph 28: Shading regime simulation mode Standard

5.2.3 Internal Loads

Internal heat loads from IT equipment and lighting generally represent a significant contribution to thermal environments in offices. However, levels of employed equipment vary broadly from building to building, depending on specific types of tasks performed there. Effort was thus undertaken within the framework of this study to assess assumable levels of internal loads. Reference is made to literature[50], professionals' experiences[51] and determinations made within the framework of a recent project funded under the "Building of Tomorrow +"program of the Austrian Federal Ministry of Transport, Innovation and Technology[52] which in turn extensively draws upon corresponding German and Swiss normative guidelines[53].

Internal loads	Standard						
			working days		**weekends**		
	Radiant Proportion	**View Coefficient**	6:00 - 19:00	20:00 - 5:00	0:00 - 24:00	**[ ]**	
infiltration	-	-	0	0	0	W/m2	
ventilation	-	-	0	0	0	W/m2	
lighting	0,48	0,490	19	0,44	0,44	W/m2	*)
occupancy	0,20	0,227	****)	0	0	W/m2	**)
equipment	0,10	0,372	6,7	0,10	0	W/m2	***)

*) fluorescent ceiling lighting
**) 2 persons/ 20m2/ 8hrs; 6,5W sensible & 5,5W latent
***) 2 PCs (4 hrs. Power, 4 hrs stand by)/ 1 printer (2 hrs. Power, 6 hrs stand by)/ 0,5 copy machine (2 hrs. Power, 6 hrs stand by) all /20m2
****) Depending on resp. situation in the sample building

Graph 29: Internal loads simulation mode „Standard"

For the investigation of different levels of internal loads values for both lighting and equipment were varied and grouped in 4 distinct categories of energy efficiency ranging from limited (IL I) to very high (IL IV). Efficiency level IL II therein corresponds to the basic mode "Standard" as depicted in Graph 29: *Internal loads simulation mode „Standard"*, page 58.

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[50] Zimmermann, Mark et al (2003); ÖNORM B 8110-5, ISO EN 7730 (1994), VDI 2078 (1996)
[51] Berger, Tania (Juni 2010)
[52] Programmlinie Haus der Zukunft (Hg.) (2010)
[53] VDI 3807, SIA 380-4

lighting	0,48	0,49				W/m2	*)
IL I			35	0,82	0,3		
IL II			19	0,44	0,3		
IL III			9	0,2	0,3		
IL IV			3	0,13	0,3		
equipment	0,1	0,372				W/m2	***)
IL I			10	0,4	0		
IL II			6,7	0,1	0		
IL III			4	0,3	0		
IL IV			2,5	0,1	0		

Graph 30: Internal loads simulation mode „Standard", different levels of internal loads for lighting and equipment

As can be seen in Graph 29: Internal loads simulation mode „Standard", page 58, assumptions were made for the time IT equipments is actually used, versus the time during which these are run in stand by mode only. This is a valid approach for the simulation of cumulated energy demands for certain periods of time. For the determination of maximum loads however this may prove to be insufficiently severe: Highest cooling requirements may well incur when most of the equipment is in active use and highest levels of solar irradiation are present.

This worst case scenario is covered by the following alternations of equipment data applied for the determination of cooling loads only:

Internal loads	Elevated levels						
			working days		weekends		
	Radiant Proportion	**View Coefficient**	6:00 - 19:00	20:00 - 5:00	0:00 - 24:00	**[ ]**	
equipment	0,1	0,372				W/m2	***)
IL II			16,3	0,1	0		

***) 2 PCs (4 hrs. Power, 4 hrs stand by)/
1 printer (4 hrs. Power, 4 hrs stand by)/
0,5 copy machine (2 hrs. Power, 6 hrs stand by)
all /20m^2

Graph 31: Internal loads simulation mode „Standard", elevated level of internal loads for lighting and equipment for the determination of cooling load only

5.2.4 Occupancy

Occupancy by office workers differs from building to building according to the rooms' layout; While the most net area per person is available in the old ONB building, the room configurations in modern Strabag and post war BGN are most tightly designed to house the required furniture, equipment and open space on least area. This fact was depicted in the simulation models by appliance of accordingly varied loads. The following table includes values for the four leading buildings; additional buildings in the respective epochs are generally pretty similar to their particular leading building

.

occupancy load					
	net area	persones	area/ person	sensibel	latent
	[m2]	[-]	[m2]	[W / m2]	
Strabag	111,521	10	11,2	5,8	4,9
ONB	168,624	12	14,1	4,6	3,9
BGN	191,475	16	12,0	5,4	4,6
SOL 4	49,134	4	12,3	5,3	4,5
base				**6,5**	**5,5**

Graph 32: Occupancy loads simulation mode „Standard"

5.2.5 Cooling

Cooling is applied to the simulated office rooms according to the following regime:

Cooling

Summer					Winter		
working days					working days		
Thermostat					Thermostat		
	Upper Limit	25	°C	*)	Upper Limit	25	°C
	Schedule	6:00 - 19:00			Schedule	6:00 - 19:00	
	Humidity Range	30 - 60	%		Humidity Range	30 - 60	%
Weekends					Weekends		
Thermostat					Thermostat		
	Upper Limit	30	°C	*)	Upper Limit	30	°C
	Schedule	6:00 - 19:00			Schedule	6:00 - 19:00	
	Humidity Range	0 - 100	%		Humidity Range	0 - 100	%

*) upper limit of the cooling control band

Graph 33: Cooling simulation mode „Standard"

All sample rooms are assumed to be adiabatic in regard to their neighbouring rooms. Mechanical cooling by means of compression machines was assumed for all buildings.

5.2.6 Heating

Winter conditions in the sample rooms are not the main focus of this study. However, for the assessment of climate change's impacts on primary energy demand, annual heating demands were calculated. During the summer months heating was assumed to be turned off. Sample rooms were assumed to be adiabatic regarding their neighbouring rooms. District heating was assumed as supply for the heating system.
Heating was applied to the simulated office rooms according to the following regime:

Heating

	Summer					Winter		
working days					working days			
Thermostat					Thermostat			
	Lower Limit	-50	°C	*)		Lower Limit	20	°C
	Schedule	6:00 - 19:00				Schedule	6:00 - 19:00	
	Humidity Range	30 - 60	%			Humidity Range	30 - 60	%
Weekends					Weekends			
Thermostat					Thermostat			
	Lower Limit	-50	°C	*)		Lower Limit	15	°C
	Schedule	6:00 - 19:00				Schedule	6:00 - 19:00	
	Humidity Range	0 - 100	%			Humidity Range	0 - 100	%

*) lower limit of the heating control band

Graph 34: Heating simulation mode „Standard"

All of the following investigations aimed at determining the differing energy demands of sample buildings due to their constructive configuration only which implies that some buildings were conditioned in simulation unlike to how they are run in reality. This is especially the case for passive house SOL 4: some integral features of the passive house standard in terms of conditioning are not applied here. This necessarily causes the building's scores to be remarkably higher than they would be with all features correctly in place. However, this mode of investigation helps to understand how a highly insulated building effectuates under the conditions of climate change.

6 Employed tools of investigation

Dynamic thermal simulation was applied for the detailed depiction of thermal conditions in single office rooms. These simulations form the main part of the investigation.

For the investigation of natural ventilation's cooling potential specific software tools provided information on wind conditions in the urban area and street canyons, respectively, both of which both provide crucial additional information surplus compared to general climate data sets depicting overall conditions under undisturbed circumstances. This information can further be processed for the assessment of indoor air movements in buildings abutting to the street canyons in question. Still, as this involves processes of elevated complexity and is influenced by several parameters which remain hard to be covered entirely the obtained results represent a magnitude of possible values rather than exact figures.

TAS

The employed software tool for thermal simulation is TAS (Thermal Analysis System), Version 9.1.4.1, provided by the British EDSL[54].
TAS builds upon two base input data files: one contains the structural 3D model of the sample building; the other one allocates thermal properties and usage profiles to the mapped building. In conjunction both generate result files containing hourly values for parameters of internal condition, such as air, radiant and resultant temperature, humidity, applied cooling and heating load and the like.

AIOLOS

Although TAS can also simulate the surrounding wind conditions and resulting air change rates in rooms this requires extensive input data in terms of pressure coefficients for the complete building. As these are unavailable without an in-depth determination of the buildings detailed aerodynamic properties (CDF-simulation[55]) recourse was taken to simplified single room analysis tools in the framework of this thesis.

Within the present study the AIOLOS software, developed by the University of Athens's Department of Applied Physics, served this purpose. AIOLOS is a

[54] TAS – Thermal Analysis System, Version 9.1.4.1 by EDSL – Environmental Design Solutions Ltd., Milton Keynes, GB, 2007
[55] Computational Fluid Dynamics

software for the calculation of the airflow rate in natural ventilation configurations. Based on the principles of network modelling, this tool offers the user many simulation possibilities, which can either be used for design purposes or simply be exploited to provide a deeper insight of the mechanisms involved in natural ventilation.

Here, AIOLOS was applied to determine achievable air change rates in the single side ventilated office rooms of the sample buildings. The computed rates were then applied to the thermal model in TAS.

URBVENT

For the closer investigation of some exemplary cases URBVENT was additionally applied. URBVENT is an assessment tool for natural ventilation in urban areas. It was developed in the course of a 5th framework European research project[56]. It allows for the consideration of street canyon effects on the cooling potential of natural ventilation.

The tool operates on the basis of wind data on high resolution incorporated for a wide range of cities. This in turn makes it impossible to apply the semi synthetic climate data sets which were used throughout this study's investigation. Results obtained by URBVENT therefore are of rather informative nature only.[57]

BKI

For the assessment of the economic feasibility of different strategies the mechanisms provided by VDI 2067 were followed. To this end, the extensive data base of construction costs BKI[58], edited by Baukosteninformationszentrum Deutscher Architektenkammern, provided the basic elements of calculation.

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[56] Ghiraus, Cristian; Germano, Mario (2005)

[57] Berger, Tania (April 2010)

[58] Kosten abgerechneter Bauwerke. Technische Gebäudeausrüstung (2006). Stuttgart: BKI (BKI ObjektdatenG1).

7 Simulation variants and assessment parameters

The following sections give an overview of the different simulation variants applied in the respective modules.

7.1 Definition of simulation variants

- **Module 1: Impacts of Climate Change**

In this module, all nine sample buildings were simulated under the mode "Standard" and investigated as to their energy demand under different energy efficiency levels of equipment applied. Both cooling energy demands and maximum loads were calculated, the latter based on elevated levels of internal loads.
Climate data sets depicting past ("howa 61"), present ("howa 80") and future ("howa 2025 and 2050") situations were applied.
The results were assessed in terms of primary and comparative parameters on energy demand.

- **Module 2: Discussion of different comfort models**

The sample buildings ONB and BGN are not or only slightly cooled at present state. This often results in precarious summer comfort conditions even today. For the purpose of discussing the differences between the so called "Fanger" and "adaptive" comfort models these two sample buildings were run under simulation mode "real" and the results were analysed in terms of number of hours surpassing specific temperature limits.

- **Module 3: Impacts of urban heat island**

Leading sample buildings were simulated under mode "Standard", incorporating spatial resolution by applying three different climate data sets from three different locations within Vienna ("howa", "inne", "dona").

- **Module 4: Impacts of optimizations in the buildings' envelope**

Changes were simulated in the outer building shell of sample buildings ONB and BGN/ FAS with regards to levels of insulation on opaque walls and quality of glazing and shading. Simulations were run under simulation mode "Standard". Resulting increase and decrease in cooling and heating energy demand as well as primary energy demand were monitored.

- **Module 5: Internal loads**

In this module, four sample buildings were simulated under the mode "Standard" and investigated as to their energy demand under different energy efficiency levels of equipment applied (see Graph 30: Internal loads simulation mode „Standard", different levels of internal loads for lighting and equipment , page

59). Both cooling energy demands and maximum cooling loads were calculated, the latter based on elevated levels of internal loads[59].
Climate data sets depicting present ("howa 80") and future ("howa 2050") situations were applied. The results were assessed in terms of primary and comparative parameters on energy demand.

- **Module 6: Usage profiles**

In this module sample building Strabag was simulated under the mode "Standard" and in steady-state Design Day conditions with the appliance of different modes of usage. Both cooling energy demands and maximum cooling loads were calculated.
A climate data set depicting the present situation ("howa 80") was applied. Results were assessed in terms of primary and comparative parameters on energy demand.

- **Module 7: Natural ventilation**

In this module the two oldest sample buildings ONB and BGN were simulated under mode "real" and their current comfort deficits assessed. Next, possible wind induced air change rates were computed and applied in the thermal model which in turn resulted in indications on these rates' impact upon thermal comfort in the buildings.
A climate data set depicting the present situation in Vienna's CBD was applied ("inne 80").
Results were assessed in terms of primary and comparative parameters on thermal comfort.

- **Module 8: Economic assessment**

In this module simulation results from module 5 and 7 underwent economic assessment by either determining economic impacts of reduction in energy consumption (module 5) or economic impacts of reducing the frequency of surpassing comfort limits (module 7).

[59] See Graph 31: Internal loads simulation mode „Standard", elevated level of internal loads for lighting and equipment for the determination of cooling load only , page 59

7.1.1 Overview of simulation modules

Module			Sample Building	Simulation Mode	Climate Data Set
Impacts of climate change		1 Climate Change (Temporal resolution)	Strabag SOL 4 ONB SPZ RHS SCP BGN FAS LES	“Standard” “Design Day”	“howa 61” “howa 80” “howa 2025” “howa 2050” “2003”
		2 Comfort models	ONB BGN	“real”	“howa 80”
		3 Urban heat island (Spatial resolution)	Strabag SOL 4 ONB BGN	“Standard”	“howa 61” – “howa 2050” “inne 61” – “inne 2050” “dona 61” – “dona 2050”
Possible measures for reduction of energy demand		4 Optimizations of buildings’ envelope	ONB BGN/ FAS	“Standard”	howa 80” “howa 2050”
	Optimizations inside buildings	5 Internal loads	Strabag SOL 4 ONB BGN/ FAS	“Standard (Design Day)”	howa 80” “howa 2050”
		6 Usage profiles	Strabag	“Standard (Design Day)”	howa 80”
		7 Natural ventilation	ONB BGN/ FAS	“real”	“inne 80”
		8 Economic assessment	Results of module 5 and 7		

Table 5: Overview of investigated sample buildings, simulation modes and employed climate data sets

7.2 Assessment parameters for simulation results

7.2.1 Primary parameters

Energy demand

Annual Cooling Demand
[kWh/m^{2}a]

- Cumulated energy demand for cooling and latent removal load required for cooling of double office room of specific size, simulated under the documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode “Standard”); Hence, cooling demand only reveals the building’s performance due to it’s constructive configuration;
- This figure includes net energy demand only, not covering system losses and auxiliary electricity for mechanical ventilation, cooling, technical equipment and lighting;
- This figure is averaged over all reference rooms of the indicated orientation in the particular building.

Maximum Cooling Load
[W/m^2]

- Maximum load required to cool a double office room of specific size under the most demanding conditions found in the applied climate data set; Simulation is carried out under documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode “Standard”); Hence, cooling demand reveals the building’s performance due to it’s construction only;
- This figure includes net energy load only, not covering system losses and auxiliary electricity for mechanical ventilation, cooling, technical equipment and lighting.
- This figure is averaged over all reference rooms of the indicated orientation in the particular building.
- Maximum cooling loads allow for a judgment on whether passive and hybrid cooling methods might be able to cover occurring loads in principle

Annual Heating Demand
[kWh/m^{2}a]

- Cumulated energy demand for heating required for the heating of a double office room of specific size, simulated under documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode “Standard”); Hence, cooling demand reveals the building’s performance due to it’s construction only;

- This figure includes net energy demand only, not covering system losses and auxiliary electricity for mechanical ventilation, heating and technical equipment and lighting;
- This figure is averaged over all reference rooms of the indicated orientation in the particular building.

Maximum Heating Load
[W/m^2]
- Maximum load required to heat a double office room of specific size under the most demanding conditions encountered in the applied climate data set; Simulation is carried out under documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode "Standard"); Hence, heating load reveals the building's performance due to it's constructive configuration only;
- This figure includes net energy demand only, not covering system losses and auxiliary electricity for mechanical ventilation, heating, technical equipment and lighting.
- This figure is averaged over all reference rooms which are investigated in a particular building.

Annual Final and Primary Energy Demand
[kWh/m^{2}a]
- Final and primary energy demand for cooling and heating of a double office room of specific size, simulated under the documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode "Standard");
- Final energy demand is calculated based on indicated values for COP of both cooling and heating plant, not covering auxiliary electricity for mechanical ventilation;
- Primary energy demand is calculated based on indicated values for COP of both cooling and heating plant and PEI of electricity, not covering auxiliary electricity for mechanical ventilation;
- These figures are averaged over all reference rooms of the indicated orientation in the particular building.

Annual CO_2 emissions
[g/m^{2}a]
- Cumulated CO_2 emissions resulting from the cooling and heating of a double office room of specific size, simulated under the documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode "Standard");
- CO_2 emissions are calculated based on indicated values for COP of both cooling and heating plant and $C0_2$ emissions of electricity, not covering auxiliary electricity for mechanical ventilation, technical equipment and lighting;

Thermal Comfort

Number of working hours surpassing operative temperatures limits (26°C, 27°C, 28°C, 29°C)
[hrs.]

- Cumulated number of working hours during which the resultant indoor temperature surpasses 26°C, 27°C, 28°C or 29°C respectively
- This figure depicts summer comfort conditions in the investigated rooms
- A single south facing room is simulated in August of data sets "howa80" and "howa 2050".
- According to EN 7730 all conditions exceeding 26° and 27°C respectively (depending on the investigated building's category) are to be regarded as uncomfortable

Number of working hours surpassing comfort limits acc. EN 15251
[hrs.]

- Number of working hours during which the resultant indoor temperatures surpass the defined comfort limits under the adaptive comfort model of EN 15251 and hence are classified as uncomfortable. The adaptive comfort model takes into account the rolling mean of the outdoor temperature.
- A single south facing room is simulated in August of data sets "howa80" and "howa 2050".

Chronological sequence of Predicted Percentage of Dissatisfied (PPD)
[%]

Predicted percentage of users dissatisfied by the prevailing thermal conditions in sample room acc. EN 7730.

7.2.2 Comparative parameters

Energy demand

Increase in summer/ yearly cooling demand
[%]

- Increase in cooling demand of a building simulated under a particular variant as compared to the base scenario or a second variant
- It depicts changes in cooling demand brought about by an optimization strategy

Increase in maximum cooling load
[%]

- Increase in maximum cooling load of a building simulated under a particular variant as compared to the base scenario or a second variant
- It depicts changes in cooling load brought about by an optimization strategy

Decrease in heating demand
[%]

- Decrease in heating demand of a building simulated under a particular variant as compared to the base scenario or a second variant

Decrease in maximum heating load
[%]

- Decrease in maximum heating load of a building simulated under a particular variant as compared to the base scenario or a second variant

<u>Thermal Comfort</u>

Decrease in number of working hours surpassing operative temperatures limits
(26°C, 27°C, 28°C, 29°C)
[%]

- Decrease in cooling demand of a building simulated under a particular variant as compared to the base scenario or a second variant
- It depicts changes in cooling demand brought about by an optimization strategy

Decrease in number of working hours surpassing comfort limits acc. EN 15251
[hrs.]
[%]

- Decrease in cooling demand of a building simulated under a particular variant as compared to the base scenario or a second variant
- This figure is averaged over all reference rooms which are investigated in a particular building.
- It depicts changes in cooling load brought about by an optimization strategy

8 Results

8.1 Module 1: Impact of climate change

This module presents results from thermal simulation undertaken to figure out the impacts of climate change upon cooling and heating demand in different types of buildings. It was to be expected that cooling demand would generally rise while heating demand declines due to increased mean outdoor temperatures. However, determining to what extent this will be the case and how different types of buildings, especially older ones, react to climate change was the aim of this module of investigation.

Therein, climate change is represented by the application of the temporal resolution of climate data set "howa" from "61" (representing nearest past) to "80" (present) and on to "2025" and "2050" (future scenarios).

This investigation was done for all nine sample buildings, four of them appertaining to the epoch of before WW1 and three buildings from after WW2. Two buildings were recently built, either highly glazed or according to passive house standard.

Simulation was carried out under documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode "Standard"); Hence, simulated demands reveal a building's performance due to it's construction only. For maximum cooling loads reference was made to both mode "Standard" and "Design Day". All simulations were run with thermal simulation software TAS, version 9.1.4.1.

The following table summarizes the framework condition of these simulations:

Module	Sample Building	Simulation Mode	Climate Data Set
1 Climate Change (Temporal resolution)	Strabag SOL 4 ONB SPZ RHS SCP BGN FAS LES	"Standard" "Design Day"	"howa 61" "howa 80" "howa 2025" "howa 2050" "2003"

Table 6: Investigated sample buildings, simulation modes and employed climate data set in Module 1

Net cooling and heating energy demands were computed in all buildings for both South and West facing office rooms. Leading buildings were scrutinized more in detail. Percentages of increase and decrease of assessment parameters were calculated. Final and primary energy demands including cooling and heating as well as resulting CO_2 emissions were established under assumption of indicated conversion factors[60].

8.1.1 Net cooling energy demand

The application of climate data sets from “howa 61” to “howa 2050” in different runs of thermal simulations models the course of time from the past (“howa 61”) to far future (“howa 2050”). Accordingly, net cooling energy demand continuously increases over the course of near and far future scenarios. This increase is most distinct in two time steps: firstly between data sets “howa 61” and “howa 80” and secondly between “howa 2025” and “howa 2050”. This finding is congruent with climate data analysis[61].

Results for the extreme year of 2003 yield even higher demands than “howa 2050” and depict the fact that extremes may well surpass average occurrences contained within “howa 2050”. It has to be kept in mind that climate data set “howa 2050” by nature of its generation does not contain any extreme climatic occurrences but rather represents the average global warming to be expected. Expressed in simplified words, summers like the one of 2003 are likely to occur significantly more frequently by 2050 than they do now, and hence, in this period of time they will no longer be considered “extreme”.

Increases in cooling demand from “howa 61” to “howa 2050” range around 20 kWh/m^2 and are fairly constant for all buildings investigated. In absolute figures, however, a visible differentiation can be drawn between the highly glazed Strabag and BGN buildings and all other sample buildings as the former ones’ demands are generally about double the latter ones’.

This insight coincides with the fact that these two buildings display by far the highest glazing fractions in their external walls[62]. At the same time the simulated rooms are comparatively densely occupied and are therefore equipped with slightly higher internal heat loads[63]. In contrast, relatively low g-values of these buildings’ glazing do not succeed in counteracting the trend to elevated cooling demands.

With the exception of BGN, the cohorts of buildings built before WW1 and after WW2 appear fairly uniform. It has been demonstrated for the cohort built after

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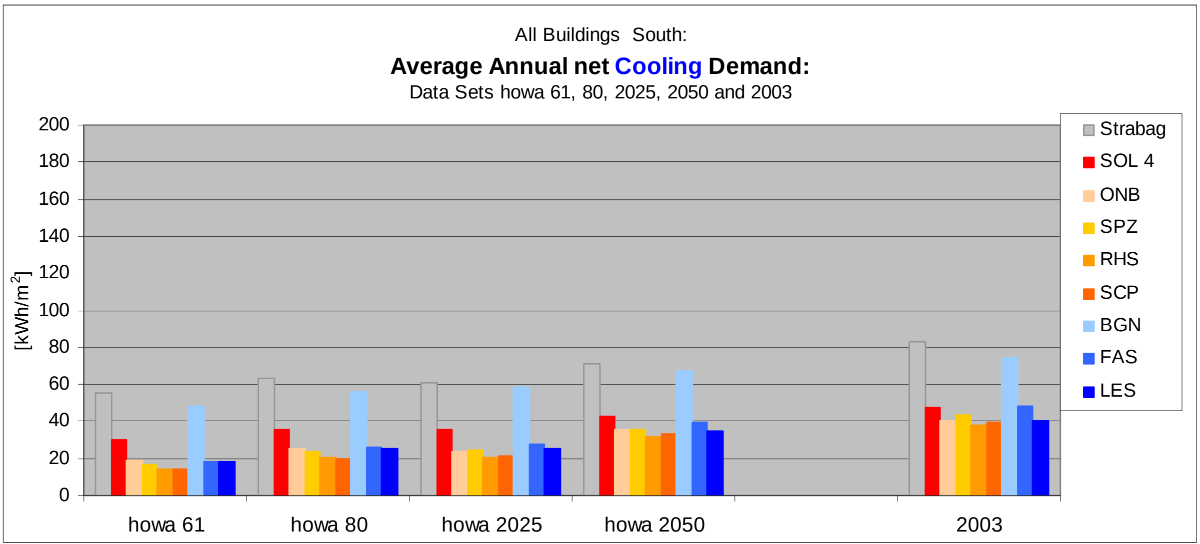
60 see Table 8: Provenience of PEI factors page 86
61 see Graph 8, page 35
62 see Graph 20, page 50
63 see Graph 21, page 51

WW2 that available data on constructive configuration was by far most consistent in BGN[64] (even so indications on u-values seem overoptimistic). Therefore, for further investigations, BGN was regarded as leading worst case example for this building's cohort.

The results of passive house SOL 4 range somewhat between Strabag and BGN on the one hand and the remaining sample buildings on the other; However, it has to be stressed that these figures have to be viewed conditionally: As has been demonstrated before[65], in SOL 4 several fundamental features have been omitted from modelling in an effort to simulate all sample buildings under comparable conditions. In consequence, the simulation results give an indication on the building envelope's performance only, not taking into account aspects such as reduced levels of internal loads and nocturnal ventilation by mechanical systems. Still, the case of SOL 4 reflects the fact that passive house planning, originating from the residential sector (in which heating is the crucial influence), so far has placed more emphasis on winter insulation than on prevention of overheating during summer.

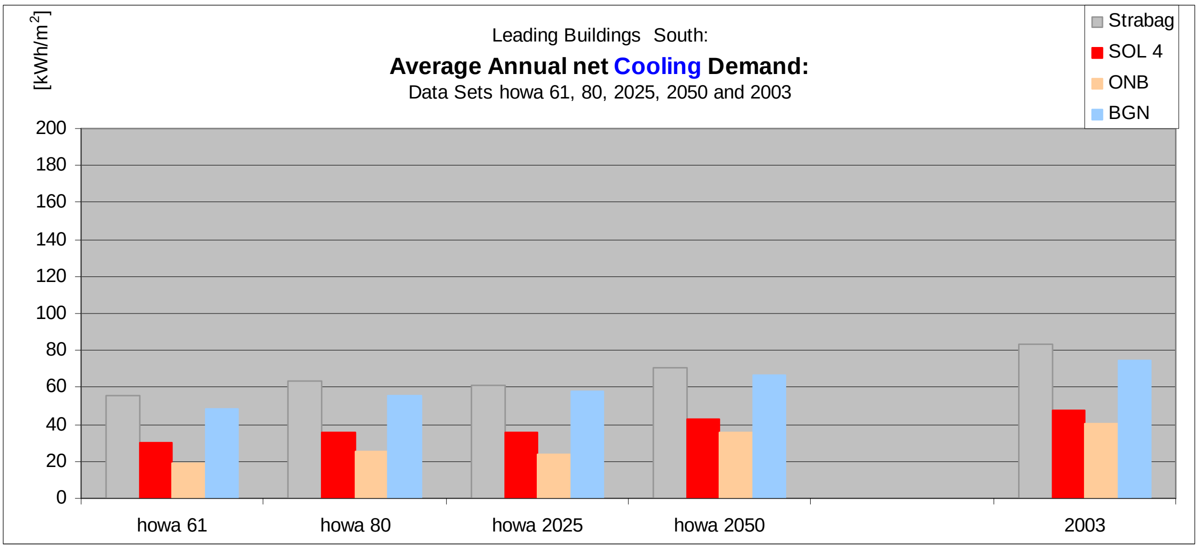
Buildings from before WW1 in general display the lowest cooling demands. This can be attributed to low glazing fraction of external walls and low occupancy rates.



Graph 35: Average annual net cooling energy demand of all buildings (South)

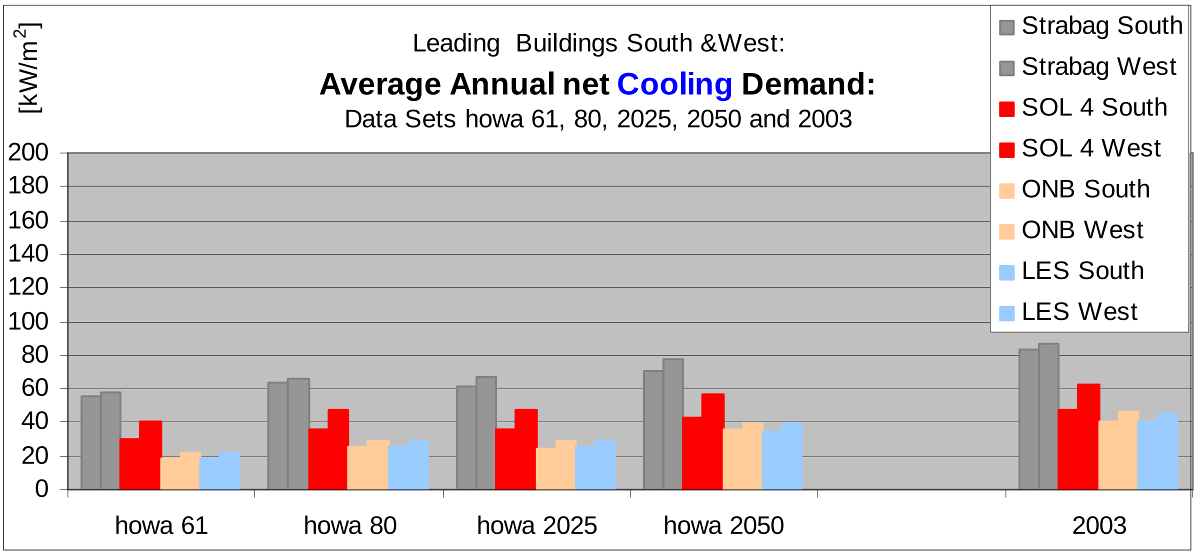
64 See chapter 4.1 Description of sample buildings, page 43

65 See chapter 5.2 Key figures for conditioning, page 55



Graph 36: Average annual net cooling energy demand of leading buildings (South)

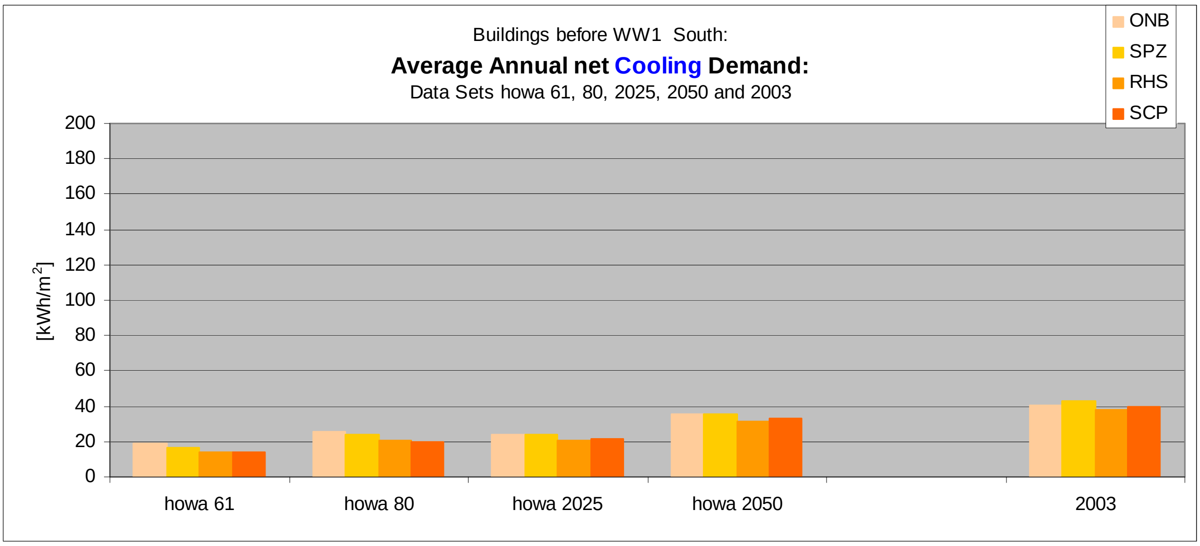
Sample rooms of different orientation have been investigated separately in the leading buildings: While South facing rooms are exposed to solar irradiation during the hottest hours of the day; sunbeams at this time intrude by a steep angle which makes it relatively easy to shade the room by means of adequate devices. In contrast, Western rooms are already well heated up when, by the end of the day, they are hit by low angled radiation which is hard to keep out. As a result, Western rooms generally require more cooling than rooms facing south.



Graph 37: Average annual Net cooling energy demand of leading buildings (South & West)[66]

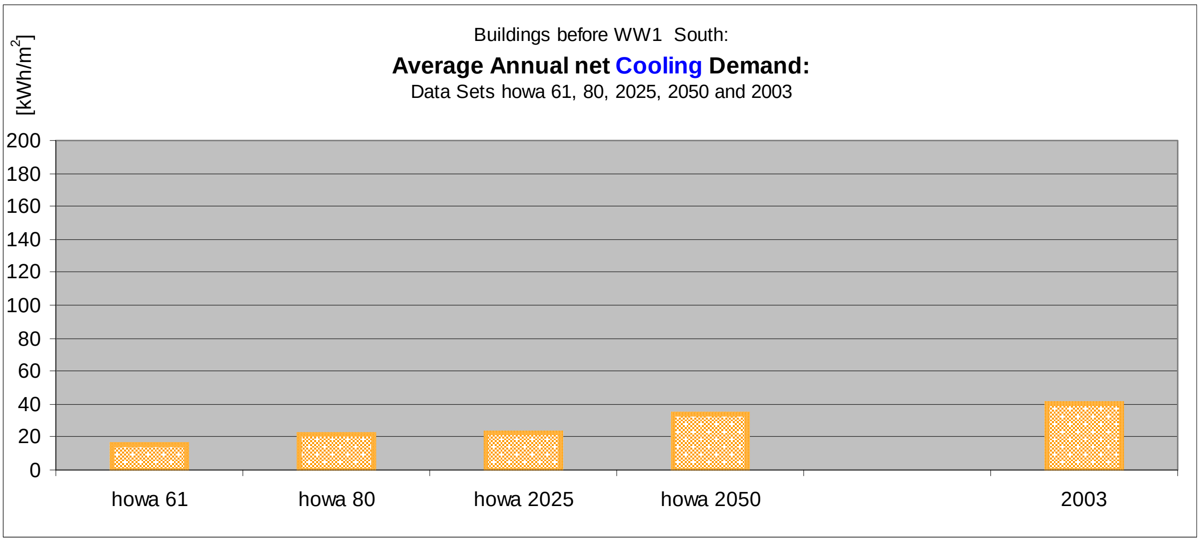
The cohort of sample buildings from before WW1 is fairly consistent and cooling demand is low in absolute figures.

[66] This graph, for once, uses LES as sample building for the cohort of buildings built after WW2. This building performs significantly better than BGN in terms of cooling demand, hence in all following simulations BGN has been used to act as a worst case scenario.

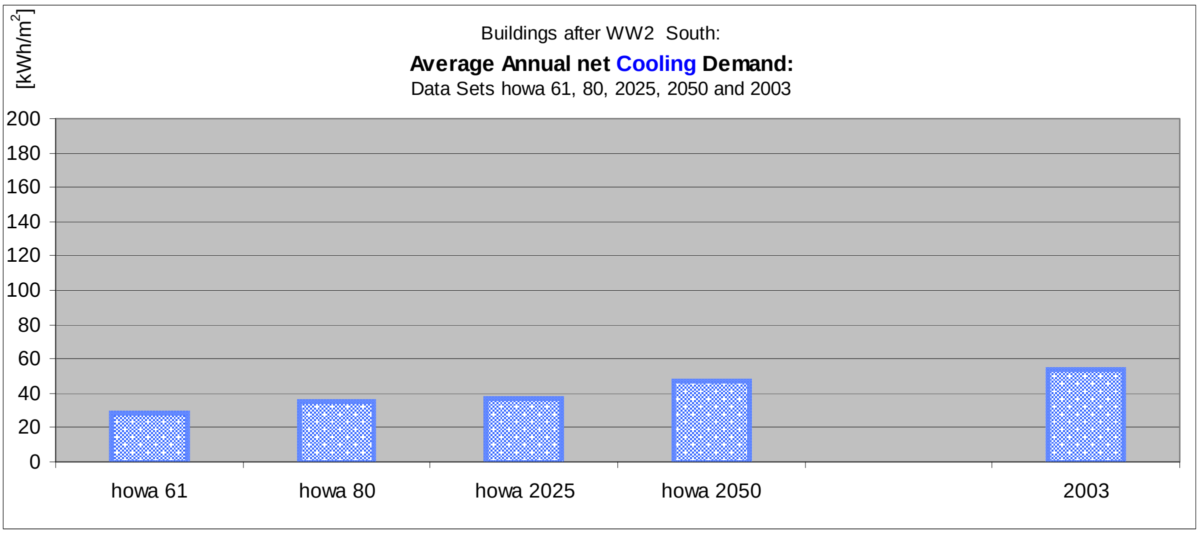


Graph 38: Annual net cooling energy demand of buildings dating from before World War 1 (South)

Comparing the averaged annual cooling demands of the two cohorts displays higher values in absolute terms for the buildings dating after WW2, the overall tendency is obvious in both.

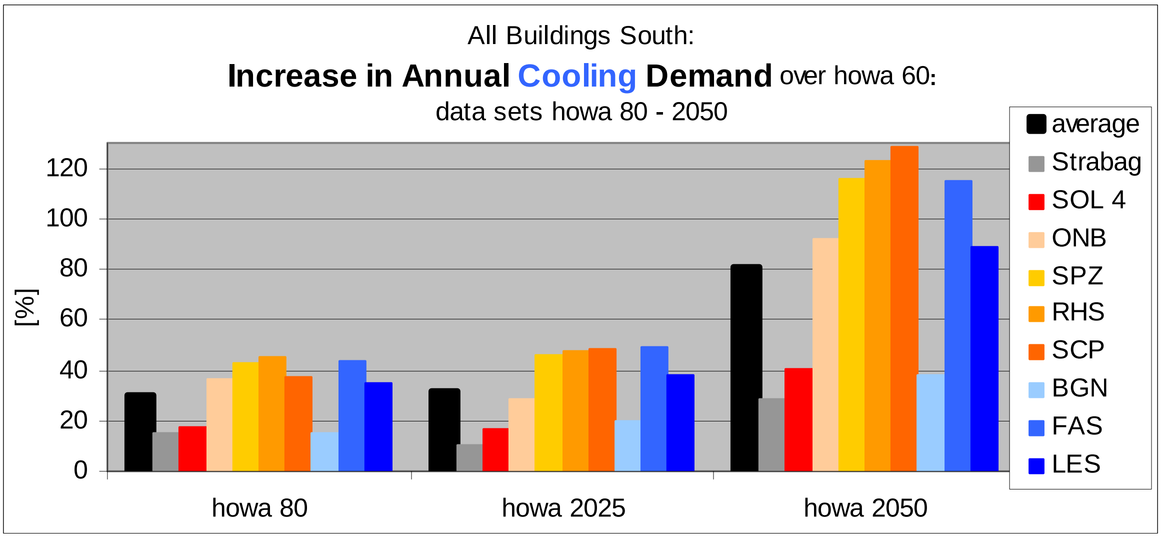


Graph 39: Averaged annual net cooling energy demand of buildings dating from before World War 1 (South)



Graph 40: Averaged annual net cooling energy demand of buildings dating from after World War 2 (South)

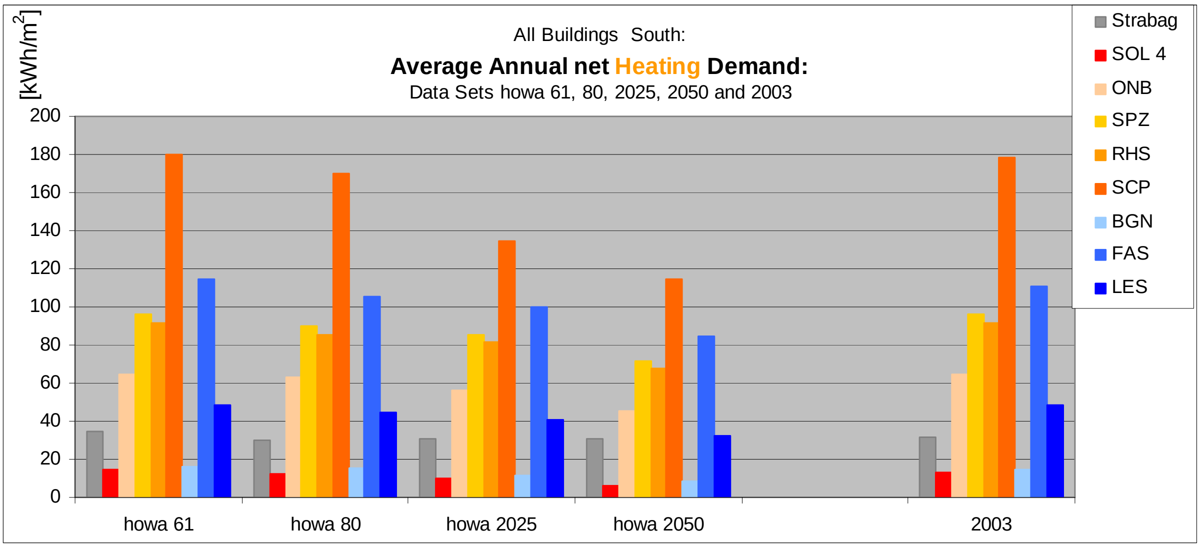
In relative terms the increase of net cooling energy demand against the baseline of climate data set "howa61" in average ranges at about 30% for all sample buildings for both climate data set "howa 80" and "howa 2025". The increase for "howa 2050" over the baseline is more than double and nearly touches 80%. In other words: net cooling demand for "howa 2050" is almost twice the demand than arising under "howa 61".



Graph 41: Increase in net cooling demand

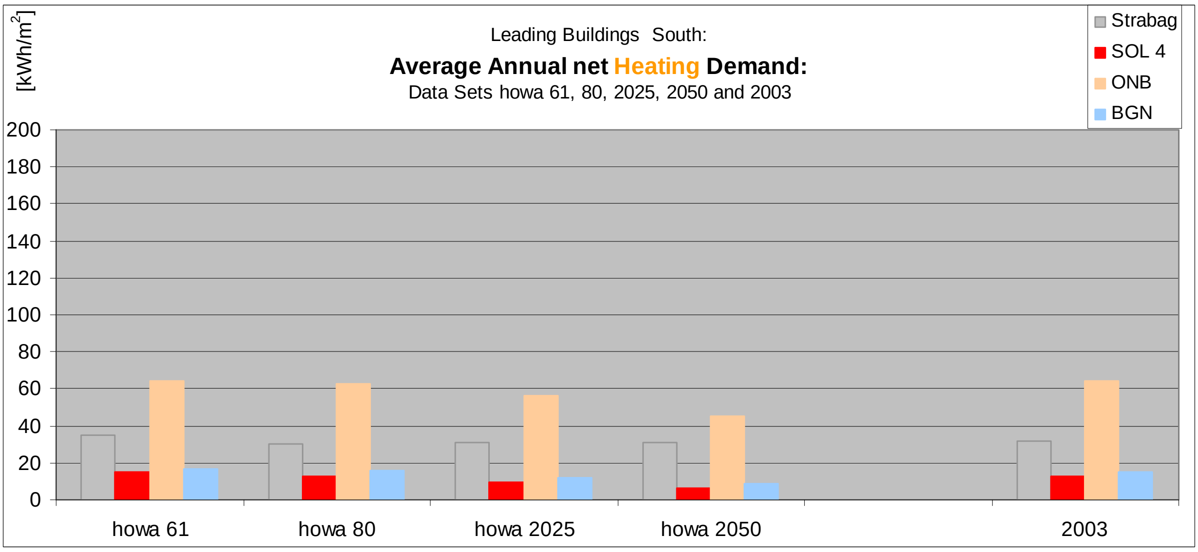
8.1.2 Net heating energy demand

While cooling demand constantly grows with the application of increasingly hot climate data sets in simulation, space heating requirements inversely decline. This decline is eminently visible in all buildings even though absolute values vary considerably.



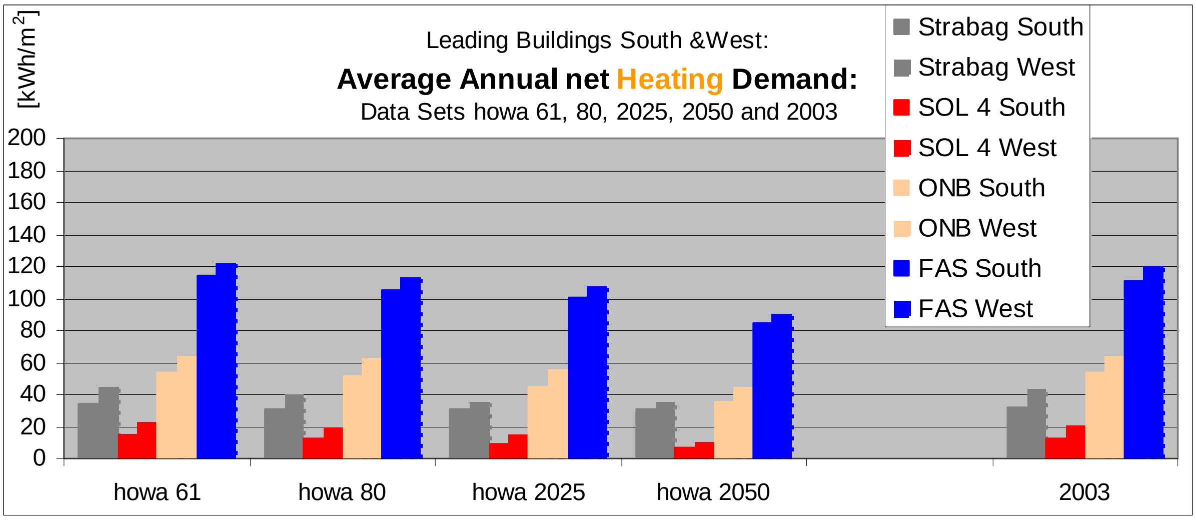
Graph 42: Average annual net heating energy demand of all buildings (South)

Within the group of leading buildings SOL4 displays the lowest heating demands even though no heat recovery was calculated in this building's mechanical ventilation system. Heating requirements appear surprisingly low in BGN. As has been mentioned above this has to attributed to overly optimistic assumptions regarding conductivity of external walls. As a consequence, this building was skipped for further investigation on heating requirements and replaced by FAS as the leading sample building of this building cohort.



Graph 43: Average annual Net heating energy demand of leading buildings (South)

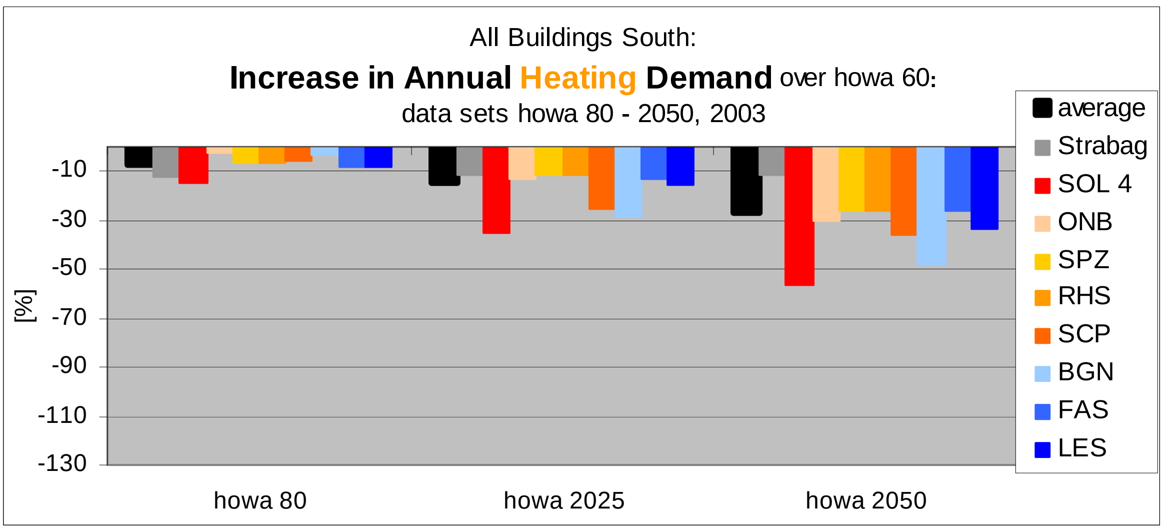
With FAS as leading building for the cohort of buildings from after WW2, as shown in Graph 44, this group clearly ranges last in regards to heating energy efficiency, while buildings from before WW1 require approximately 50% less heating. This is still more than modern buildings (highly glazed or passive) need for heating purpose.



Graph 44: Average annual net heating energy demand of leading buildings (South & West)

2003 clearly does not display any decrease in heating demand as this year featured a rather cold winter. It is therefore only included in simulation here as evidence that even in very hot future years heating requirements can still remain high.

In relative terms the decrease of net heating demand against the baseline of climate data set “howa61” ranges in average at about 10 to 15% for all sample buildings for both climate data sets “howa 80” and “howa 2025”. The decrease for “howa 2050” below the baseline amounts to roughly twice as much and nearly touches 30%. In other words: net heating demand for “howa 2050” is reduced by almost a third compared to demand under “howa 61”.

