StartClim2009.E

Adapting office buildings to climate change:
Optimization of thermal comfort and energy demand

Annex

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Content

Abstract

The following interdependencies and impacts of climate change for existing and newly built office buildings are, by now, predictable and common knowledge:

- climate change will negatively impact upon thermal comfort of office users by rising indoor temperatures
- productivity of office workers is directly influenced by increased indoor temperatures
- reduced thermal comfort thereby raises 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 upon the availability of electricity at peak hours.
- Due to significantly increased electricity demand this availability might generally not be guaranteed everywhere at any time.
- At the same time, the generation of the requested electricity involves emissions of climate gases which further induce global warming and further aggravate the above mentioned effects.

By simulating thermal conditions in four existent Viennese office buildings, the project aims to investigate the potential for the optimization of thermal comfort in office blocks despite increased outdoor temperatures due to climate change.

Herein, emphasis was placed upon fundamental research on relatively robust and straight forward approaches which do not rely on complex technology. This includes relatively new, poorly researched strategies which withhold certain innovativeness.

1 Introduction

1.1 Context

Within the last years, global climate scenarios have gradually been downscaled to geographic resolutions allowing for more precise forecasts of local climate conditions in the decades to come. Local developments have hence become predictable.

Urban areas are well known to generally display climatic conditions quite distinct from surrounding rural regions, most pronouncedly detectable in higher ambient temperatures. Although the actual future impacts of global warming specifically in major cities remain yet to be comprehensively researched, it is most likely that climatic conditions there will generally further deteriorate.

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 the impacts of global warming which are already inevitable. Regarding the building sector, this primarily signifies to ensure comfortable indoor conditions despite raising outdoor temperatures without augmenting corresponding energy consumption.

Offices are especially prone to overheating and consequently to active cooling requirements; they generally display raised internal loads due to both high rates of occupancy and significant density of technical equipment, likewise resulting in heat production. At the same time office workers strongly rely on comfortable conditions to be able to perform complex tasks.

Besides recourses to scientific findings in the afore mentioned research areas, this study builds upon results currently being generated within the framework of a project funded under the “Building of Tomorrow plus” program of the Austrian Federal Ministry of Transport, Innovation and Technology. With the approval of the funding agency FFG, the present study applies climate data sets for future scenarios which have been computed within this project. As for the precise impacts of these scenarios on investigated sample buildings reference is made to the upcoming project report[1]. Furthermore, the four sample buildings investigated in the present study form part of the building pool of this project.

Strategies for a reduction in energy demand in buildings generally aim at primarily reducing either loss (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.

[1] Project„Büros_im_Klimawandel“, completion due by April 2011

1.2 Goals

This study aims to explore possible strategies for safeguarding thermal comfort in office rooms under climate change conditions while keeping energy consumption low. Conventionally, these two factors are directly linked: thermal comfort, herein understood as the compliance with normative indoor temperature limits - is safeguarded by means of mechanical (convective) cooling. A general rise in outdoor temperature due to global warming thus results in increased energy demand for cooling. Interdependencies between elevated indoor temperatures and reductions in office workers' performance have been accounted for in several investigations[2].
Hence, strategies for a decoupling of indoor thermal Comfort and energy demand are requested.

Two general points of intervention are addressed here:

- Reductions in heat gains: Firstly and foremost, the building's construction and the profile of its usage can substantially contribute to reductions in heat gains, resulting in decreased energy demand. Options for these purely passive strategies are broadly investigated here: reduction of internal loads (heat gains from occupants, equipment and lighting), shifts in usage profiles, harnessing natural ventilation potentials. Thermal building simulation is employed to assess these approaches' impact on energy demand and/ or thermal comfort of representative sample buildings.
  It has to be indicated here that the reference to internal loads, usage profiles and natural ventilation strategies represents a slight depart from the alignment of the original proposal for this study: it was initially intended to place a somewhat stronger focus on possible interventions in the buildings envelop. This approach was broadened for the incorporation of more basic strategies as preparatory investigations revealed promising potentials here.
  An economic assessment of the presented reduction strategies for reduced energy demand in cooling is presented.

- Hybrid cooling systems: In a sustainable building concept, it makes sense to additionally apply cooling systems only if a building's cooling load is reduced to justifiable magnitudes. Herein, hybrid cooling systems permit the exploitation of cold sinks by means of HVAC systems withdrawing warmth and using storage capacities"[3]. Whilst the use of ground, ground water and activated thermal mass has already been extensively investigated and is increasingly employed in mainstream construction

[2] Seppänen, O., Fisk, W. & Faulkner, D. COST BENEFIT ANALYSIS OF THE NIGHT-TIME VENTILATIVE COOLING IN OFFICE BUILDING. Lawrence Berkeley National Laboratory, University of California.

[3] In contrast, systems are labelled "active" when they "withdraw warmth by means of refrigeration machines". (See Zimmerman, Mark (2003, S. 11)

business, most innovative systems for radiative and evaporative cooling have not yet reached marketability, their performance data still being subject to testing. An overview of these systems and an outlook of accomplishable performance key figures form the second part of this study.