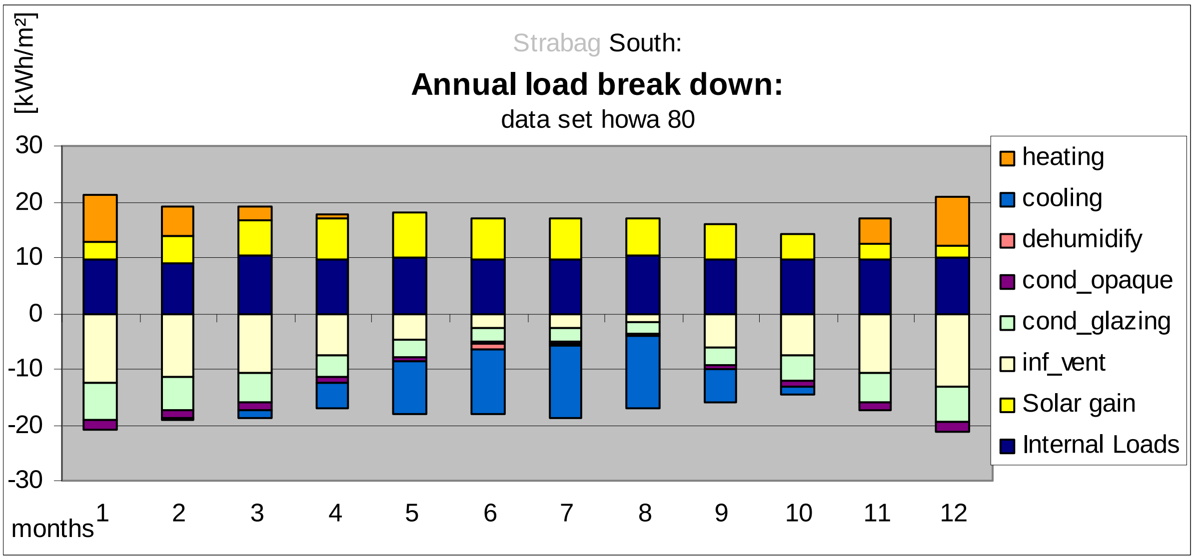


Graph 45: Increase in heating demand

8.1.3 Annual load-break down

Annual net cooling and heating demand don't give indications as to how energy demand is spread over the months of the year. This can only be determined by means of annual load-break downs. These show clearly which heat gains and losses occur in each month and how these gains and losses have to be counteracted by cooling and heating in order to constantly keep indoor conditions comfortable.

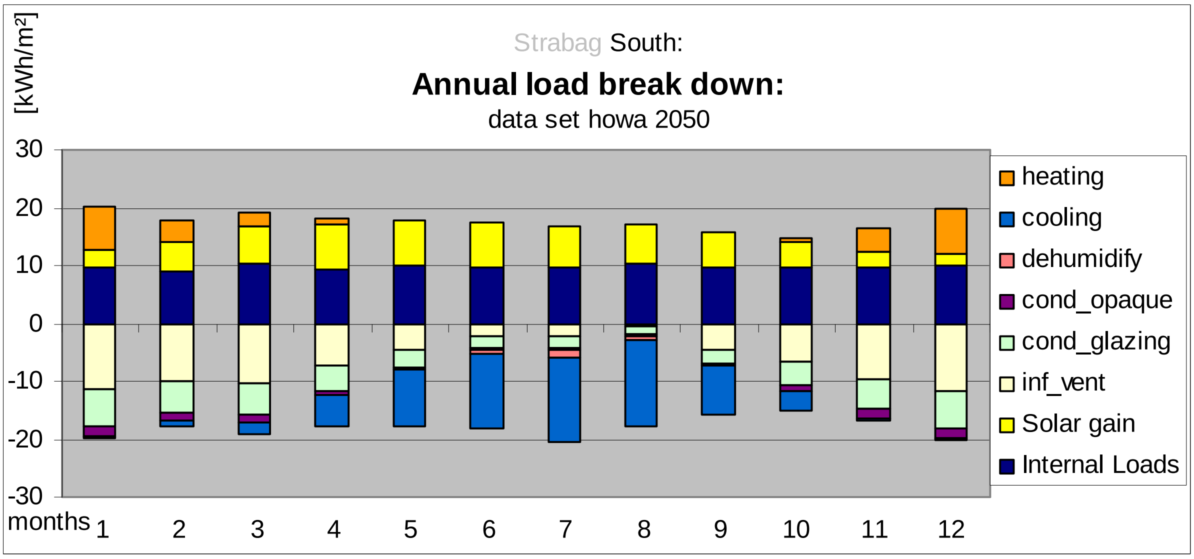
The annual load-break down for the highly glazed Strabag building at present stage (climate data set "howa 80") shows considerable solar gains throughout the year. While during winter this helps to keep heating demand down, solar gains in summer increase cooling demand. Cooling already starts in February and only ends in October.



Graph 46: Annual load break-down for "howa 80" in Strabag

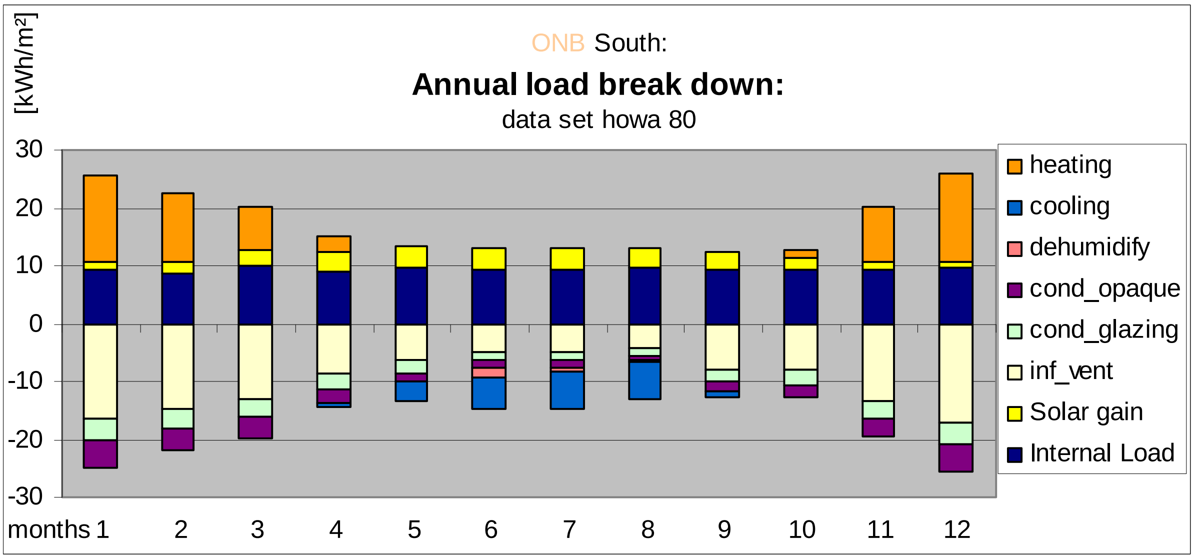
Abbreviations:
cond_opaque: heat gained through the inside surfaces of exposed transparent components
cond_glazing: heat gained through the inside surfaces of exposed transparent components
inf_vent: heat gained by the zone due to the exchange of air between the zone and the external environment

In the future (climate data set "howa 2050") cooling will be necessary in nearly all months. Less heat removal will occur due to ventilation and conduction on glazing (which makes up for nearly all outer surfaces) will likewise be reduced, resulting in even higher cooling demand.



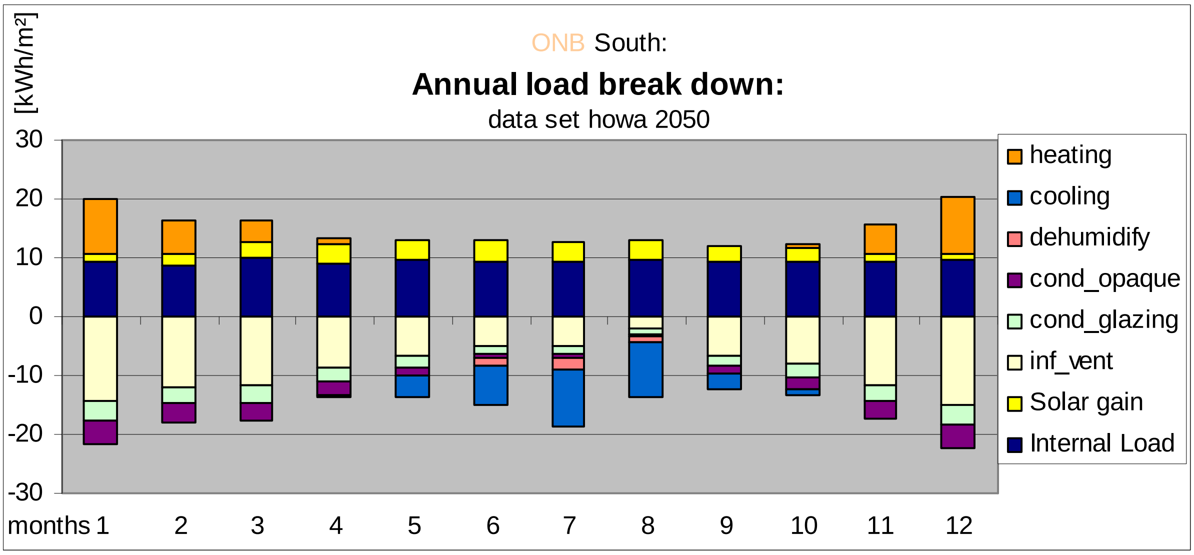
Graph 47: Annual load break-down for "howa 2050" in Strabag

The picture is different in the historic ONB building: solar gains are significantly lower here, thanks to reduced glazing fractions of the outer wall. In winter, however, this also induces more heating demand. Just as in Strabag, internal loads make up for the single most influential heat supply nearly year round – only during cold winter months this amount is outweighed by heating itself. Heat conduction via opaque building parts – negative as it might be in winter – helps to reduce indoor temperature in summer and thereby reduces cooling demands. The same holds true for transparent windows, although to a significantly smaller absolute amount.



Graph 48: Annual load break-down for "howa 80" in ONB

Cutbacks in heating demand in the future (climate data set "howa 2050") are evident for ONB and so is the increase in cooling demand. Both are mainly caused due to reduced losses by ventilation and conduction in winter as in summer.



Graph 49: Annual load break-down for "howa 2050" in ONB

8.1.4 Final and primary energy demand

The previous pages clearly showed that while heating demand is going to decrease moderately, cooling demand will nearly double over the next 40 years. These two components have to be viewed jointly for an overall picture of future developments. This is done in terms of final and primary energy demand in the following.

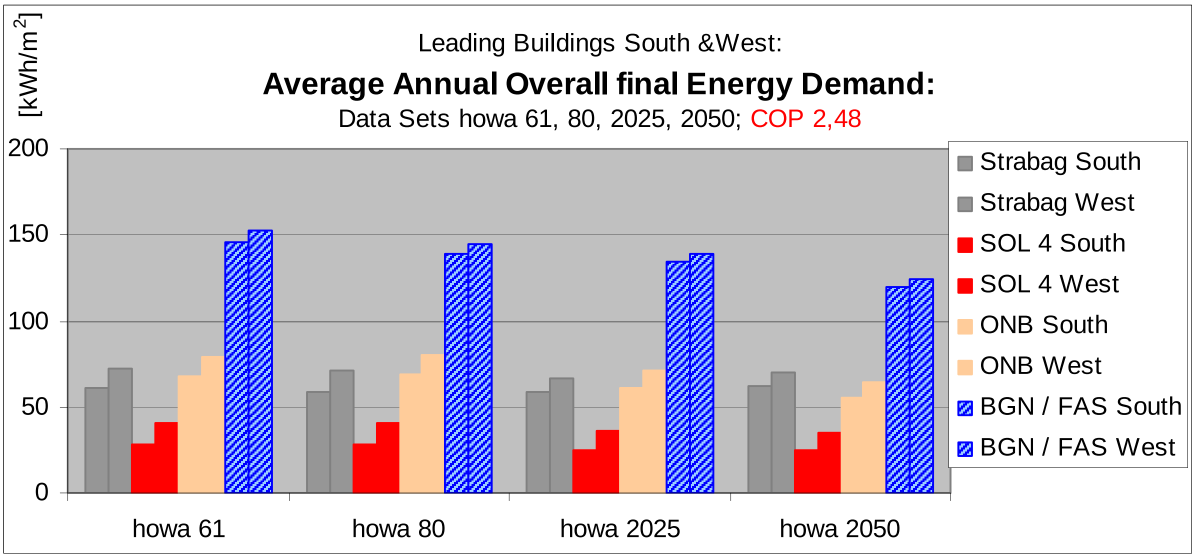
The calculation of both final and primary energy demand however strongly depends upon the conversion factors chosen for COPs (especially for cooling) and – for primary demand only: - PEI (primary energy index) of electricity for mechanical cooling. For the present investigation several sources of literature on this subject have been consulted and exemplary calculations run. The following tables indicate the chosen factors as well as their source while the following graphs outline the margin of values these factors can result in for final and primary energy consumption in the leading sample buildings. [67]

COP cooling	
Value	**Source**
3,0	Project "PH Office. Standard für energieeffiziente Bürobauten" [68]
2,48	Recknagel[69]

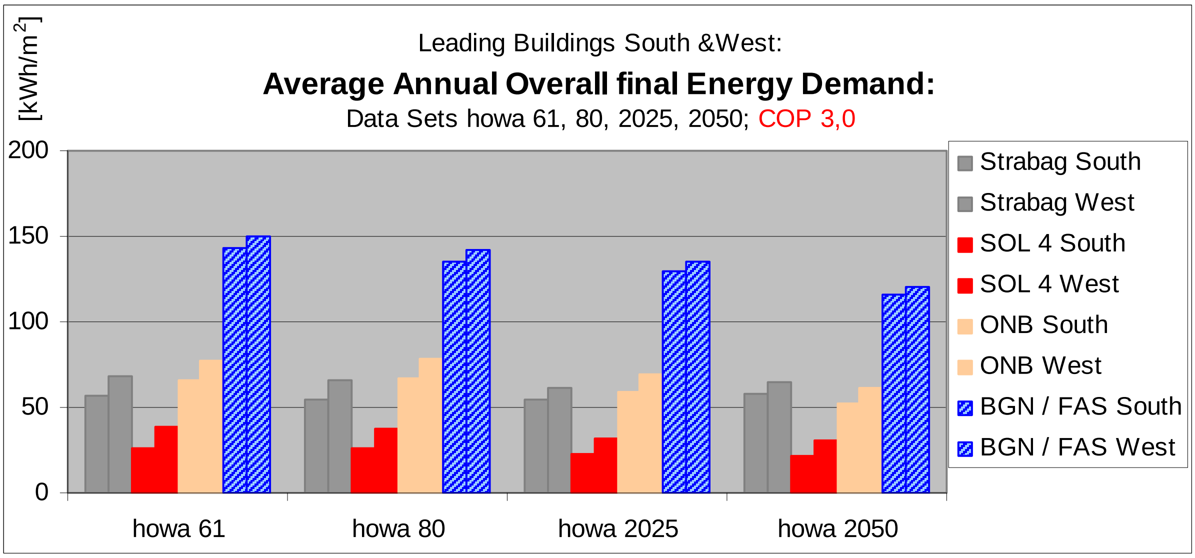
Table 7: Provenience of COP factors

For final energy demand, the two different COP factors applied resulted in minor but discernable differences for the overall energy requirement. Regardless of COP applied, the temporal trend for Strabag stagnates while it slightly decreases for the other leading buildings.

[67] For the heating system (both combustion and distribution) a degree of efficiency of 95% was assumed, including 5% of auxiliary electricity (as in project "PH Office. Standard für energieeffiziente Bürobauten").
[68] Programmlinie Haus der Zukunft (Hg.) (2010)
[69] Recknagel, Hermann; Schramek, Ernst-Rudolf; Sprenger (2001)

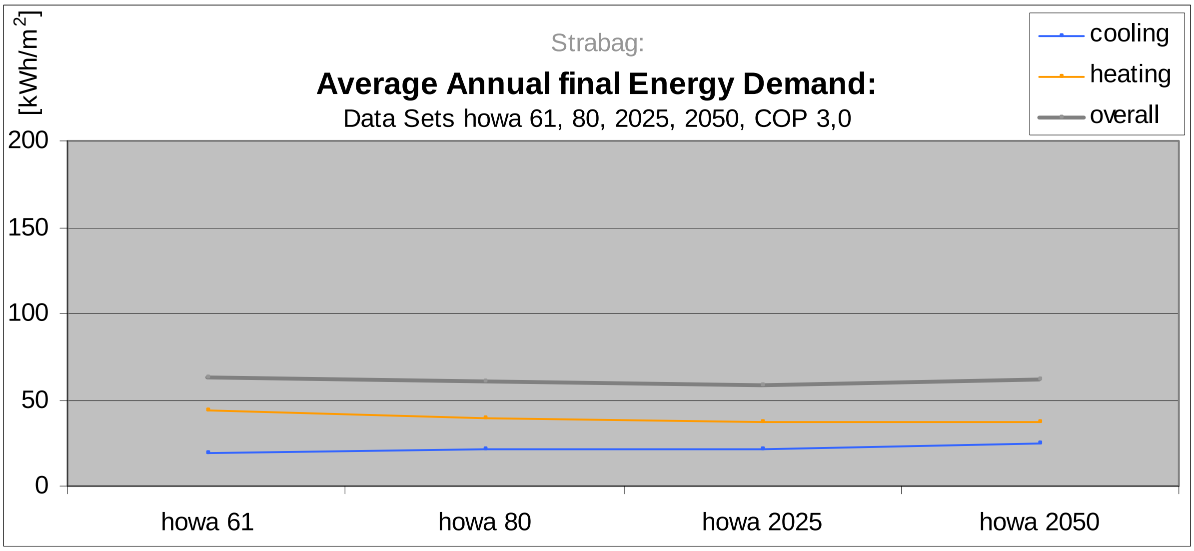


Graph 50: Average annual final energy demand for COP 2,48

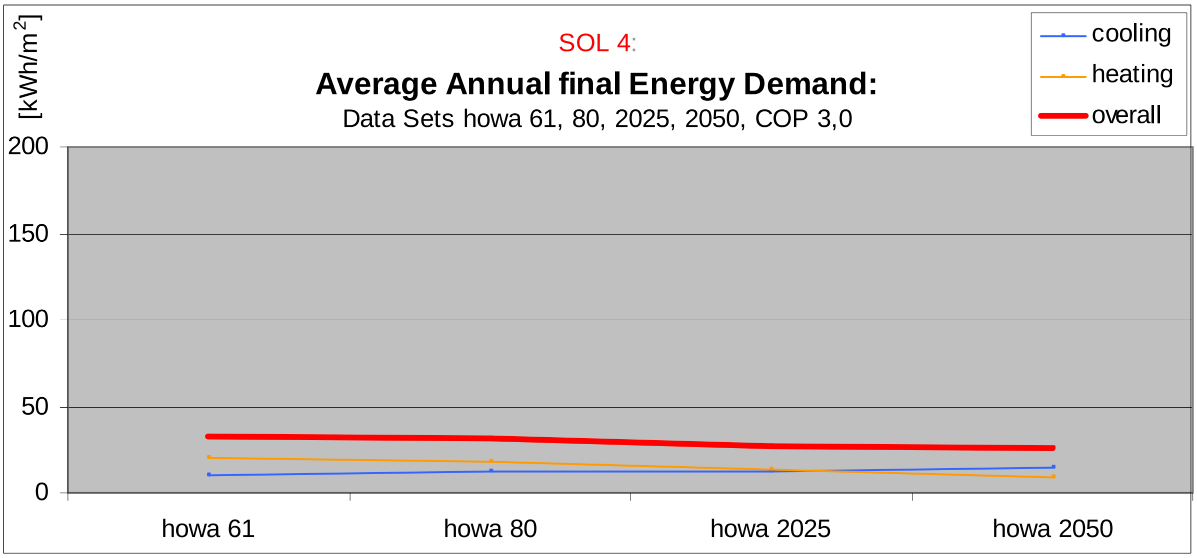


Graph 51: Average annual final energy demand for COP 3,0

Modern buildings with net cooling surpassing net heating demand already today display final energy demands for cooling which are only slightly lower than those for heating. These values gradually approximate towards the end of the temporal resolution. Overall final energy demand in consequence stagnates or decreases slightly.

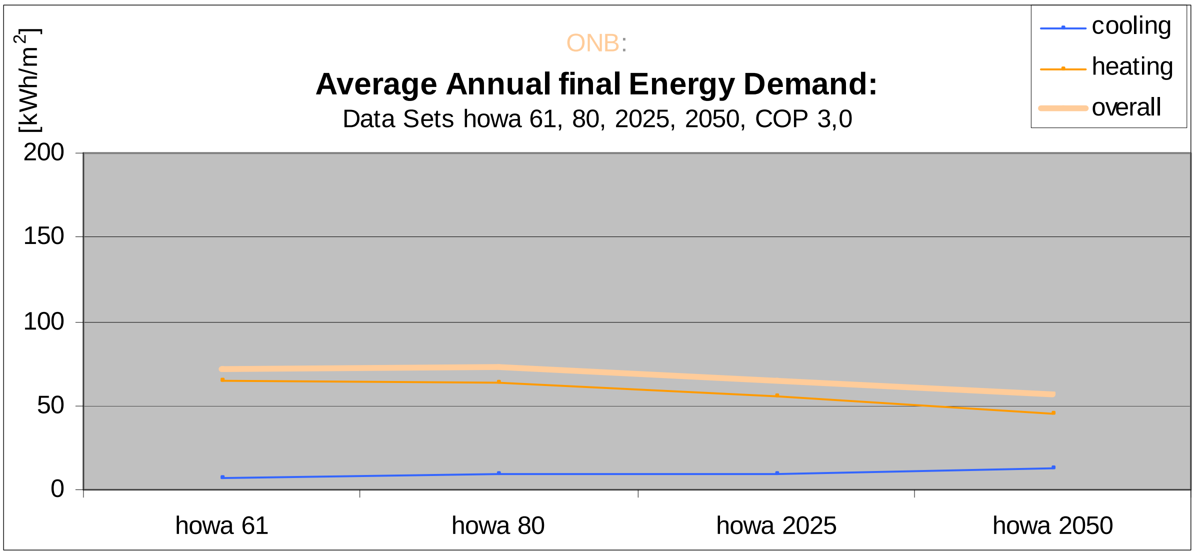


Graph 52: Average annual final energy demand for COP 3,0 in Strabag

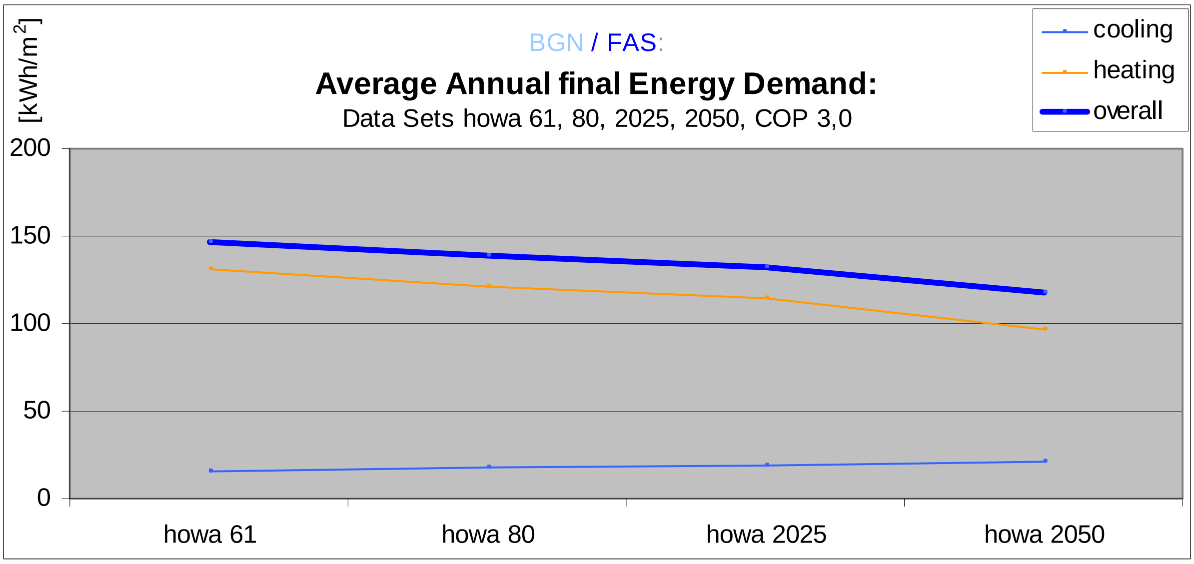


Graph 53: Average annual final energy demand for COP 3,0 in SOL 4

In contrast, existing buildings with net cooling demands significantly lower than net heating demands at present state, display final energy demands for cooling which are even more significantly lower than those for heating. Although these values gradually approximate towards the end of the temporal resolution they still range in different orders of magnitude then. Due to the decrease in the dominant heating fraction of the overall final energy demand, this demand decreases visibly.



Graph 54: Average annual final energy demand for COP 3,0 in ONB



Graph 55: Average annual final energy demand for COP 3,0 in BGN/ FAS

Results of calculation on primary energy demand as shown hereafter have to be considered with high caution; Not only are these results strongly influenced by the choice of conversion factors as demonstrated but it also has to be kept in mind that PEI might well change over the course of the decades to come, PEI factors might end up being significantly different by 2050 from what they can correctly be assumed to be today; therefore, the figures given here at best serves as pure indicators of possible trends.

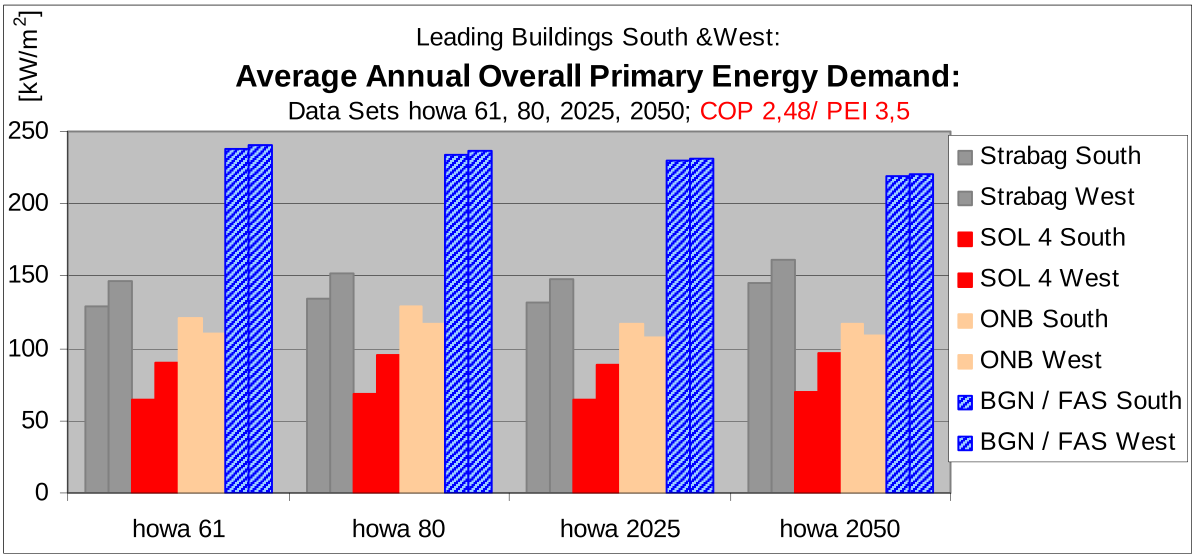
PEI electricity	
Value	**Source**
3,51	OIB guideline, draft October 27, 2010 [70]
2,6	Project "PH Office. Standard für energieeffiziente Bürobauten [71]"

Table 8: Provenience of PEI factors

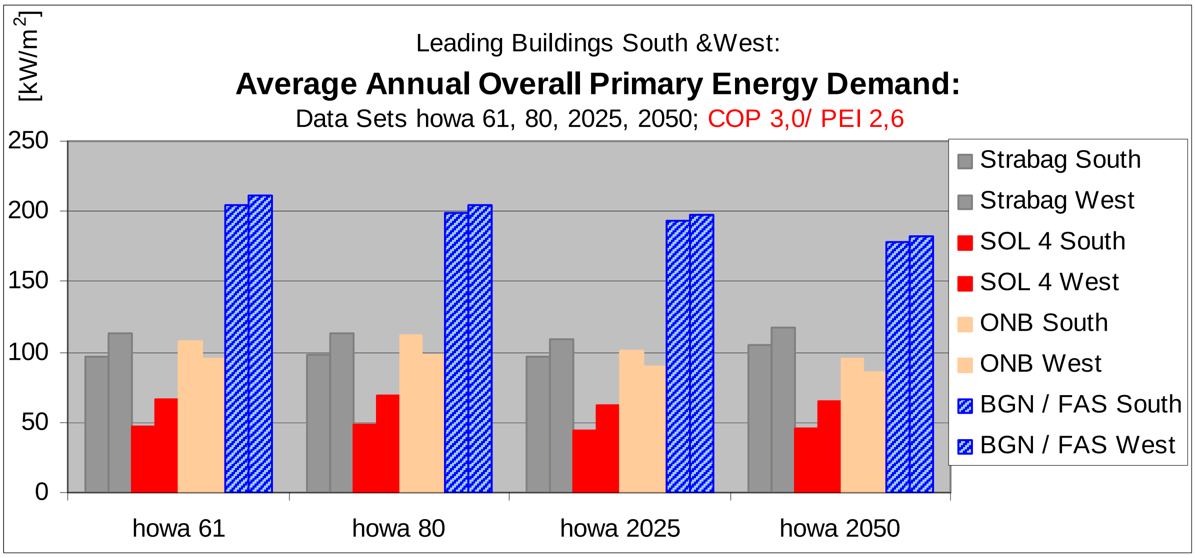
Evidently, when both the COP of the cooling system and the PEI are taken into account for electricity, they remarkably impact upon the resulting primary energy demand. Still, this overall demand slightly declines between data sets "howa 80" and "howa 2050" in buildings which display heating demand more prominently than cooling – this is the case for both the cohorts built before WW1 and after WW2.

The differences between results from different climate data sets are clearly outnumbered for all buildings by differences effectuated by various conversion factors which range up to 50 kWh/m^2. Herein, COP and PEI are likewise influencing.

[70] Richtlinie 6, Energieeinsparung und Wärmeschutz (Österreichisches Institut für Bautechnik, Wien, 2010), Österreichisches Institut für Bautechnik, 27.10.2010.
[71] see Table 7: Provenience of COP factors, page 82

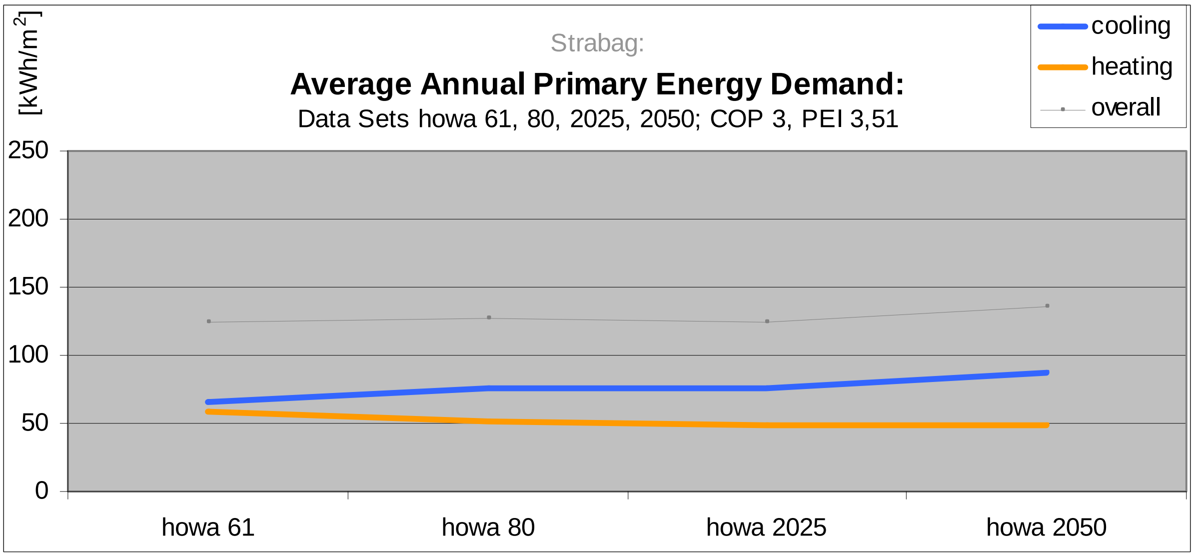


Graph 56: Average annual primary energy demand for COP 2,48 & PEI 3,51

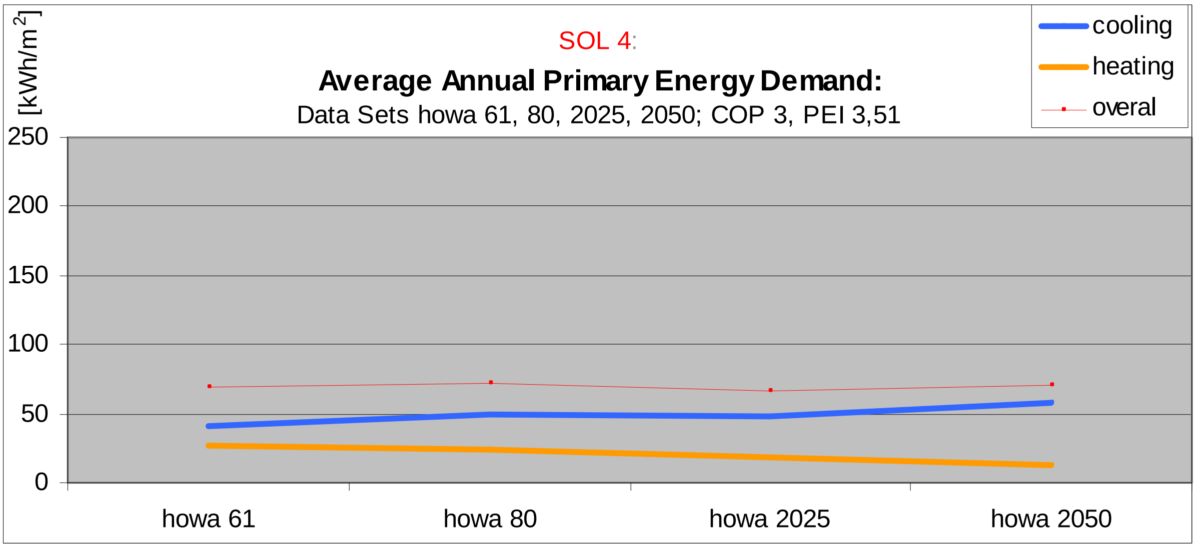


Graph 57: Average annual primary energy demand for COP 3,0 & PEI 2,6

When taking a closer look at the development of primary energy demand in each leading building it becomes evident that those buildings which were constructed rather recently (Strabag and SOL 4) are characterized by a primary energy demand for cooling that – already today – is higher than the demand for heating. Hence, in the future the dominant role of cooling in this respect will become even more proliferated. In consequence, these buildings' overall primary energy demand – depending on the factors of conversion chosen – slightly increases or stagnates at best. This is due to the higher relevance of cooling in terms of primary energy use.

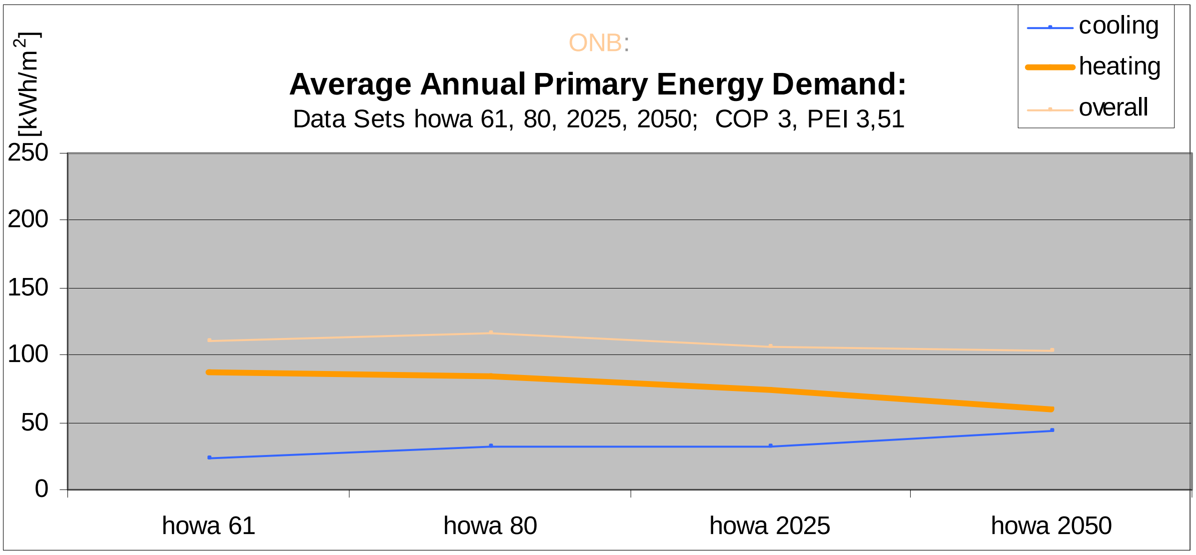


Graph 58: Trend of primary energy demand for Strabag COP 3,0 & PEI 3,51

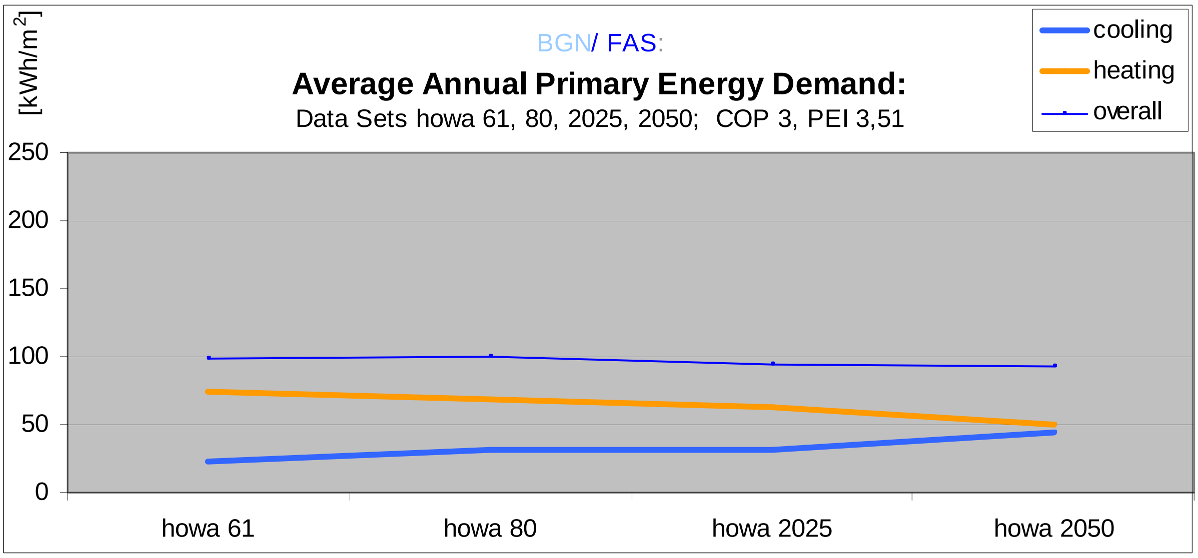


Graph 59: Trend of primary energy demand for SOL 4 COP 3,0 & PEI 3,51

The situation is distinctly different both in the buildings dating from before WW1 and those from after WW2: in these, heating is the dominant factor in terms of energy demand today. This will remain principally unchanged in the future even while heating and cooling demands will slowly approximate in value; only under climate data set 2050 are these two nearly equal. As a result, the overall primary energy demand slightly decreases over the span of time.



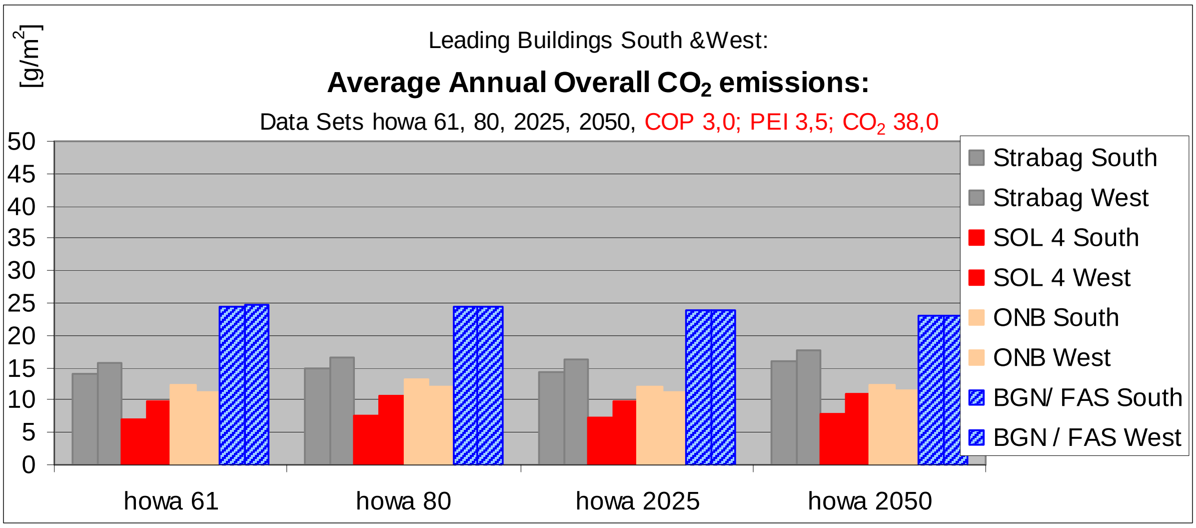
Graph 60: Trend of primary energy demand for ONB, COP 3,0 & PEI 3,51



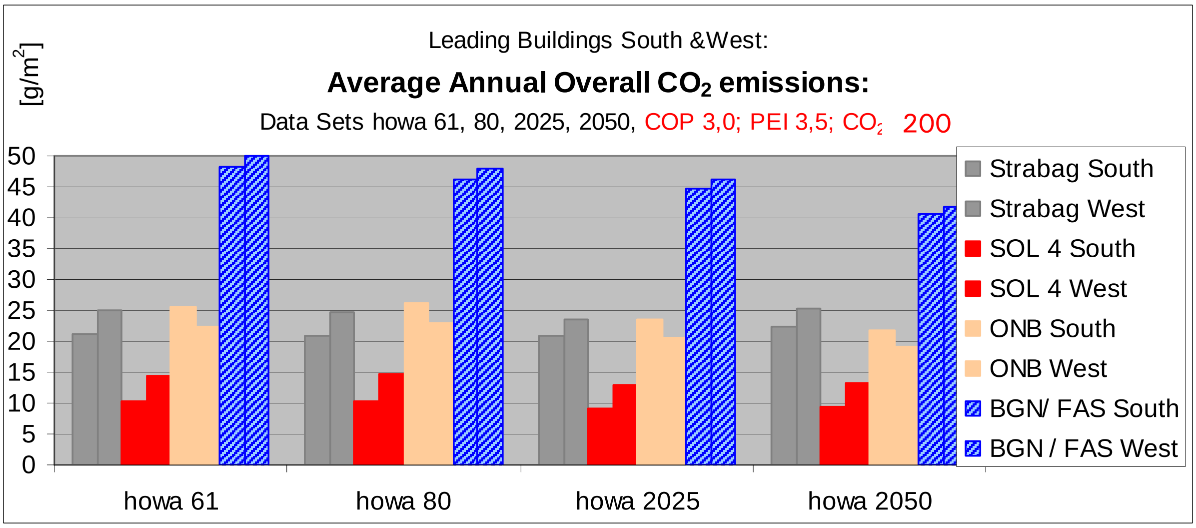
Graph 61: Trend of primary energy demand for LES, COP 3,0 & PEI 3,51

8.1.5 CO_2 - Emissions

Similar to final and primary energy demands, values for CO_2 emissions are influenced by the conversion factor underlying the calculation. The corresponding Austrian OIB guideline 6 in its draft from October 27, 2010, contains two different such factors which depend on the district heating plant's size: a figure of 38g/kWh applies for plants bigger than 300 MW, while 200g/kWh have to be calculated for minor plants. The calculated emissions for all leading sample buildings vary accordingly while temporal trends develop as they do for final energy demands.



Graph 62: Average annual CO_2 emissions for leading buildings, COP 3,0; PEI 3,51, CO_2 38,0;



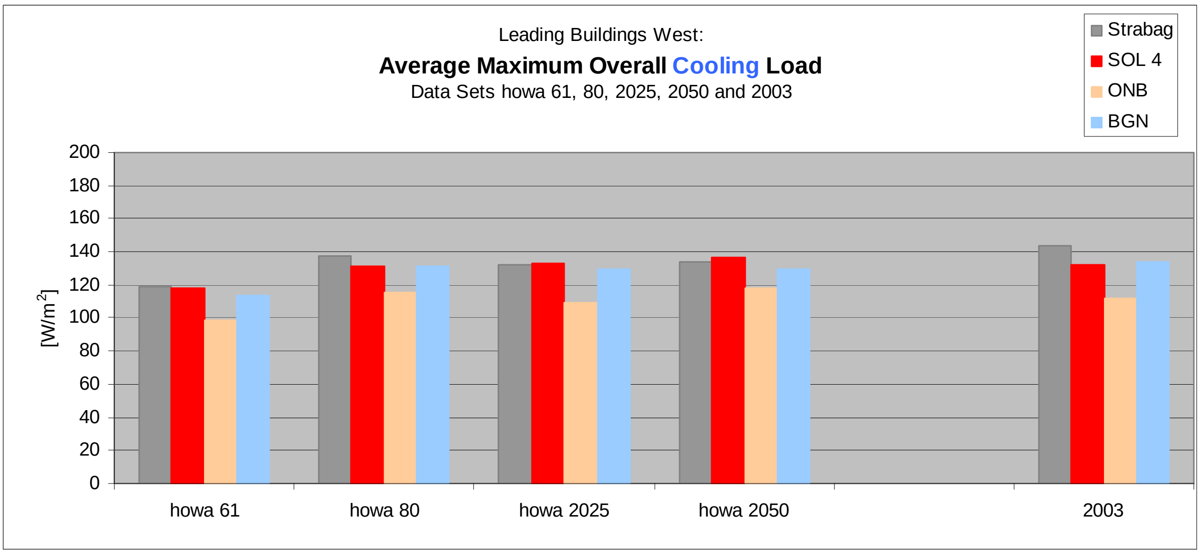
Graph 63: Average annual CO_2 emissions for leading buildings, COP 3,0; PEI 3,51, CO_2 200

8.1.6 Maximum cooling load

The values depicted in the following for maximum cooling load correspond to the most adverse conditions met in the sample buildings during office hours in terms of heat loads which have to be removed. Hence, these are peak values from annual simulation.

Maximum cooling loads of all leading buildings clearly range above the threshold of approximately 40 W/m^2, which can be provided by hybrid cooling measures only[72]. Again, results for passive house SOL4 have to be regarded with caution as they do not reflect the actual situation in a full-scale passive house but only reflect the constructive properties of the building shell.

Highest loads are required in highly glazed Strabag and the post WW2 building BGN while ONB displays lowest values. In nearly all buildings, highest cooling loads are found under the conditions of the extreme summer of year 2003.

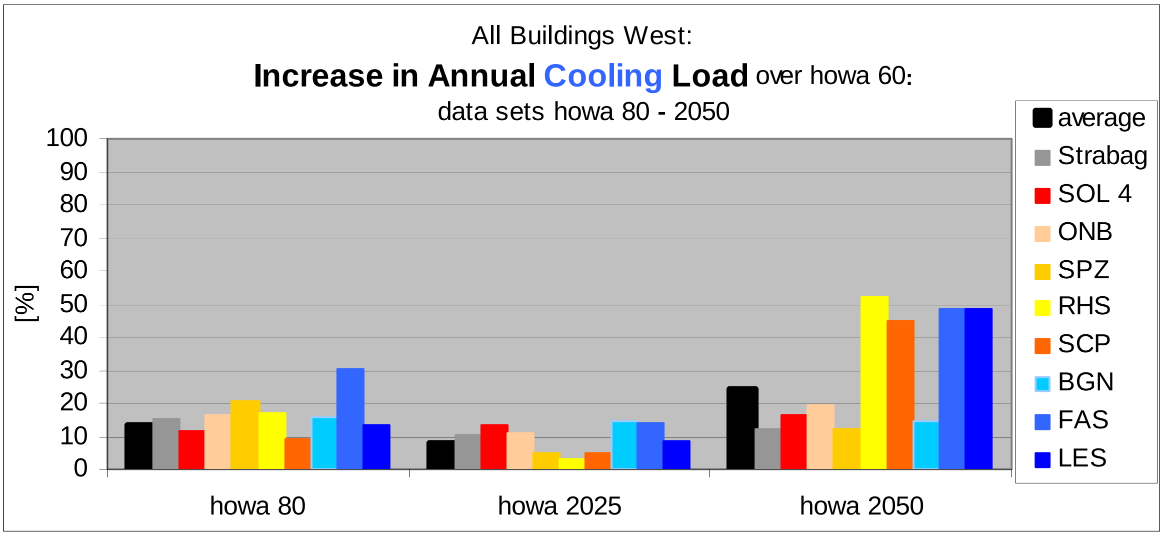


Graph 64: Average annual maximum cooling load

The increase in maximum cooling over the temporal resolution from climate data set "howa 61" to "howa 2050" is not as clear and consistent as is the increase in cooling demand[73]. In some buildings such as Strabag and BGN higher loads are found under climate data set "howa 80" than under "howa 2025" and even "howa 2050".