1.3 Methodology

This study comprises two distinct approaches:
Firstly, thermal building simulation of up to four representative sample buildings is employed to assess options for passive strategies: reduction of internal loads, shifts in usage profiles, harnessing natural ventilation potentials. The framework of this investigation is presented hereafter and comprises indications on both the climatic data sets employed and the buildings (construction and conditioning) investigated as well as definitions of simulation variants and assessment parameters.

The second part of this study renders an overview of innovative systems for radiative and evaporative cooling and an outlook on their accomplishable performance key figures. This in itself provides the explanation, why thermal simulation, equivalent to the one performed in the first part of the study, turned out not to be feasible here (and hence the framework of investigation presented in the methodology hereafter does not apply for this part): Due to the innovative nature of the investigated cooling systems, performance figures which form a necessary prerequisite of such simulation still lack sound documentation. Therefore, the endeavour of such a documentation was undertaken here.

1.3.1 Climate data sets

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, 4 semi synthetic climate data sets[4] have been generated, 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:

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[4] s. Krec, K. Halbsynthetische Klimadaten für Wien. Erläuterungen zum Klimadatensatz, 2010.
also see: 2.2 *Key figures for the analysis of climate data* sets, page 15

Table 1: Climate data set description

Climate data set denomination		description
Temporal resolution	"80"	averaged weather observations for the period of 1980 to 2009
	"2050"	Scenario for the period of 2050
Spatial resolution	"howa"	Abbr. "Hohe Warte", main weather station
	"inne"	Abbr. "Innere Stadt", CBD

Accounting for the climatic differentiations found in the metropolitan area of the City of Vienna, two localized climate data sets were used: For general investigations into the impacts of different levels of internal loads climate data sets for the city's main weather station at the city's outskirts were employed, while specific simulations of natural ventilation's impact were run under climate condition of the central business district.

1.3.2 Sample buildings' constructive configuration

Four Viennese office building, fairly representative for the city's three main construction periods[5], were selected. These sample buildings represent three main building epochs and hence cover the majority of building types to be found in this typical Central European City:

Table 2: Sample Building description

Sample building denomination	description
ONB	Built from before World War 1
BGN	Built after World War 2
Strabag	Built 2003, entirely glazed façade
SOL 4	Built 2005, passive house standard

In all these buildings several (two to eight) single office rooms were investigated. These rooms cover all orientations; 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 type. 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.

1.3.3 Sample buildings' conditioning

The undertaken investigations sought to satisfy two distinct ambitions: on one side findings were requested, which would not only be applicable for a specific building, but yield general insights. On the other side, diverging constructive properties of distinct building époques should be accounted for as it was to be expected, that these properties would implicate different applicability of optimization strategies.
Therefore, two different modes of simulation were distinguished:

- **Standard**: in this simulation mode care was taken to maintain comfort conditions acc. Austrian standards[6] in all sample buildings. With comfort conditions equally secured, resulting cooling loads and demands are compared. Lighting and ventilation regimes in each building were therefore

[5] Main construction periods in a quantitative sense: in the present building stock, those dating from the described laps of time make up form the vast majority.
[6] ÖNORM EN 8110-3 requiring 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.

uniformly modelled. It has to be stressed here, that this simulation mode does not necessarily depict the actual 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 and low levels of internal loads) for the sake of comparability of constructive properties.[7]

- **real**: this simulation mode depicts the present day situation without respectively with little cooling in two of the sample buildings. Consequently, large discrepancies in comfort conditions (frequency of overheating) are observed.

1.3.4 Employed tools of investigation

Dynamic thermal simulation 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.

For the investigation of natural ventilation's cooling potential specific software tools provided information on wind conditions in urban area and street canyons respectively, which both offered a crucial 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 entirely covered the obtained results represent a magnitude of possible values rather than exacts figures.

1.3.5 Variants and Assessment parameters

For the impact assessment of internal loads all four sample buildings were simulated under four different levels of internal loads representing four different levels of energy efficiency of IT appliances and artificial lighting. These simulations were run under climate data sets representing both present and future situations.
Both cooling and heating demand were calculated for all variants and depicted in their monthly break down. Maximum cooling and heating loads were identified.

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7 Design day: 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.

For the impact assessment of usage profiles one sample building was simulated under different time profiles of users' presence (and hence the application of IT devices and artificial lighting).
These simulations were run under climate data sets representing both present and future situations.
Cooling demand was calculated for all variants and depicted in their monthly break down. Maximum cooling loads were identified.

For the impact assessment of natural ventilation two sample buildings were simulated under real conditions (Simulation mode "real") depicting precarious comfort conditions already occurring in these buildings today. Using these uncomfortable conditions as baseline scenario, different natural ventilation strategies were simulated and their impact on thermal comfort registered. Decreases in the amount of office hours displaying indoor temperatures beyond comfort limits was monitored, exemplary temperature sequences during summer heat waves were analysed.