[72] Zimmermann, M. et al. (2003).

[73] see Graph 41: Increase in net cooling demand , page 76



Graph 65: Increase in maximum cooling load

In conclusion it can be stated that conditions of climate change tend to impact more pronouncedly upon cooling demand than maximum cooling load. This is to be attributed to the fact that summers will include longer periods of elevated outdoor temperatures more frequently rather than single days with extreme peaks.

8.1.6.1 Cooling load under Design Day conditions

For cooling plant sizing, climate engineers normally do not refer to maximum cooling loads in annual simulations but rather simulate by use of Design Days. The building in question is exposed to conditions arising from the continuous (at least: 15fold) repetition of this single day's data set. By this, heat waves are modelled and in consequence sizing figures are achieved which can be expected to fall on the safe side under all conditions.

The corresponding Austrian technical norm ÖNORM B 8110-3 (1999)[74] includes two descriptions for the compilation of Design Day climate data sets.

Option 1 can be applied regardless of local conditions. It includes a sinusoidal swing of the outdoor temperature on base of a mean outdoor air temperature of 23°C and amplitude of 7K. Irradiation data for these 24 hours is to be withdrawn from Table E.2 of the norm.

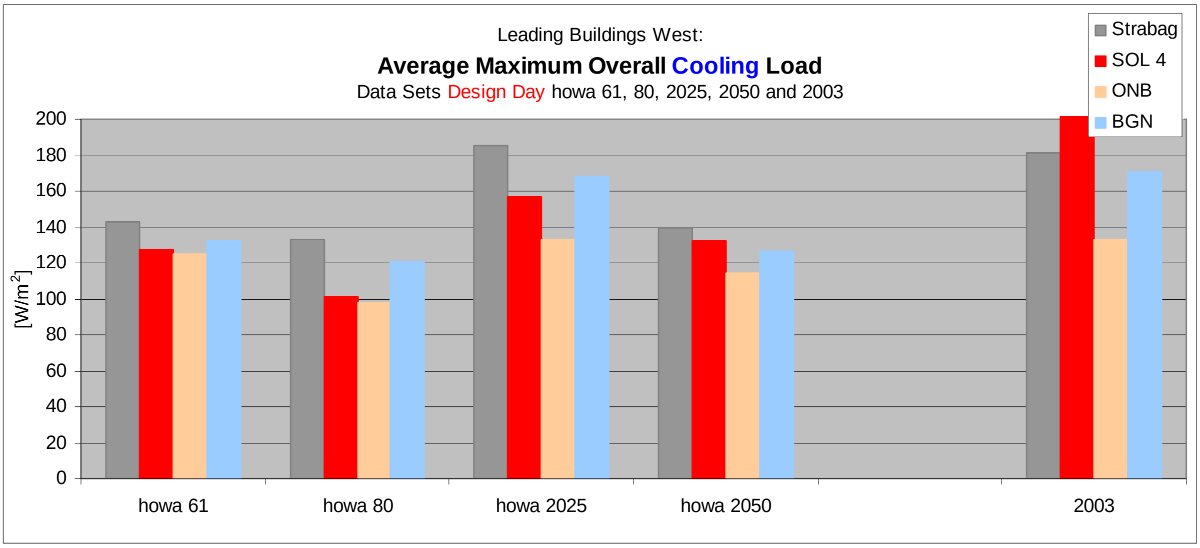
Not only does this mode of compilation mode disconnect the complex relationship of corresponding data for both temperature and irradiation, it is also useless for the depiction of several different climate data sets referring to different stages in the temporal evolvement of climate change.

[74] ÖNORM B 8110-3 (1999): chapter 7, page 8

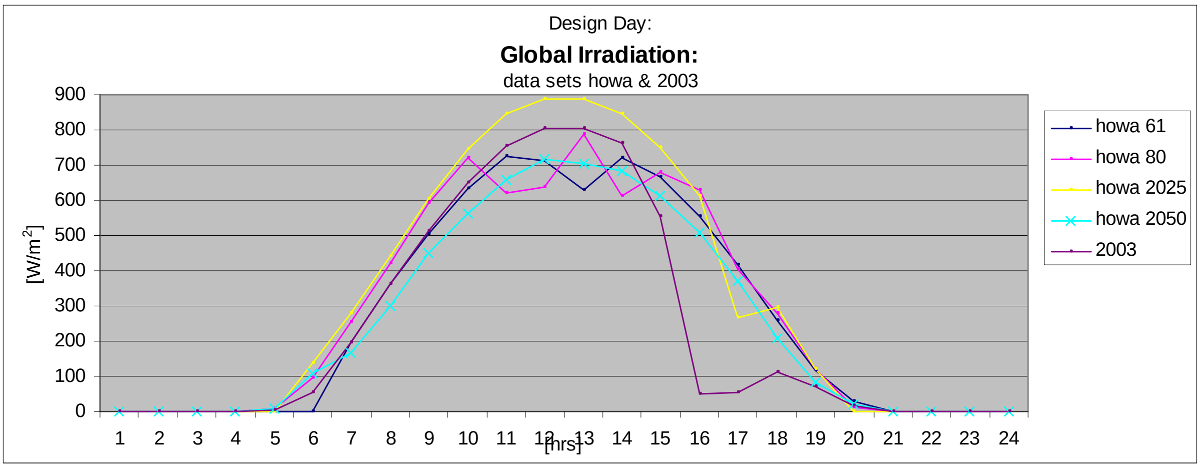
Option 2 takes local conditions into account and asks for a 24 hours' set of outdoor air temperatures which is not surpassed on more than 13 days in long term mean. Irradiation data for these 24 hours is to be drawn from June 15 of this long term mean.

Again, this compilation mode again disconnects the complex relationship of corresponding data for both temperature and irradiation. However, it represents the only feasible way of implementation: for all climate data sets investigated here ("howa 61" to "howa 2050") those days where selected which display outdoor temperatures not found more than 13 times throughout the year. Temperature course of these days with the associated irradiation values were utilized as Design Days which represent the corresponding climate data set.

However, as can be seen from the following cooling loads, the Design Days thus compiled do not necessarily represent properly the corresponding climate data set: they do not depict differences in both temperature and irradiation between the climate data sets themselves. This, for instance, results in cooling loads being highest under Design Day of "howa 2025" while the annual climate data set "howa 2025" yields comparatively low maximum cooling loads. This becomes understandable by scrutinizing global irradiation of the utilized Design Days: here values for "howa 2025" range highest. It is barely possible to depict differing conditions of the annual climate data sets "howa 61" to "howa 2050" in their respective Design Days. Hence, the results for cooling loads gained by application of these Design Days have to be regarded under these premises.



Graph 66: Average Maximum cooling load under Design Day conditions



Graph 67: Global irradiation of Design Days

8.1.7 Conclusions and discussion

The following limiting factors have to be kept in mind when analyzing the results gained in thermal simulation:

- Statistic data on office buildings in Vienna is very limited, especially when it comes to construction and conditioning of these buildings. Many assumptions underlying the simulation perforce rely on empiric findings only.
- Construction data appears most uncertain for buildings from after WW2. Thermal properties of these buildings were found to be least homogeneous. In consequence, results of simulation strongly vary for this building cohort.
- Results for the extreme year of 2003 depict the fact that extremes may well surpass average occurrences contained within “howa 2050”. It has to be kept in mind that climate data set “howa 2050” by nature of its generation does not contain any extreme climatic occurrences but rather represents the average global warming to be expected. Future extremes may well go beyond “howa 2050” and even 2003.
- Conversion factors for COP (and PEI) strongly influence overall final and primary energy demands and their development trends.
- Caution is required for the calculation of primary energy demands: not only are results strongly influenced by conversion factors but PEIs have to be expected to change in unforeseen ways over the decades to come, making any current calculation highly speculative.
- Conversion factors likewise strongly influence results for CO_2 emissions.

Cooling demand
Increase:

- Net cooling demands generally increase over the course of time by an average of 80%.

- Two distinct steps are discernable in this increase: one (between "howa 61" and "howa 80") has actually already taken place while the second one is detectable between "howa 2025" and "howa 2050".
- The average increase in absolute figures ranges around 20 kWh/m^2.

Orientation

- Demands for office rooms facing West are generally higher than those for rooms to the South.

Building types

- Modern buildings tend to be less optimized in regards to reduced cooling rather than heating demands.
- Glazing fraction of external wall and occupancy rate were found to be most influential for cooling demand.
- Buildings from before WW1 display comparatively low cooling demand due to reduced glazing fractions, generous room layout and volume.

Heating demand

Decrease

- Heating demand decrease is generally lower in percentage than cooling demand increase, ranging around 30% between "howa 61" and "howa 2050".
- Two distinct steps are discernable in this decrease: one (between "howa 61" and "howa 80") has actually already taken place while the second one is detectable between "howa 2025" and "howa 2050".

Orientation

- Demands for office rooms facing West are generally higher than those for rooms to the South.

Building types

- Heating demand in absolute figures is significantly higher than cooling demand in buildings from before WW1 and after WW2.

Final energy demand

- For recently erected buildings, final energy demand will stagnate or decrease slightly over the course of time. For buildings from before WW1 and after WW2 final energy demand will decrease due to the dominance of heating in their energy requirements.

Maximum cooling load

- Maximum cooling increase ranges around 25% in average between "howa 61" and "howa 2050" and is thus less in percentage than cooling demand increase.

Simultaneous decrease of heating and increase of cooling demand will require a shift in paradigm of conditioning. Many old buildings as of today are not at all equipped with cooling devices. This will bring them to the verge of not being usable under future conditions in summer[75]. Their significant heating demands will be somewhat diminished by milder winters, although remaining high in absolute values.

In contrast, recently built office blocks display comparatively low heating demands which will further decrease. Their cooling demands however tend to be even higher than heating requirements (in terms of net energy) - which is why they are increasingly being equipped with cooling devices.

Solar and internal heat loads from electronic equipment make up for the most significant drivers of cooling demand. Thus high glazing fractions of the exterior wall and high occupancy strongly influence a building's performance under hot summer conditions[76]. Options to reduce both offer first approaches to reduce cooling demands.

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[75] for conditions to be expected in ONB and BGN without cooling refer to chapter 8.2 Module 2: Discussion of comfort models, page 97

[76] The energy efficiency of electronic equipment which constitutes the single most relevant internal heat source was kept constant for all buildings here. For effects of different levels of energy efficiency of electronic equipment see: 8.5 Module 5: Impacts of different levels of internal loads on cooling energy demand, page 120

8.2 Module 2: Discussion of comfort models

Mechanical cooling in offices is always applied with the aim of providing thermal comfort for office workers and thus enabling them to fruitfully pursue their daily work. This is to say that thermal comfort and energy demand for cooling are reciprocally linked: In conventional buildings, safeguarding high thermal comfort standards generally ask for high energy imputs.

For the assessment of thermal comfort in buildings there exist two somewhat contradictory comfort models, both of which are depicted in corresponding normative framework:

“Fanger”- (PMV & PPD) Model
Both ÖNORM EN 7730 and ÖNORM B 8110-3 refer to the widely applied comfort model that has been established, in essence, by Per Ole Fanger. It links physical parameters of indoor conditions to statistical indications of the predicted mean vote (PMV) of buildings’ users on these conditions and of the predicted percentage of dissatisfied (PPD) users. Its algorithms apply first and foremost to conditioned buildings.

- ÖNORM EN 7730

comprises the PPD/ PMV comfort model and categorises comfort according to a buildings’ function. Therein **Category B** (applicable for Strabag) asks for comfort temperature limits of 24,5°C +/- 1,5° (**26°C**) in office rooms whereas **Category C** (applicable for ONB, BGN) displays a limit of 24,5°C +/- 2,5° (**27°C**). The corresponding thresholds are 15% for PPD and a PMV between -0.7 and +0.7.

- ÖNORM B 8110-3

contains calculation methods to evidence thermal protection against overheating in summer. Thermal protection is assumed to be satisfactory when indoor temperatures are kept below **27°C** during daytime. Part 1 of the same norm asks for an indoor temperature of 26°C as basis of cooling load calculation.

Adaptive Comfort Model
In contrast, the following norm is laid out according to the so called “adaptive” comfort model which takes into account people’s ability to adapt to prevailing temperatures in free running buildings:

- ÖNORM EN 15251

categorises buildings according to their users’ expectations regarding thermal comfort. Therein **Category II** refers to new and refurbished buildings with normal expectations; this applies for Strabag. If mechanical cooling is applied – which is the case in Strabag – the PPD/ PMV comfort model acc. ÖNORM 7730 should

be followed and a temperature limit of **26°C** should not be surpassed in single occupancy office rooms.
Category III refers to existing buildings with moderate expectations; this applies for ONB and BGN. In these mainly naturally ventilated buildings which allow for a certain influence by users on indoor climate an adaptive comfort model may be applied. Therein comfort temperature limits depend upon a gliding average outdoor temperature which takes into account shifting weather conditions and users' expectations depending thereon. However, for cooling load calculation a comfort temperature limit of **27°C** is applied.
Surpassing comfort temperature limits is acceptable for 5 % of working hours weekly, monthly and yearly.

However, ÖNORM EN 15251[77] contains two remarkable, limiting statements concerning the foreseen comfort limits:

- Temperature limits are based on comfort studies which did not take workers' productivity into account.
- In the range above 25°C these temperature limits are based on a restricted amount of data. In Graph 13, page38, this applies for all values of "EN 15251 K3_up_lim" above the black line: significantly more than half the years time is concerned.

In the study at hand, so far all sample buildings were assumed to be mechanically cooled in such a way that comfort limits acc. ÖNORM EN 7730 are kept during all office hours and the resulting energy demands were analysed. In contrast, this present chapter refers to the actual situation in sample buildings ONB and BGN: these in reality are not at all or just barely cooled today and hence experience elevated indoor temperatures in summer.

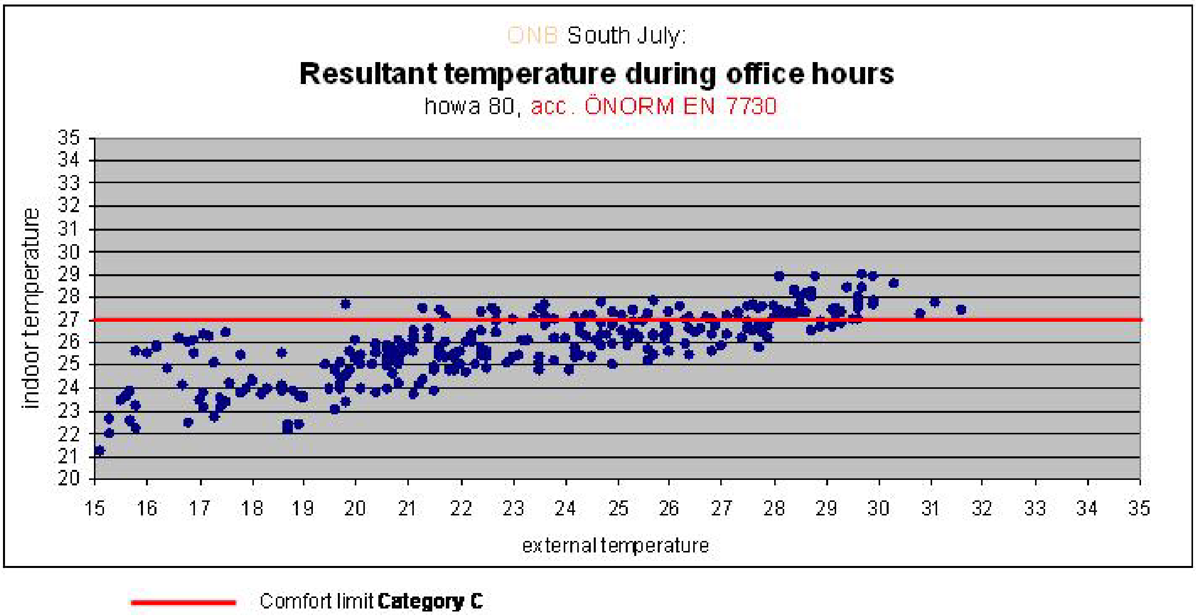
This present situation was taken as a starting point for the following investigation: both buildings hereafter are simulated under uncooled conditions (Simulation mode "real") and the resulting indoor temperatures are scrutinized. For the assessment of the comfort situation thus evolving in the buildings reference is made to both comfort models.

Module	Sample Building	Simulation Mode	Climate Data Set
2 Comfort models	ONB BGN	"real"	"howa 80" "howa 2050"

Table 9: Investigated sample buildings, simulation modes and employed climate data set in Module 2a

[77] ÖNORM EN 15251 chapter A.2., page 28

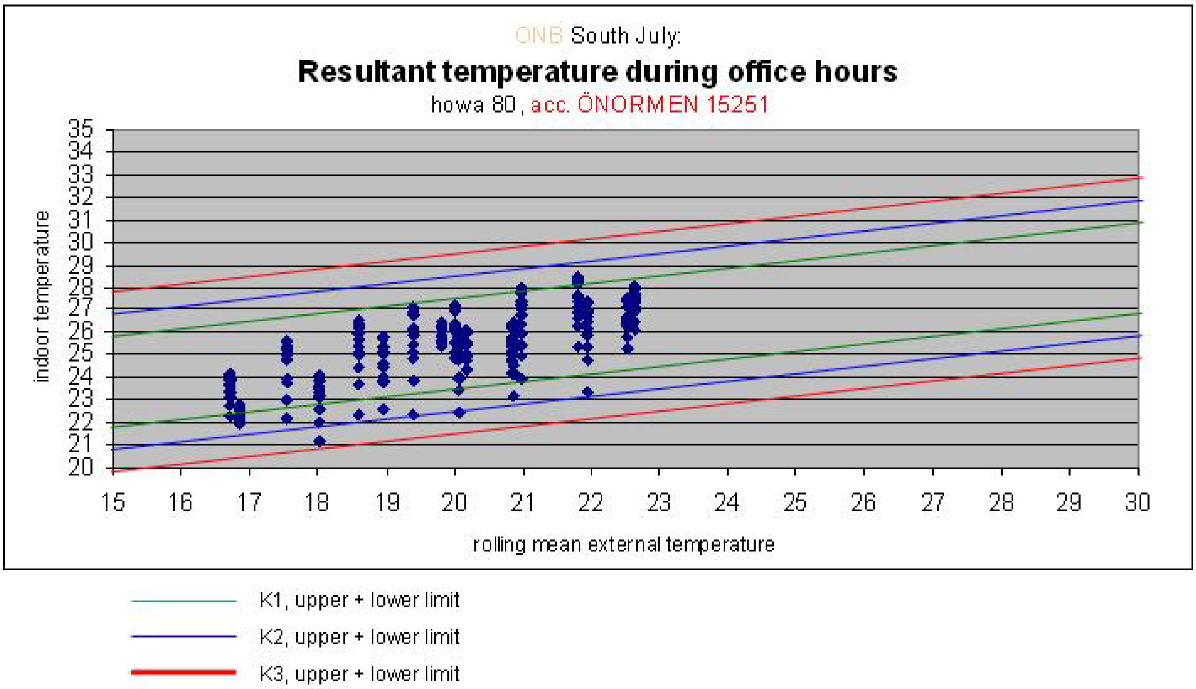
8.2.1 Comfort in buildings from before WW1: ONB



Graph 68: Resultant hourly temperatures in ONB during July under data set „howa 80" according to EN 7730

The applicable comfort temperature limit of category C is discernably surpassed in 23 office hours during the investigated month of July of "howa 80" in ONB. Furthermore, it can be seen from Graph 68 that indoor temperatures tend to run about 2 to 3 K in excess of outdoor temperatures as long as these outdoor temperatures range up to 24°C. Beyond this threshold, internal and external temperatures gradually approximate, therein manifesting the damping effect of the building's thermal mass.

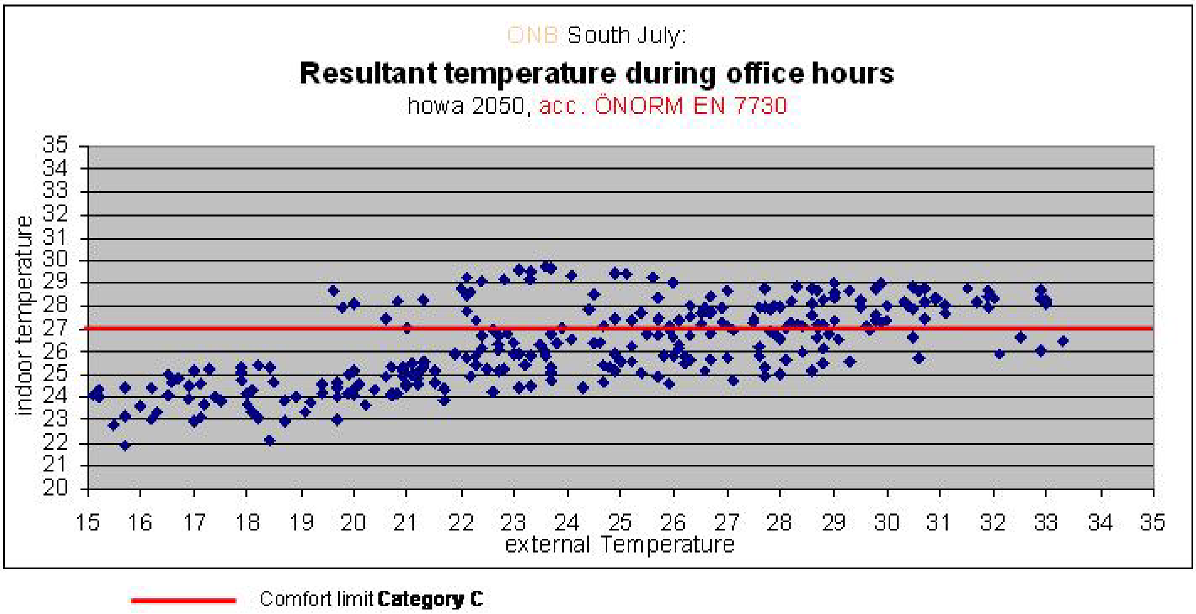
Under ÖNORM EN 15251 all values of indoor temperature are plotted over the rolling mean of the external temperature. This figure takes into account the temperatures which prevailed during the precedent days and does not reach beyond 23°C under climate data set "howa 80". Each working day is represented in the graph by a column of internal temperatures over the rolling mean of this particular day. None of these temperatures falls outside comfort limits of category III.



Graph 69: Resultant hourly temperatures in ONB during July under data set „howa 80" acc. to EN 15251

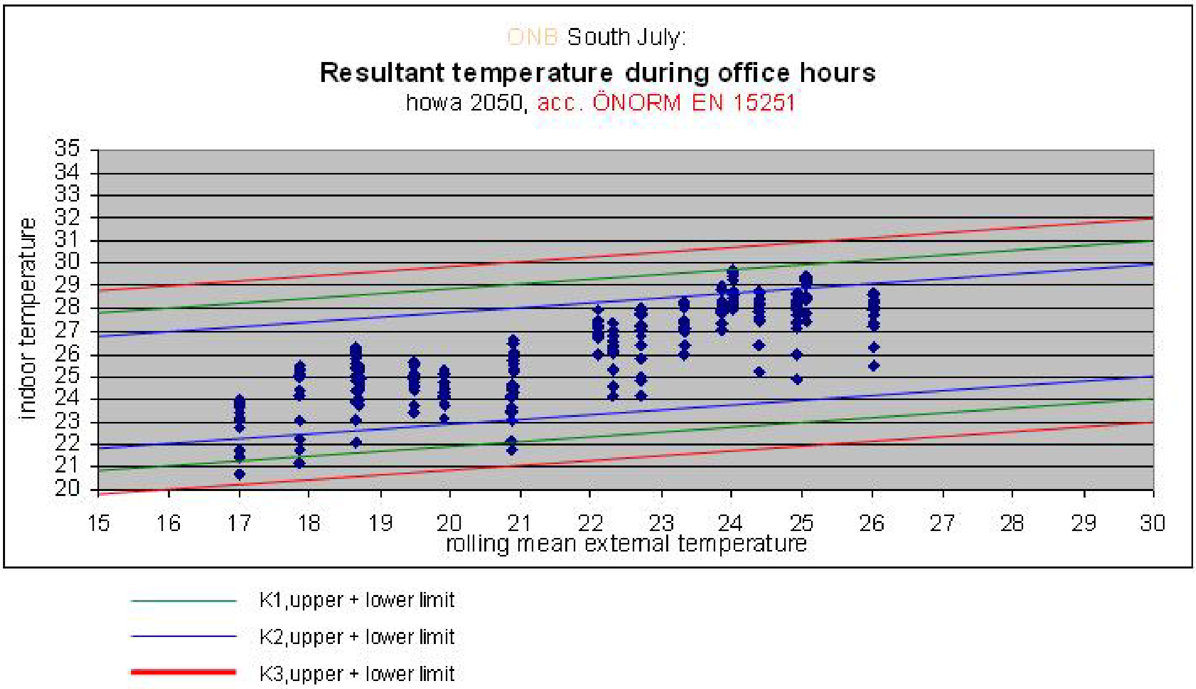
K1 to K3 marking comfort limits acc. for building categories I to III (see chapter 8.2 Module 2: Discussion of comfort models/ Adaptive comfort model, page 97).

Simulated under climate data set "howa 2050" ONB not only displays considerably higher maximum indoor temperatures (up to 30°C as compared to max. 28°C under "howa 80"), it also marks a visible increase in office hours beyond the comfort limit of 27°C.



Graph 70: Resultant hourly temperatures in ONB during July under data set „howa 2050" acc. to EN 7730

When comparing results under ÖNORM EN 15251 for "howa 80" and "howa 2050" the shift of rolling mean temperatures to higher values around 26°C is obvious. Still, no surpassing of comfort limits takes place as temperatures up to 31°C would be acceptable under these conditions for buildings of category III.

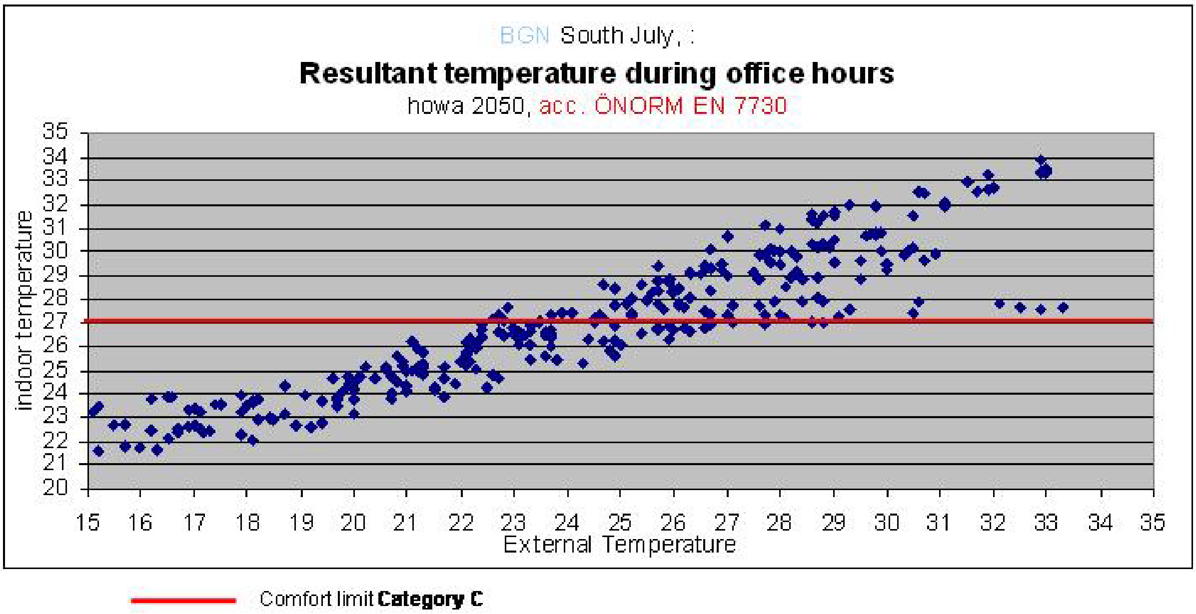


Graph 71: Resultant hourly temperatures in ONB during July under data set „howa 2050" acc. to EN 15251

K1 to K3 marking comfort limits acc. for building categories I to III (see chapter 8.2 Module 2: Discussion of comfort models/ Adaptive comfort model, page 97).

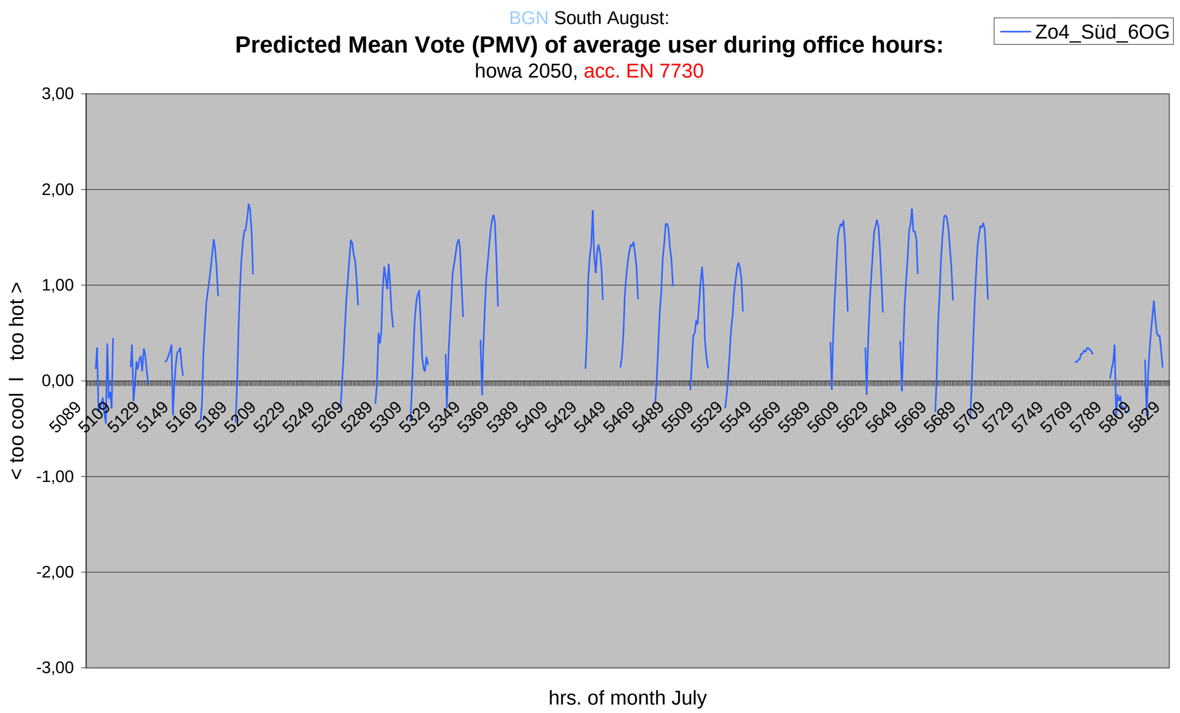
8.2.2 Comfort in buildings from after WW2: BGN

The scatter plot of indoor temperatures achieved in BGN under climate data set "howa 2050" shows a steeper ascent than of ONB, indicating a reduced temperature dampening capacity of the building's thermal mass. Office hours, during which comfort limits according EN 7730 are surpassed, amount for nearly 50% of all hours.



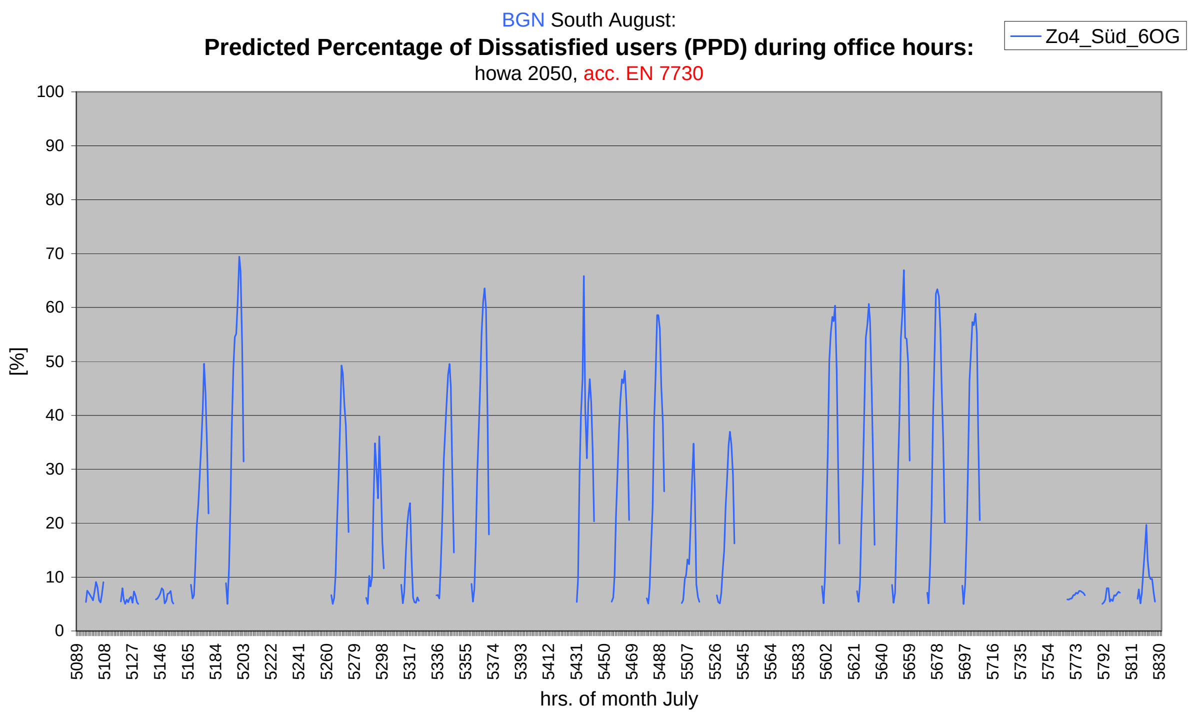
Graph 72: Resultant hourly temperatures in BGN during July under data set „howa 2050"acc. to EN 7730

The calculation of predicted mean vote (PMV) during office hours shows that chilly morning hours are experienced as being slightly too cold by the average building user whereas noon and afternoon indoor temperatures are judged as way too hot nearly every day of the simulated period.



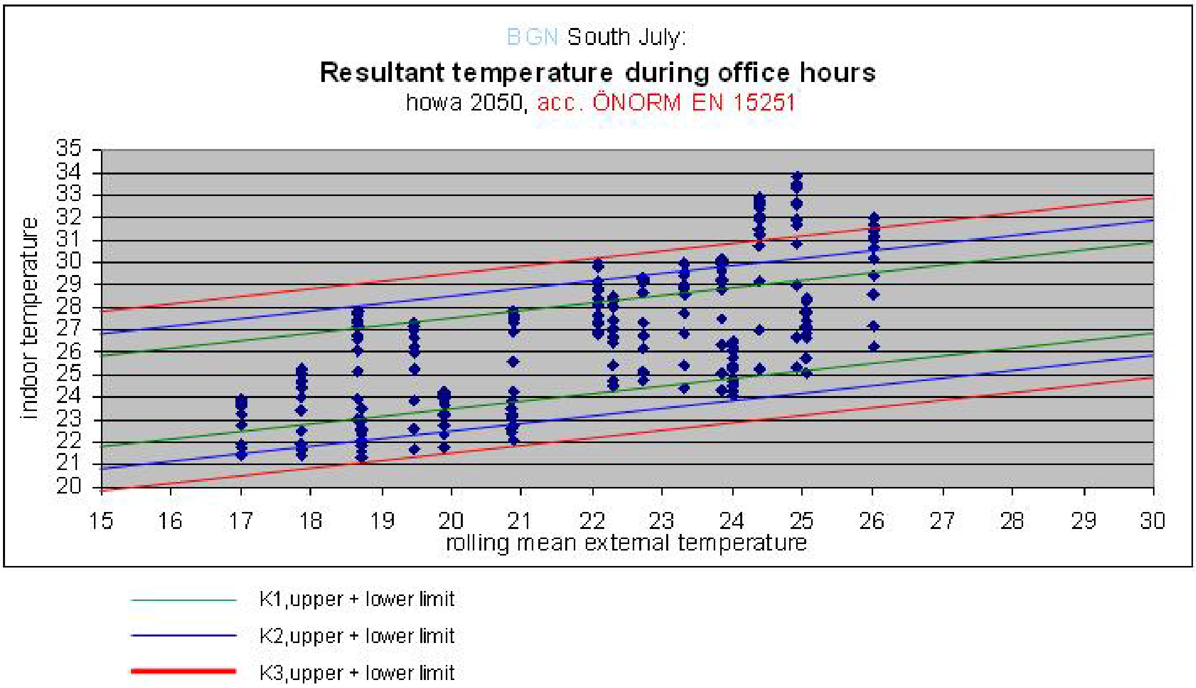
Graph 73 : Predicted mean vote during office hours in BGN under data set howa 2050

In accordance with predicted mean vote, the predicted percentage of dissatisfied users (PPD) likewise displays high levels of users' concern with too hot indoor temperatures: this percentage reaches up to 70% of all workers predicted to be unsatisfied with the thermal comfort in the building. In other words: the majority of the building's users feels strongly uncomfortable under the simulated conditions.



Graph 74: Predicted percentage of dissatisfied users during office hours in BGN under data set howa 2050

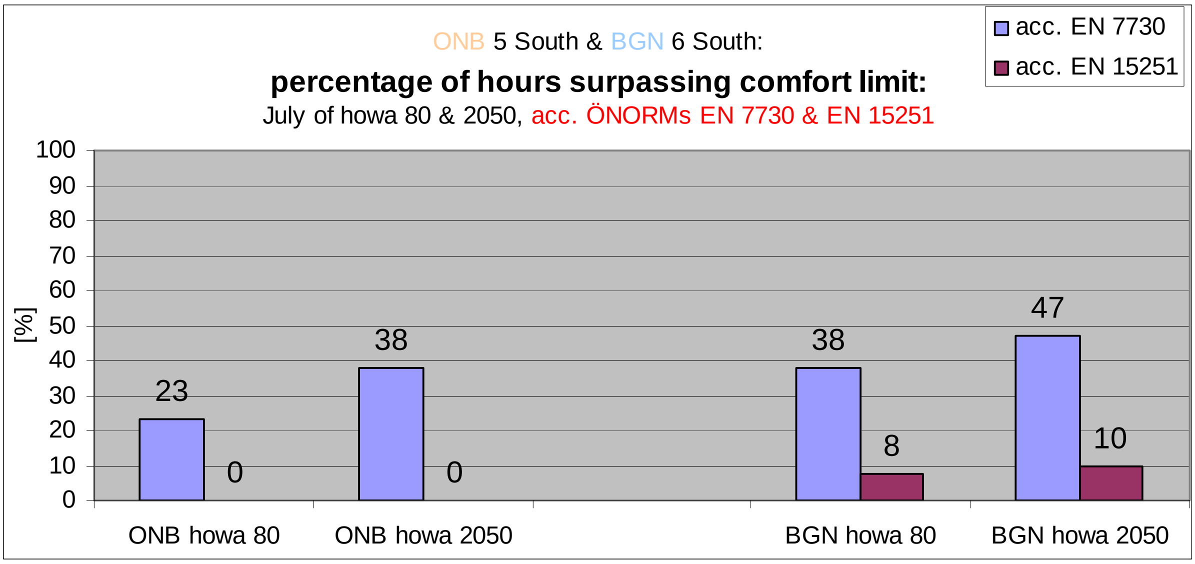
Simulated under climate data set “howa 2050” BGN surpasses of comfort limits even according to ÖNORM EN 15251. This surpassing occurs in 10% of office hours and hence falls beyond acceptable figures of 5% maximum.



Graph 75: Resultant hourly temperatures in BGN during July under data set „howa 2050“acc. to EN 15251

K1 to K3 marking comfort limits acc. for building categories I to III (see chapter 8.2 Module 2: Discussion of comfort models/ Adaptive comfort model, page 97).

The following graph provides an overview of the differences in limit surpassing for both buildings under different climate data sets and according to the two investigated comfort models. It is evident that summer conditions are regarded as still being acceptable for a much higher amount of time under the adaptive comfort model of ÖNORM EN 15251 than under ÖNORM EN 7730. However, in BGN conditions fall beyond acceptable limits under both comfort models for both climate data sets (even 8% of office hours under “howa 80” are beyond the threshold of 5%). This reflects the severe comfort restrictions which are already present in this building today.



Graph 76: Percentage of office hours surpassing comfort limits

8.2.3 Conclusions and discussion

The exemplary comparison of comfort assessments according to the two comfort models in question showed clear differences for two hardly cooled, free running buildings under present and future climatic conditions: Whereas these historic buildings would both barely be usable according to the Fanger model, the ONB building still scores acceptable under the adaptive comfort model. Conditions in BGN, in contrast, are beyond limits under both comfort models.

When analyzing these evident differences in the assessment of comfort some points have to be kept in mind: Not only does ÖNORM EN 15251 contain two important limitations regarding users' productivity under elevated indoor temperatures and the limited data basis for comfort limit determination (up to 31°C would be acceptable under the conditions of "howa 2050" for buildings of category III according to ÖNORM EN 15251); it is also defined as being valid for free running buildings in the first place.

This explains the decisive difference to the Fanger model which clearly aims at conditioned buildings although, in day-to-day engineering, it is generally applied to all sorts of office blocks. Extensive studies by Michael Humphreys and Fergus Nicol[78] have evidenced, however, that people in free running buildings react differently, especially if they are in control of their personal microclimate by means of shading, window opening etc.

[78] Nicol, J. F. & Humphreys, M. A. (2002).

8.3 Module 3: Impacts of urban heat islands

Urban heat island effects have been abundantly described in respective literature[79] and are well known to result in increased urban outdoor temperatures as compared to the surrounding countryside. The present module's simulation aimed at exemplary calculation of differences in cooling and heating energy demand at different urban locations within the city of Vienna.

Three such locations[80] were examined for the complete temporal resolution from "61" to "2050" in all leading buildings. Internal conditioning of these buildings was kept uniform (simulation mode "Standard").

Module	Sample Building	Simulation Mode	Climate Data Set
3 Urban heat island (Spatial resolution)	Strabag SOL 4 ONB BGN	"Standard"	"howa 61" – "howa 2050" "inne 61" – "inne 2050" "dona 61" – "dona 2050"

Table 10: Investigated sample buildings, simulation modes and employed climate data sets in Module 3

8.3.1 Net cooling energy demand

Climate data sets "inne" represent the innermost location of the three different spatial resolutions simulated within this study. As was to be expected from abundant literature on the phenomenon of urban heat island, this location is the hottest one[81] and yields the highest net cooling demand in consequence, with "dona" ranking second and "howa" showing lowest figures. Differences between hottest and coldest location are within a margin of about 5 kWh/m^2. This is roughly a quarter of the difference found for each location for the temporal resolution from "61" to "2050".
Again, west facing office rooms are found to have slightly higher cooling demands than those oriented to the South

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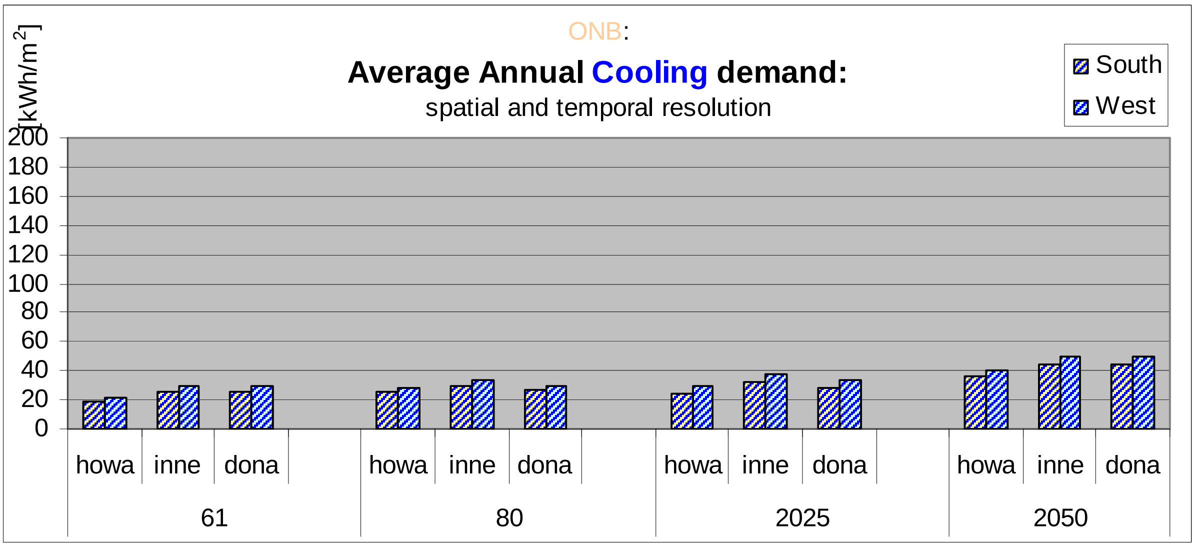
[79] see Oke, T. R. (1999), Oke, Tim R. (2006).

[80] as described in chapter 3.3 Description of climate data sets, page 31

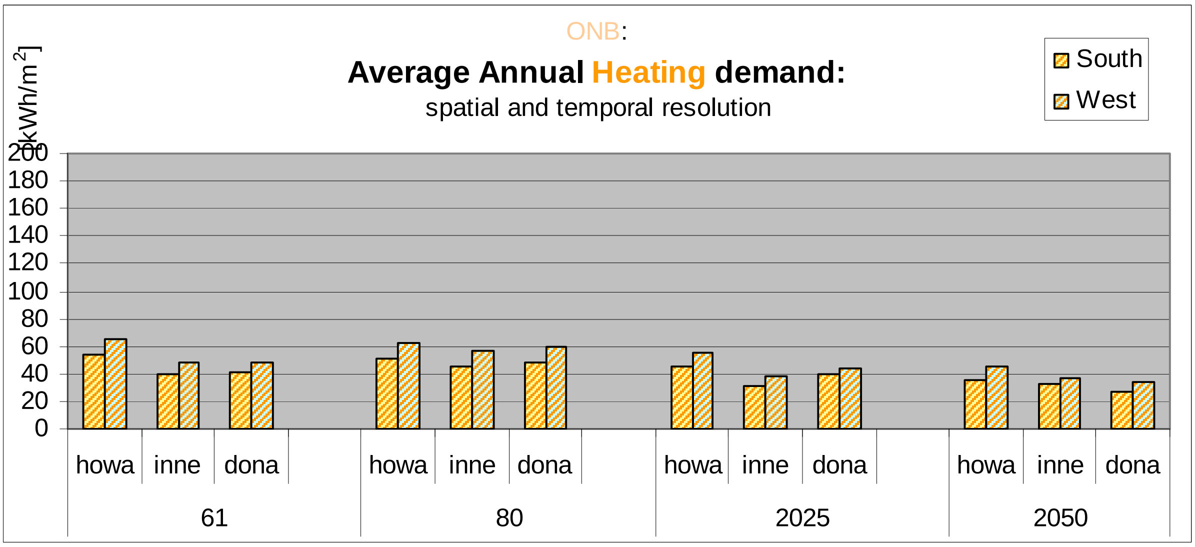
[81] see Graph 10, page 36



Graph 77: Impact of urban heat island on average annual net cooling energy demand for ONB

8.3.2 Net heating energy demand

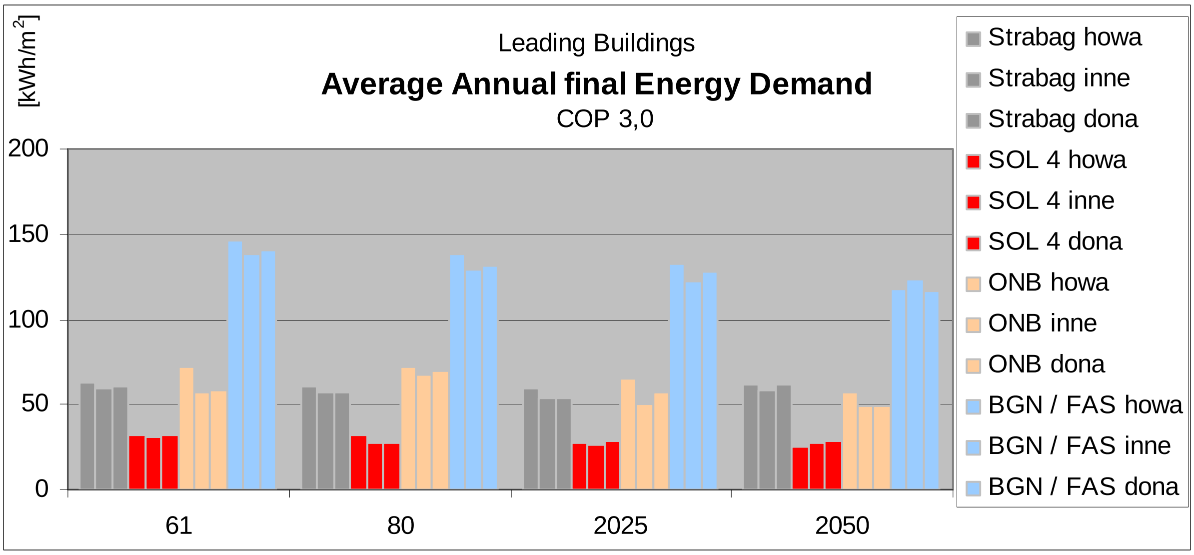
Mirror-inverted to the situation for cooling, the hottest location out of the three urban sites investigated displays the lowest heating demands, the coldest requires most heating. The difference between these two tends to be slightly higher than in the case of cooling, reaching up to 10 kWh/m^2. The overall decrease of heating demand in temporal resolution from "61" to "2050" remains detectable for all locations.



Graph 78: Impact of urban heat island on average annual net heating demand of ONB

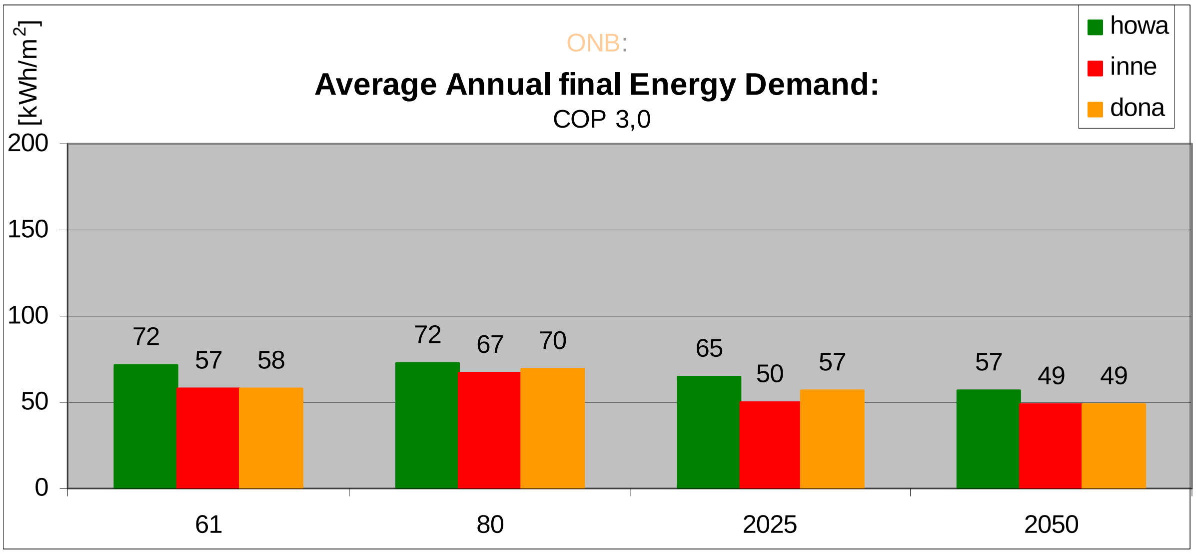
8.3.3 Final and primary energy demand

Final and primary energy demands are generally lowest for the inner city location due to its reduced heating demand. The size of differences between locations and temporal development, however, differ for the leading buildings[82].



Graph 79: Temporal and spatial resolution of average annual final energy demand in leading buildings

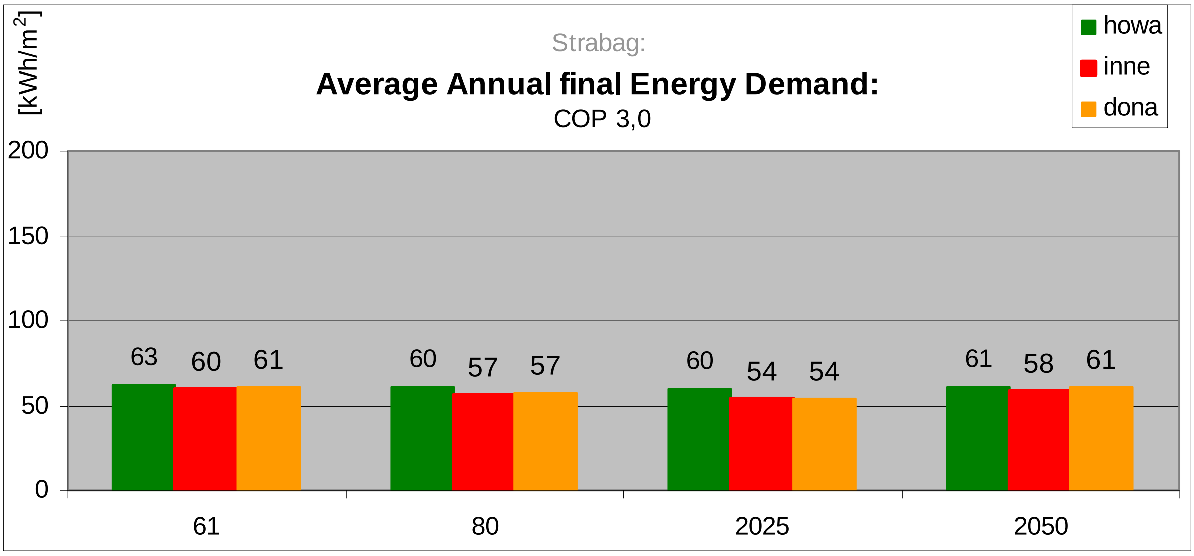
Historic buildings from before WW1 and those from after WW2 are clearly dominated by heating demand. This makes them even less energy demanding in a CBD location. Spatial differences are well pronounced in terms of final energy demand. The overall demand decreased over the course of time.



Graph 80: Temporal and spatial resolution of average annual final energy demand in ONB

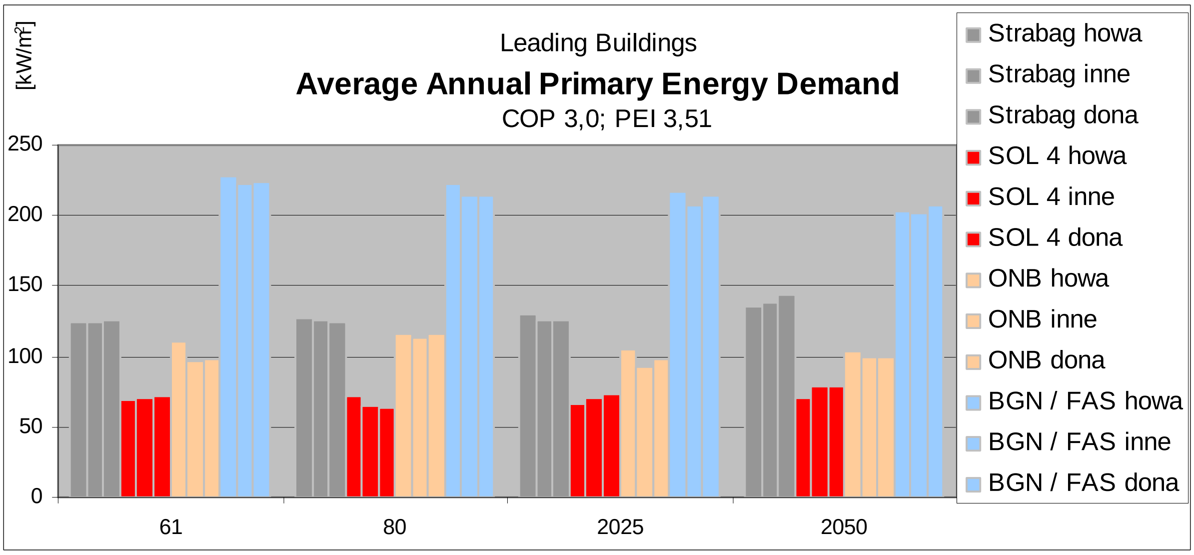
82 For the purpose of simulation, the leading buildings were consequently switched to all locations in question, regardless of their real placement.

In modern buildings, heating only slightly prevails in terms of final energy demand. This makes differences between locations less pronounced. The overall demand stagnates over the temporal resolution.



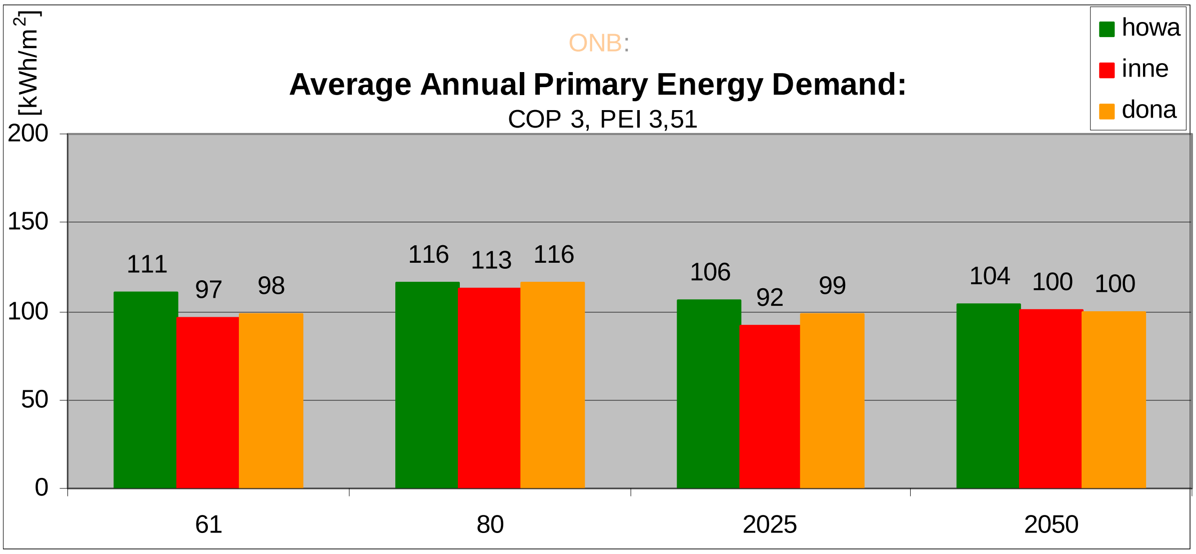
Graph 81: Temporal and spatial resolution of average annual final energy demand in Strabag

The situation is slightly less uniform when looking at overall primary energy demand: as can be seen in Graph 58 to Graph 61, page 88, the trend of temporal resolution, apart from being partly influenced by the chosen conversion factors, differs for building types, again depending on whether cooling or heating is predominant in a particular building.



Graph 82: Temporal and spatial resolution of average annual primary energy demand in leading buildings

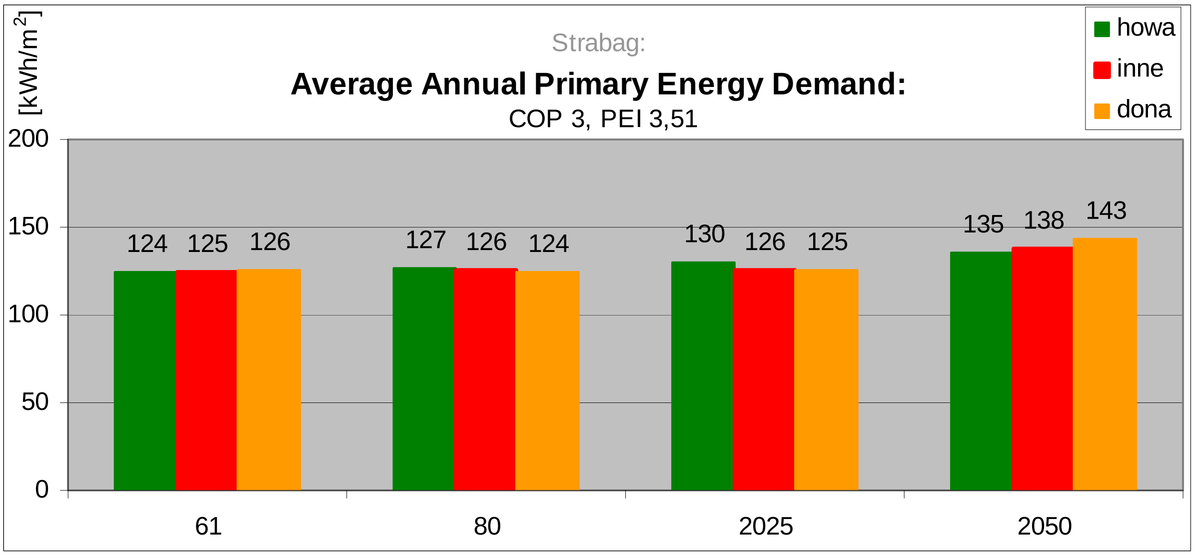
In buildings from before WW1 such as ONB heating demand by far exceeds cooling demand. Hence, due to the overall decrease in heating demand in temporal resolution overall demand also decreases slightly and does so for all spatial resolutions. The hottest location "inne" therefore yields the lowest overall primary energy demands even so, differences are minor.



Graph 83: Temporal and spatial resolution of average annual primary energy demand in ONB

Buildings from after WW2 react similarly, but on higher absolute levels of primary energy demand. Here again, comparatively high heating demands cause hotter locations to need less primary energy than cooler ones.

In highly glazed buildings such as Strabag, cooling demand surpasses heating requirements. This causes overall primary energy demand to slightly increase over time as hotter climate data sets require more cooling (see Graph 58, page 88). However, as these differences are small, the trend for spatial resolution is unambiguous: the hottest location "inne" mostly ranges medium.



Graph 84: Temporal and spatial resolution of average annual primary energy demand in Strabag

8.3.4 Conclusions and discussion

- Differences in net cooling and heating demand between hottest and coldest location are within a margin of about 5 and 10 kWh/m^2 respectively. This is roughly a quarter of the difference found for each location for temporal resolution from "61" to "2050".

- In buildings from before WW1 and after WW2 heating demand exceeds cooling demand. Final and primary energy demand decreases slightly and does so for all spatial resolutions. The hottest location "inne" generally yields the lowest overall energy demands.

- In modern buildings net and primary cooling demands are higher than net and primary heating demand, while final demand for heating ranges only slightly higher than cooling. Overall final and primary energy demand stagnate or slightly increase over time.

The obtained results might tempt to simply conclude that climate change will reduce overall final and primary energy demand in old buildings. Even though this is the investigation's result, it has to be stated that this decrease takes place on elevated absolute values of energy demand. Furthermore, this decrease only takes place because of high values of heating demand at present stage. Because this building type's cooling demand is low today, even dramatic cooling demand increases will not result in overall demand increases.

In contrast, modern buildings are optimized in regard to winter performance, resulting in net heating demands being lower than cooling requirements. This results in stagnation or even increase of final and primary energy over time.

8.4 Module 4: Impacts of optimizations in the buildings' envelope

The main focus of this study is outlining the impacts to be expected upon energy demand and thermal comfort in office buildings under the conditions of climate change; notwithstanding, this present module investigates possible optimizations for reduction of energy demands. As sample buildings have been compared in regard to their constructive properties throughout this study so far, this chapter likewise scrutinizes constructive interventions in the buildings' envelope.

These interventions include additional insulation of opaque exterior walls as well as improvements in the sun-protective qualities of transparent building fractions. Finally, sun shading measures are investigated.

In doing so, not only is resulting cooling demand calculated for each measure, but the overall impact on net, final and primary energy demand is taken into account.

The focus of these investigations is on historic buildings. Present ("howa 80") and future conditions ("howa 2050") are investigated.

Module	Sample Building	Simulation Mode	Climate Data Set
4 Optimizations of buildings' envelope	ONB BGN/ FAS	"Standard"	howa 80" "howa 2050"

Table 11: Investigated sample buildings, simulation modes and employed climate data set in Module 4

8.4.1 u - value

Additional layers of insulation (preferably to be applied externally[83]) turn out to be the single most effective optimisation of the outer building shell in terms of both net and final energy demand. While this measure insignificantly increases cooling demand in summer due to slightly hindered heat removal during night time hours it remarkably reduces the buildings' heating demand and thereby further enhances the effects of shrinking demands due to global warming.

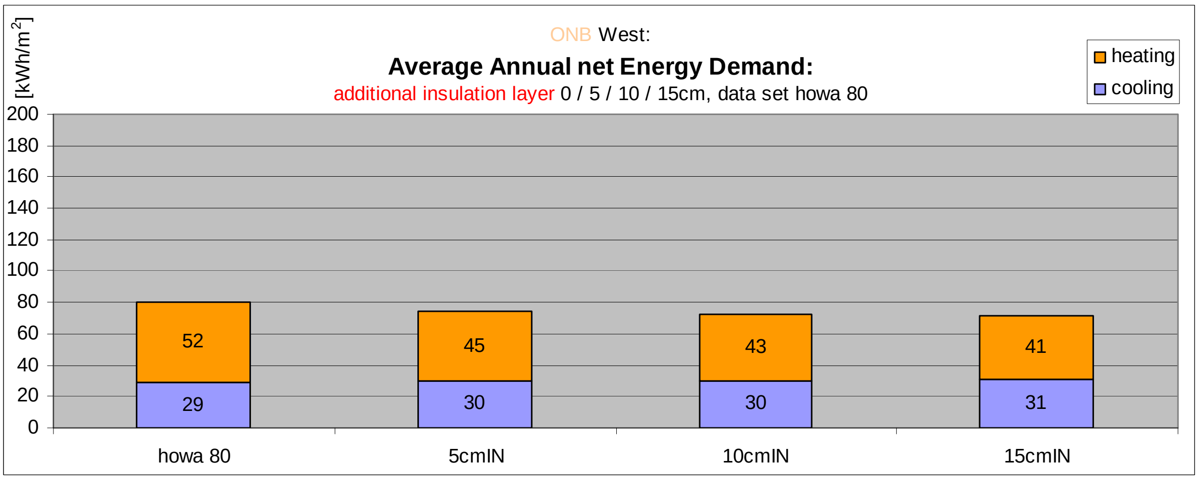
[83] Exceptions have to be considered in historical buildings such as ONB where internal insulation was assumed in order to leave the external appearance untouched. Related concerns about condensation and thermal bridges have to be taken into account.

ONB

The following graph illustrates the impact of increasing levels of additional insulation on the overall net energy demand: as has already been shown in innumerable studies as well as successful renovation projects, heating demand is considerably reduced by additional insulation even under the assumption of unchanged climate conditions.

At the same time cooling demand slightly increases; however, it has to be made clear here that this is due to the unchanged conditions in the sample buildings: with additional insulation in place, these buildings slightly less effectively deposit of heat during cool nocturnal phases. In reasonable, holistic refurbishment strategies this minor effect should be easily counteracted by effective ventilation strategies.

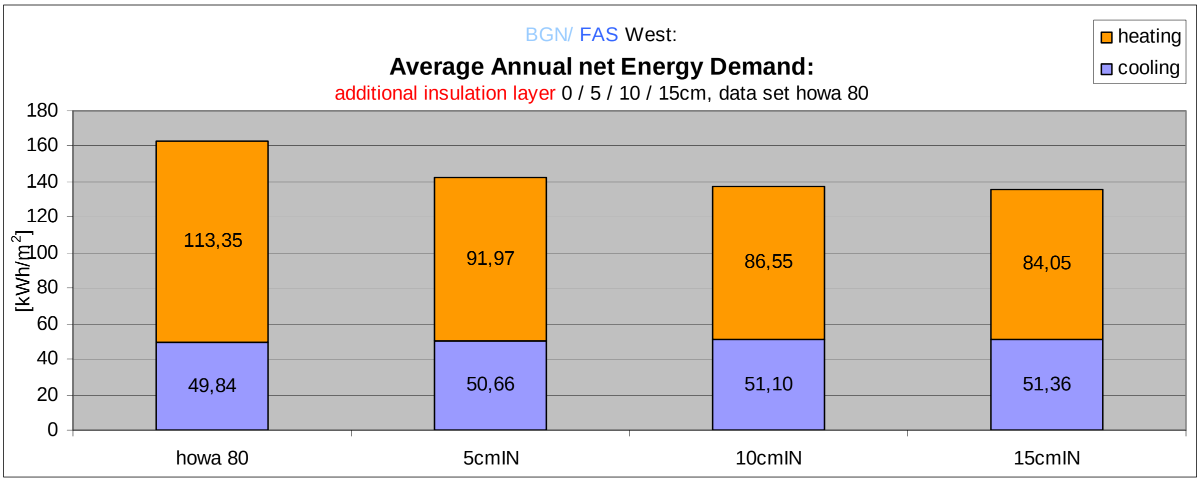
The overall picture of insulation's effectiveness is evident: minor cooling increases are clearly out-weighted by substantial reductions in heating demands.



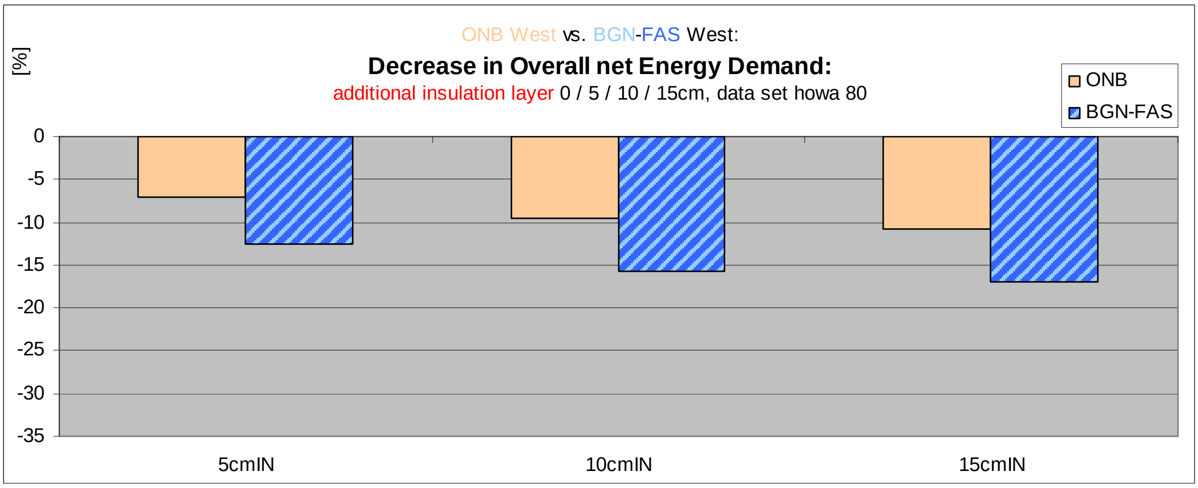
Graph 85: Influence of additional internal insulation layers on overall net energy demand in ONB

BGN / FAS

The same effect can be shown for both types of buildings investigated here. The worse the original u–value of the sample building, the bigger is the achievable reduction in overall net energy demand as can be seen in the comparison of ONB and BGN/ FAS: while the first one displays medium heating demand in the original state, the latter one is characterized by very high figures in this category. In consequence, higher decreases in percentage of net overall demand are possible in BGN/ FAS.

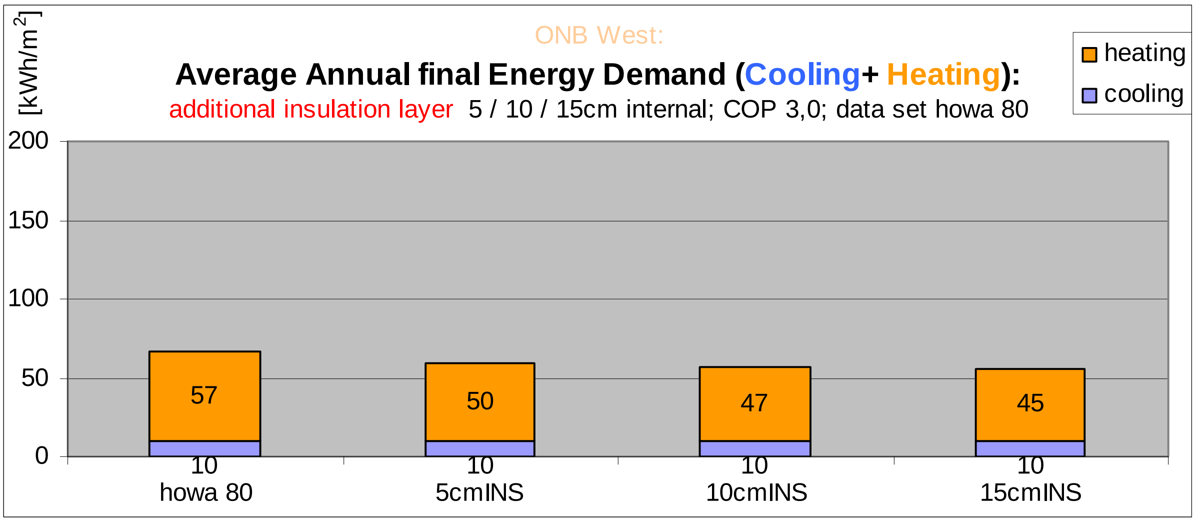


Graph 86: Influence of additional internal insulation layers on overall net energy demand in BGN/ FAS



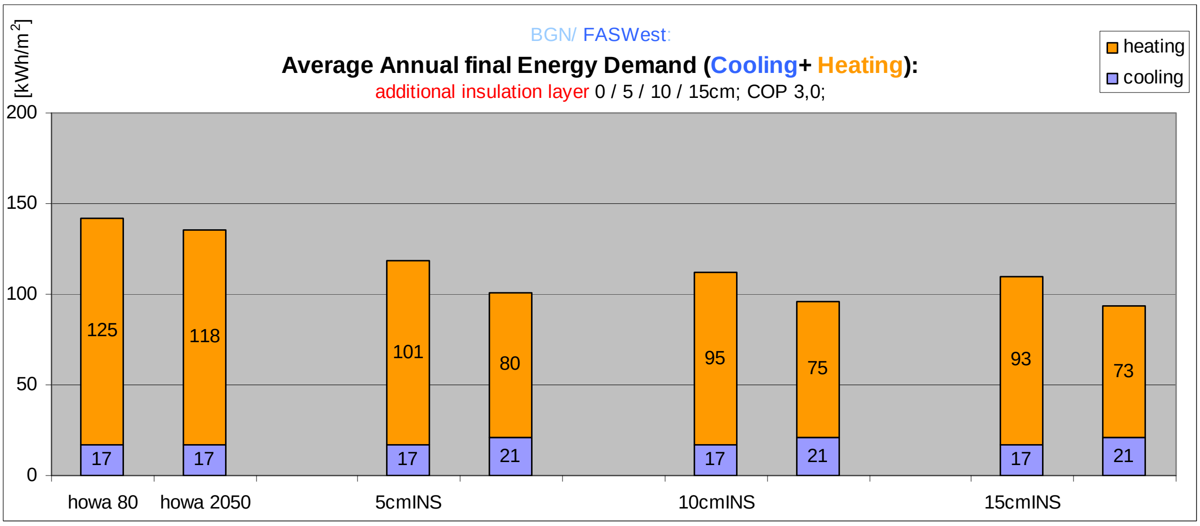
Graph 87: Comparison of decrease in overall net energy demand due to additional insulation layers

Values on final energy demand confirm the effectiveness of additional insulation: while cooling demand remains virtually unchanged, final heating demand drops evidently.



Graph 88: Final energy eemand due to additional layers of internal insulation in ONB

The overall reduction trend is also visible under climate change conditions: additionally to the overall reductions to be expected due to declining heating demands, further substantial cut backs are possible by the appliance of external insulation. Regarding the high absolute demand values, such reductions appear highly recommendable.



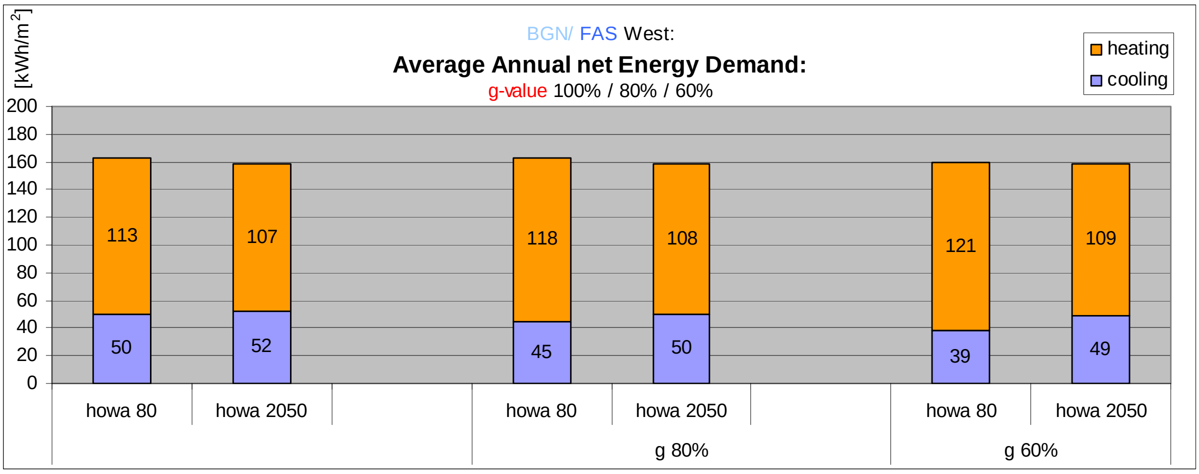
Graph 89: Final energy demand due to additional layers of internal insulation in BGN/ FAS

8.4.2 g - value

Reducing the energy transmittance over the entire solar spectrum (characterized as g-value) proves to be a two-sided measure: Strategies for maximization of winter heat gains such as the passive house standard have for a long time struggled to turn u-values of windows down while keeping their g-values up because the latter allow for elevated solar gains during chilly winter days.

Inversely, low g-values are applied in modern glass technology to avoid or reduce overheating in summer, again by cutting down solar gains through transparent fractions of the exterior walls.

These conflicting tendencies are clearly visible in the simulation's results on impacts of reduced g-values: while the measure brings about a slight decrease in cooling demand, this success is almost completely reverted out mastered by the simultaneous increase in heating demand due to restricted solar gains in winter. The resulting reduction in overall net energy demand is nearly non-existent.



Graph 90: Influence of g – values on overall net energy demand in BGN/ FAS

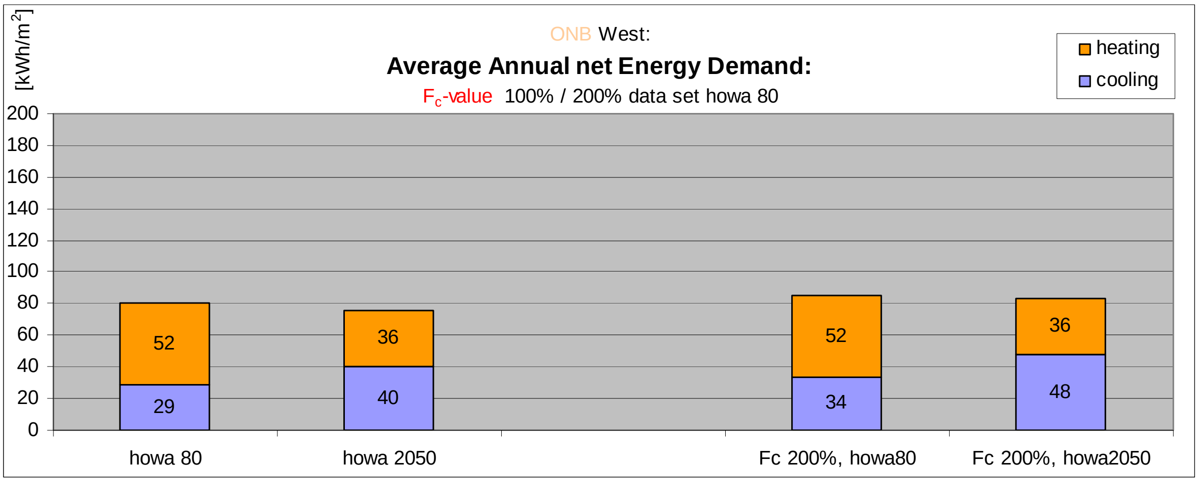
8.4.3 F_c -value

This chapter demonstrates the influence of different shading strategies on energy demands and therein investigates step by step the differences between external, inter-space and internal shading.

From external to inter-space shading

External blends are well known to be most effective in keeping out solar irradiation. Such devices are in place in sample building ONB, but these blends date from a later adjustment and were not mounted originally. Therefore, it has to be assumed that other buildings of this epoch still lake such effective shading.

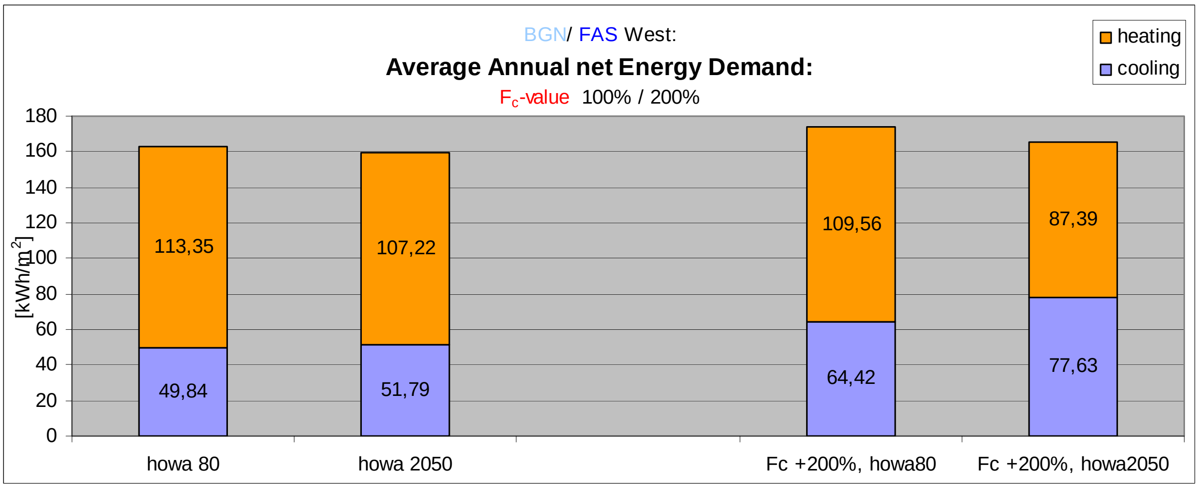
If shading is instead placed in between two window panes, this is equivalent to an increase of F_c-value by approximately 100%. The resulting overall net energy demands are depicted hereafter: while heating demand is assumed to stay unchanged, cooling demand is increased by approximately 5%.



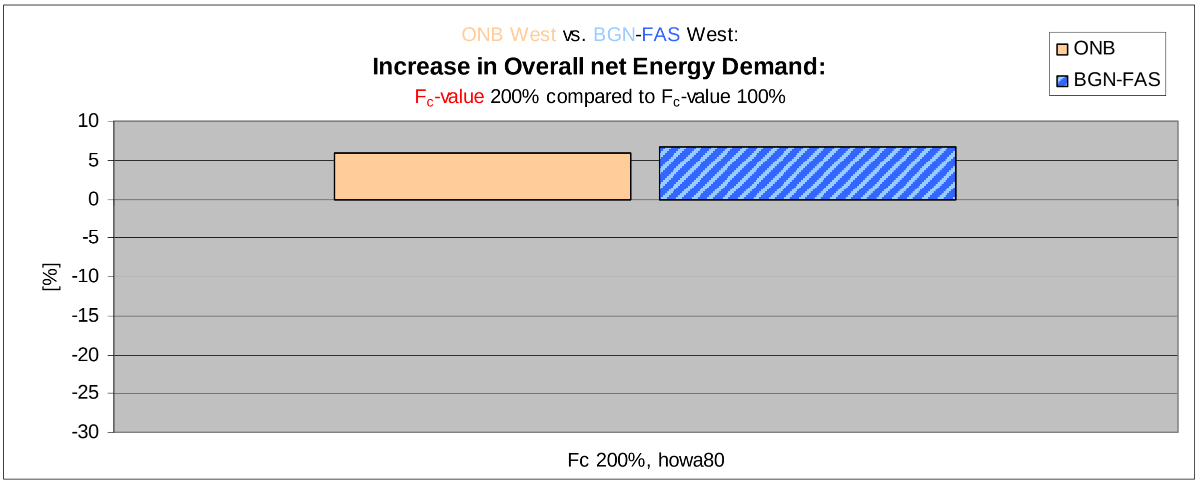
Graph 91: Influence of F_c – values on overall net energy demand in ONB

From inter-space to internal shading

BGN/ FAS buildings are equipped with inter space shading between window panes. Would this be changed to even less effective internal shading, the Fc-value again increases by roughly 100%. This again results in comparative cooling demand increases.



Graph 92: Influence of F_c – values on overall net energy demand in BGN/ FAS



Graph 93: Increase of overall net energy demand due to increases of F_c – value

8.4.4 Conclusions and discussion

Additional insulation of opaque, external walls proves to remain the single most effective optimization measure in the building envelope with regards to overall net and final energy demand even under the conditions of climate change. This is due to the fact that the achievable reductions in heating demand even as such demands are shrinking by far outweigh reductions in cooling demand which are possible by application of sun protective glass.

Sun shading is known to be likewise effective, however, it strongly depends on where it can be placed in relation to the window. Both measures have to be treated especially sensible in most buildings from before WW1: substantial amounts of these buildings are covered by regulations of cultural heritage which makes interventions on the exterior difficult. While this difficulty can partly be avoided for insulation by the application of internal layers (with all technical problems associated), most effective, regulative compromises for external shading need to be envisaged. This also calls for further technological development.

8.5 Module 5: Impacts of different levels of internal loads on cooling energy demand

Exigencies for safeguarding comfort conditions in offices differ from those in residential buildings first and foremost due to the presences of elevated levels of internal loads in the office buildings. Three groups of factors contribute to these loads as compared to residential buildings: the presence of more people on a smaller area, the intensive usage of IT and communication equipment and the intensive appliance of artificial lighting.

While the presence of office workers is regarded as an indispensable necessity here[84] energy efficiency in both lighting and equipment may contribute to lower overall loads and reduced cooling energy demand in consequence. The aim of this module is to demonstrate to which extent this is the case.

For this module, the climate data sets "howa 80" and "howa 2050" were applied.
For a first glimpse of the driving factors for cooling demand an hourly load break-down under a steady state Design Day was performed.
All four sample buildings were investigated under simulation mode Standard. Investigated sample rooms of all orientations were averaged.

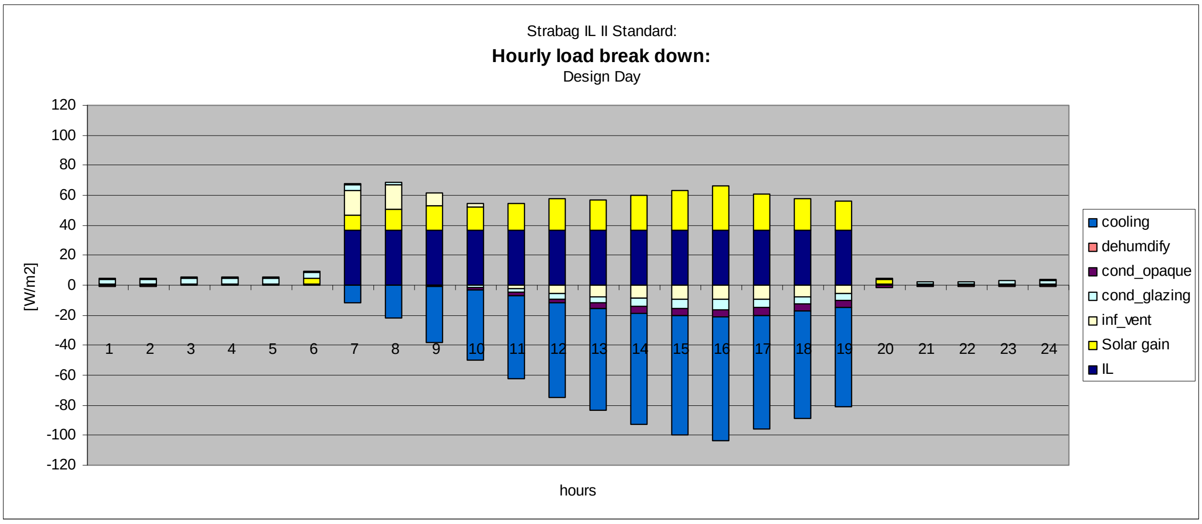
Module	Sample Building	Simulation Mode	Climate Data Set
5 Internal loads	Strabag SOL 4 ONB BGN/ FAS	"Standard (Design Day)"	howa 80" "howa 2050"

Table 12: Investigated sample buildings, simulation modes and employed climate data set in Module 5

8.5.1 Investigated efficiency levels

Heat gains due to transmission through walls and glazing and due to ventilation play a minor role in office blocks. Gains from internal loads and solar gains prevail and have to be compensated for by cooling. This can be understood from the following hourly load break down for sample building Strabag.

[84] The impacts of different presence patterns are discussed in chapter 8.6 Module 6: Impacts of different usage



Graph 94: Hourly cooling load break-down in Strabag

Abbreviations:
inf_vent: heat gained by the zone due to the exchange of air between the zone and the external environment
IL: Internal Loads (lighting, equipment, occupancy)

Thus, cutting down internal loads and keeping out solar irradiation by application of shading appears as the most promising way for reduction of cooling energy demand and safeguarding thermal comfort indoors.

It has to be kept in mind that simulation mode "Standard", as applied here in a steady state Design Day, already represents a rather optimized ventilation and shading regime.

This leads to the reduction of internal loads as the single most effective starting point for optimization. By the selection of energy efficient devices such reduction has become increasingly feasible during the last years[85]. More efficient IT–equipment and lighting thus represents a means of reducing cooling loads and demands.

According to **Graph 30:** Internal loads simulation mode „Standard", different levels of internal loads for lighting and equipment , page 59, four different levels of efficiency were defined.

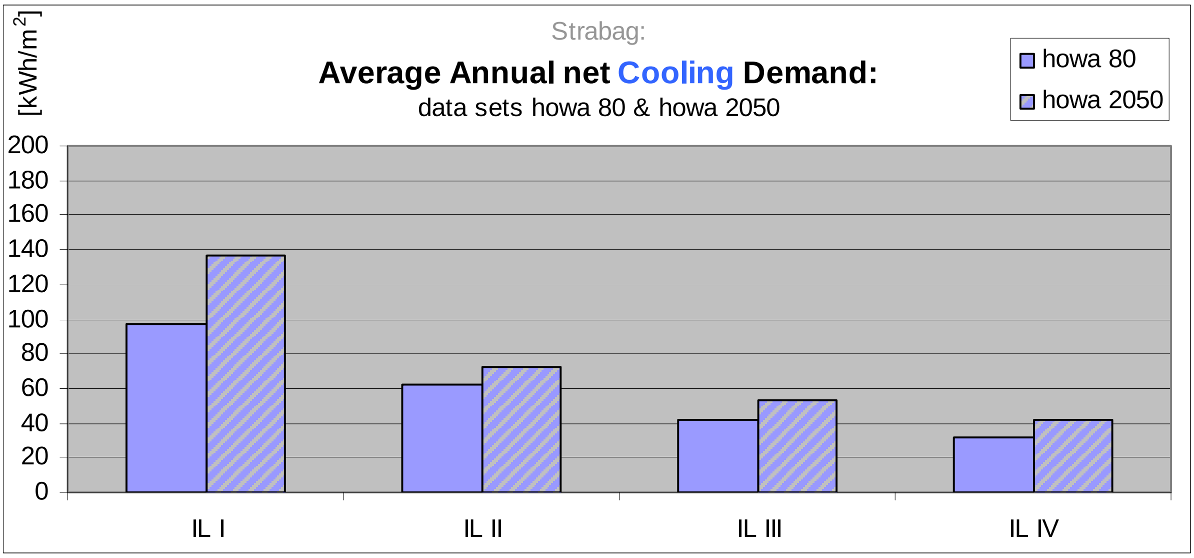
[85] At the same time, however, the overall appliance of IT and communications tool has continuously increased as well, hence offsetting any efficiency gains. Prognoses for the further developments are discordant, but slightly tend to the estimation of a slight flattening of the trend curve.

Efficiency level denomination	Description
IL I	very low efficiency; seldom but yet still encountered in offices, representing a worst case situation
IL II	average efficiency frequently encountered in offices; in further investigations this level is applied as Standard
IL III	high efficiency according to the requirements of passive house standard
IL IV	very high efficiency requiring the appliance of most efficient available devices in all categories

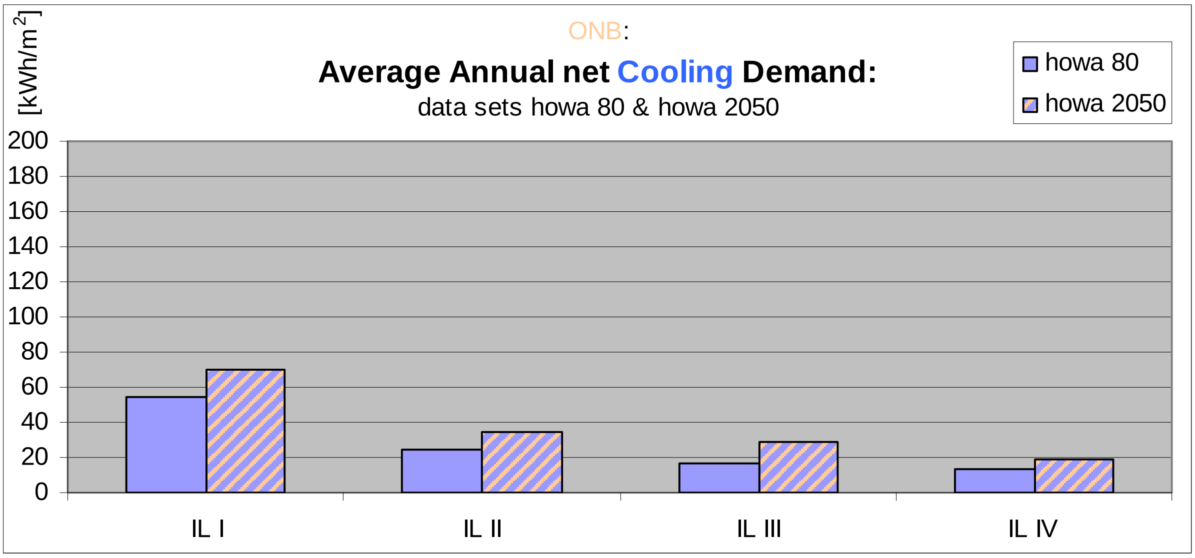
Table 13: Description of investigated efficiency levels (IL stands for Internal Loads)

8.5.2 Results

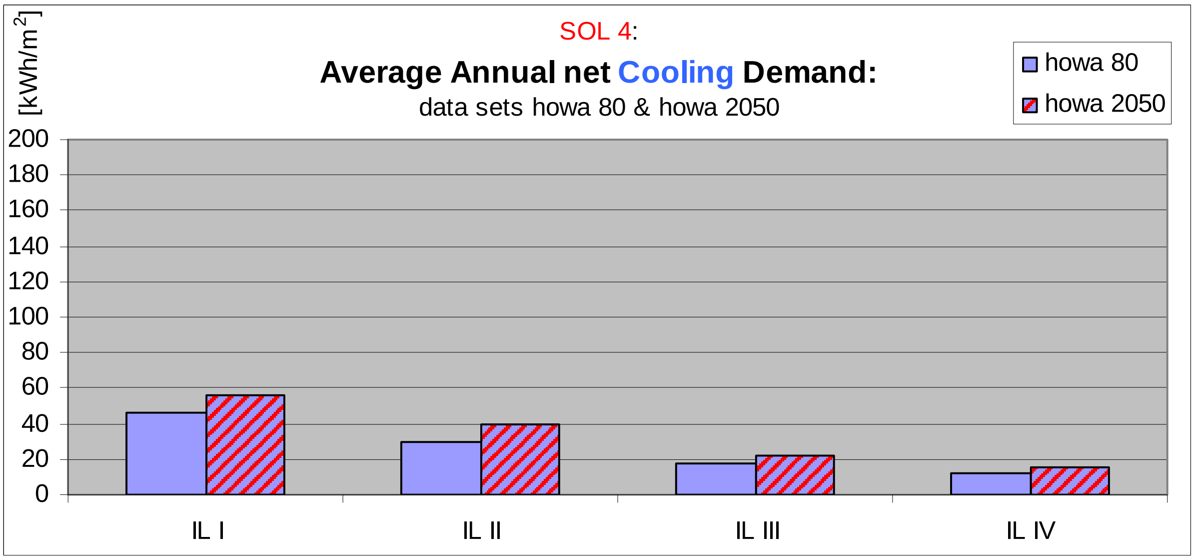
All sample buildings were simulated under these different efficiency levels for both current (climate data set "howa 80") and future situations ("howa 2050"). The results reveal that differences in cooling demand between these two climate sets are slightly outweighed by differences of cooling demand for different levels of internal loads.



Graph 95: Strabag: average annual net cooling demand for "howa 80" & "howa 2050" under different levels of internal load



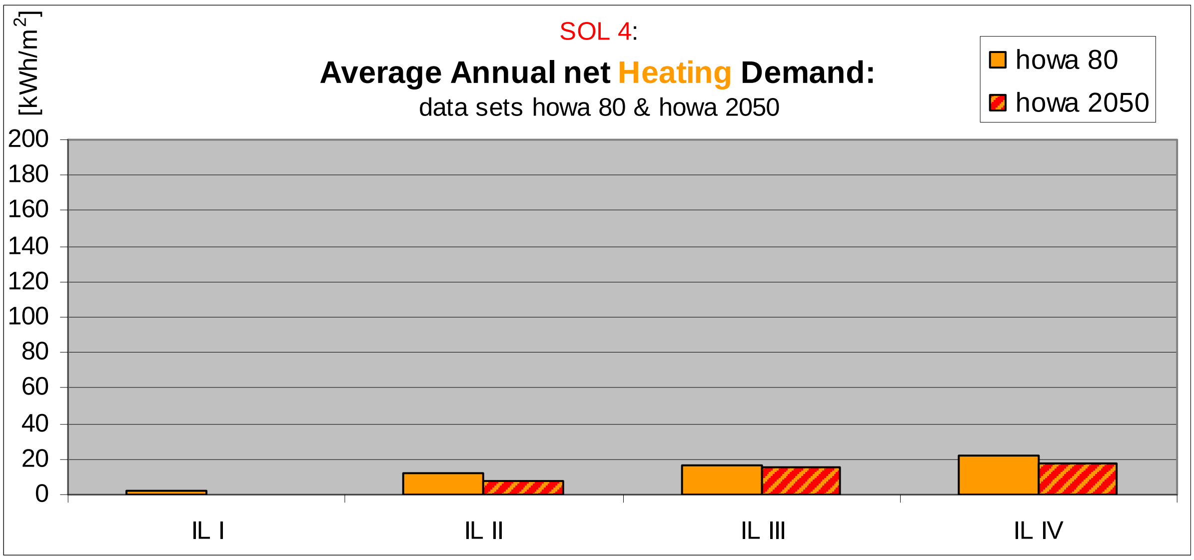
Graph 96: ONB: annual cooling demand for "howa 80" & "howa 2050" under different levels of internal load



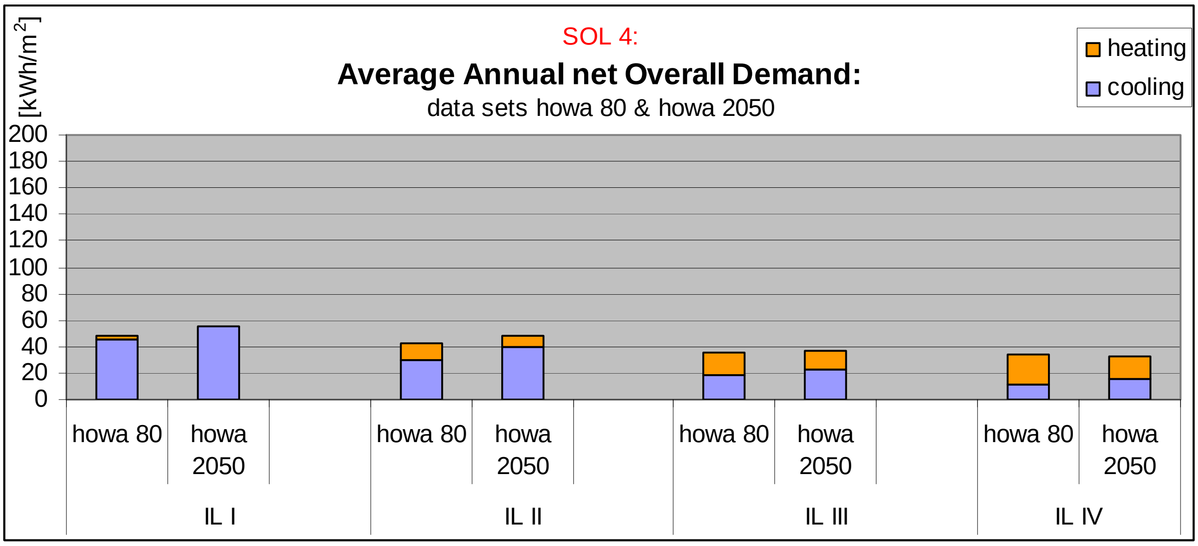
Graph 97: SOL 4: annual cooling demand for "howa 80" & "howa 2050" under different levels of internal load

However, there again is a drawback to this very efficient measure for reduction of cooling energy demand: internal loads also compensate for heat losses during winter and thereby reduce heating demand. This clearly is an extremely inefficient mode of heating as it operates via the production of warmth by electrical power. Still, when calculating cooling demand reductions due to increased efficiency of IT and communications technology, it has to be kept in mind that this in turn increases heating demand during cold periods.

This is shown here for the case of sample building SOL 4. In this highly insulated building, the appliance of IL I, though counterproductive, would reduce heating demand almost to zero, while IL IV displays almost 20-fold increase to this demand. In absolute figures, 20 kWh/m^2 are still very moderate and still do not incorporate the effects of heat recovery, which is crucial for passive houses. Furthermore, the comparison of both heating and cooling demand reveals that the savings in cooling demand due to higher efficiency of equipment clearly surpass increases in heating demand.



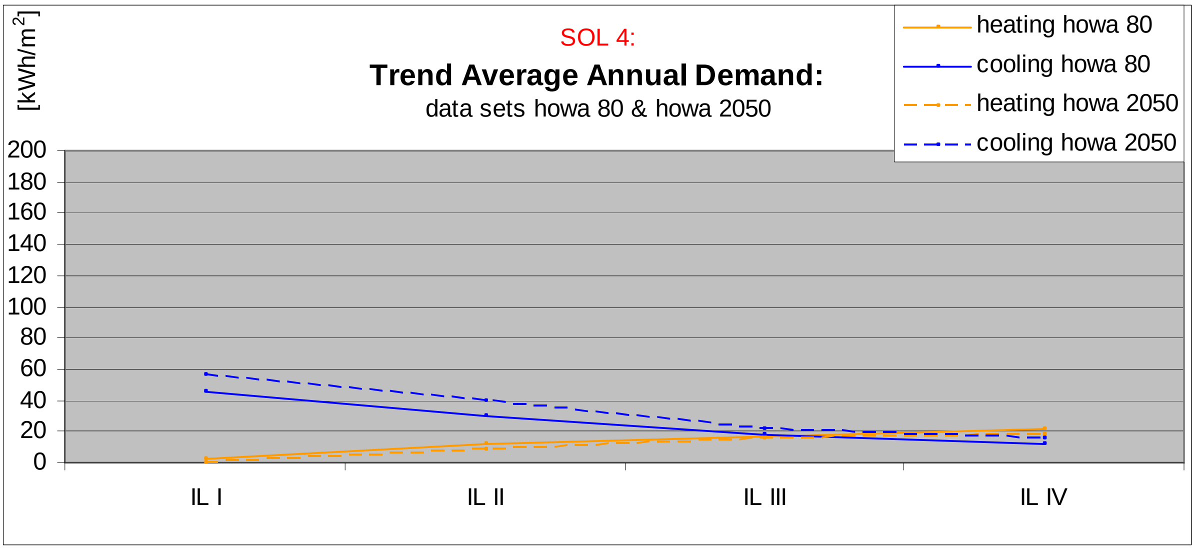
Graph 98: SOL 4: annual heating demand for "howa 80" under different levels of internal load



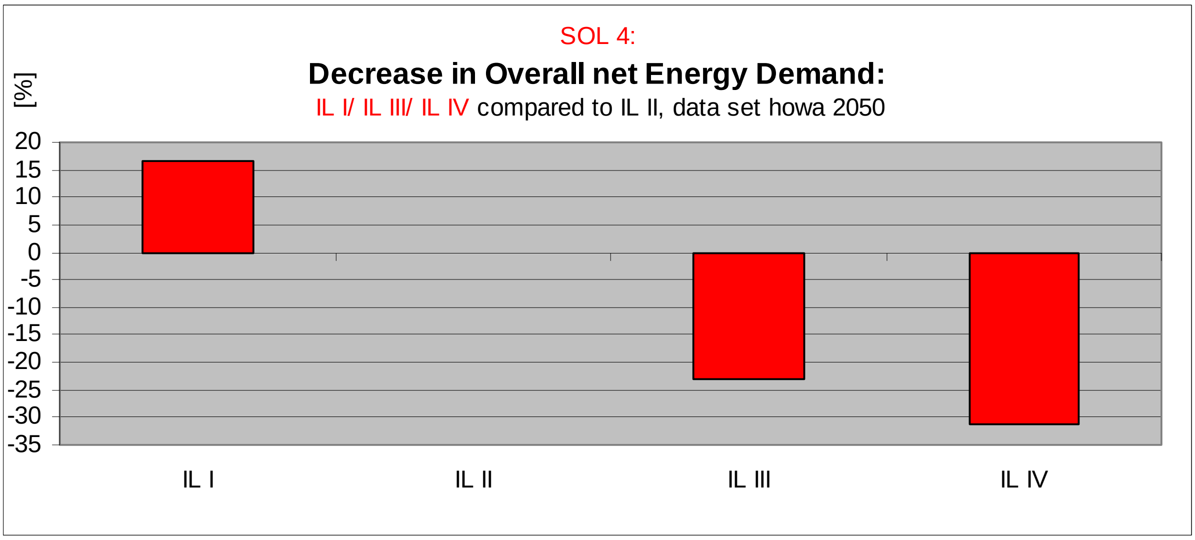
Graph 99: SOL 4: average annual net overall energy demand due to different levels of internal loads

When looking at the trends of both cooling and heating ("howa 80" and "howa 2050") over the resolution of different levels of internal load it becomes evident that cooling is the dominant net energy demand as long as internal loads are high. In contrast, very efficient equipment leads to equal heating and cooling demand.

This clearly shows that in an extremely well insulated building like SOL 4, reductions in internal loads effectuate high cuts in overall net energy demand; reduced internal loads minimize cooling demands while heating demands can't go up simultaneously due to high insulation.

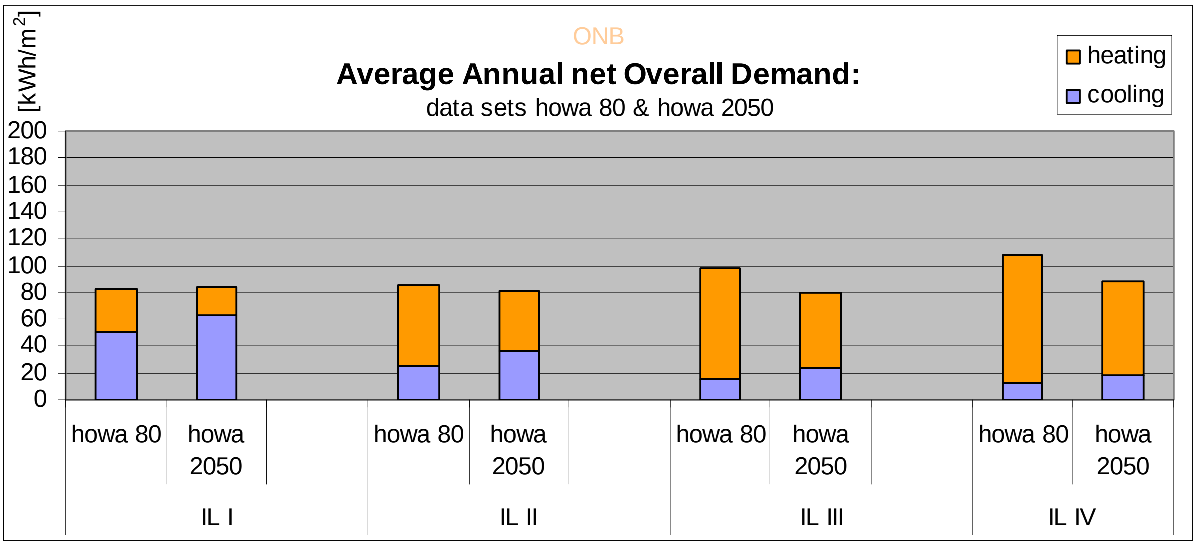


Graph 100: SOL 4: Trend for average annual net overall energy demand due to different levels of internal loads

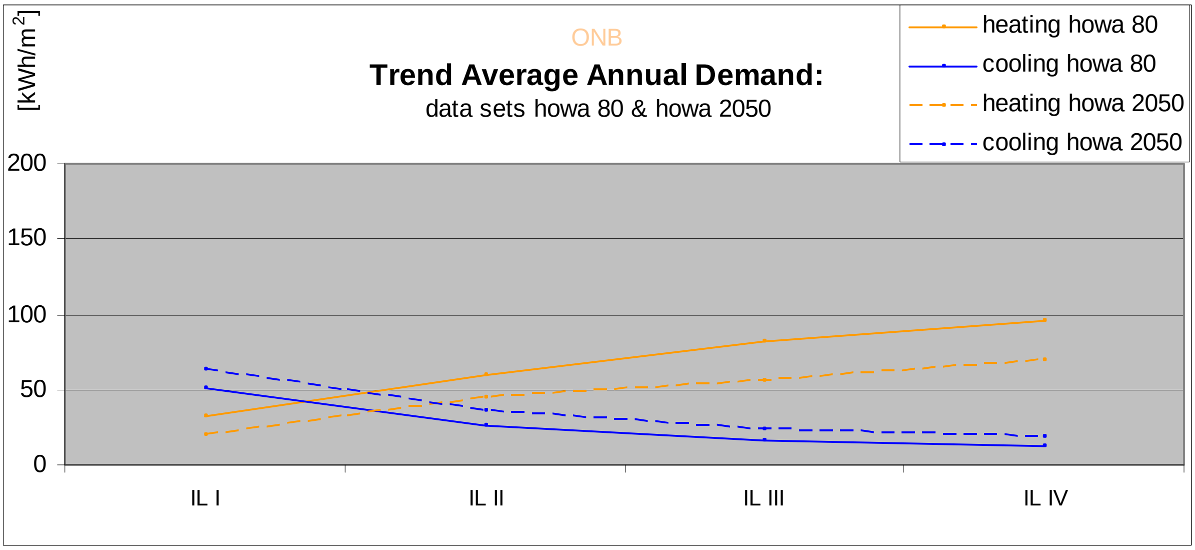


Graph 101: In-/ Decrease in overall net energy demand due to different levels of internal loads in SOL 4

The situation is distinctly different in less insulated buildings like ONB:
While reduced internal loads clearly cut down on cooling demand, they likewise and nearly mirror-invertedly cause heating demand to increase. Only under worst case scenario IL I is net cooling higher than net heating demand in this type of building. From there it follows that improved efficiency levels IL III and IL IV effectuate hardly any or no decrease at all respectively in overall net energy demand under future conditions.



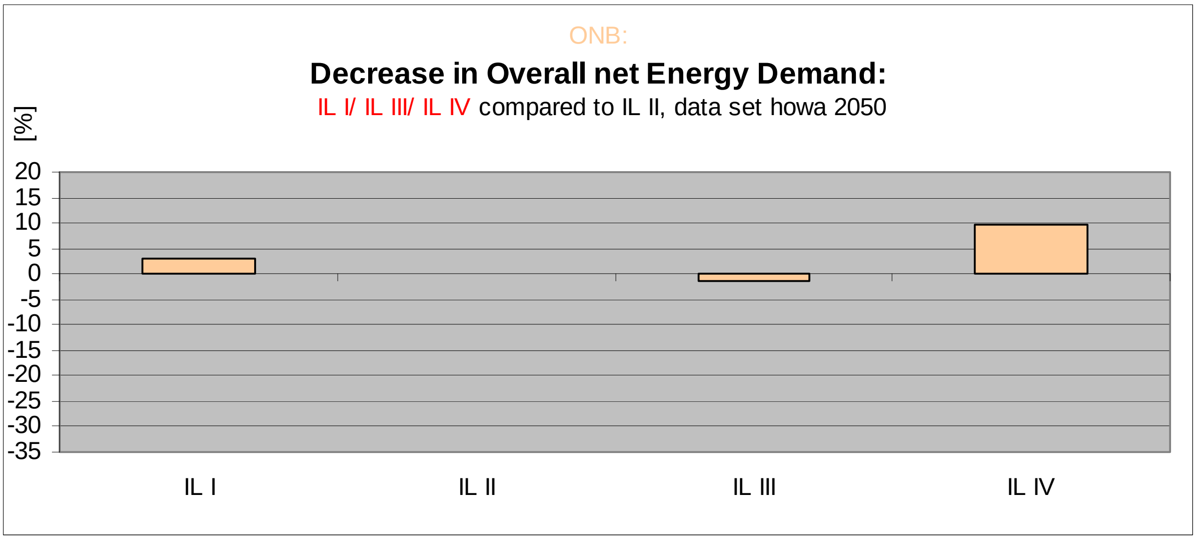
Graph 102: ONB: average annual net overall energy demand due to different levels of internal loads



Graph 103: ONB: Trend for average annual net overall energy demand due to different levels of internal loads

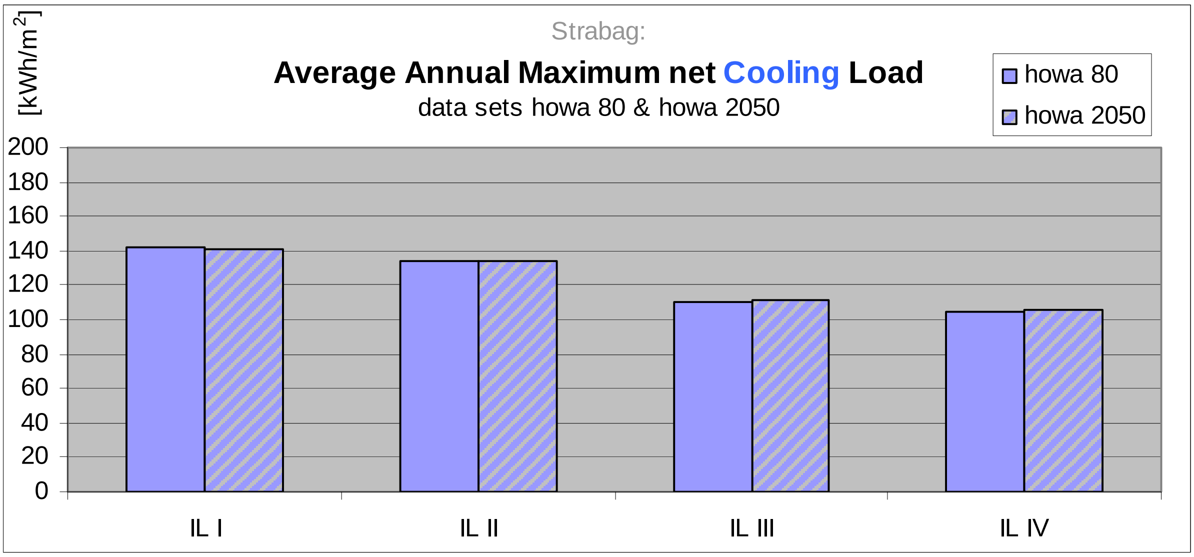
This, however, is not to say that reduction of internal loads makes no sense in old buildings! Quiet the contrary: as has been shown, these measures facilitate considerable minimizations in cooling demand. For the overall, year round effectiveness it is highly recommended to combine them with improvements in the insulation of the outer building shell. As has been shown above[86] additional insulation likewise effectuates considerable reductions in energy demand, especially with regard to heating. Combining these two measures takes care of both heating and cooling demand reduction and thus appears highly recommendable.

[86] See chapter 8.4.1u - value, page 112



Graph 104: In-/ decrease in overall net energy demand due to different levels of internal loads in ONB

Lower internal loads may also result in lower maximum cooling loads, which are crucial for the dimensioning of the respective cooling plant. Therefore the sample buildings are additionally simulated under the elevated levels of internal loads for lighting and equipment depicted in Graph 31: Internal loads simulation mode „Standard", elevated level of internal loads for lighting and equipment for the determination of cooling load only , page 59.



Graph 105: Strabag: maximum cooling loads for "howa 80" and "howa 2050" under different levels of internal load

More efficient equipment contributes to bringing down the required cooling loads, but these generally still do not fall below approximately 40 W/m^2. This threshold by rule of thumb represents the limit for adoption of hybrid cooling strategies (see footnote 50, page 58).

8.5.3 Conclusions

Internal loads are demonstrated to be the single most influential drivers for cooling demand. Therein, IT equipment and lighting form two out of 3 contributors (occupancy by office workers forming the 3rd part, which remained unchanged in this module of investigation).

It can be demonstrated that different levels of energy efficiency in equipment and lighting will influence net cooling demand in the sample buildings to a more significant extent than does the influence of a changing climate. This is even more so the case when regarding maximum cooling loads.

At the same time reduced internal loads increase heating demand in winter. As "heating" a building by its internal loads is extremely inefficient in terms of primary energy consumption this does not represent a counterargument for increased energy efficiency in equipment. Instead, reasonable combinations of improvements in equipment and insulation of the building envelope have to be developed. This is especially true for older buildings with comparatively high heating demands in the original state.

8.6 Module 6: Impacts of different usage modes on cooling energy demand

As has been demonstrated above, three groups of factors contribute to internal loads in office blocks: the presence of more people on a smaller area – as compared to residential buildings -, the intensive usage of IT and communication equipment and the appliance of artificial lighting.

While the presence of office workers has been assumed as uniform in the simulations discussed so far, alternations seem conceivable in this respect: In conventional time models, the presence of most workers and the most intense use of equipment coincide with the highest outdoor temperatures and solar gains. Transition to more flexible time schemes permit working hours to be partly shifted to morning and/ or evening hours.

Limitations of such interventions are quickly detected:

- Flexible working hours are already a fact in a globalized economy. However, this has not shifted load peaks but rather extended the overall time of workers' presence in office blocks, thus increasing the working hours of equipment by trend
- Strict shifts in working hours, especially when moving to earlier periods of the day, are hardly enforceable in a modern office, as these would strongly affect individual life styles
- Cooling systems' ability to closely follow users' presence/ absence is limited; so is simulation tools' controllability to depict these individual work patterns
- Time models incorporating a longer lunch break – such as traditional "Siesta" – represent a nuisance for those workers not living nearby, as they can't commute back home during the break. In consequence, daily hours spent at their work place are increased, while their leisure time is reduced.

The following investigations of possible shifts in usage profiles therefore have to be assessed against the background of these limitations. They are regarded as an analysis of potentials only; their afore mentioned social implications are not investigated further.

Last but not least, new concepts of life–work – balance may be considered in this respect: as modern communication tools allow for office work partly being done outside the actual office, modes of teleworking are frequently discussed and slowly becoming common place. In terms of energy consumption, this signifies a reduction of employees constantly present in the office and thus a decrease in internal loads. The extent to which this is taking place remains hard to judge; still, a rough estimation is rendered hereafter.

Module	Sample Building	Simulation Mode	Climate Data Set
6 usage profiles	Strabag	"Standard (Design Day)"	howa 80"

Table 14: Investigated sample buildings, simulation modes and employed climate data set in Module 6

8.6.1 Investigated usage profiles

For this module climate data set "howa 80" was applied.
For a first glimpse on the impacts of different usage profiles on the buildings' cooling demands hourly cooling load break-downs under a steady state Design Day were performed.

As Strabag has been shown to display comparatively high cooling demands and loads in Module 5: Impacts of different levels of internal loads (and hence a high potential for improvement is assumed here), this sample building was investigated under simulation mode Standard.
Investigated sample rooms of all orientations were averaged.

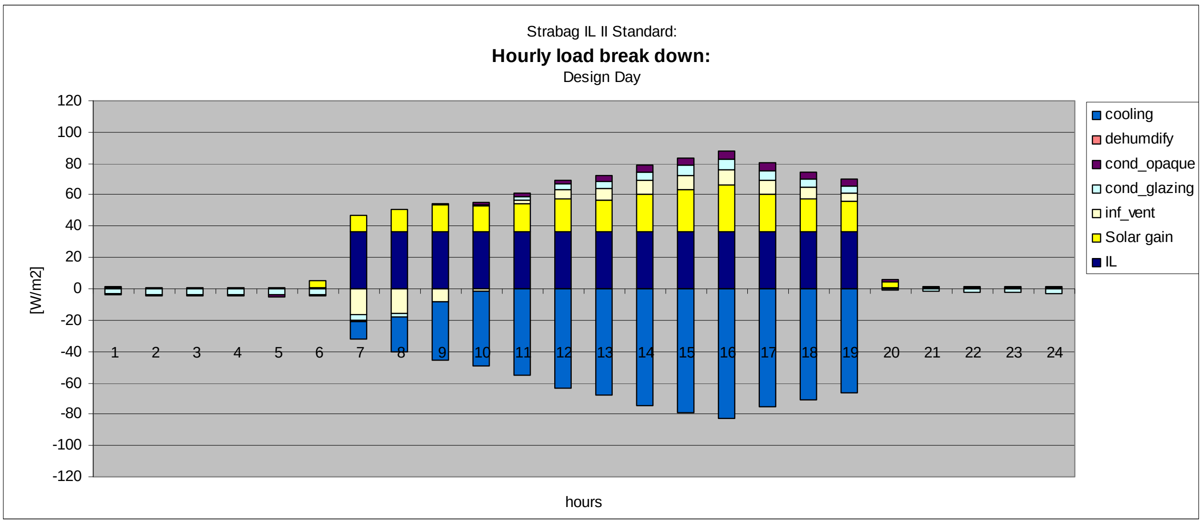
Different usage profiles both in terms of occupancy presence schedule and intensity were investigated. These profiles are prescribed hereafter:

Usage profile denomination	**Description:** occupancy schedule
Standard	6:00 am to 7:00 pm
Standard real	8:00 am to 5:00 pm
Early	7:00 am to 4:00 pm
Siesta	8:00 am to 12:00 am, 4:00 pm to 7:00 pm
Tele	6:00 am to 7:00 pm, 30% of occupants permanently absent
Tele Siesta	8:00 am to 12:00 am, 4:00 pm to 7:00 pm 30% of occupants permanently absent
Shade	6:00 am to 7:00 pm shading closes at irradiation of150W/m^2 [87]

Table 15: Description of investigated usage profiles

8.6.2 Results

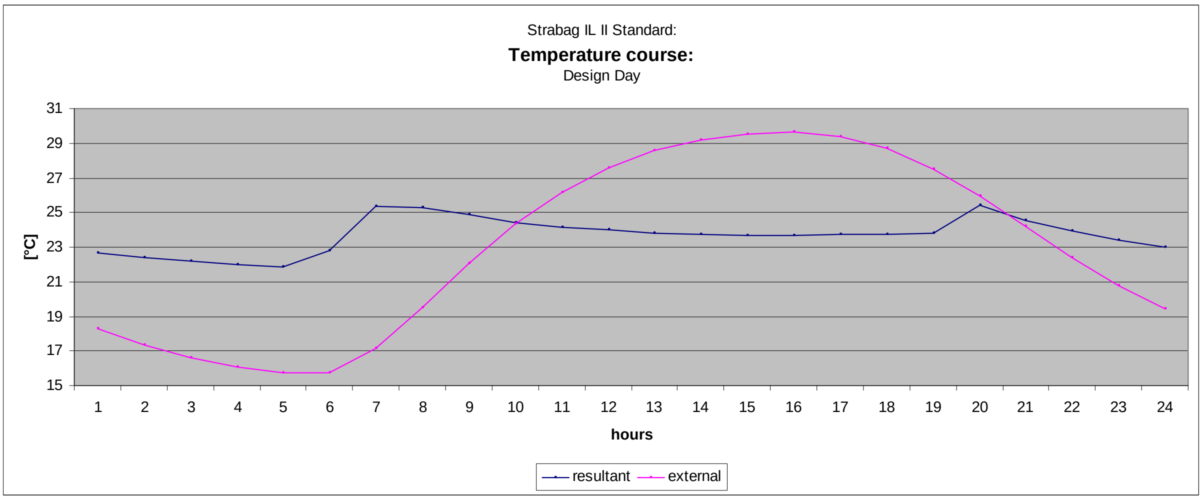
The hourly load break-down for a steady state Design Day in sample building Strabag clearly shows internal loads and solar gains as driving factors for internal heat, which are compensated by cooling. Natural ventilation during hours displaying outdoor temperatures ranging from 18 to 26°C does not render cooling, as the incoming outdoor air is mostly hotter than the cooled indoor environment.



Graph 106: Hourly load break-down in Strabag mode "Standard" (same as Graph 94)

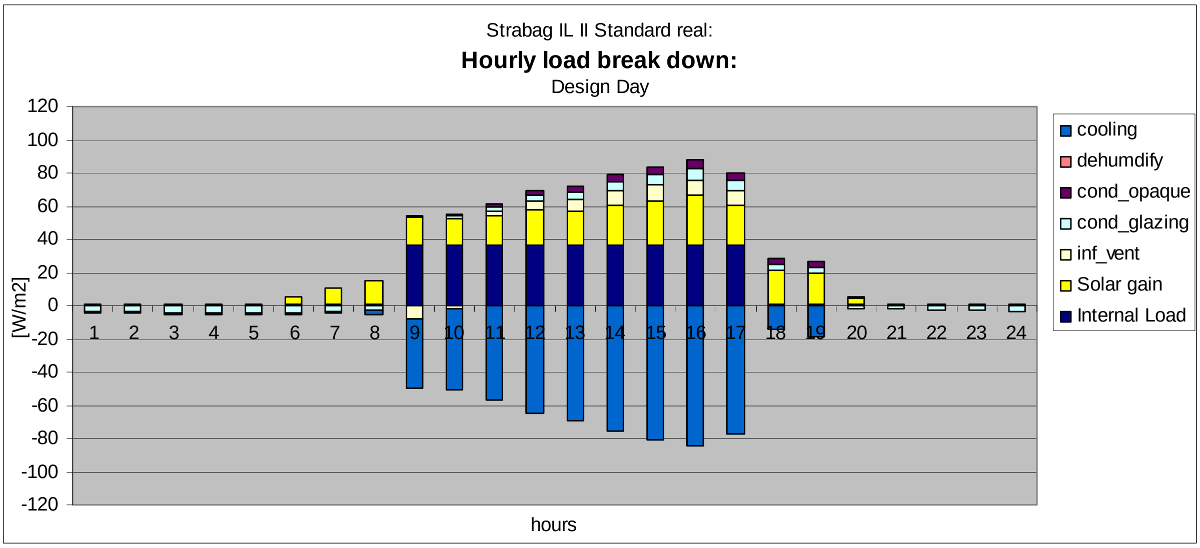
87 on vertical window pane

The corresponding temperature swing documents how an indoor temperature rise due to outdoor conditions is suppressed by means of cooling during office hours. After closing time, the temperature control is loosened, resulting in a slight peak. For most of the day though, indoor temperatures are kept below outdoor ones.



Graph 107: Temperature course in Strabag mode "Standard"

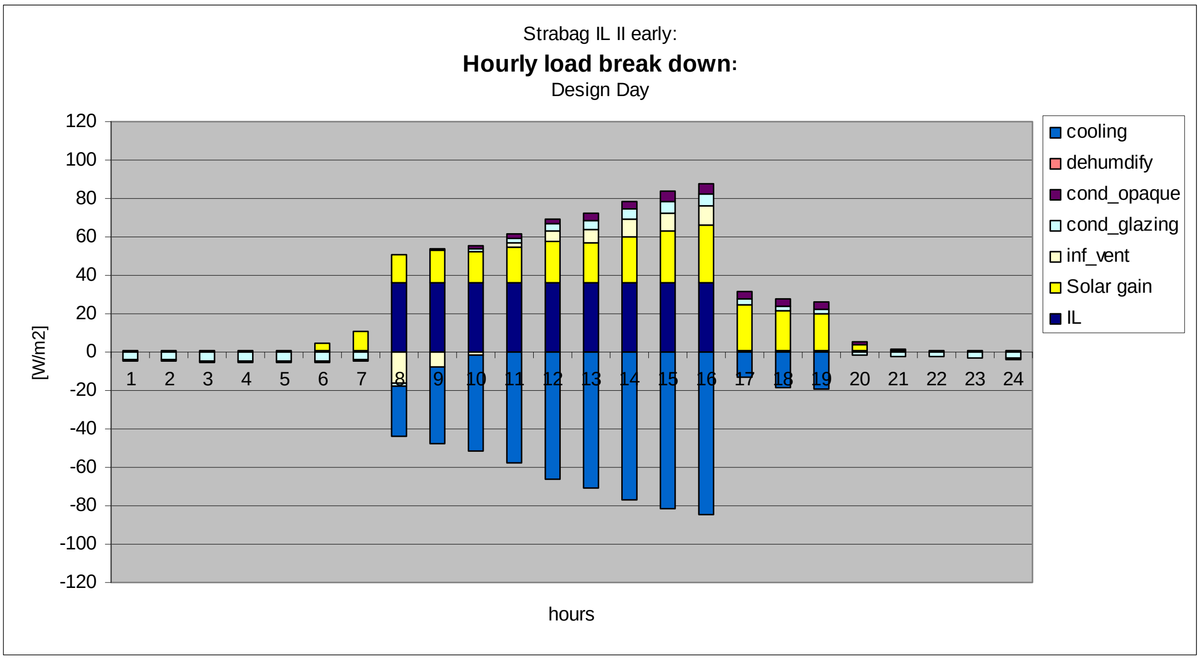
While simulation mode "Standard" accounts for 13 office hours (6:00 am to 7:00 pm), most office workers are present for only eight hours or less. Applying a tighter time scheme "Standard real" (8:00 am to 5:00 pm) would already decrease cooling demand by 16%. For those workers, however, who do come earlier or stay longer, this would imply comfort reductions.



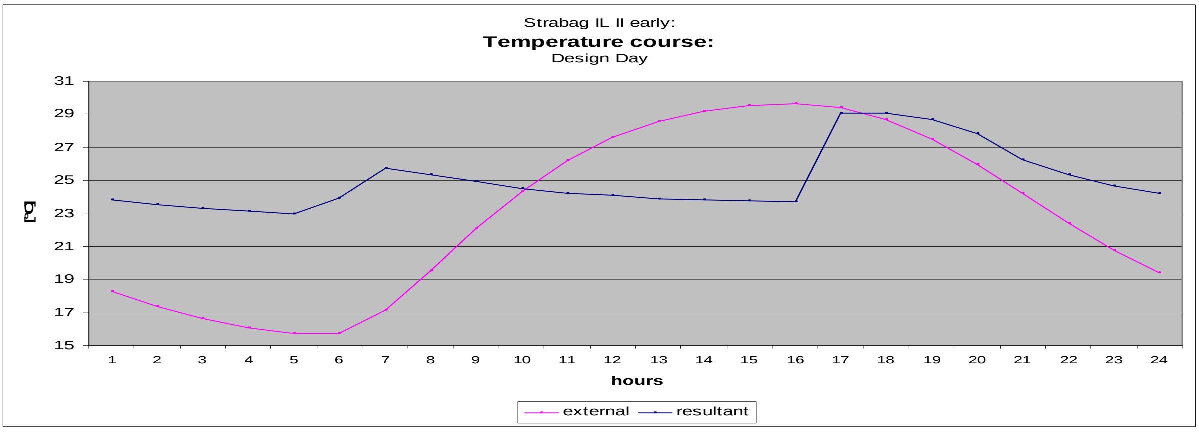
Graph 108: Hourly load break-down in Strabag mode "Standard real"

Shifting working hours to early parts of the day would allow for a higher proportion of working time being over before outside temperature peaks occur, resulting in a cooling demand reduction of almost 20% as compared to mode "Standard".

As can be seen from the temperature course for mode "Early" (working hours 7:00 am to 4:00 pm), this again would imply, that employees are discouraged to work longer as comfort conditions worsen after 4:00 pm.

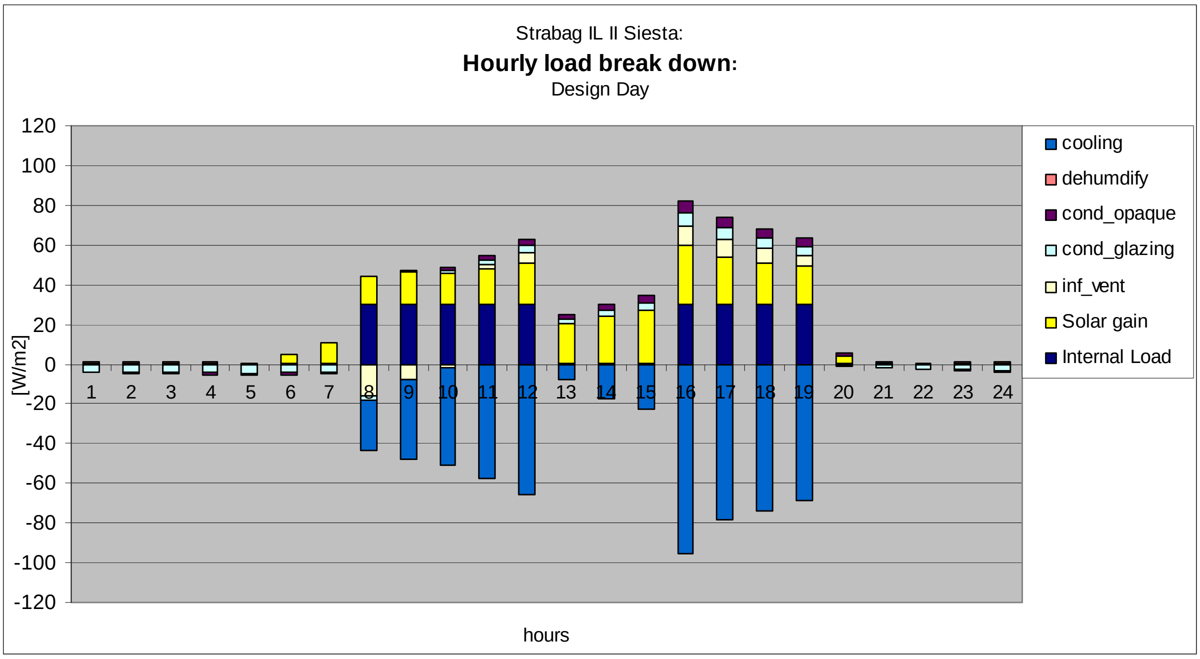


Graph 109: Hourly load break-down in Strabag mode "Early"

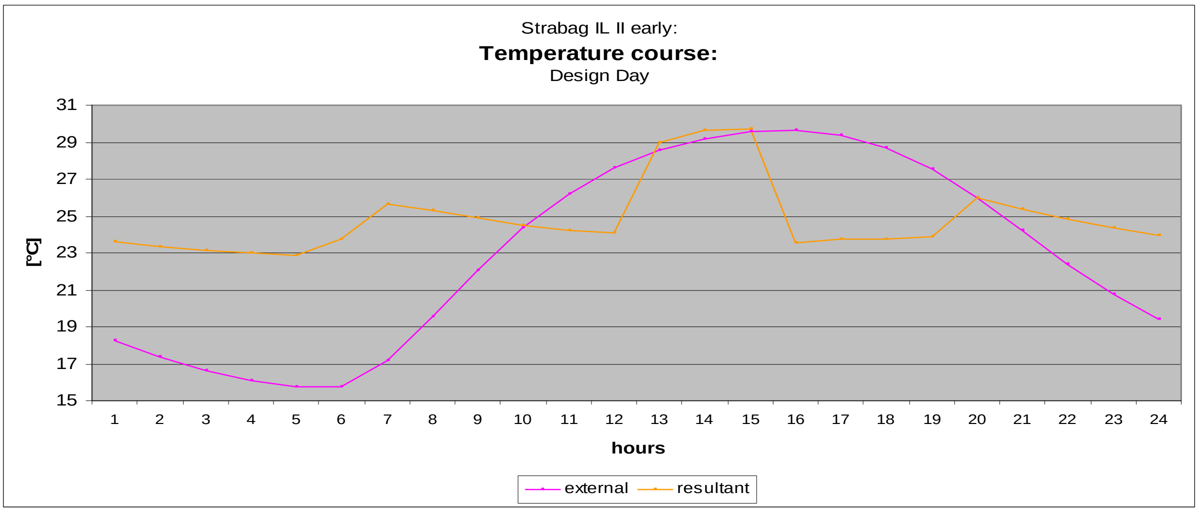


Graph 110: Temperature course in Strabag mode "Early"

The traditional concept of a midday Siesta strives to avoid working during the hottest hours of the day. In terms of energy consumption, this only makes sense, if equipment and lights are switched off for the lunch break and higher temperatures are allowed in office rooms. Again, reductions in cooling energy demand for this mode "Siesta" (8:00 am to 12:00 am, 4:00 pm to 7:00 pm) range around 20%, equalling those of mode "Early".



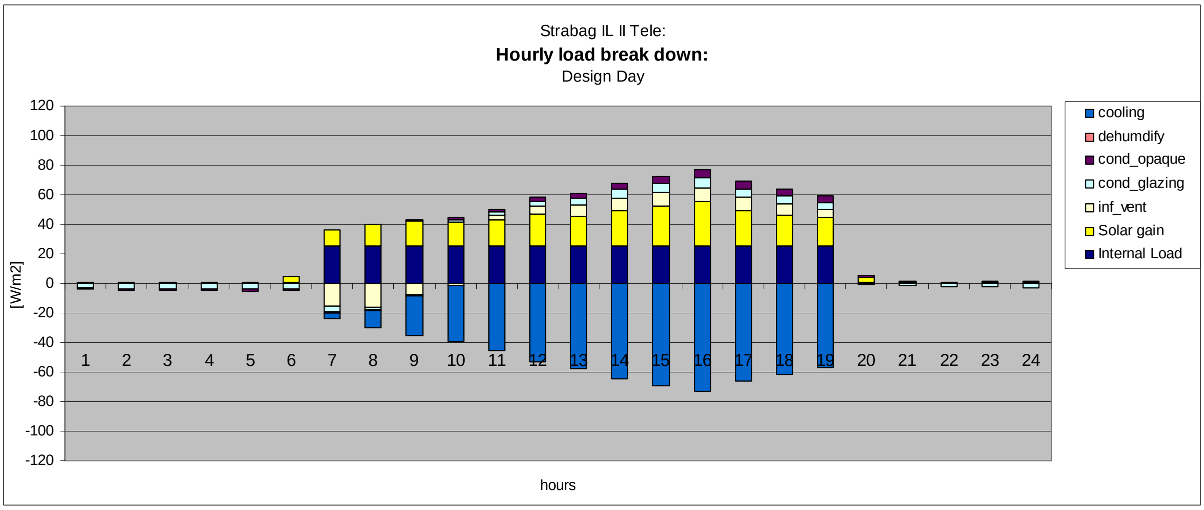
Graph 111: Hourly load break-down in Strabag mode "Siesta"



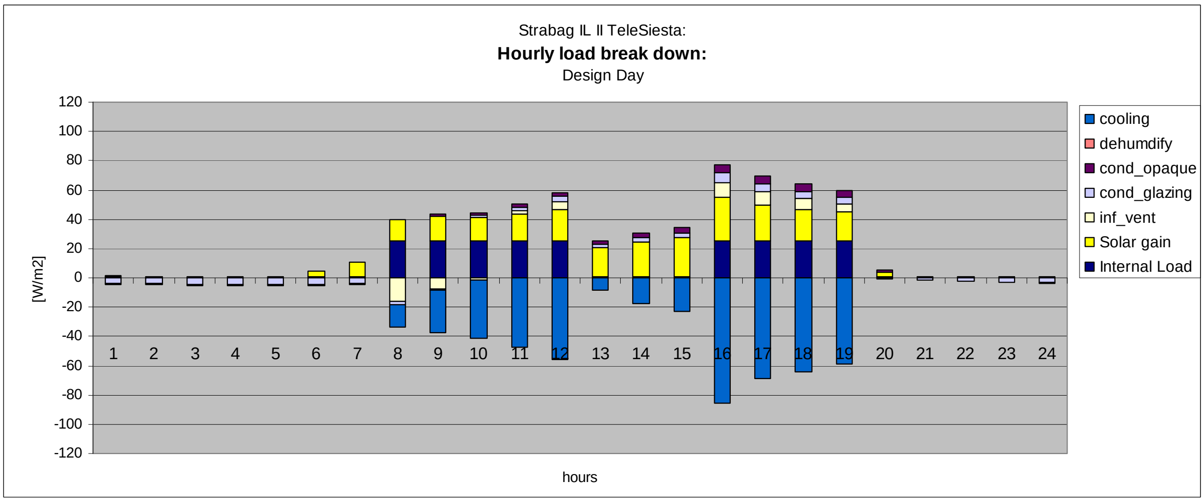
Graph 112: Temperature course in Strabag mode "Siesta"

In an attempt to depict possible impacts of modern work modes, a reduction of workers' presence due to teleworking was depicted in mode "Tele" by an overall reduction in internal loads of 30% for working hours from 6:00 am to 7:00 pm (13 hours, corresponding to mode "Standard"). This causes a decrease in energy demand for cooling of roughly 16% as compared to mode "Standard".

Contrary to modes "Early" and "Siesta", this mode does not represent a change in the patterns of working hours but rather a different level of internal loads due to changed working modes. Thereby, energy demand is reduced without affecting comfort conditions in offices during early morning and late afternoon[88].



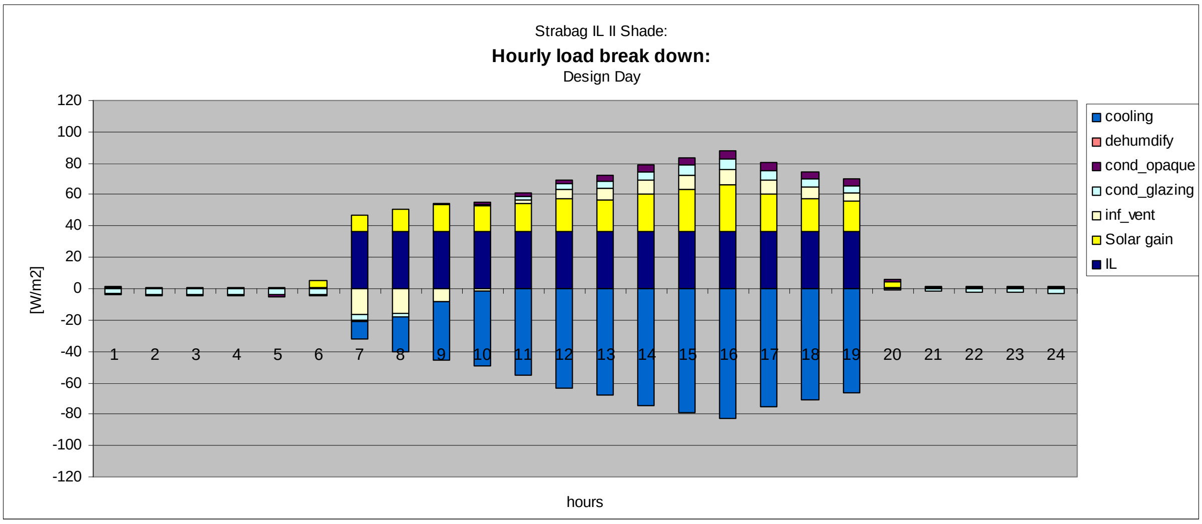
Graph 113: Hourly load break-down in Strabag mode "Tele"



Graph 114: Hourly load break-down in Strabag mode "TeleSiesta"

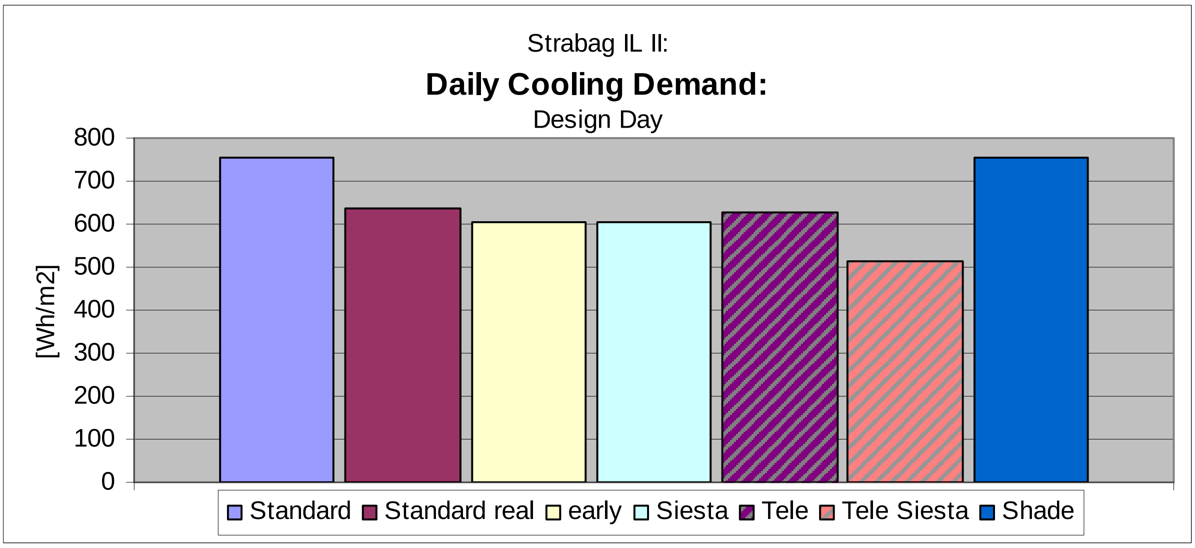
It has been indicated above that the shading regime implemented in mode "Standard" already illustrates a fairly well adapted usage mode. In reality, it might be challenging to have users activate shading as soon as solar irradiation on the respective vertical pane exceeds 180 W/m^2. In simulation mode "Shade" the threshold has been decreased to 150 W/m^2 only. But this does not result in any cooling demand reduction: obviously all significant irradiation is already covered for by a threshold of 180 W/m^2. Further reductions of solar gain in sample building Strabag are feasible only by the adoption of external shading rather than blinds in the panes' cavity.

[88] It may be brought forward, that internal loads of both workers and their equipment and lighting are only displaced to other locations by teleworking. This location most probably will be a working desk in the employee's home, which might not normally be equipped with cooling devices. The issue of displaced heat production is thus regarded as minor and not further treated here.



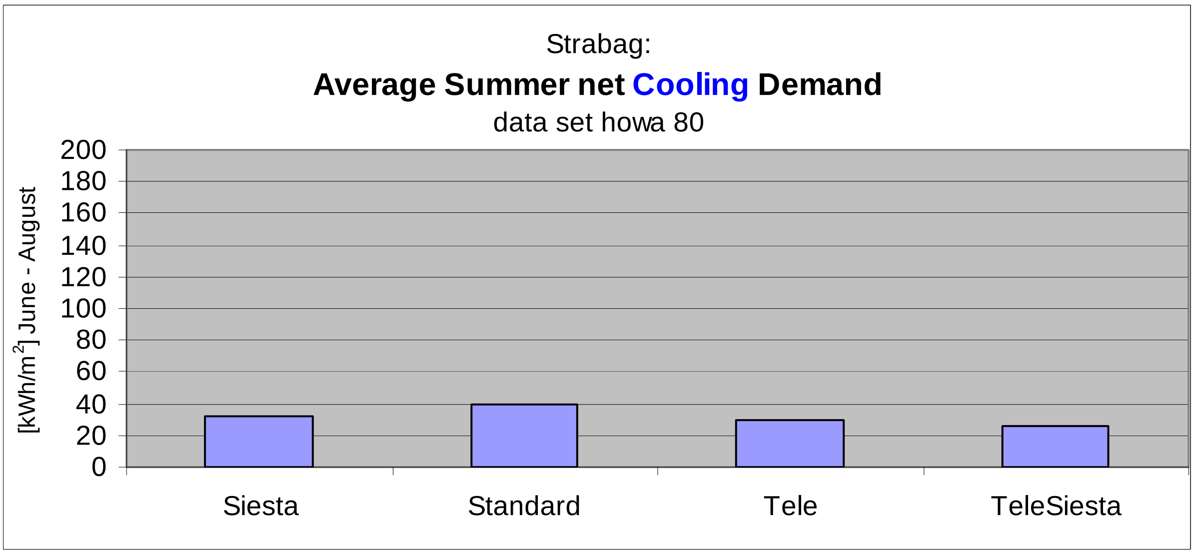
Graph 115: Hourly load break-down in Strabag mode "Shade"

In conclusion, rough estimates based on simulations under steady state conditions (Simulation mode "Design Day") show that changes in the patterns of working hours as well as a different level of internal loads due to changed working modes – as well as the combination of both as portrayed in mode "TeleSiesta" – promise to be effectual in terms of reduction in cooling energy demand.



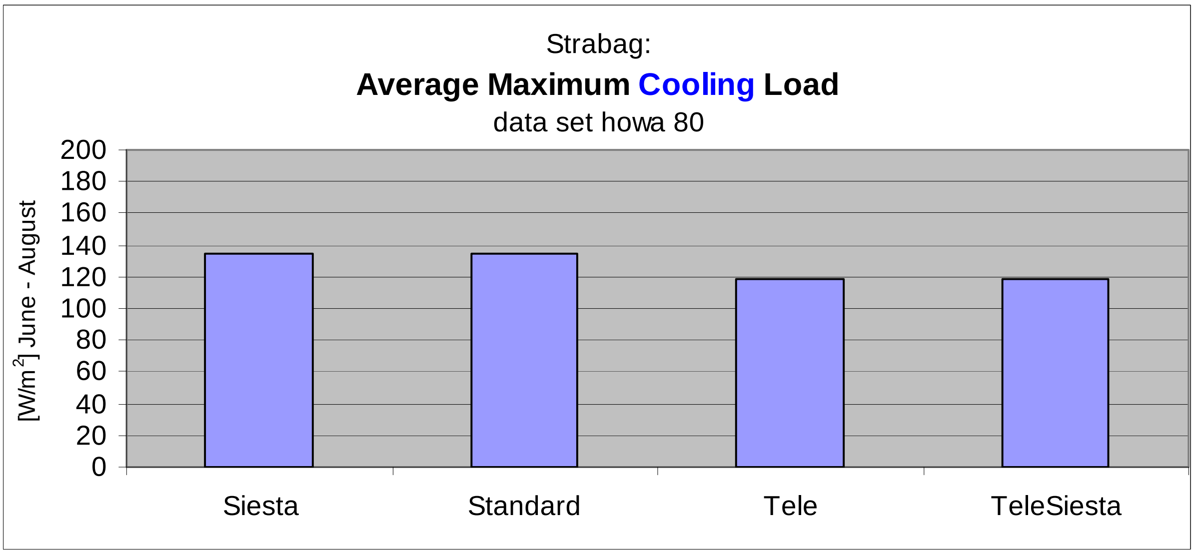
Graph 116: Daily cooling demand for different usage profiles

The appliance of these optimized modes under long term conditions of a whole summer period reveal that this potential can in fact be harnessed; In particular, the twofold approach of mode "TeleSiesta" with reduced workers' presence and shifted office hours results in savings of up to 35%. This makes the mode a considerable alternative even with the above mentioned limitations in place.



Graph 117: Summer cooling demand of different usage modes[89]

An investigation of maximum cooling loads makes it clear that shifted working hours do not allow for more modest cooling plants as high loads can still occur. Reducing internal loads by means of teleworking also reduces maximal cooling loads, though to a minor extent.



Graph 118: Cooling load of different usage modes

These findings are backed by monthly demand break-downs for modes "Standard" and "Telesiesta", which clearly attribute the lower demands in the latter to its lower levels of internal loads. Solar gain, second driver in cooling demand, remains unchanged.

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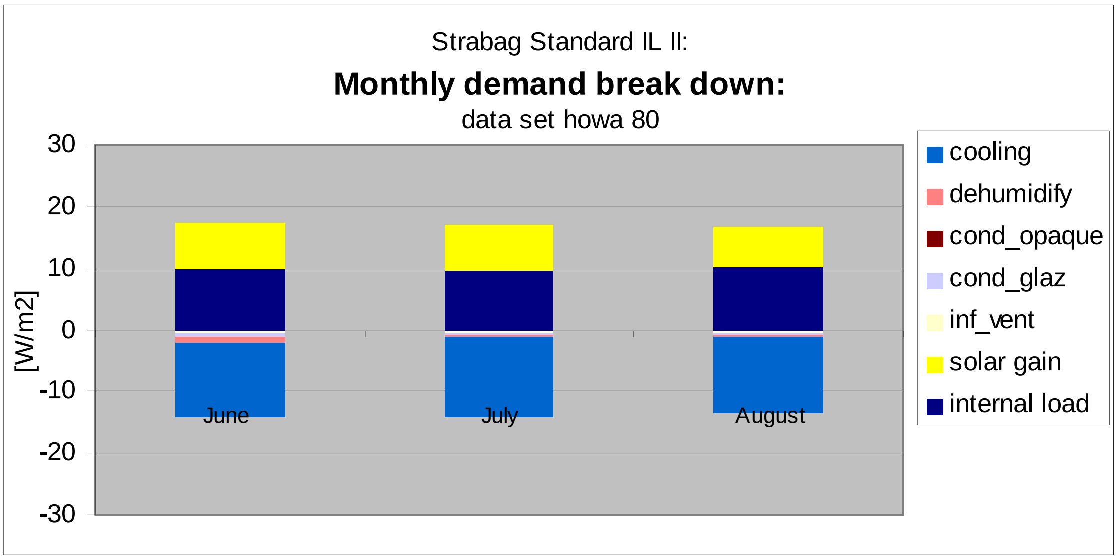
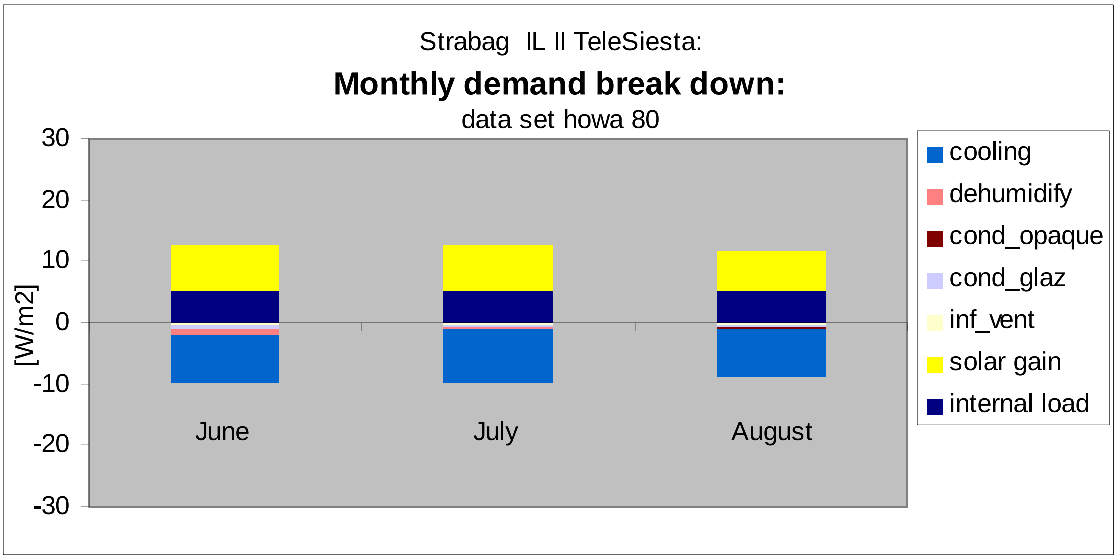
[89] This graph portrays cooling demand in summer months (June to August) only. When comparing the value of "Standard" with those of Strabag/ howa 80 in Graph 35: Average annual net cooling energy demand of all buildings (South) , page 73, it becomes evident that roughly 40 kWh/m^2 out of the net annual cooling demand of 63 kWh/m^2 are consumed in summer.



Graph 119: Summer load break-down for Strabag mode "Standard"



Graph 120: Summer load break-down for Strabag mode "Tele Siesta"

8.6.3 Conclusions

Simulations run in this module demonstrate that cooling demand in office buildings is largely influenced by users' behaviour both in terms of their presence and their usage of shading devices. While this in itself does not represent any novelty, innovative though quite simple changes in usage pattern were investigated and found to be effectual. Social and practical limitations of such patterns were highlighted. A broader discussion beyond purely technical matters hence appears advisable in this context as technology in its own right might fall short of coping with the impacts of climate change.

8.7 Module 7: Impacts of different natural (and mechanical) ventilation regimes on thermal comfort

This module investigates the possible impacts of natural ventilation strategies on thermal comfort in buildings. Office blocks in urban areas however forward the most demanding circumstances for such strategies: they normally display high internal loads, their surrounding areas are characterized by comparatively minor nocturnal cooling potential due to urban heat islands and furthermore users are absent during night time which makes open windows a security issues.

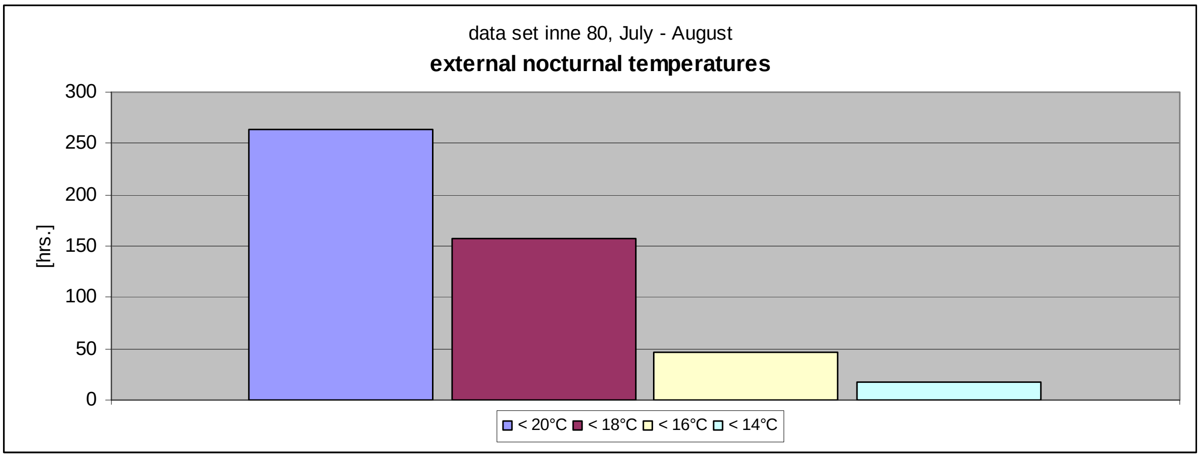
Hence, testing natural ventilation strategies under these conditions equals a worst case investigation. Still, it appears worthwhile doing so because natural ventilation as a purely passive cooling strategy holds the strong advantage of basically not demanding energy consumption.

All investigations in this module are run under the conditions of climate data set “inne”: As has been described, the envisaged ventilation strategies should be tested under the assumption of urban conditions. Would data sets be used, that represent conditions at main weather stations only – which in the case of Vienna would be represented by data set “howa” –, the results thus obtained run danger of overoptimistic assessment of possible impacts.

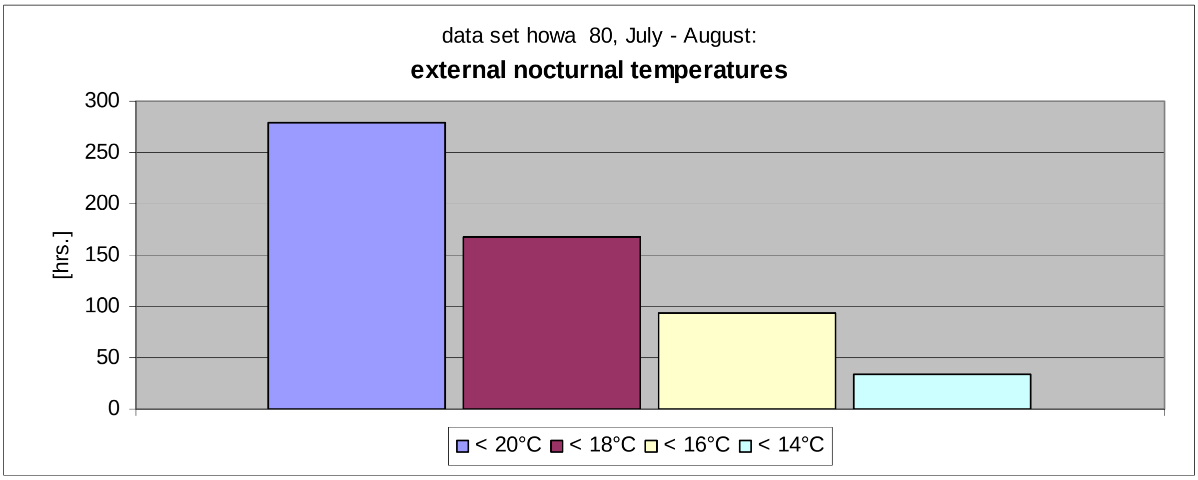
Therefore, one single summer month out of “inne 80” is applied for investigations. Assessments of future situations still lake sound basis as localized climate scenarios, so far, make no allusions as to what wind environments might be like in the decades to come.

It has been described above that wind data within the applied climate data sets was generated on the assumption of largely unchanged conditions. Natural ventilation in buildings, however, dwells on two distinct components: stack effect and external wind. While the former is directly influenced by outdoor temperature and hence subject to implicit changes as outdoor temperatures are generally on the rise, the latter has to be assumed to remain as it is in present days.

In order to assess ventilation potentials during night time (outside office hours; 20:00 pm to 5:00 am) those hours were identified during which various outdoor temperatures are under-run. These results clearly depict the elevated nocturnal temperature level of the CBDs (“inne80”) as compared to Vienna’s main weather station at the green fringe of the city (“howa80”).



Graph 121: Number of hours with external nocturnal temperatures under-running various limits, data set "inne 80"



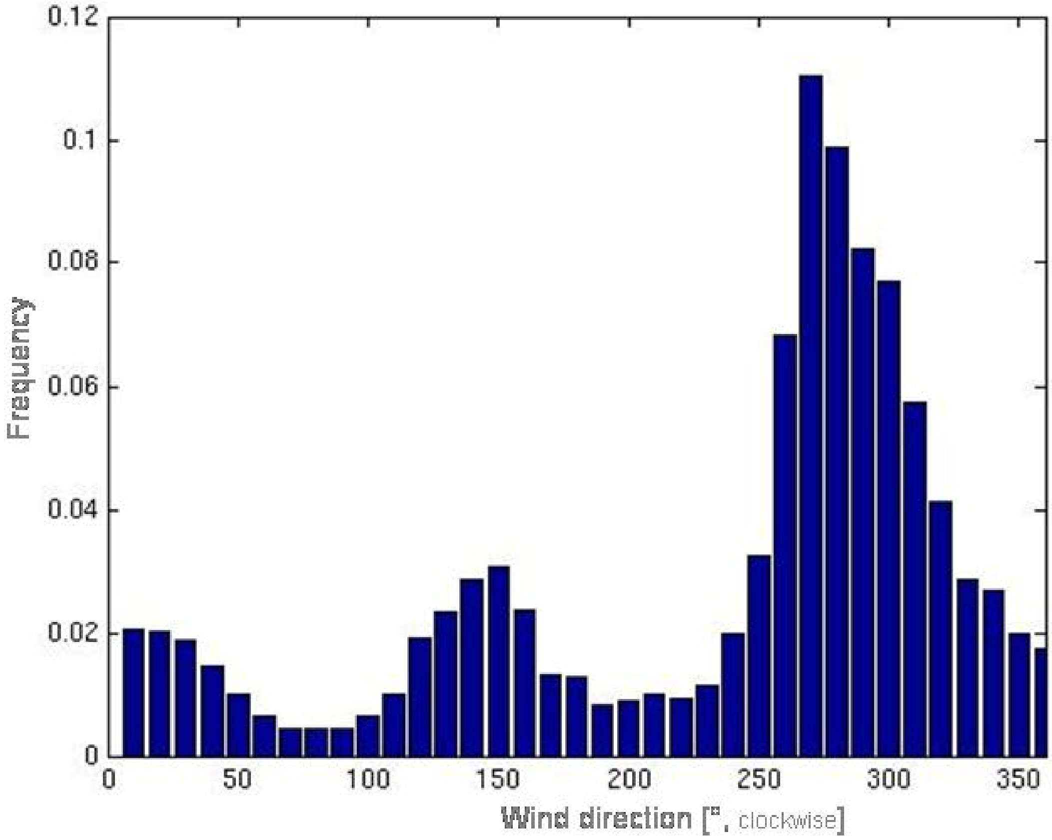
Graph 122: Number of hours with external nocturnal temperatures under-running various limits, data set "howa 80"

Hot indoor areas displaying temperatures beyond 27°C are likely to lose warmth even to outdoor conditions hotter than 20°C, but the cooling effects are plainly restricted to the exchange of hot air by warm air.

For detailed analysis of ventilation processes, the sample buildings were investigated under steady state conditions of climate design days in order to reveal independencies of loads, gains and losses. To this end, 15 preconditioning days were assumed.

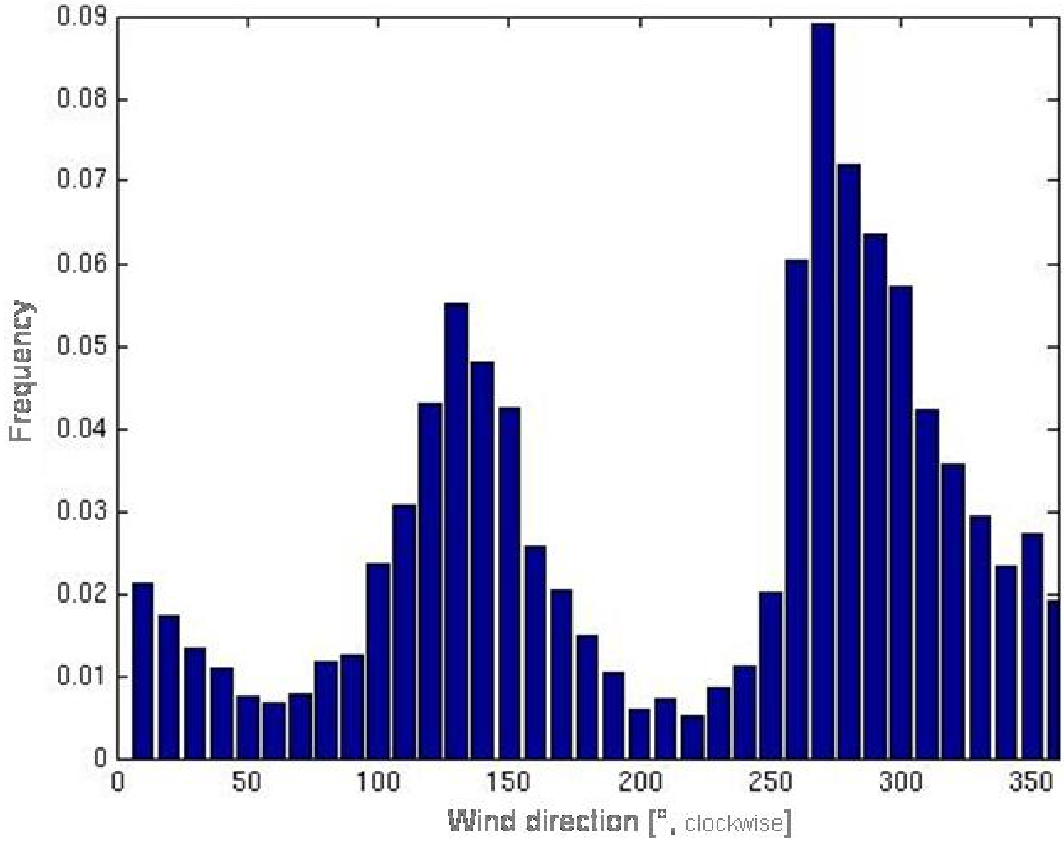
For the assessment of natural ventilation's efficiency, the local wind environment is crucial. Statistical analysis reveals that two wind directions are predominant in the metropolitan area of Vienna: westerly winds (270°) are most frequent, while south-easterly ones (130°) are often encountered likewise, especially during daytime. Highest wind speeds occur under West wind conditions, fainter winds from the South-East are to be expected on hot days.

This means that wind speeds tend to be limited when most needed during hot periods.



Graph 123: Statistical distribution of wind directions (indication of degrees clockwise) for 6:00 p.m.

To assess natural ventilation potentials on the safe side, reduced wind speeds from a South-Eastern direction have to be taken into account.



Graph 124: Statistical distribution of wind directions (indication of degrees clockwise) for6:00 a.m.

Two of the sample buildings – ONB and BGN – are already facing severe comfort deficits under present conditions (simulation mode "real"). Both historic buildings command hardly any or no cooling at all at present day. This fact has been taken as a starting point for the quest of directly applicable optimization strategies.

Module	Sample Building	Simulation Mode	Climate Data Set
7 natural ventilation	ONB BGN/ FAS	"real"	"inne 80"

Table 16: Investigated sample buildings, simulation modes and employed climate data set in Module 7

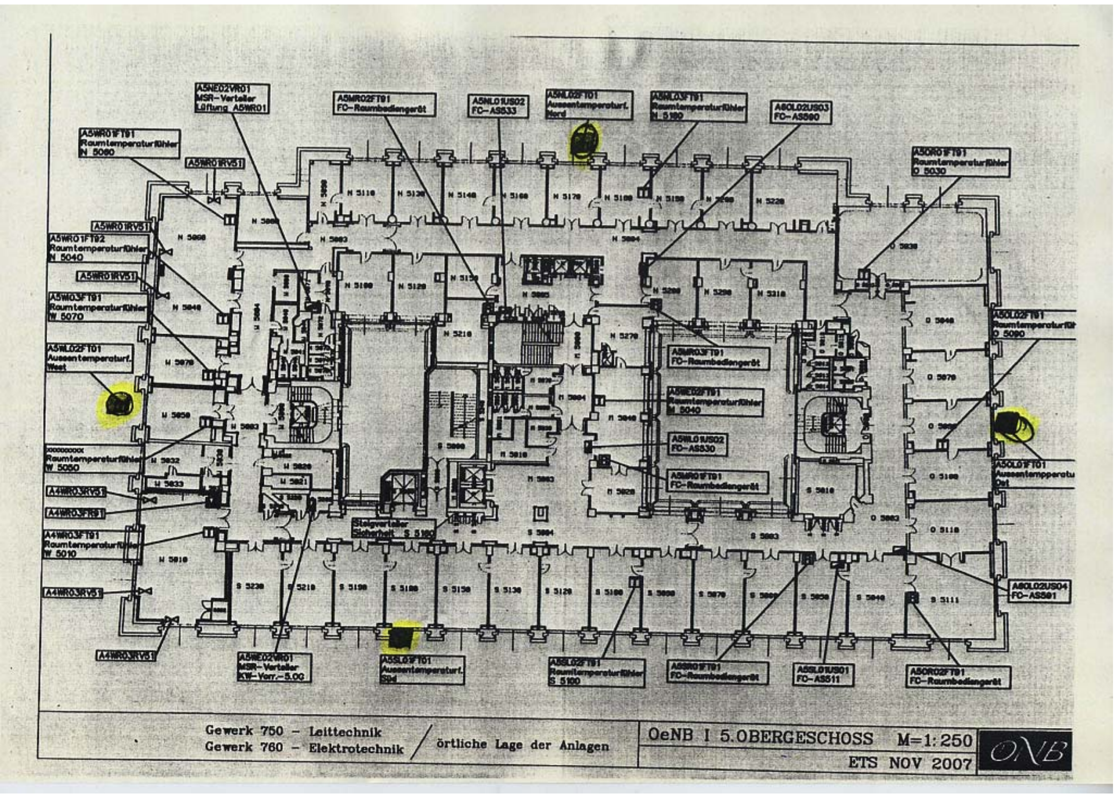
8.7.1 Validation of simulated indoor temperatures

In order to obtain reliable results about the viability of natural ventilation it was necessary as a first step to validate simulation assumptions of simulation mode "real" against actual temperature observations in the depicted sample buildings; Only if congruence can be established between simulation results and present day situations in the buildings in question will the simulation model yield sound results for alternative options.

8.7.1.1 ONB: Placement of external temperature sensors

As a first step of validation the placement of external temperature sensors in the building were documented. One such sensor is placed on each of the four façades respectively.

All these sensors are mounted in front of the external walls, with only a few centimetres in between. This proximity to heavy brickwork walls which are exposed to direct sunlight during prolonged hours makes it highly probable that the temperature observations of these sensors contain measurements of the walls' radiant temperatures to a high degree. Therefore, it is assumed that the temperature observations used hereafter for validation purpose exaggerate outdoor temperatures as compared to those indoors. This appears to be true not only for ONB but even more so for BGN. When assessing simulation results against actual temperature readings in the building, this fact has to be kept in mind.

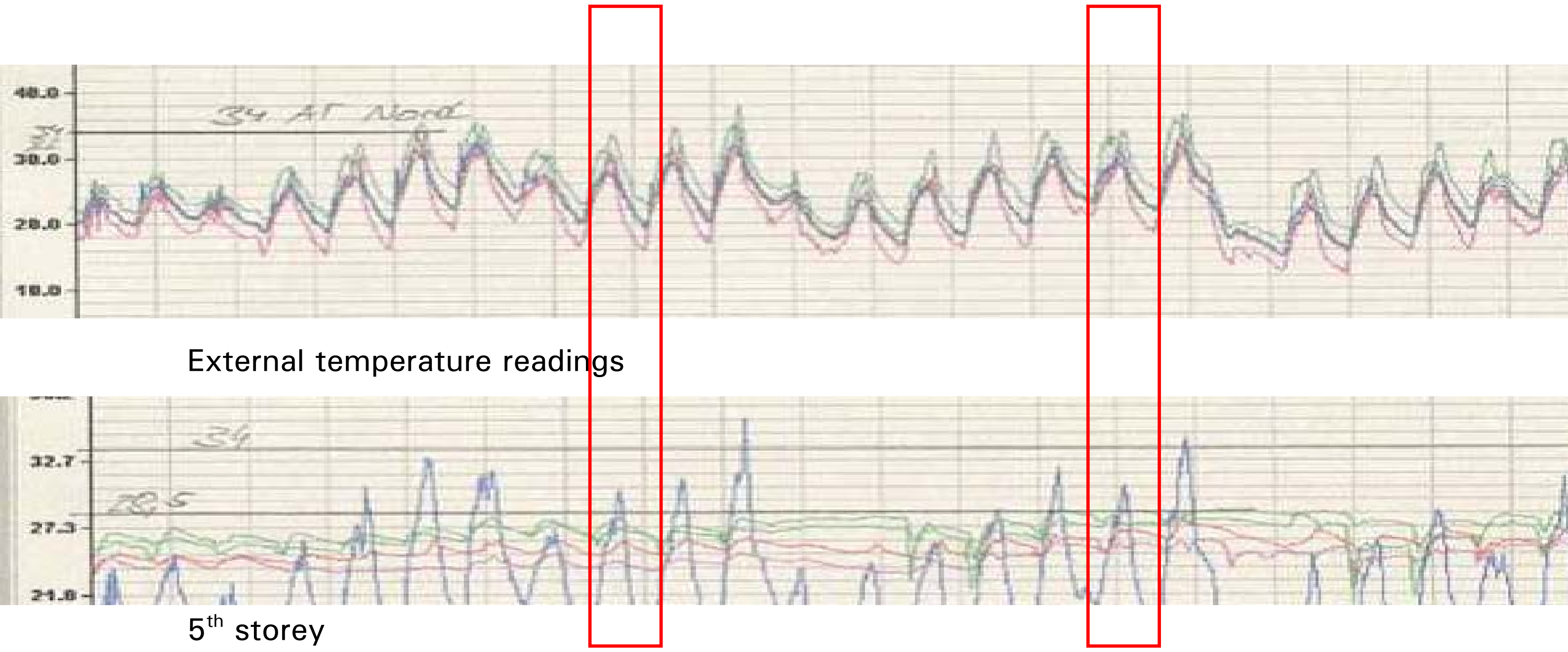


Graph 125: ONB floor plan with external temperature sensors

Graph 126: Placement of temperature sensor on west facade

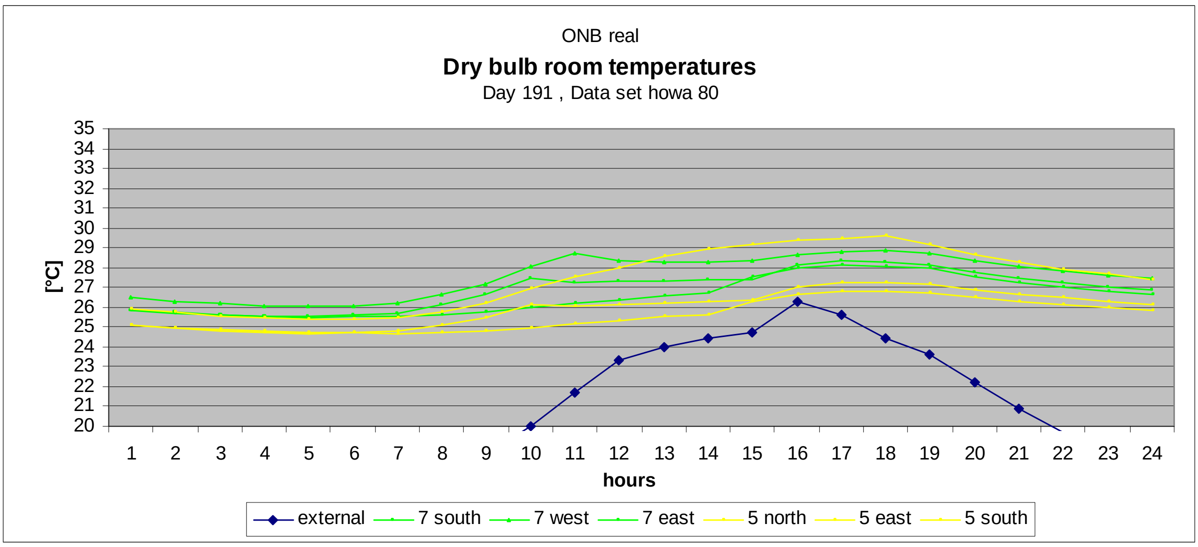
Graph 127: Placement of temperature sensor on east facade

8.7.1.2 Observations of external and internal temperature sensors



Graph 128: Indoor air temperature observations

(including outdoor air temperature: blue line; the red rectangles frame the measurements of August 18 and August 27,2009, which are scrutinised against simulation results hereafter)

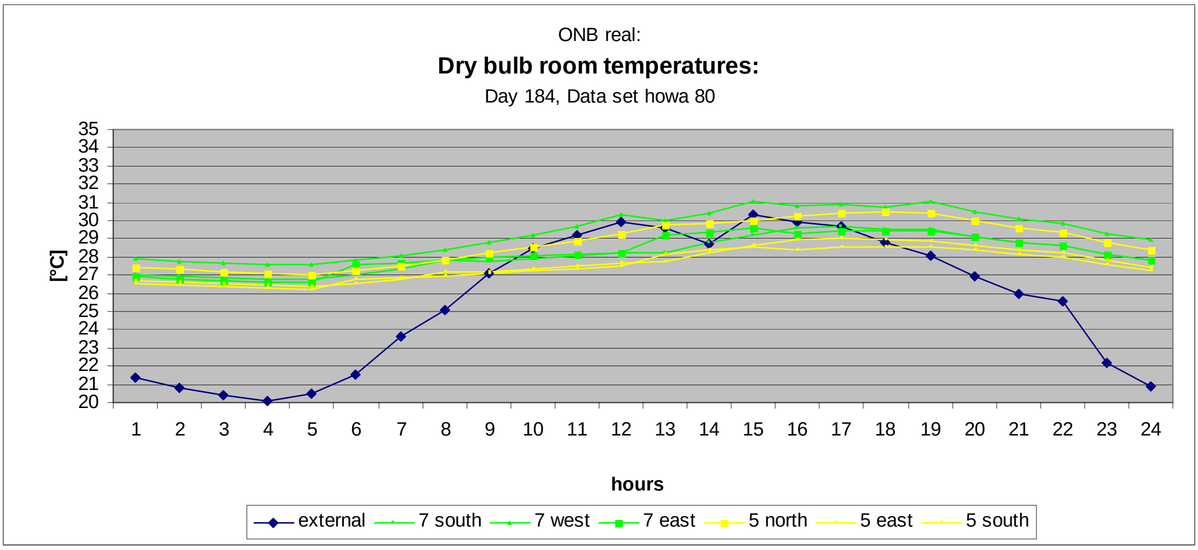


Graph 129: Simulation results for a day comparable to August 18, 2009 (in terms of external temperature);

Note: Green curves display 7th storey indoor temperatures, yellow ones those of 5th storey rooms;

Temperature observations of August 18, 2009 display peak outdoor temperatures ranging around 26,2°C.
Corresponding temperature readings indoors reach 25,1 to 27,9°C in both the 5th storey and 7th storey.

Simulation results for a comparable day (Day 191) with outdoor temperatures going up to 26,3°C show indoor temperatures of 26,9°C to 29,4°C in storey 5 and 28,16 to 28,82°C in the 7th floor.



Graph 130: Simulation results for a day comparable to August 27, 2009 (in terms of external temperature reached)

Note: Green curves display 7th storey indoor temperatures, yellow ones those of 5th storey rooms;

Temperature observations of August 27, 2009 displays peak outdoor temperatures ranging around 30,6°C.
Corresponding temperature readings indoors reach 26,2 to 28,4°C in the 5th storey and 25,1 to 28,4°C in the 7th storey.

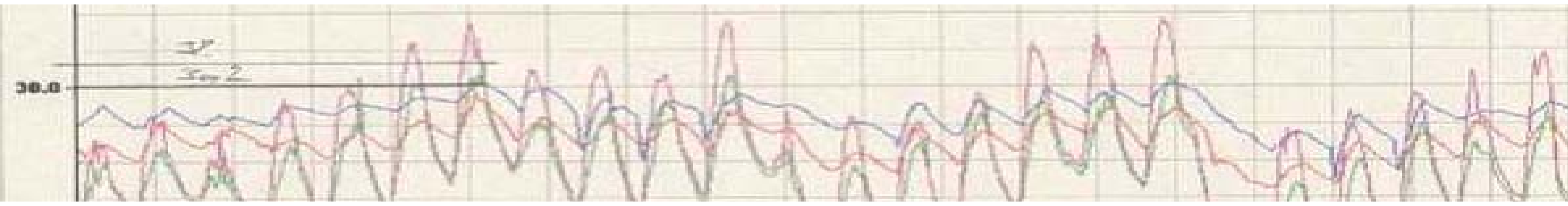
Simulation results for a comparable day (Day 184) with outdoor temperatures going up to 30,6°C show indoor temperatures of 28,4°C to 30,24°C in storey 5 and 29,1 to 31°C in the 7th floor.

Therefore, simulation results do not exactly match with measurements in the existing building, but rather tend to be slightly higher than indoor measurements; However, it has to be taken into account that the given readings of outdoor temperature must be assumed to exaggerate the actual external air temperature due to the sensors being installed very close to the outer wall and therefore most probably displaying a mixture of both air temperature and radiant temperature of hot nearby wall surfaces.

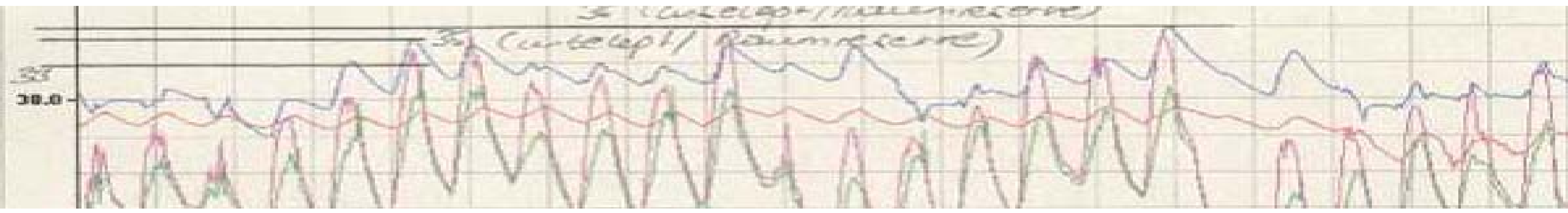
Even taking this into account, the discrepancy in thermal conditions of 5th and 7th storey, which is discernable in simulation results, does not match with temperature observations in the building itself as temperatures unexpectedly tend to be higher in the 5th floor there. Still, these trends are not consistent neither in measurements nor in simulation results, therefore only limited significance has to be attributed to them.

8.7.1.3 BGN: Observations of external temperature sensors

4th storey: outdoor (red, green) and indoor (red, blue) temperatures



6th storey: outdoor (red, green) and indoor (red, blue) temperatures



8th storey: outdoor (red, green) and indoor (red, blue – unused room) temperatures

Graph 131: BGN temperature observations

Temperature observations: At first glance, the temperature observations in the existent building reveal an obvious discrepancy with simulation results as outdoor temperatures frequently top indoor ones. This hardly ever matches with simulation results. However, a closer look reveals that this significant discrepancy is invariably forwarded by outdoor temperature observations of a single sensor on the building's southern façade (red line). It has to be assumed that these measurements depict radiant temperatures to a high degree rather than air temperature. Controversially, temperature readings at the northern side of the building (green line) most probably converge closer with actual outside air temperature. If these readings are employed as the comparison's reference, the indoor readings tend to exceed outdoor temperatures and show a satisfying convergence with simulation results.
Measurements for August 19, 2009 display outdoor temperatures ranging between 25 and 31°C (green line).
Corresponding temperature observations indoors reach 27 to 28°C in the 4th, 26 to 28°C in the 6th and 27 to 31°C in the 8th storey.

Simulation results for a comparable day with outdoor temperatures going up to 25,1°C show indoor temperatures of around 27 to 28°C in floor 4, 27 to 28°C in storey 6 and 28°C in the 8th floor.

The comparison of temperature readings' amplitudes in both sample buildings acknowledge simulation results: as BGN is directly linked to outside air temperature by manually operated windows as single ventilation strategy, this building displays the most pronounced amplitudes in resultant room temperature. ONB runs a mechanical ventilation system, which additionally supplies office rooms with restricted cooling (it goes without saying that this system has been installed decades after the original erection of the building at the occasion of a refurbishment process). Temperature amplitudes appear smoothed here while still on a high level.

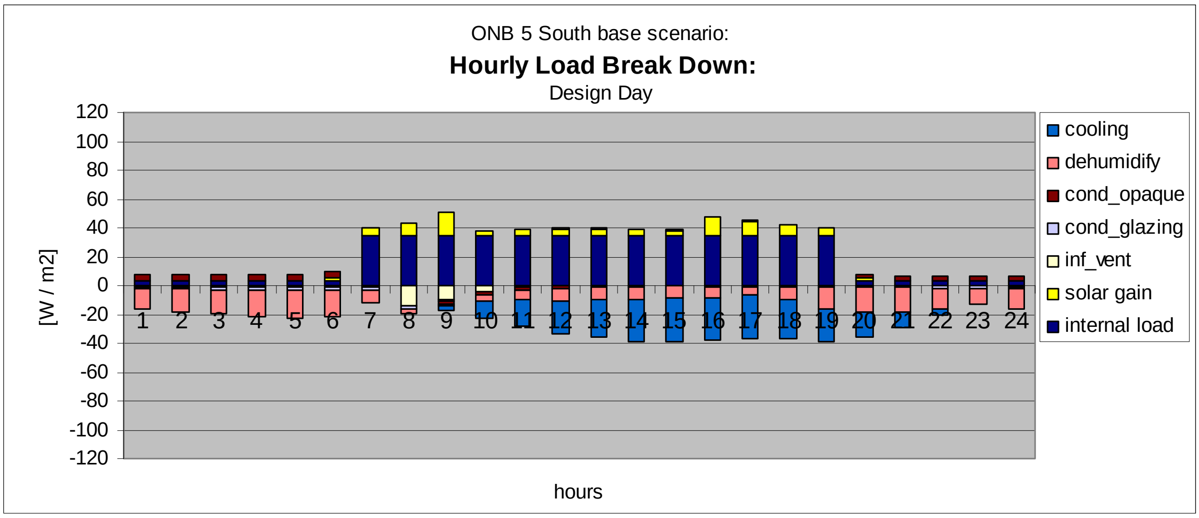
8.7.2 Results

8.7.2.1 ONB

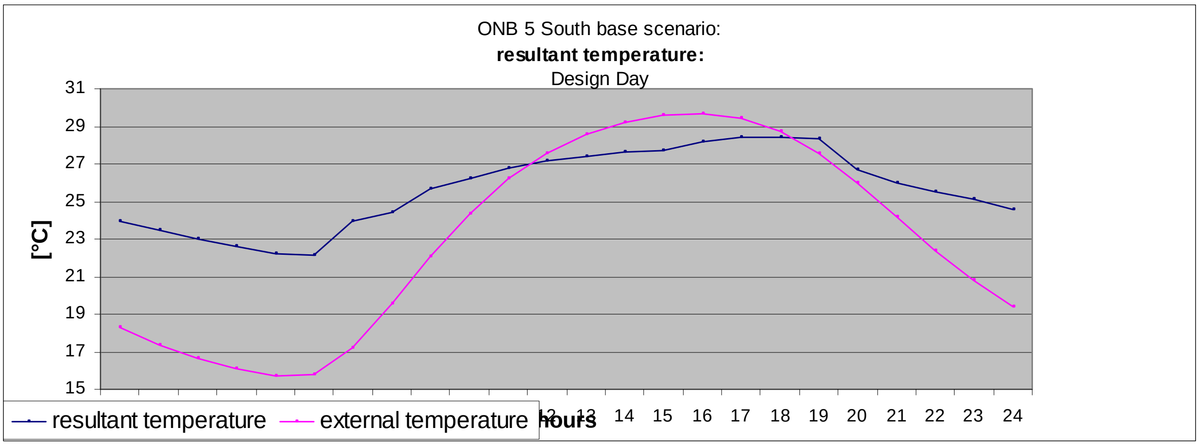
One single reference room (5th floor, facing South) has been investigated in this sample building. The present day situation in this room serves as base scenario for optimization hereafter: The room is served by mechanical ventilation, which induces fresh air on a constantly low temperature level (21°C) but does not further counteract overheating tendencies in the room. Thus no air conditioning in the conventional meaning of this term is applied.

Additional natural ventilation by users is enabled for those hours during which external temperatures range between 18 and 26°C. Likewise, sun shading is applied by external blinds when external solar gain exceeds 180W/m^2 on the vertical pane.

The investigation of hourly gains and losses under steady state design day conditions for this base scenario reveals driving forces for overheating: while solar gains are clearly cut to a minimum for most of the day, internal loads (lighting, occupants and equipment) during office hours outweigh cooling applied by the mechanical ventilation system. Dehumidification loads are not discharged here. Gains and losses by conductance through opaque and transparent external walls are of minor magnitude. Natural ventilation via windows is only applied during early morning.



Graph 132: Hourly gains and losses for ONB base (sample room 5th floor, facing South)



Graph 133: Temperature course for ONB base

Whilst external temperature will top indoor temperature for several office hours during this pronouncedly hot design day, indoor conditions still surpass the 27°C threshold for roughly the same time lapse.

8.7.2.2 Achievable air change rates due to single sided nocturnal ventilation

Single zone wind simulation of the reference room was carried out under the assumption of single side ventilation, a constant pressure coefficient Cp[90] for the outside wall and discharge coefficients Cd[91] for the opening's shape, both equally obtained from literature[92].

ONB	Wind direction West	Wind direction South
C_p	- 0,3	+0.25
C_d	0,6	

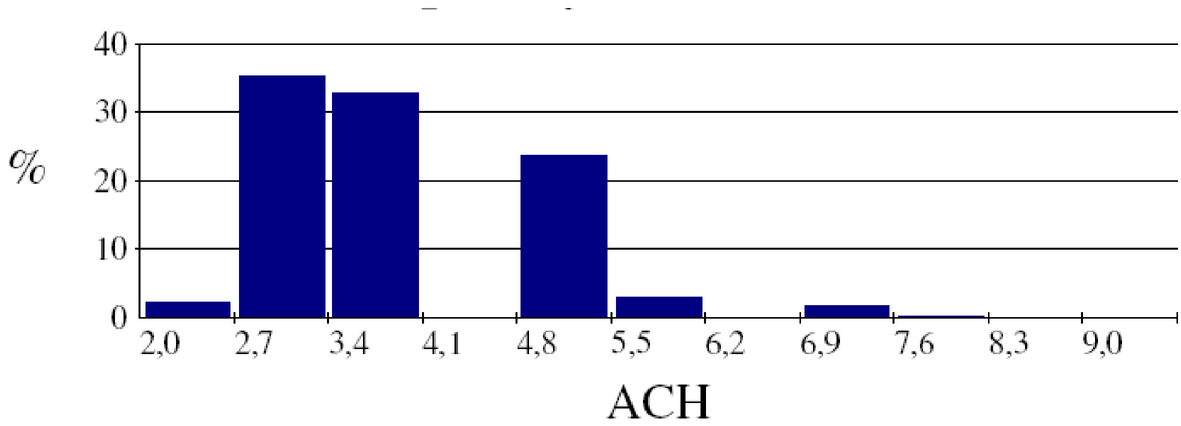
Table 17: Applied values for C_p and C_d

[90]The pressure coefficient in general is a dimensionless number which describes the relative pressures throughout a flow field in fluid dynamics. In the case of a flow hitting a building's façade, this coefficient varies with the flow's angle of attack and the relative position in the façade.

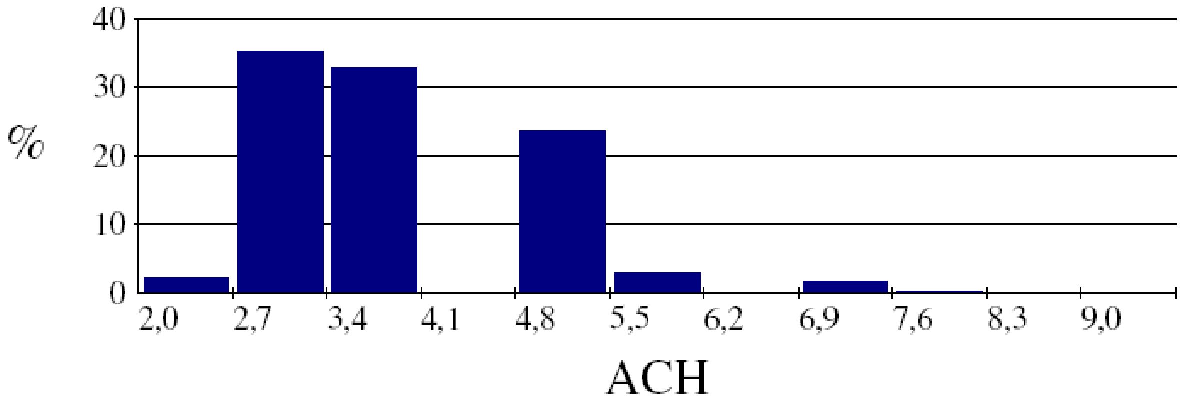
[91]The discharge coefficient is the ratio of the mass flow rate at an opening to that of an ideal opening.

[92]Allard, Francis; Santamouris, Mat; Alvarez, Servando (2002): Natural ventilation in buildings. A design handbook. Reprint. London: James & James, page 53 & 100

The application of these framework conditions revealed that remarkable air change rates are likely to arise from outdoor wind induction. At the same time, the obtained frequency distributions also indicate the limits of application: although air change rates of up to 4,8 ach are to be expected for approximately 80% of the time, there are some hours during the investigated month, that display minor air changes. Should they occur during hours of highest loads, these reduced air change rates are to be implicated, hence presenting a worst case scenario.



Graph 134: Frequency distribution of achievable air change rates due to natural ventilation for ONB s12 (nocturnal ventilation), wind direction West



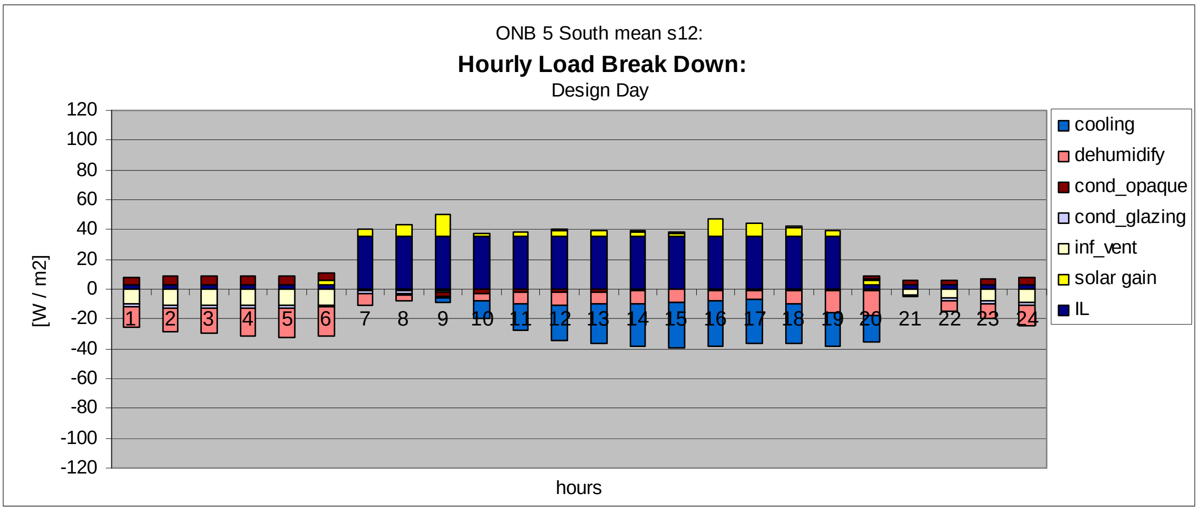
Graph 135: Frequency distribution of achievable air change rates due to natural ventilation for ONB s12 (nocturnal ventilation; see Table 18, page 154), wind direction South

The nocturnal air change rates thus generated were applied to the simulation of the reference room under steady state conditions. The comparison with the hourly load break-down of the base scenario clearly shows the difference in ventilation applied: taking use of the cool night time air, heat is discharged during non-office hours whilst windows remain closed during day time. Unfortunately, night time cooling is not sufficient for positive effects on the daytime temperature course.

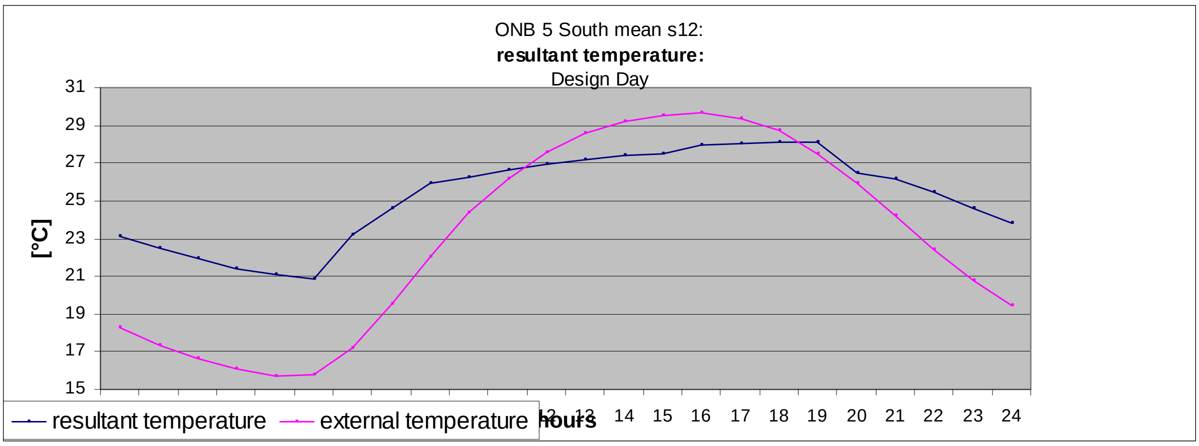
Although increased discharging of heat stored in external walls is visible in Graph 136: Hourly gains and losses for ONB s12 (nocturnal ventilation; see Table 18, page 154) , page 153) as compared to Graph 132: Hourly gains and losses for ONB base (sample room 5th floor, facing South) , page 150) this does not significantly increase these walls' capacity to dampen heat peaks during the following day. As long as ventilation is absent in the cool morning hours, indoor temperature rises quicker than in the base scenario and improvements remain insignificant.

Generally speaking, it has to be stated that the rather inferior heat capacity of air (as compared to water) makes it impossible for this medium to discharge higher amounts of heat, which has been stored during the day, even if high air change rates are applied. By any means, the internal loads encountered in this building clearly outweigh ventilation heat losses.

The applied steady state portrays a day at the end of a heat wave, which has seen 15 days of identical conditions. This means that heat, discharged at night, is regularly recharged by daytime heat. This represents severe conditions.



Graph 136: Hourly gains and losses for ONB s12 (nocturnal ventilation; see Table 18, page 154)



Graph 137: Temperature course for ONB s12 (nocturnal ventilation; see Table 18, page 154)

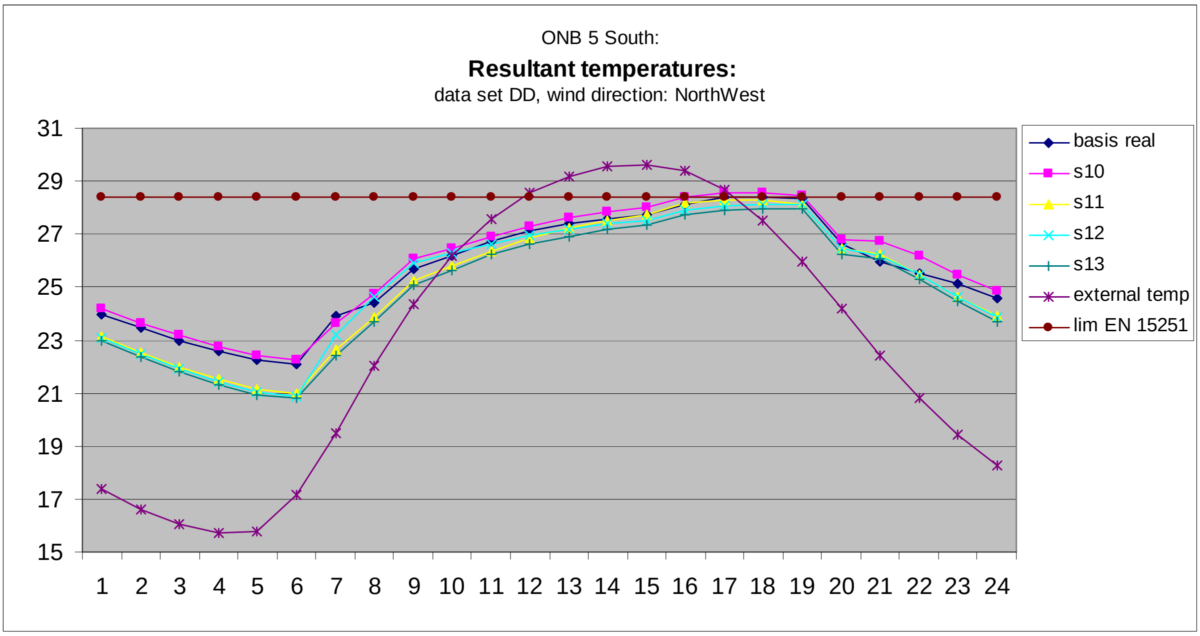
8.7.2.3 Analysis and optimization

Further ventilation schedules were simulated under steady state conditions:

Ventilation schedule denomination	Window opening hours	Description
Basis real	depending on external temperature	Window opens when external temperatures range between 18 and 26°C
s10:	6:00 am to 7:00 pm	daytime ventilation
s11	0:00 am to 12:00 pm	constant ventilation
s12	8:00 pm to 06:00 am	nocturnal ventilation
s13	8:00 pm to 10:00 am	extended nocturnal ventilation

Table 18: Natural ventilation schedules' definition

For all of these schedules achievable air change rates were determined beforehand and applied in thermal simulation. This led to the following results during the course of day:



Graph 138: Analysis of temperature courses for ONB

0:00 – 6:00 am:
Windows are closed in base scenario and s10 due to the absence of users, temperatures are therefore higher than in nocturnal ventilation scenarios s12 and s13.

6:00 – 10:00 am
Windows are opened in base scenario as outdoor temperatures range between 18 and 26°C. The indoor temperature experiences a slight deflection due to stack effect by cooler outdoor air.

Windows are likewise open in s10 due to the presence of users; in contrast to base scenario, only wind induced air change rates are applied in s10; this is why s10 sees hardly any deflection in temperature rise.

In s11, windows remain open constantly; starting from lower nocturnal values, this schedule's temperature course remains low due to chilly morning air.

Windows are shut in s12 during this period, thereby causing a rise in the room's temperature.

10:00 am – 1:00 pm
Outdoor temperature surpasses 26°C, thus triggering window closing in the base scenario. In this phase, windows are shut in base scenario and s12, while they remain open in s10 and s11. The temperature courses of the former pair therefore run almost simultaneously, while the latter ones' approximate continuously. At 1:00 pm – 3 hours after windows have been closed in base scenario – outside air intrusion yields higher temperatures in s11 than can be found when windows are shut.
Anyhow, for all applied schedules indoor temperatures start surpassing 27°C, the temperature limit according to ÖNORM 8110-3.

1:00 – 4:00 pm
Temperature courses of all schedules remain roughly unchanged in relation to each other.

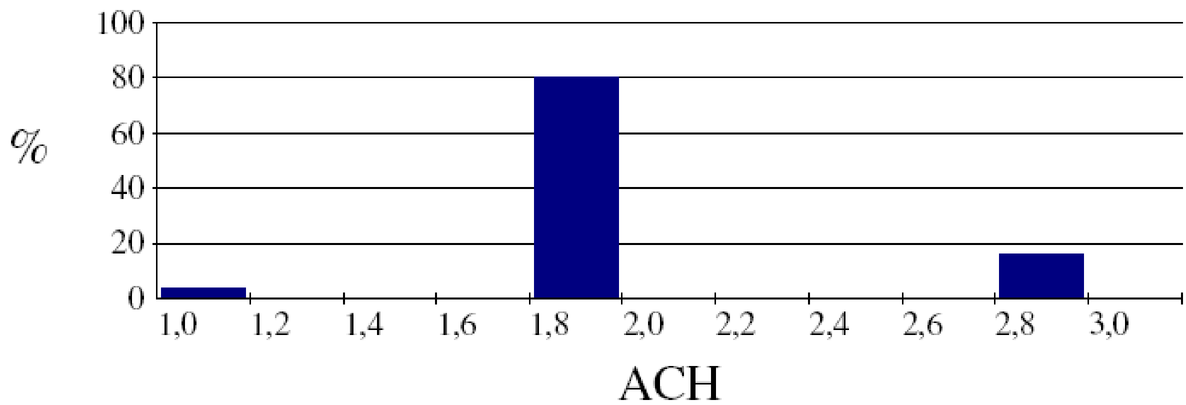
4:00 – 7:00 pm
Comfort temperature limit acc. EN 15251 is surpassed with windows opened under s10. Similarly, the temperature course under s11 touches this limit without surpassing it. It may be assumed that reserves gained during night time hours make up for the difference here, though ranging in the magnitude of a tenth part of 1K.
While outdoor temperatures are on the decline since 4:00 pm, indoor temperatures generally start falling only 2 hours later. At this point of time, outdoor values have already fallen below those inside.

7:00 – 8:00 pm
Last users finish work and switch off equipment as well as lighting, thus causing a sharp fall in indoor temperatures below the 27°C threshold, though these still

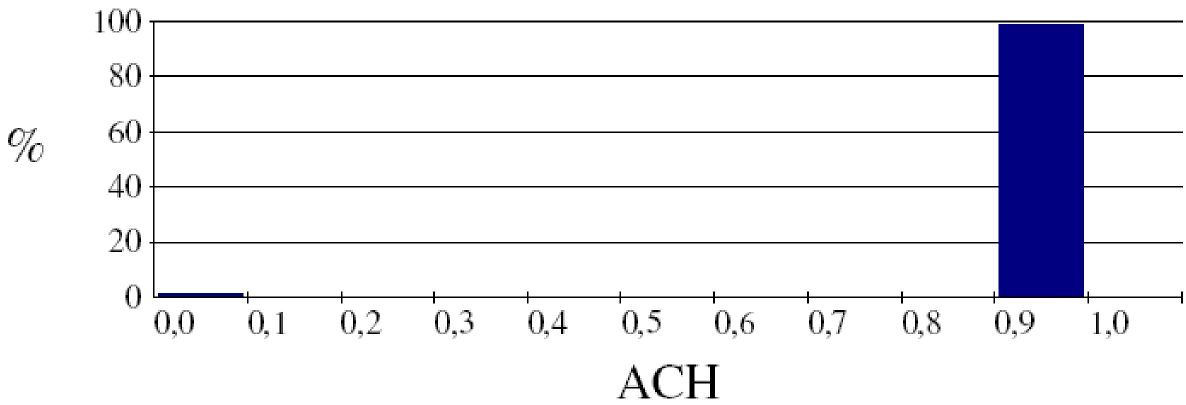
remain remarkably high. Altogether, this comfort limit is over-run for at least 6 hours in all variants. In contrast, the comfort limit acc. EN 15251 is generally kept by all variants.
During this hour, only s11 displays open windows, resulting in its temperature course to drop to those of s12 and base scenario. In the latter one, windows remain closed as external temperature still exceeds 26°C.

8:00 – 12:00 pm
The internal temperature drop generally slows down as nearly all internal loads have already been removed. Schedule s10 is the only variant with openings closed during this the whole period – a fact, which clearly yields elevated temperatures as compared to the other variants.

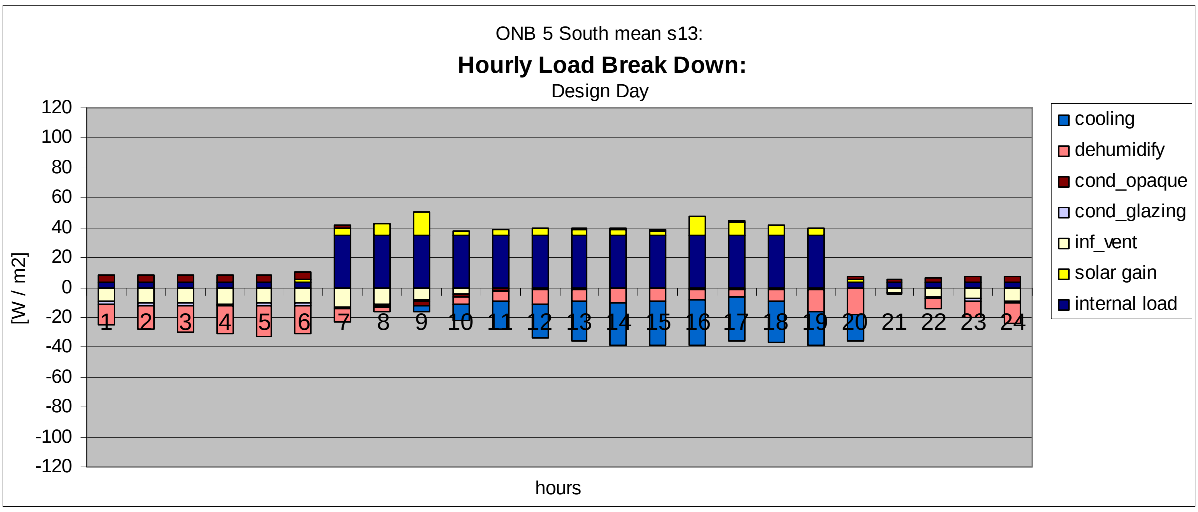
Schedule s13
On basis of the above analysis of hourly temperature courses in dependency on ventilation strategies the schedule s13 was created. It was found that base scenario profited from morning stack effect due to chilly morning air, while s12 takes advantage of cold nocturnal outside conditions. Both slightly decrease indoor temperature by window closing during hot day time hours. Schedule s13 therefore forms a synthesis of these two approaches: it largely uses nocturnal ventilation but likewise harnesses cool morning hours until 10:00 am. During hot hours, windows remain closed under s13. In conclusion, s13 displays the most favourable temperatures of all variants through out the day. This is possible even with minor air change rates encountered during the opening period:



Graph 139: Frequency distribution of achievable air change rates due to natural ventilation for ONB s13 (extended nocturnal ventilation), wind direction West



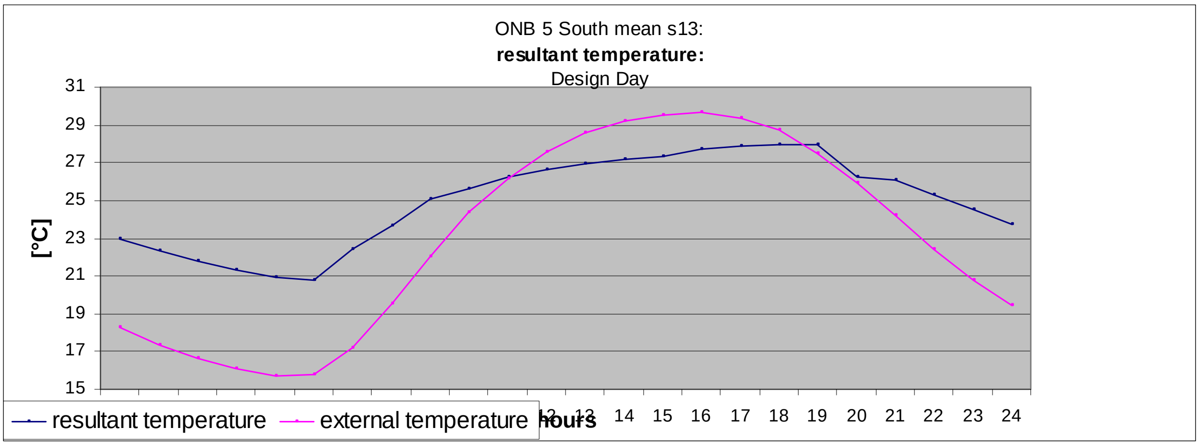
Graph 140: Frequency distribution of achievable air change rates due to natural ventilation for ONB s13 (extended nocturnal ventilation), wind direction South



Graph 141: Hourly gains and losses for ONB s13 (extended nocturnal ventilation)

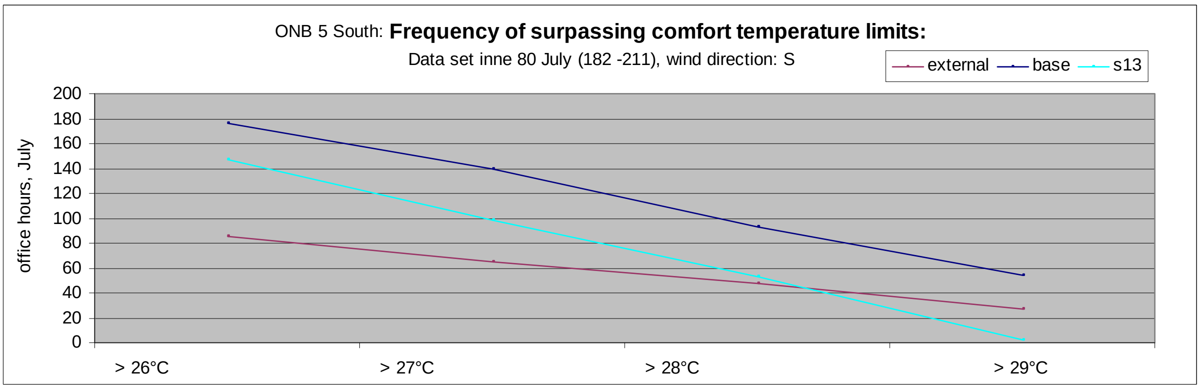
The analysis of s13's hourly load-break down under steady state reveals a – limited - potential to harness nocturnal ventilation losses for improved comfort conditions during the hottest hours. Still, it has to be kept in mind:

- the improvements range in the magnitude of a few tenth of 1K only
- these results are obtained under steady state conditions, which implies that they represent the buildings performance under severe conditions of a prolonged heat wave with all heat storage recurrently charged every day
- the energy demand for mechanical ventilation remains unchanged



Graph 142: Temperature course for ONB s13 (extended nocturnal ventilation)

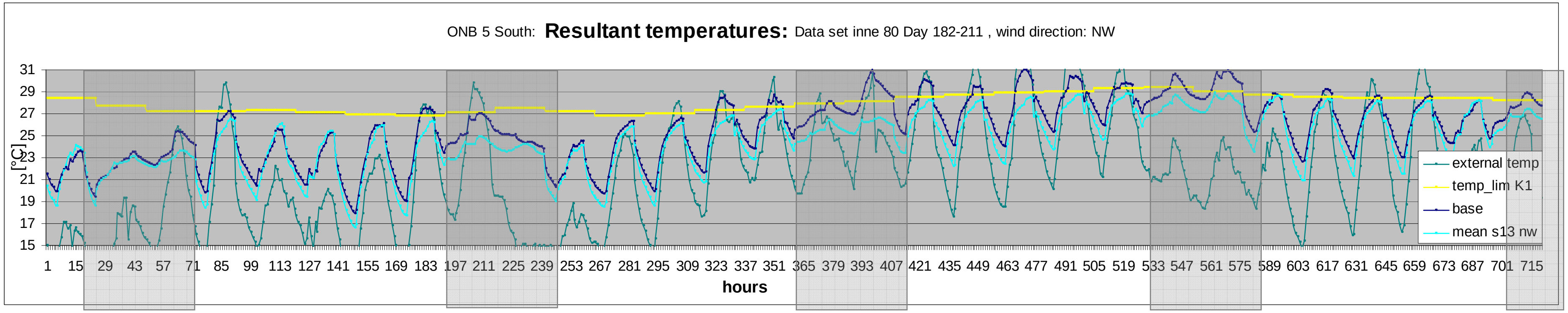
Schedule s13 has been applied to the reference room under the conditions of climate data set "inne 80" for July (day 182 – 211). In comparison with the base scenario this results in a decrease of office hours[93] during which certain comfort temperature limits are surpassed by indoor resultant temperature.



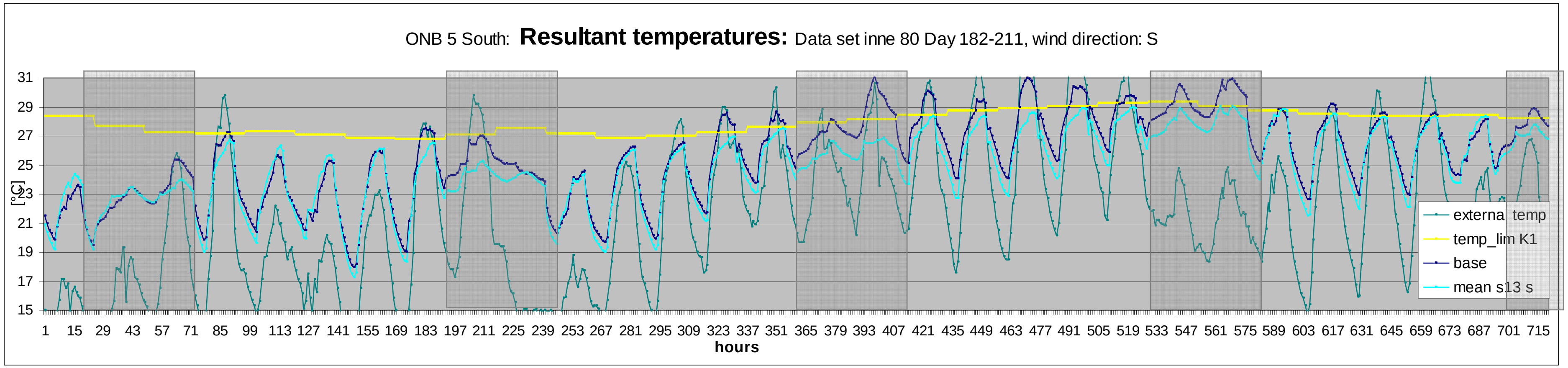
Graph 143: Number of hours during which temperature limits are surpassed in ONB under base and s13 (extended nocturnal ventilation) respective

The temperature course of both variants documents comparatively high values, with the important distinction that the one of s13 remains under the limits of EN 15251 for buildings of the most demanding category (K1). It has to be stressed that this is also possible with Southern winds of reduced speed and thus reduced indoor air change rates. At the same time, it remains clear that these results are to be regarded as analysis of improvement potential only, as they rely on rather schematic wind analysis. For more reliable statements, in-depth investigation of the micro scale wind environment by means of CFD are required.

[93] Weekends were not at all investigated



Graph 144: Resultant temperature courses in ONB under base and s13 (extended nocturnal ventilation), wind direction North West; weekends are shaded in grey;



Graph 145: Resultant temperature courses in ONB under base and s13 (extended nocturnal ventilation), wind direction South; weekends are shaded in grey;

8.7.2.4 Mechanical Ventilation

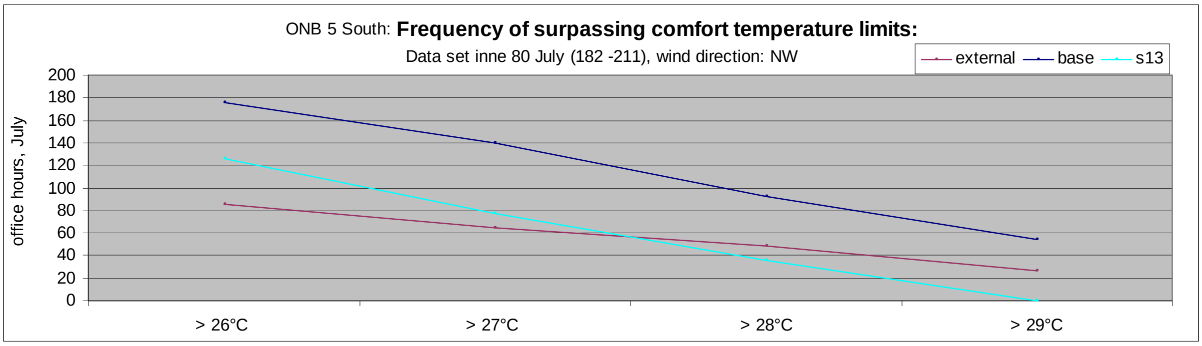
In this section, impacts of mechanical ventilation in terms of energy demand are investigated.

Natural ventilation strongly relies on local wind environments which are difficult to predict in detail. Thus, while holding the potential of offering comfort improvement free of energy demand, natural ventilation incorporates the risk of not occurring due to still air at the moment of most uncomfortable outdoor conditions.

In contrast, mechanical ventilation, due to its reliance on constant energy supply, is always readily available and controllable in its magnitude.

Thus, improvements in terms of comfort conditions, which would be achievable by the appliance of mechanical ventilation but not by the natural ventilation strategies presented above, were investigated therefore.

As has been stated before, the base scenario employed as a reference here already includes mechanical ventilation, which provides hygienically determined air change rates. That is why the variant presented hereafter constitutes of an additional air change. This air change was assumed to be 3 ach. In allusion to s13, it was applied during extended night time hours (8:00 pm – 10:00 am). Minor heat gains due to mechanical heat generated by ventilation fans were not taken into account.



Graph 146: Number of hours during which temperature limits are surpassed in ONB under base and mechanical ventilation respectively

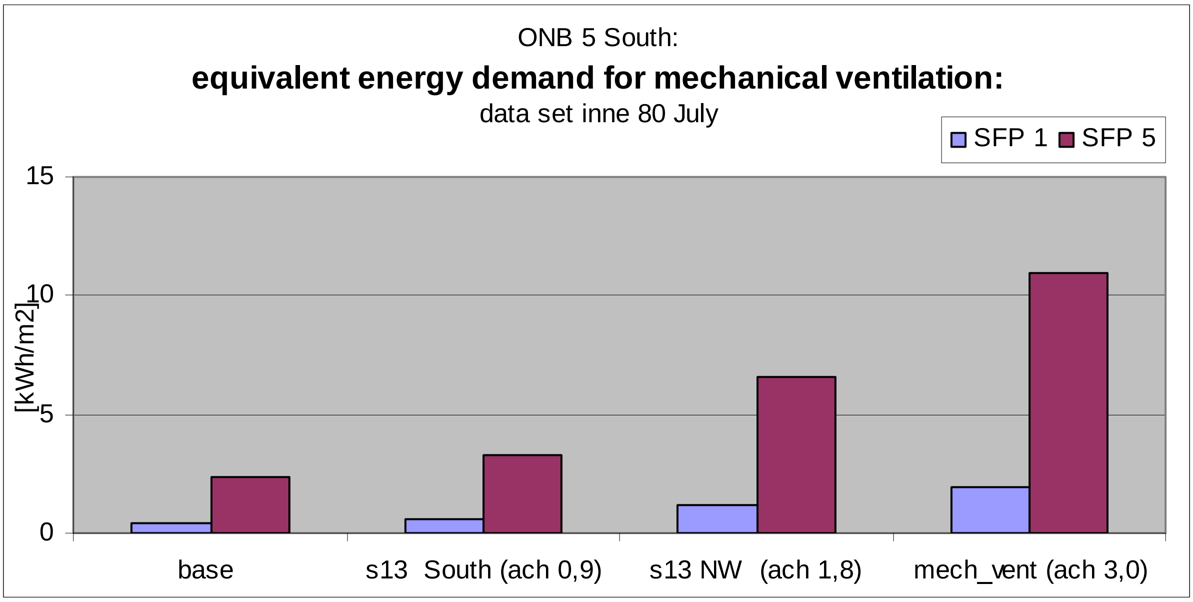
The results show that, while s13 displayed a reduction of surpassing hours (s. Graph 143, page 158) between 16% (for hours > 26°C) and 96% (for hours > 29°C), the reductions due to mechanical ventilation account for 28% to 100%.

8.7.2.5 Energy demand and savings

The comfort improvements due to mechanical ventilation have to be paid for by energy costs for running the ventilation fans. The amount of energy in question strongly depends upon the energy efficiency of these fans. EN 13779 identifies five different categories of energy efficiency (SFP 1 to SFP 5).

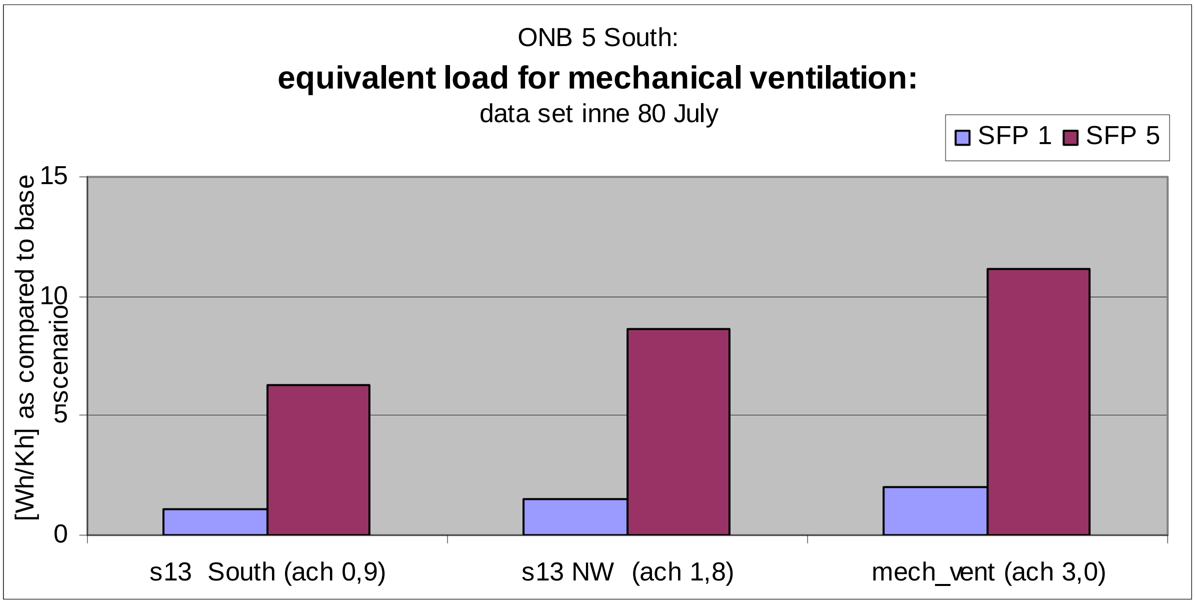
This categorization has been employed to assess the energy demand for mechanical ventilation as well as the energy savings by application of natural ventilation. Again, these calculations do not take into account the energy demand of the mechanical ventilation which provides the ventilation rate necessary for hygienic reasons, as this is contained in all variants.

The following graph depicts the energy demand that will arise if air change rates induced by natural ventilation are instead provided by mechanical ventilation. This energy will not be consumed in case of natural ventilation; in this case it has to be regarded as saving and is therefore marked accordingly. In contrast, mechanical ventilation for surplus air change to safeguard thermal comfort effectively produced energy demand.



Graph 147: Energy demand which would arise would natural ventilation be replaced by mechanical ventilation under different levels of energy efficiency of ventilation fans

The same methodology is used to evaluate the surplus energy demand per unit of comfort improvement: as such, the demand per 1K of indoor temperature reduction and hour was established and the following values calculated for both natural and mechanical ventilation; herein, the base scenario serves as reference to which temperature decreases are calculated.



Graph 148: Energy demand which would arise would natural ventilation be replaced by mechanical ventilation under different levels of energy efficiency of ventilation fans

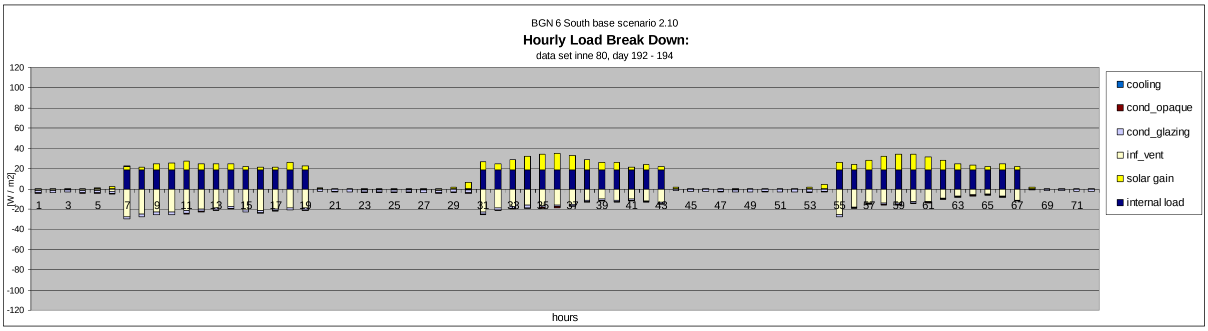
8.7.2.6 BGN

If conditions in ONB had already been near to uncomfortable they are even more unpleasant in BGN. Contrary to ONB this building is neither equipped with a mechanical ventilation system for hygienic air supply nor with any cooling device. Both these amenities have to be rendered by window opening only.

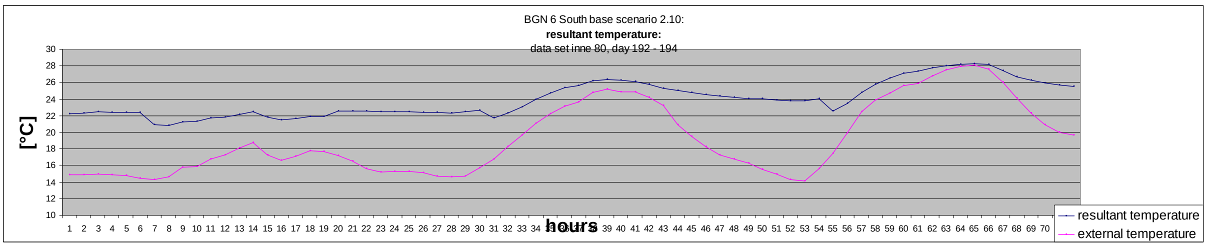
To further worsen conditions, BGN displays no external shading. Instead, blinds are installed in the spces between the twofold glazing. At the same time internal loads due to lightning, occupancy and equipment fall within usual ranges.

The following hourly load break-down for three days of moderate conditions out of climate data set "inne 80" demonstrate the mentioned effects: in the presence of substantial external solar radiation (days 193, 194) high internal solar gains are registered even though the shading devices are already activated already during morning hours.

Natural ventilation has to be regarded as optimized to a great extent: as indoor temperatures constantly range above external ones, it makes sense to keep the window open all day long. This actually appears to be a pure necessity in order to keep temperatures below 30°C. In a way, the unfortunate conditions somehow force the building's users to employ the few applicable devices in the best possible manner.

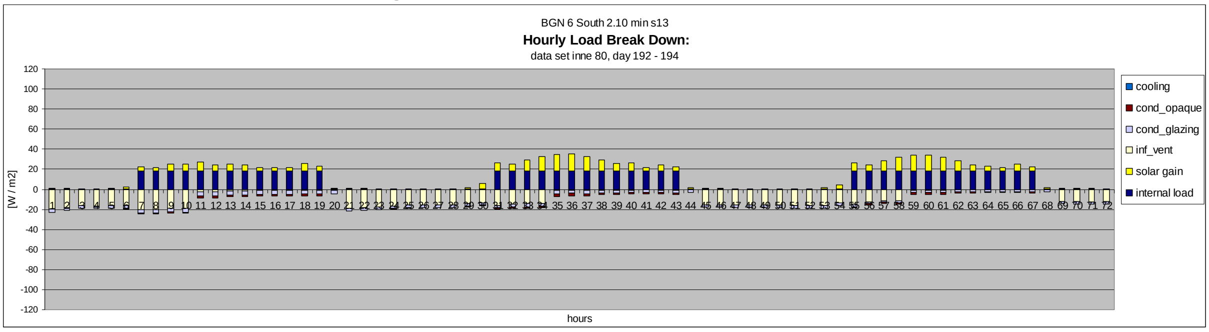


Graph 149: Hourly gains and losses for BGN base

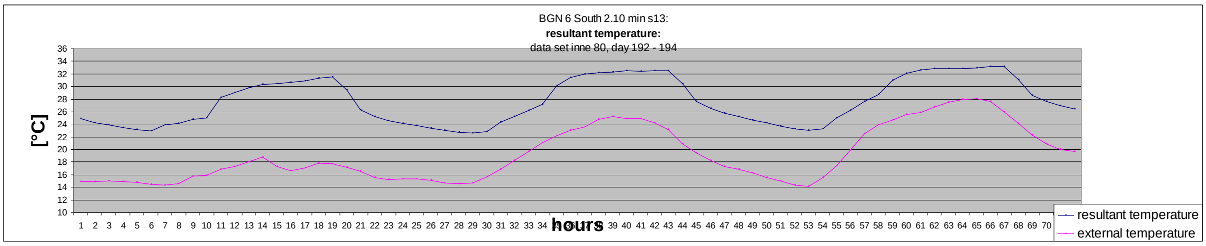


Graph 150: Temperature course for BGN base

The reason why nocturnal ventilation (s13) will not alleviate the comfort conditions in the building can be deduced from the graphical analysis: the construction's thermal behaviour proves unapt to transfer night time heat losses to hot office hours, while at the same time closed windows during the day are counterproductive in terms of comfort. Under s13, indoor temperature would dramatically increases under the application of extended nocturnal ventilation and closed windows during daytime.



Graph 151: Hourly gains and losses for BGN s13 (extended nocturnal ventilation)

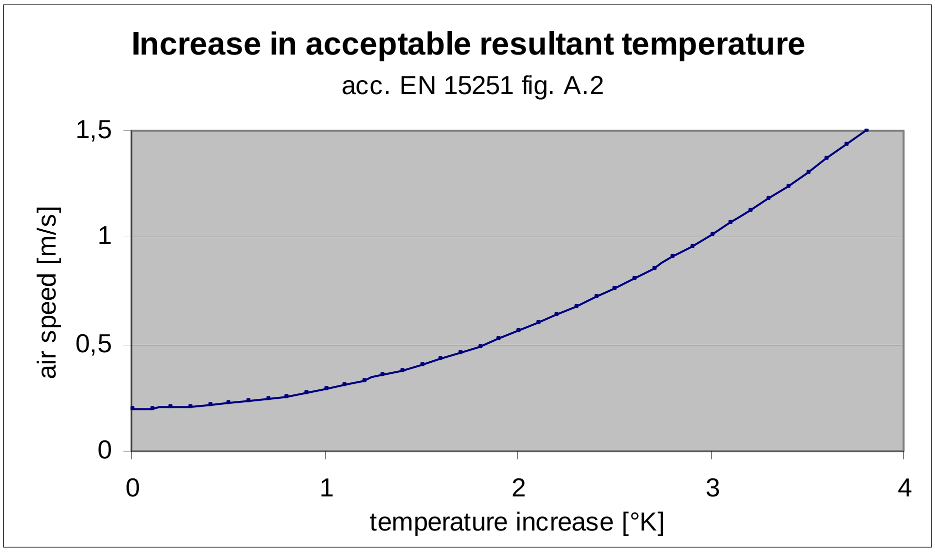


Graph 152: Temperature course for BGN under s13 (extended nocturnal ventilation and closed windows during daytime)

In conclusion, it has to be stated that the margin of comfort amendment is fairly limited in BGN unless measures are taken further upstream in the design process:

- better shading devices, especially placed externally
- glazing with sun protective properties
- reduced internal loads
- improved thermal mass, if applicable in an existent building
- active cooling, at least in the form of cooled mechanical ventilation

Even though ventilation can not be improved in terms of actual decrease in resultant indoor temperature, EN 15251 describes the positive effects that air movement in rooms may have on the comfort sensation of users: the higher the air speed the more the comfort limit can be elevated according to the following chart because air movement increases sweat condensation on human skin and thereby reduces heat sensation.

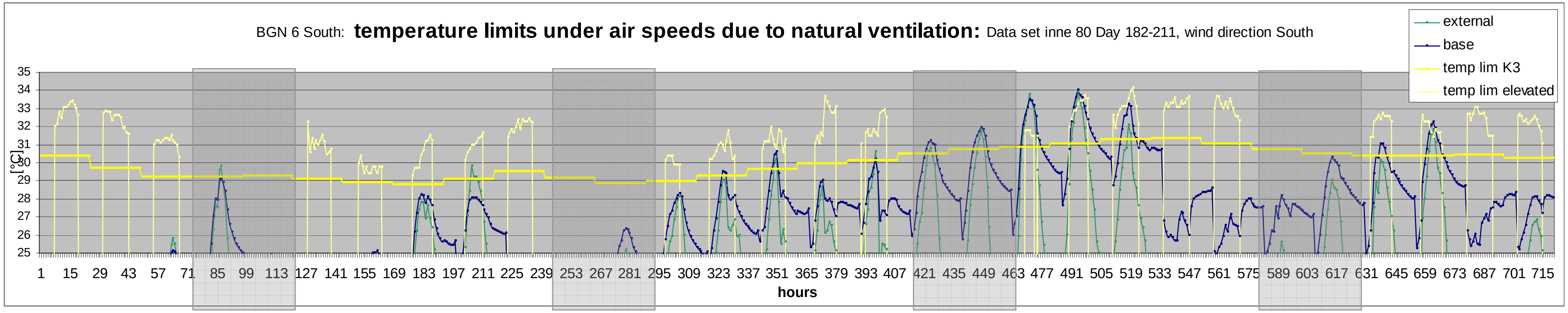


Graph 153: Increase in acceptable resultant temperature in dependence of air speed

EN 15251 proposes to achieve the required air movement by means of desktop fans, attributed to a single workplace each. Air movement induced by the outside wind environment is not particularly mentioned as a possible source, still, simulation of this environment allows for the consideration of wind as a source of indoor air movement.

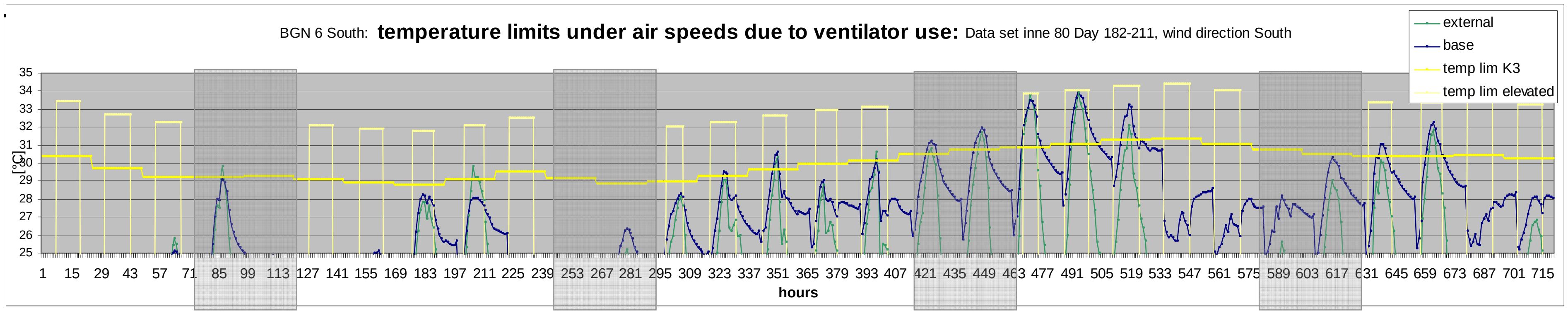
A rough estimation of possible indoor air speeds under the outside wind conditions is thus needed. This calculation was conducted according to literature indications and under the assumption of unobstructed, completely opened windows (which might prove difficult to obtain under working conditions). For details of this calculation see Appendix 10.1 Rough estimation of possible indoor air speeds under the outside wind conditions, page191).

The appliance of the wind speeds thus calculated allows for the determination of an elevated comfort limit according to the indications of EN 15251 (see Graph 153, page 165 of the present study) and results in the following temperature limits for July of climate data set "inne 80".



Graph 154: Temperature limits due to wind induced air speed (acc. EN 15251) and outside temperature course

The investigation of temperature course in a reference room in 6th floor, orientation South, shows that comfort limits are surpassed only for a few working hours for the applicable building category K3 ("moderate range of expectations from users' side, applicable for existent buildings").



Graph 155: Temperature limits due to fan induced air speed (acc. EN 15251) and outside temperature course

As indicated by EN 15251, indoor air speed can be provided by ceiling or desktop fans. Customary products display achievable air speeds ranging from 0,9 to 2,4 m/s. As high air speeds may inhibit efficient office work an average air speed of 1m/s was assumed and the resulting elevated comfort limits calculated. The results turn out to be comparable to those of wind induced air speed, though lying on the safer side in terms of safeguarding limits for comfort sensations

From Graph 151 it is clearly visible that fans would only be needed for a limited number of hours per day only. If these devices are switched on whenever indoor temperatures exceed outdoor ones this will results in an overall additional energy demand of 0,04 kWh/m^2 for a double-occupancy office room within the investigated month of July.

8.7.3 Discussion

As has been stressed before, all results presented here in respect to achievable air change rates and air speeds have to be regarded as estimates of possible orders of magnitude only.

This is due to the fact that a missing link of information separates regional wind data (as collected at weather stations such as “inne” for Vienna’s CBD) from thermal conditions inside buildings: while they are both equally assessable, the former’s influence on the latter’s air change rates and air speeds can only be deduced via the knowledge of the local wind environment at micro scale. This, however, is influenced by a broad range of complex factors, including the configuration of neighbouring buildings, the thermal behaviour of their external surfaces to the presences (or absence) of fresh air aisles.

Prolonged CFD simulations of the neighbouring situation are therefore required should ventilation potentials be assessed with higher certitude. Even though, such assessments would always remain limited to the particular situation of the single building investigated, as no two buildings reside in entirely comparable settings.

The investigation undertaken here therefore aimed at demonstrating an assessment processes and its likely results. It could be demonstrated that different optimization strategies are successful in different buildings in terms of comfort. The improvements realized here could not simply be converted into energy savings in simulations under mode “Standard” as has been done in the previous module of this study.

Applying increased air change rates to buildings, which’s temperature is kept within comfort range under mode “Standard”, controversially increases cooling demand, as this signifies to allow for the intrusion of hotter outdoor air into cooled indoor spaces.

8.7.4 Conclusions

It was demonstrated that wind induced air change is able to improve the comfort condition in a building with limited cooling supply (cooled air in mechanical ventilation system only); this however faces two limitations:

- Outdoor wind conditions vary; if indoor air conditions are linked to them, they likewise are subject to constantly changing wind speeds and directions. Hence, natural ventilation remains a "ventilation strategy by chance"

- Liability issues have to be addressed: natural ventilation strategies demand for opening windows during night time. As this time of the day in office blocks coincides with the absence of users and hence of social control, risk of theft and burglary may increase. It remains to be discussed under a broader focus, whether this holds the potential (but also bears the costs) of new job profiles in the sense of nocturnal watchmen.

The situation in office blocks devoid of any cooling device was shown to be demanding, especially if powerful load reduction in form of external shading, thermal mass and low internal loads are missing. In these cases, indoor air speeds present possible means of alleviation in temperature sensation. Indoor air speeds may be rendered by admitting outdoor wind or by the appliance of ceiling and desktop fans. Energy consumption of the latter is evident, but minor.

8.8 Module 8: Economic assessment on impacts of optimization strategies

Principles of sustainable building have it that constructions and equipment should not only respond to ecological demands but also yield economic feasibility. Keeping this requirement in mind, an economic assessment of the optimization strategies discussed above has been undertaken here. This, however, does not include an economic assessment of measures to be undertaken in the building envelope since such investigations have been rendered in abundance in respective studies[94] and economic feasibility analysis forms part of the conventional preparation work for mayor refurbishment projects, even though the effects of climate change currently do not normally play a prominent part in such calculations.

8.8.1 Applied approaches of investigation

Therefore, only results of Module 5 and 7 of this study underwent economic assessment here. Due to the nature of the results obtained in the aforementioned modules, two different approaches were applied:

- In **Module 5** the comparison of four different levels of energy efficiency in IT-equipment and lighting had revealed corresponding levels of demand in cooling energy. Thus, a reduced life cycle model for a standardized cooling plant was implemented to demonstrate achievable reductions in annual costs for investment, consumption and operation.

- This method could not equally be employed for the assessment of the impacts of natural ventilation. In the corresponding **Module 7** of this study, these impacts had been calculated in terms of reducing working hours that display indoor temperatures beyond comfort limits.

Literature on the topic clearly reveals links between increased temperature and workers' reduced productivity[95]. Dwelling on this fact, the present study demonstrates the increase in time required by employees to fulfil equal tasks under less comfortable conditions. This provides a clue for the calculation of the amount of wage payments paid for unproductive time due to overheating.

[94] For samples of such well documented studies refer to the data bases available under www.passiv.de and www.hausderzukunft.at

[95] Seppänen, Olli; Fisk, William; Faulkner, David (2003)

The described twofold approach for economic assessment also differs in the period of time investigated: While the impacts of different levels of internal load were investigated for all sample buildings for a complete year, the in-depth simulation on natural ventilation concentrated on one single summer month in sample building ONB which displays serious comfort deficits already today and was therefore simulated under mode “real”. No improvements had been proven achievable in BGN by means of natural ventilation; therefore no economic assessment was possible for this sample building.

8.8.2 Applied tools

The impacts of different levels of internal load were investigated by a life cycle model for a standardized cooling plant. This model was based on VDI 2067[96] which describes profitability calculations using the annuity method. Herein, annual costs for investment, consumption and operation are accounted for during a chosen observation period of 50 years for the entire building and 15 years for the cooling plant respectively.

Several cost related indices were derived from available statistics and literature[97]. The provenience of the chosen values is documented in chapter 10.2 Economic Assessment: Provenience of calculation values, page192.

[96] VDI - Richtlinie, 2067, September 2000: Economic efficiency of building installations Fundamentals and economic calculation.

[97] See Appendix 10.2 Economic Assessment: Provenience of calculation values, page 192

	symbol	unit	value	remarks
capital related costs				
investment 1 premium max		EUR/ m2	290,73	investment 1: compression cooling system
investment 1 premium min		EUR/ m2	27,12	
investment 2 premium max		EUR/ m2	-	investment 2: IT equipment *)
investment 2 premium min		EUR/ m2	-	
index for regional price adaption		[%]	1,11	
factor for repairs investment 1	f K	[%]	0,02	
factor for repairs investment 2	f K	[%]	-	
price change factor investment 1	r	[%]	1,06	investment 1: compression cooling system
price change factor investment 2	r	[%]	-	investment 2: IT equipment
interest factor investment 1	q	[%]	1,03	investment 1: compression cooling system
interest factor investment 2	q	[%]	-	investment 2: IT equipment
observation period	T	[a]	50	
service life of installation component 1	T N1	[a]	15	investment 1: compression cooling system
service life of installation component 2	T N2	[a]	5	investment 2: IT equipment
consumption related costs				
annual price change factor f. consumption-related costs	r V	[%]	**1,04**	
degree of efficiency/ COP component 1	n	[%] / [-]	2,4	component 1: compression cooling system
degree of efficiency/ COP component 2	n	[%] / [-]	1	component 2: IT equipment
electricity price		[EUR/ kWh	0,17	
operation related costs				
effort on repairs and servicing		[%]	0,0125	
price-dynamic annuity factor for operation-related costs	ba B	[%]	1,01	
*) no extra expenses for energy efficient equipment assumed investment equally assumed as 0 for all variants				

Graph 156: Overview of all input parameters of life cycle model

Upper and lower limits for probable investment costs were derived from BKI[98]. This database contains processed and detailed cost data from existing, newly erected or refurbished buildings. Furthermore, an index to adapted prices to regional conditions is provided for Germany and Austria.

98 Kosten abgerechneter Bauwerke. Technische Gebäudeausrüstung (2006). Stuttgart: BKI (BKI ObjektdatenG1).

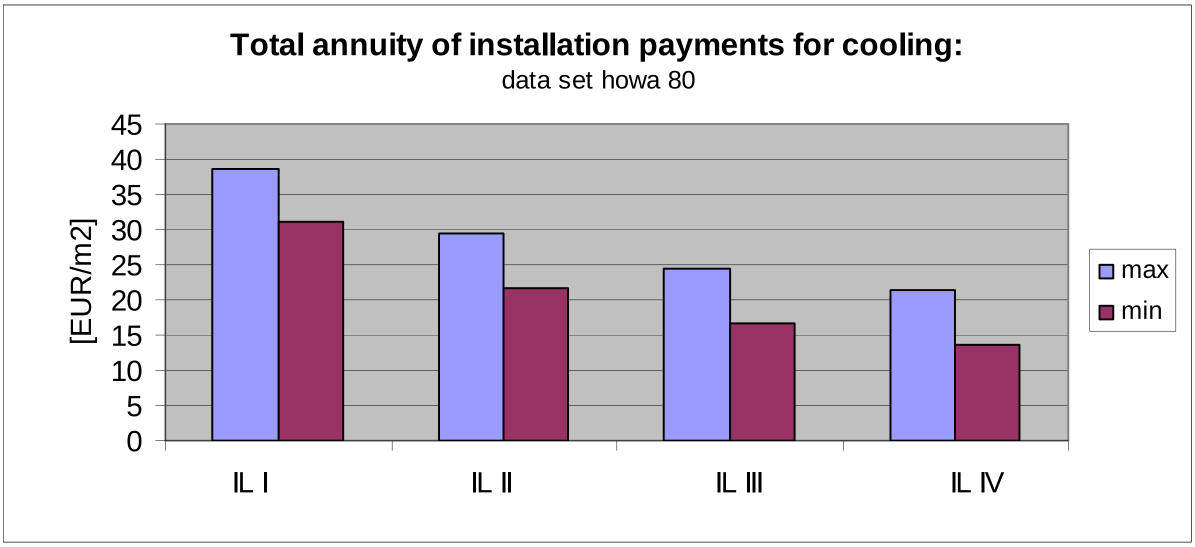
8.8.3 Results

8.8.3.1 Internal loads: assessment of economic impacts of reduction in energy consumption

As has been demonstrated above (see chapter 8.5: *Module 5: Impacts of different levels of internal loads*, page 120), reduced internal loads effectuate lower cooling energy consumption and reduced maximum cooling load. The first effect reduces running costs for energy demand, the latter allows for smaller plant size and thereby reduces investments.

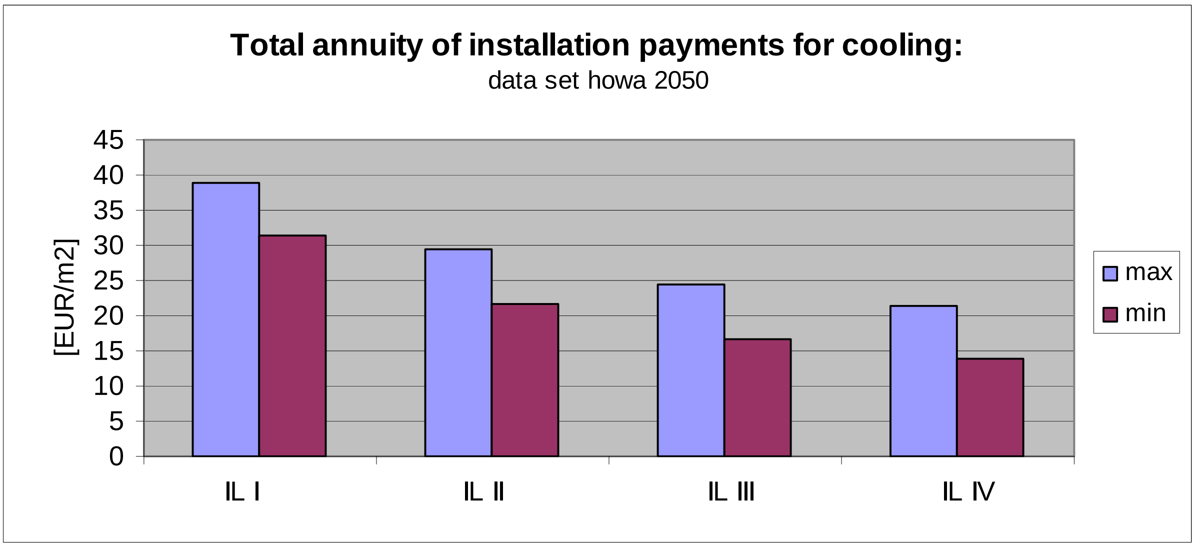
Only a few years ago, more efficient IT equipment and lighting demanded higher purchasing costs than standard devices. This, however, has gradually changed over the last decade, so that no more extra expenses can generally be detected for such equipment today[99]. Investments for this category therefore were assumed equal for all variants investigated and could hence be neglected in the life cycle model.

Increases in heating demand due to lower internal loads are not taken into account because higher energy efficiency in equipment should go along with improvements in the building's thermal shell. The calculation of the required scale of improvement and the related costs, however, were found to fall beyond the scope of this rough assessment. In this sense, the annuity surpluses generated by efficient equipment should be understood as a compensation range for refurbishment of the building's thermal envelop.



Graph 157: Ranges of total annuity of installation payments under different levels of internal load for data set "howa 80": values include annuities for investment, consumption and operation

[99] Berger, Tania (September 3, 2010)



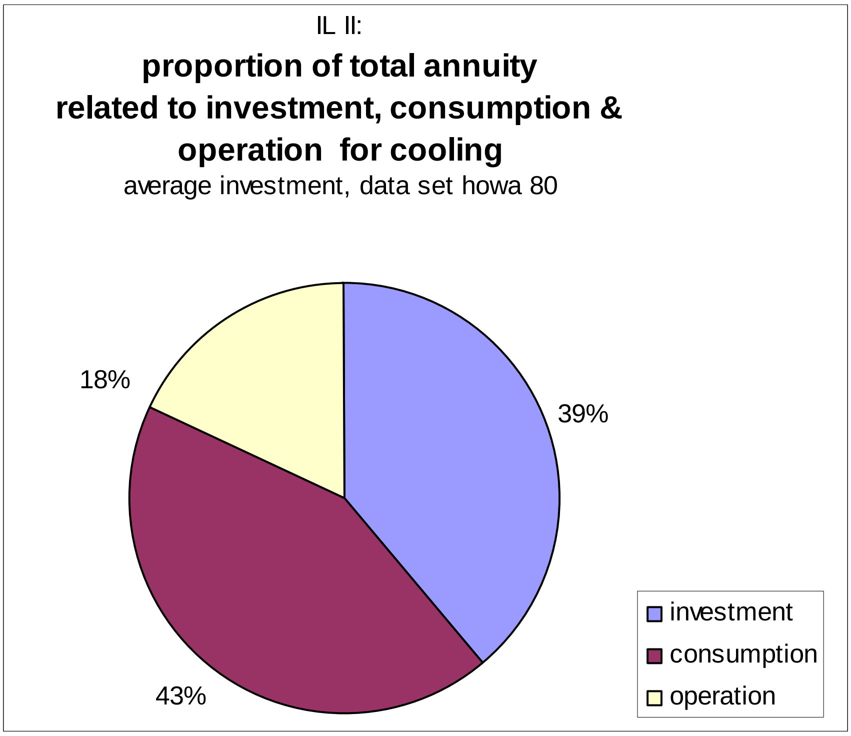
Graph 158: Ranges of total annuity of installation payments under different levels of internal load for data set "howa 2050": values include annuities for investment, consumption and operation

While the cost models reveal remarkable differences in annuity for the four applied levels of efficiency, the values remain roughly unchanged by influences of climate change. Thus, this observation, which could already be documented in terms of energy consumption, remains valid under the economic assessment, too.

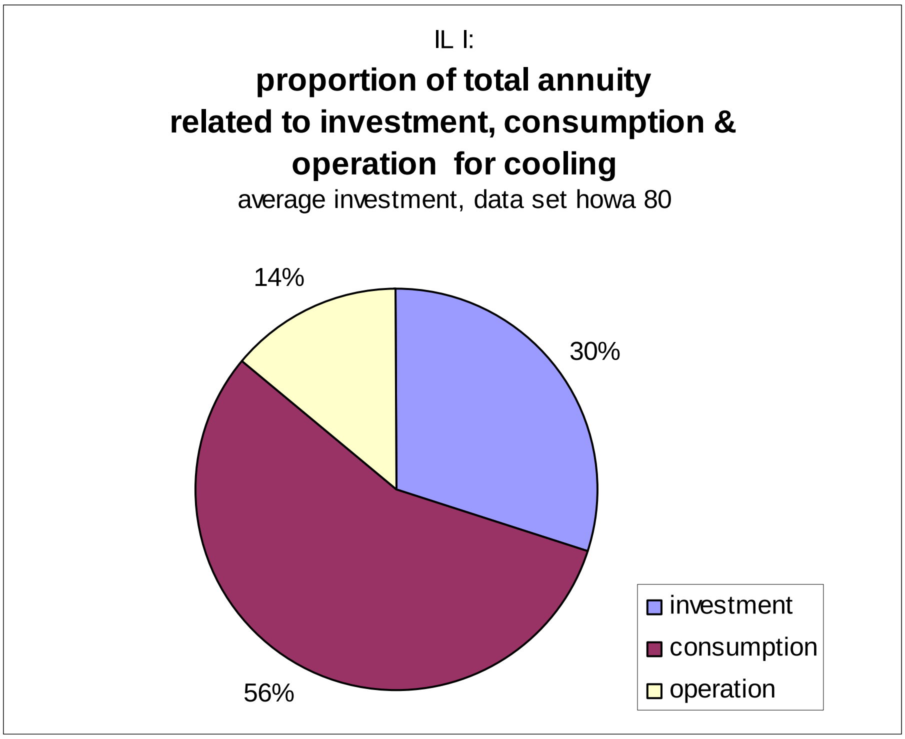
It had also been observed that climate change increases cooling energy demand rather than maximum cooling load. As the latter influences investment and operational costs differences between the two climate data sets applied are further diminished.

Finally, averaging the results of all sample buildings - some of which display minor sensitivity to climate change owing to their construction - furthermore reduces differences between climate data sets.

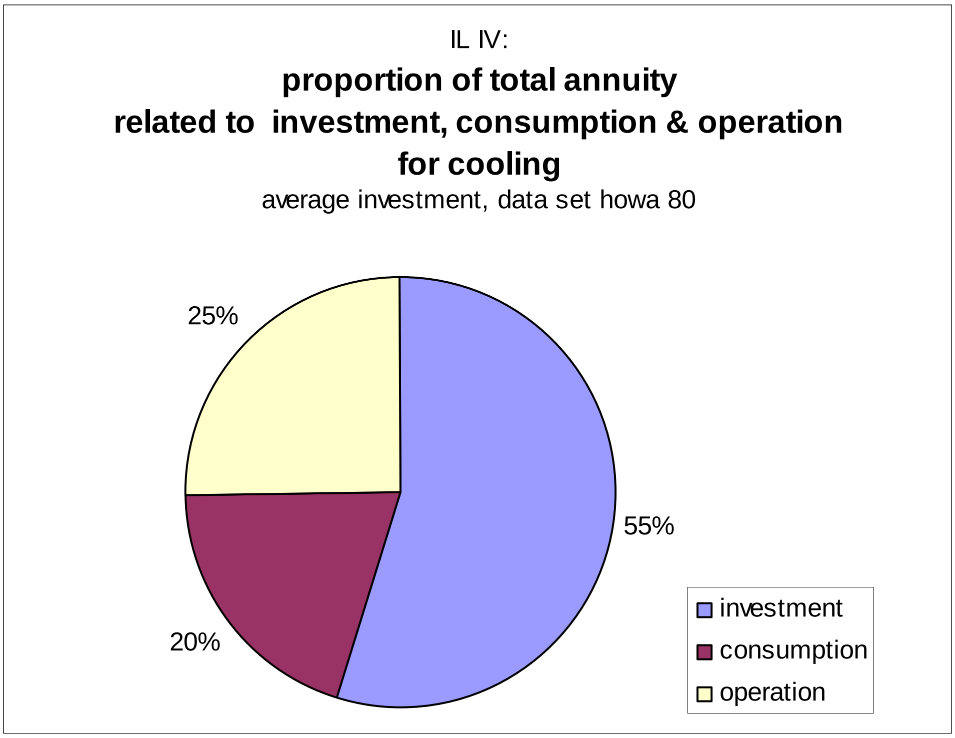
Comparing the proportions of cost fractions contributing most to the overall annuity clearly demonstrates the influence of energy efficiency in terms of IT equipment and lighting on both consumption-related and over all costs: While under the standard IL II consumption-related costs contribute by 52% to the overall annuity, this value drops down to only 27% for most efficient IL IV and surges to 65% for IL I.



Graph 159: Proportion of total annuity for standard energy efficiency in internal loads (IL II), all sample buildings



Graph 160: Proportion of total annuity for low energy efficiency in internal loads (IL I), all sample buildings



Graph 161: Proportion of total annuity for very high energy efficiency in internal loads, all sample buildings (IL IV)

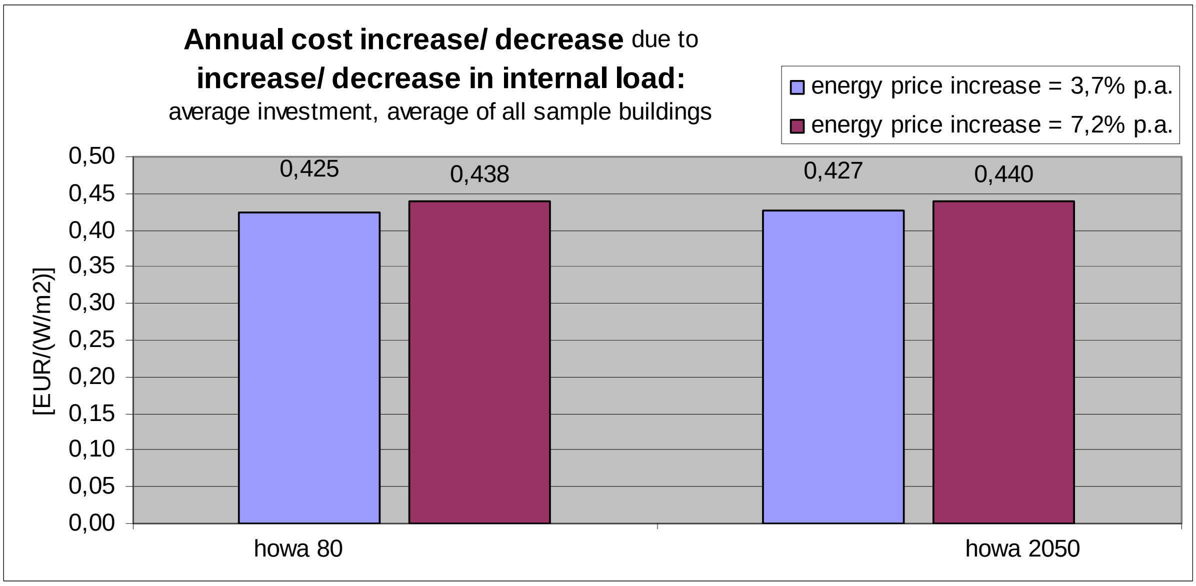
Relating differences in annuity to differences in cooling energy demand brings up figures for annuity reduction per Watt load reduction due to more efficient equipment.

Further developments of energy prices (denoted as "*annual price change factor for consumption related costs*") over the decades to come are frequently under debate. In life cycle cost models, this value plays a crucial part as it directly influences all consumption related costs. Therefore, two different assumptions were investigated for the overall annuity calculation:

Minimum assumption of energy price increase: 3,7% p.a.
Maximum assumption of energy price increase: 7,2 % p.a

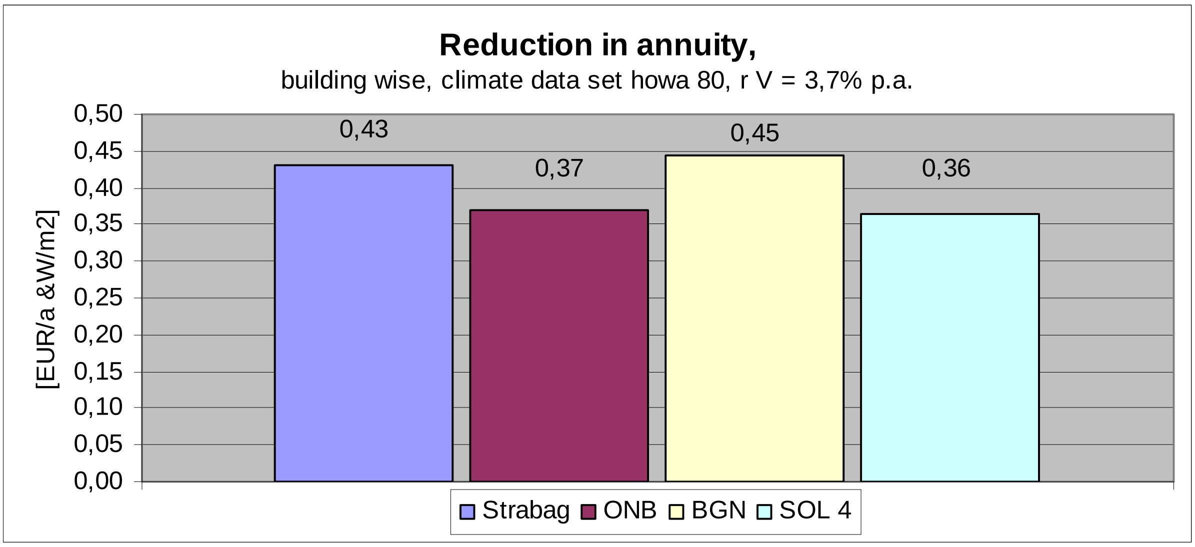
These two values were inserted for all sample buildings and climate data sets. The reductions in annuity for each climate data set and energy price index are equal, regardless whether minimum or maximum investment costs are considered.

The difference between minimum and maximum assumptions for energy price development range in Euro cents per square meter, while, again, differences between climate data sets remain barely perceivable.



Graph 162: Reductions in annuity for different climate data sets and assumptions on energy price increase

Reductions in annuity, however, do vary for different sample buildings; SOL 4 possesses the most insulated thermal building envelope and powerful shading devices; thus the potential for feasible improvement by means of more efficient equipment is least here. At the other end of the spectrum, Strabag is highly glazed and displays no exterior shading, which leaves a broader monetary range for optimization.

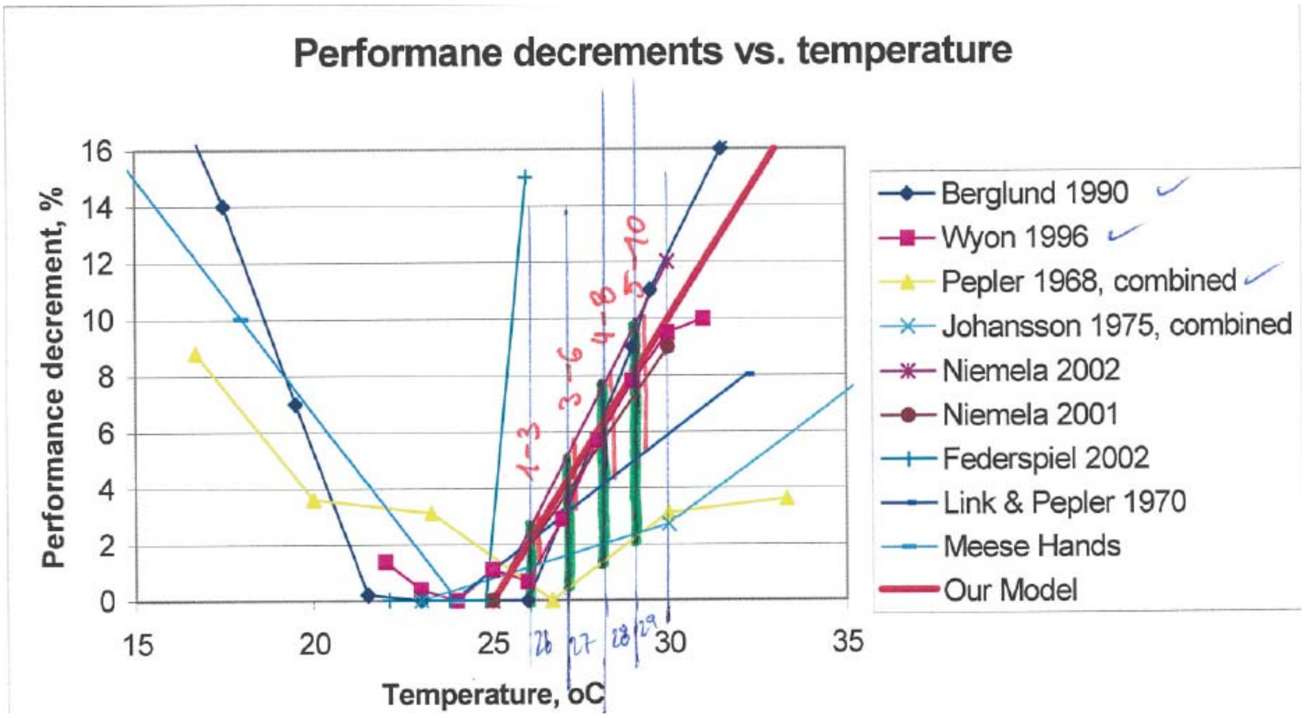


Graph 163: Reductions in annuity for sample buildings

8.8.3.2 Natural ventilation: assessment of economic impacts of reduction in surpassing comfort limits

In module 7 of this study, the impacts of natural ventilation on indoor comfort have been calculated in terms of reduction of working hours which display indoor temperatures beyond comfort limits.

Literature on this topic clearly reveals links between increased temperature and workers' reduced productivity[100]. Dwelling on this fact, the present study demonstrates the increase in time required by employees to fulfil equal tasks under less comfortable conditions. Minimum and maximum values of productivity reduction as indicated by the cited literature were applied to establish a range of possible productivity losses.



Graph 164: Summary of studies on the decrement of performance and productivity[101]

An optimum of all working hours within the limits of conformability acc. to ÖNORM 8110-3[102] was implemented as a reference for the investigated room and summer month in ONB. According to literature indications, minimum and maximum percentages for productivity decrement were taken into account for all working hours within the respective ranges beyond limit temperature.

---

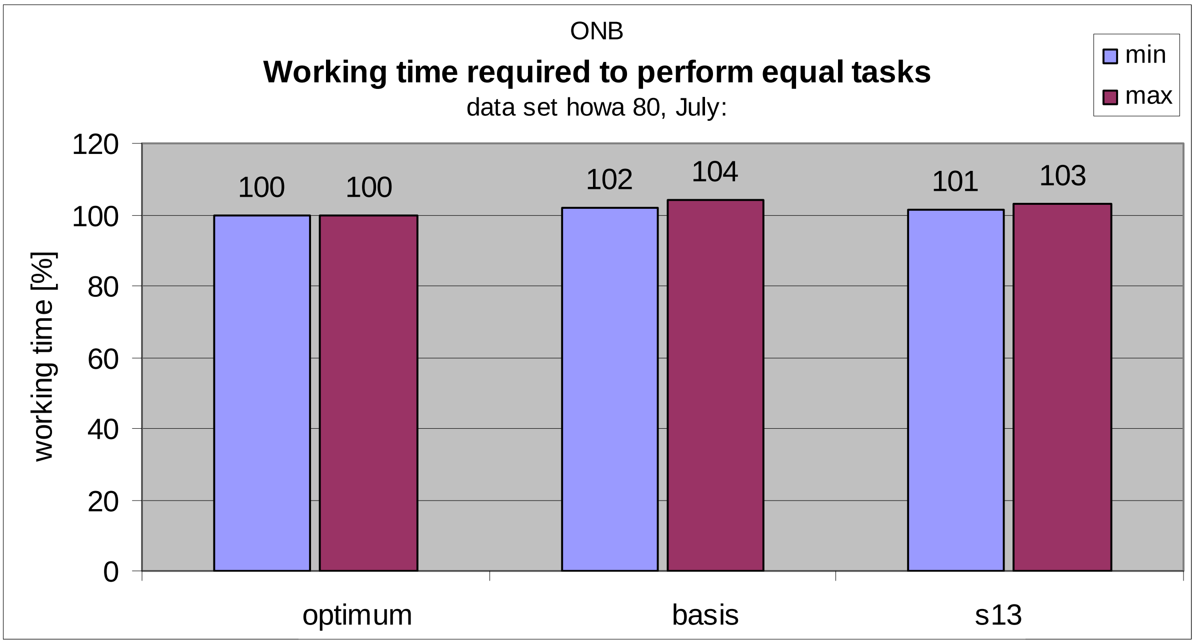
[100] Seppänen, Olli; Fisk, William; Faulkner, David (2003):

[101] ibidem

[102] daytime indoor operative temperature not exceeding 27°C

By means of the time required to fulfil equal tasks under different ventilation regimes, an economic assessment of the impacts of optimized ventilation variant s13 against base scenario is thus rendered possible; the improvement is shown to account for roughly 1% of time, regardless whether minimal or maximal productivity decrement is assumed.

In absolute terms, losses in productivity may be as high as 4% under the base scenario (as compared to an optimum), while ranging at 3% for s13. This may directly be translated into sunken wage payments, i.e. the amount of wages paid for unproductive time.



Graph 165: Impacts of reduction in surpassing comfort limits on productivity in ONB: When comfort limits are surpassed, workers' productivity decreases, working time required to perform equal tasks increases.

8.8.4 Conclusions

Internal Loads
Reduction in both cooling energy demand and maximum load were shown to directly yield economic benefits which can be invested in improvements of the building envelope to compensate for higher heating requirements during winter time.

Natural Ventilation
Scientifically documented decrements in productivity due to elevated indoor temperatures were calculated for base and optimized scenario, thereby yielding the proportion of wages paid for unproductive time which is to be expected under hot summer conditions in poorly cooled spaces. The impacts of natural ventilation were found to be limited but recognisable.

9 Summary and Conclusions

9.1 Concluding Portraits of the Leading Buildings

This chapter summarizes the hitherto presented results on the level of the leading buildings which are regarded as representatives for buildings dating from the same epoch. General and frequent properties of the portrayed building type allow for the resulting findings to be applied to other buildings of the type in question; however, some constructive properties have to be regarded as individual features of the respective building and hence results due to these specific properties are likewise individual. Therefore, in the following portraits of the leading buildings care is taken to differentiate general from specific building properties.

9.1.1 Strabag: highly glazed

Constructive properties

- This building type is characterized by its extremely high glazing fraction of the outer wall which may well reach up to nearly 100%. This glazing displays a low g-value with solar protective properties. Still, given the high share of transparent building elements in the external wall, these properties are insufficient to completely counteract the impacts of high solar loads.

- Even this building's u-value ranges low, although of course higher than opaque building elements would. In other words: good glass (in terms of heat insulation) is still worse than average opaque walls.

- F_c-value is rather high as shading can't be positioned on the outside due to considerations of possibly occurring wind pressures. Instead, shades are securely, but less effectively placed in the panes' interspaces.

- Office space is optimized to accommodate workplaces on the least necessary floor area resulting in comparatively high occupancy rates and in consequence high internal loads due to occupancy.

- Thermal mass of walls is almost inexistent, with the mass of ceilings being the single source for thermal storage.

Net energy

Cooling demand absolute
Strabag displays the highest net cooling demands of the sample buildings in absolute values. These demands increase continuously over the temporal resolution.

Heating demand absolute
Heating demand of this leading building is moderate as compared to the other sample buildings. This demand decreases continuously over the temporal resolution.

Cooling load absolute
Strabag displays the highest absolute value for maximum cooling loads in the sample.

Final and primary energy

Final energy demand trend (COP 3,0)

Combined final energy demand is slightly dominated by heating demand today. While this heating demand decreases over the temporal resolution, cooling demand increases at the same time resulting in the values of heating and cooling demand to be nearly equal by the time of data set "howa 2050". Hence, the overall final energy demand of this building type stagnates over the temporal resolution.

Primary energy demand trend (PEI 3,51)
In terms of primary energy demand cooling dominates already today, regardless of conversion factor chosen for PEI. This domination further increases over the run of time. By "howa 2050", primary energy heating demand for Strabag makes up for roughly half its cooling demand. The overall primary energy demand slightly increases, depending on the conversion factor chosen for PEI.

Influence of the urban heat island

- The overall net energy demand for both cooling and heating is pretty similar for all urban locations with the coldest one on the city outskirts ranging highest by a small margin. Seen over the temporal resolution, net energy demand for all locations slightly increases. Overall final energy demand differentiates more clearly between the locations but stagnates over time.

Possible Optimizations

- This building type allows for very limited optimization only; due to the highly glazed external wall, additional insulation is practically impossible. Likewise, g-values of the glazing can hardly be improved as solar protective glazing is already in place. External shading would be more effective, but would require further technological to develop a robust shading that can withstand high wind pressures. Furthermore, such external glazing strongly impacts upon the building's appearance and may well be contradictatory to the original design perception. This stated, the reduction of internal heat loads[103] remains as single most effective measure to decrease the dominant cooling loads of this building type.

[103] See Berger, T., Pundy, P. (2010)

9.1.2 SOL 4: passive house

Constructive properties

- Being a passive house, SOL 4 displays an extremely low u-value for both its opaque and transparent external wall fractions. Due to triple glazing the g-value of the windows is low. High quality shading is in place. The glazing proportion of the outer wall ranges at average levels (as compared to the other sample buildings). Occupancy rates are rather high reflecting the contemporary effort to maximize floor area exploitation. Comparatively high thermal mass is available for thermal storage.

Net energy

- Cooling demand absolute
  Results of simulation indicate rather high cooling loads; however, these results have to be viewed in the light of considerations described in chapter 8.1.1 Net cooling energy demand, page 72, and do not necessarily depict the real situation in the building which employs nocturnal ventilation not accounted for here.

- Heating demand absolute
  Keeping heating requirements low is a major goal of the passive house standard. Therefore, this building type displays very low demand, even so, again, results do not take into account some integral features of the passive house standard for the building's conditioning - such as heat recovery in the mechanical ventilation system which would decrease demands roughly by a further annual 15kWh/m^2.

- Cooling load absolute
  Absolute cooling load is comparatively high.

Final and primary energy

- Final energy demand trend (COP 3,0)
  Already today, cooling nearly reaches values of heating demand in final energy. Under "howa 2050", these two values are equal. The overall final energy demand decreases over temporal resolution.

- Primary energy demand trend (PEI 3,51)
  Depending on the chosen PEI, primary energy demand for cooling may well exceed heating demand already today. Under "howa 2050", cooling demand clearly dominates. Overall primary energy demand tends to stagnate over time.

Influence of the urban heat island

The overall net energy demand for both cooling and heating is pretty similar for all urban locations with the coldest one on the city outskirts ranging highest by a small margin. Seen over the temporal resolution, net energy demand for all locations slightly increases. Overall final energy demand differentiates more clearly between the locations but stagnates over time.

Possible Optimizations

SOL 4 is optimized towards cold winter conditions. Additional insulation layers therefore appear economically senseless. For summer conditions, the simulation indicates few points of possible intervention in terms of optimization of the building’s constructive properties. However, the analysis shows that heat loads should be restricted internally (which, actually, is already applied in the real building).

9.1.3 ONB: built before WW1

Constructive properties

- The u-value of the exterior opaque walls is average in this building. The g-value is rather high, but F_c-value is very good. This is due to exterior shading which did not form part of the original building design and therefore might not be in place in all buildings of this period. Glazing fraction of the outer wall is low and so is occupancy rate. High room heights are not reflected in this rate but also contribute to the building's robust summer behaviour. Still, thermal mass is limited due to wooden ceilings.

Net energy

- Cooling demand absolute
  ONB displays the lowest cooling demands in absolute terms within the sample of buildings investigated here. These demands increase continuously over the temporal resolution.

- Heating demand absolute
  This building displays average heating demands among the sample buildings. This demand decreases continuously over the temporal resolution.

- Cooling load absolute
  Maximum cooling loads are comparatively low in ONB.

Final and primary energy

- Final energy demand trend (COP 3,0)
  Heating demand clearly dominates the overall final energy demand of this building type. Even though values for heating and cooling slowly approximate over the course of time, heating remains dominant also under "howa 2050". The overall final energy demand decreases over the temporal resolution.

- Primary energy demand trend (PEI 3,51)
  Heating demand is still dominant today and in future scenarios also in terms of primary energy demand as well, regardless of conversion factors chosen. These factors, however, do influence whether overall primary energy demand decreases more or less pronouncedly over time.

Influence of the urban heat island
As differences of locations are generally bigger in heating than in cooling demands and ONB is dominated by its heating demand, colder sites such as "howa" yield remarkably higher overall net energy demands than locations in the

city centre. Overall demands decrease over the temporal resolution. The same is true for final and primary energy demand.

Possible Optimizations
Additional layers of insulation impact strongly on the building's overall energy demand, even though these layers might have to be placed on the internal surfaces of external walls due to considerations of cultural heritage. The requirements of building physics regarding the avoidance of condensation and moisture build-up have to be strictly observed in this case. Structurally incorporated thermal bridges may pose problems.
F_c-values appear barely improvable in this building; however, other buildings of this epoch may still lake effective exterior shading and therefore show potential in this area. If windows are replaceable under considerations of cultural heritage better, g-values might be achieved.

9.1.4 BGN/ FAS: built after WW2

Constructive properties
Contrary to the other three sample building, for the building epoch of after WW2 is not represented by a single building. BGN/ FAS rather represent the combination of two buildings of this period, each being some sort of worst case for either winter or summer requirements, respectively. Hence, the broad range of possibilities covered by construction dating from this time is shown.
The u-value of BGN is surprisingly low and underlying data therefore has to be doubted. The u-values of FAS appear more plausible for this epoch.
The g-values are rather high, permitting high solar gains. As rooms are small and heights limited, their windows – although of medium size in absolute terms – result in high glazing fractions, again allowing for high solar loads. Small rooms furthermore lead to high occupancy rates. Mass in BGN appears surprisingly high, especially for ceilings.

Net energy

- Cooling demand absolute
  Cooling demand is high and continuously increasing over the temporal resolution.

- Heating demand absolute
  Heating demand is likewise high and continuously increasing over the temporal resolution.

- Cooling load absolute
  Maximum cooling load is high.

Final and primary energy

- Final energy demand trend (COP 3,0)
  Heating demand clearly dominates the overall final energy demand of this building type. Even though values for heating and cooling slowly approximate over the course of time heating remains dominant also under "howa 2050". The overall final energy demand decreases over the temporal resolution.

- Primary energy demand trend (PEI 3,51)
  Heating demand is still dominant today and in future scenarios also in terms of primary energy demand as well, regardless of conversion factors chosen. These factors, however, do influence whether overall primary energy demand decreases more or less pronouncedly over time.

Influence of the urban heat island
As differences of locations are generally bigger in heating than in cooling demands and BGN/ FAS is dominated by its heating demand, colder sites such as howa yield remarkably higher overall net energy demands than locations in

the city centre. Overall demands decrease over the temporal resolution. The same is true for final and primary energy demand.

Possible Optimizations

Additional layers of exterior insulation hold high potentials of improvements, especially as concerns with cultural heritage might not to be expected as frequently as with buildings dating from before WW1. F_c- values are optimize able as the appliance of exterior shading seems generally feasible in this building type. Reductions of glazing fraction by the application of smaller windows can be considered; however, the availability of natural lighting for office use has to be kept in mind. Internal heat loads could be reduced by lower occupancy rates. This might require removal of light interior walls and new room layouts.

9.2 General Conclusions

Again, it has to be stressed that, due to the standardized nature of the sample buildings' conditioning (under simulation mode "Standard"), results can't be directly applied to an existing building. Instead, these results' main indications are to be analysed and understood.

9.2.1 Impacts of climate change

Impact of different climate data sets:
Future climate data sets yield increasing cooling energy demands, while heating demands shrink. Trends for overall final and primary energy demand evolve differently, depending on buildings' properties: recently constructed buildings tend to yield higher net cooling than heating demands already today; their overall final energy demand will stagnate or slightly increase over the years. Historic buildings constructed before WW1 and after WW2 will be clearly dominated by high net heating demands even by the year 2050. Hence, overall final energy demand of these buildings decreases over the decades to come due the decrease in heating requirements. Notwithstanding, these overall demands remain high in absolute terms. Furthermore, a significant amount of these kinds of historic buildings is not equipped with any cooling device today. In reality thus their cooling demand will raise from zero!

The picture is slightly less uniform for the development of maximum cooling loads; Even though they, too, will increase, this increase is less pronounced and its trend over the course of time is less consistent.

It has to be kept in mind that both simulated demands and maximum loads are based on averaged climate data sets which do not necessarily include possible extremes.

Impact of different comfort models:
The definition of what is regarded as "uncomfortable" according to the two existing normative comfort models ("Fanger" and "Addaptive") remarkable impacts upon cooling requirements and, consequently, energy demand. Care has to be taken to distinguish between conditioned buildings (which call for the application of the "Fanger" model) and free running buildings (to be assessed according to the "Adaptive" model). Users' ability to adjust to outdoor climatic conditions should be harnessed in free running buildings by giving users control over their direct indoor environment. When doing so, potential reductions in cooling demand can be harnessed.

Impact of urban heat island:
Locations in CBDs generally display higher cooling and lower heating demands than sites on the city's fringes already today. Annual differences range in the

order of magnitude of up to 5 kWh//m^2 for cooling and about 10kWh/m^2 for heating in Vienna. In consequences, both net and final energy demand is lower in inner city locations than on the outskirts. This relation appears consistent over the course of time, leaving inner city locations as those with least overall final energy demand.

9.2.2 Possible measures for reduction of energy demand

Impact of optimization of buildings' envelopes:
Even in view of climate change, external thermal insulation of opaque buildings' surfaces yields best results in terms of overall final energy requirements due to significant reductions in heating energy demand. This is especially true for old buildings which are dominated by their heating demand. Changes in quality of windows rather aim at decreasing cooling demand and therefore run second in the consideration of overall final energy demand.

Optimizations inside buildings
Internal Loads: the effects of increased energy efficiency in office equipment (IT equipment and artificial lighting) are tremendous with respect to cooling demand reductions: Achievable decreases in annual cooling energy demand range in the order of magnitude of increases due to climate change.

Improvements in this area are likely to take place in considerable scale during the next years as additional costs for energy efficient equipment (as compared to less efficient equipment) tend towards zero. Care has to be taken for this reduction not to be counteracted by further increases in equipment density and/ or more powerful devices.

In old buildings, however, effects of reduced cooling run danger of being outweighed by increases in heating demand when less internal loads are available in winter. Therefore, better electronic equipment should always run in parallel with additional insulation of the external wall: thereby heat losses are cut in winter and heat gains remain small in summer.

Usage Profiles: Innovative though quite simple changes in usage pattern aim at minimizing users' presence during the hottest hours of the day. Traditional siesta models are effective in this sense if users' absence is coupled with complete shut-down of equipment and lighting and indoor temperatures are allowed to rise above certain limits during the break. Impacts of such usage profiles on employees' everyday life are considerable and must be discussed beyond purely technical matters. The same holds true for tele-working modes which likewise influence cooling energy demand by reducing user's presence and hence internal loads.

Natural ventilation was shown to hold certain potential for improvements in thermal comfort of free running buildings. Exact and reliable calculations of achievable air change rates in rooms require CDF simulations of the specific site

in question. Rather general potential analysis performed within this study demonstrate that natural ventilation in urban settings can suffice to improve thermal conditions in sample office rooms to the extent that requirements of an adaptive comfort model are met. To stay within fixed comfort limits, however, may not always be possible.
Wind induced air movement within rooms with open windows can contribute to improve comfort conditions. A similar service can be rendered by desktop fans.
Natural ventilation strategies in historic buildings show only restricted effectiveness under the investigated urban conditions. Although significant air change rates are achievable, their impact is insufficient to withdraw significant amounts of heat from thermal building mass which is highly charged during prolonged heat waves.

10 Appendix

10.1 Rough estimation of possible indoor air speeds under the outside wind conditions

Graph 166: Calculation of indoor air speed acc. Melaragno[104]

5	**BGN 6 SÜD**															
6	width of aperture	4,1														
7	Width of wall	5														
8	ratio	0,82														
9					**ration 0,66**				ration 1							
10					**V avg**		V max		**V avg**	V max						
11	bei Wind direction 130° (S)	single aperture, windward, perpendicular			13		18		16	20						
12	bei Wind direction 270° (NW)	two apertures in leeward, wind at angle			22		56		23	50						
13																
14							bei Anwendung ration 0,82						bei Anwendung ration 0,66			
15																
16					**Wind speed**		**V avg S s11**	**V avg S s10**	V max S s11	V max S s10			**V avg S s11**	**V avg S s10**	V max S s11	V max S s10
17					182 - 211		24 h	6-19 UHR	24 h	6-19 UHR			24 h	6-19 UHR	24 h	6-19 UHR
18					inne 80											
19																
20					Wind Speed (m/s)											
21			0	182	4,2		0,6	0,0	0,8	0,0			0,5	0,0	0,5	0,0
22			0	2	3,8		0,5	0,0	0,7	0,0			0,5	0,0	0,5	0,0
23			0	3	3,3		0,5	0,0	0,6	0,0			0,4	0,0	0,4	0,0
24			0	4	3,3		0,5	0,0	0,6	0,0			0,4	0,0	0,4	0,0
25			0	5	0,9		0,1	0,0	0,2	0,0			0,1	0,0	0,1	0,0
26			0	6	0,9		0,1	0,0	0,2	0,0			0,1	0,0	0,1	0,0
734			1	18	3		0,4	0,4	0,6	0,6			0,4	0,4	0,4	0,4
735			1	19	2		0,3	0,3	0,4	0,4			0,3	0,3	0,3	0,3
736			0	20	1,7		0,2	0,0	0,3	0,0			0,2	0,0	0,2	0,0
737			0	21	1,7		0,2	0,0	0,3	0,0			0,2	0,0	0,2	0,0
738			0	22	0,7		0,1	0,0	0,1	0,0			0,1	0,0	0,1	0,0
739			0	23	0,7		0,1	0,0	0,1	0,0			0,1	0,0	0,1	0,0
740			0	24	1		0,1	0,0	0,2	0,0			0,1	0,0	0,1	0,0
741																
742			286		gesamt		328,9	160,1	432,3	210,4			296,7	144,4		
743					durchschnittl.		0,5	0,6	0,2				0,4	0,6		
744					max		1,8	1,6	2,3	2,1			1,6	1,4		
745					min		0,0	0,1	0,0				0,0	0,1		
746																
747																

[104] Allard, Francis; Santamouris, Mat; Alvarez, Servando (2002)

10.2 Economic Assessment: Provenience of calculation values

Capital related factors

Factor for repairs investment 1

Value: **0,015**

Provenience: acc. VDI 2067

Tab. A.3 "Calculated service life and effort on repairs, servicing and operation of ventilation and air-conditioning systems"

- p. 31, 2nd row: 2.1.3.3. 1 Closed refrigerated cases, several types of case: value = 1 (0,01)
- p.35, 2nd row: 2.3.2.1.1 Compression cooling system: value = 2 (0,02)

Average value: 1,5 (0,015)

Price change factor investment 1

Value: **1,06**

Provenience:

- http://www.statistik.at/web_de/static/ergebnisse_im_ueberblick_baupreisindex_fuer_den_hoch-_und_tiefbau_aktuelle_022822.pdf, (Access: September 1,2010)
- http://www.statistik.at/web_de/dynamic/statistiken/preise/baupreisindex/publdetail?id=233,314&listid=233,314&detail=386, (Access: September 1,2010)

23 Zentralheizungen und Belüftungsanlagen/ 2010/I: 127,3, 2010/ II: 128,5 (as compared to 2005) > average: 127,9

24 Gas- und Wasserinstallationen/ 2010/I: 127,0; 2010/ II: 128,1 > average: 127,55

> average of both maintenance groups 2005 to 2010: 127,725 (27,725 %)

> average 5,545 % annual (1,05545)

Interest factor investment 1

Value: 1,03

Provenience:

= Oekb Bond Benchmarks

lt. http://kurse.banking.co.at/023/Default.aspx?action=securityDetails&id=tts-2237706&menuld=7_2&pathName=Sekund%C3%A4rmarktrendite%20Bund&lang=de, (Access: September 1,2010)

Average price 1Y: 2,7004 (1,027004)

Consumption related factors

Annual price change factor for consumption-related costs

Value: **1,04** resp**. 1,07**

acc. Gazon[105], p. 57

[105] Gazon, Siegfried (2010):.

Conservative: 3,7% (1,037)
Pessimistic: 7,18% (1,0718)

Degree of efficiency/ COP component 1
Value: 2,4
Provenience:
acc. Recknagel& Sprenger[106]
COP Compression cooling machine: 3
Degree of efficiency Motor: 90%
Degree of efficiency Distribution: 92%
Cumulative: 2,4

Electricity price
Value: 0,17 EUR/kWh
Provenience:
acc. Gazon[107], p. 86: 0,17€/kWh electricity

Operation related factors
effort on repairs and servicing
Value: **0,0125**
Provenience: acc. VDI 2067
Tab. A.3 "Calculated service life and effort on repairs, servicing and operation of ventilation and air-conditioning systems"

- p. 31, 2nd row: 2.1.3.3. 1 Closed refrigerated cases, several types of case: effort on servicing = 0,5 (0,005), : effort on operation = 0,0 (0,00)
- p.35, 2nd row: 2.3.2.1.1 Compression cooling system: effort on servicing = 1 (0,01), : effort on operation = 1 (0,01)
-

Average: effort on servicing = 0,75 (0,0075), : effort on operation = 0,5 (0,005)
Cumulative: 1,25 (0,0125)

Price-dynamic annuity factor for operation-related costs
Value: **1,01**
Provenience: acc. Floegl[108]
main cooling plant: 4%, panel coolers ceiling, tubes: 0,1%, air conditioning system: 1,5%, mechanical ventilation: 1%
average 1% (1,01)

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106 Recknagel, Hermann; Schramek, Ernst-Rudolf; Sprenger (2001)
107 Gazon, Siegfried (2010)
108 Floegl, Helmut (2010): LEBENSZYKLUSKOSTENPROGNOSEMODELL. Version 2.3.08.03.2010. Krems.

10.3 Tables & Graphs

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