Modular configuration of investigation
These three fields of investigation (internal loads, usage profiles and natural ventilation) 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, sample buildings, simulation modes and employed tools.

1.3.6 Results

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 existent building. Instead, these results' main indications are to be analysed and understood.

Internal Loads: the effects of increased energy efficiency in office equipment are tremendous; differences in cooling energy demand between applied levels of efficiency overweigh impacts of different climate data sets applied.
The economic assessment reveals that these measures additionally display reduced life cycle costs.

Usage Profiles: Innovative though quite simple changes in usage pattern were investigated and found to be effectual. Social limitations of such patterns were highlighted. A broader discussion beyond purely technical matters hence appears advisable in this context.

Natural Ventilation Strategies reveal 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 highly charged during prolonged heat waves. Rather than applying nocturnal ventilation therefore, the daytime use of air movement as means of providing comfort appears advisable.

2 Climate data sets

2.1 Description of climate data sets

For modelling of climate conditions semi synthetic data sets[8] 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 two time periods and two distinct Viennese locations within the framework of a project funded under the "Building of Tomorrow plus" program of the Austrian Federal Ministry of Transport, Innovation and Technology[9]. Hence four different data sets were employed:

- "howa 80": semi synthetic data set covering the observation period 1980 – 2009 for the location of Vienna's main weather station
- "howa 2050": semi synthetic data set depicting future climate conditions in 2050, based on localized climate scenarios
- "Inne 80": analogue "howa 80", for Vienna's central business district
- "inne 2050": analogue "howa 2050", for Vienna's central business district

2.2 Key figures for the analysis of climate data sets

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

- Average external temperature (year, summer): yearly average 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 for different time periods and locations. Additional information is rendered by appraisal of an average summer

[8] W. Heindl, T.Kornicki, A.Sigmund, „Erstellung halbsyntetischer Klimadatensätze für meteorologische Messstationen", Forschungsbericht im Auftrag des Bundesministeriums für Wissenschaft und Forschung (GZ 70.630/18-25/88) und des Amtes der NÖ Landesregierung (Zl. NC 23-1988/1989, Wien (1990)

[9] Project„Büros_im_Klimawandel", under the coordination of the author, completion due by April 2011

temperature which indicates whether a data set displays especially hot summer months (June – August).

- Average hourly irradiation (year, summer):

[W/m²]
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 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). Aberrant 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.[10] Therefore, the yearly swing of the rolling mean external temperature was depicted.

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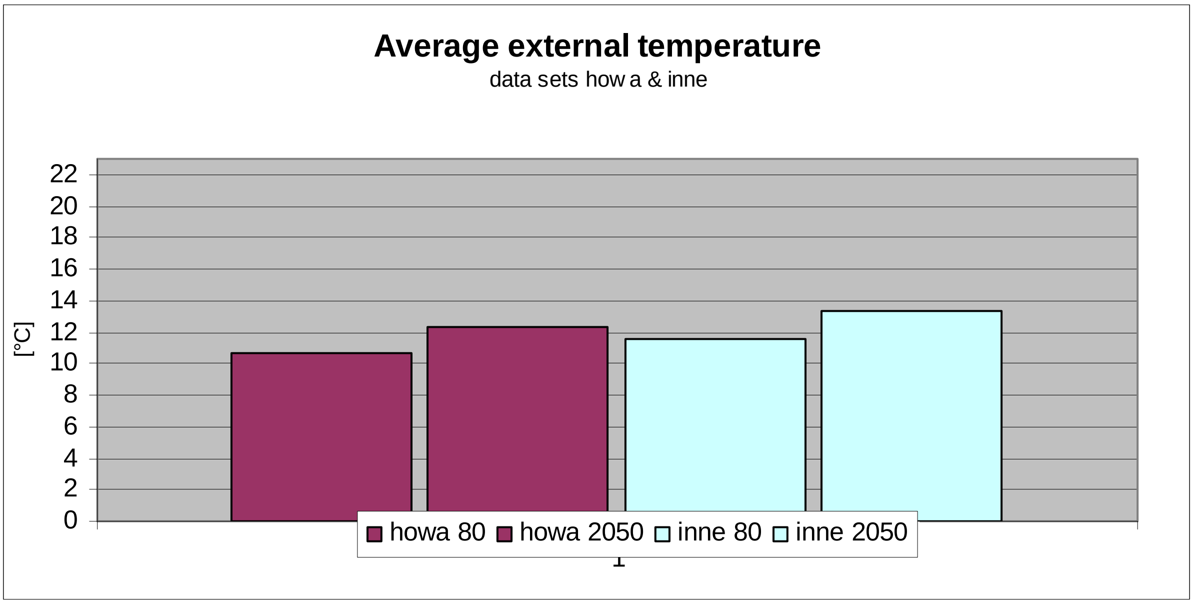
[10] 2 limitations of the adaptive comfort model have to be kept in mind:
1) predictions above 25°C rely on reduced statistic data
2) users' subjective comfort judgements were taken independent of their actual working performance under the documented conditions

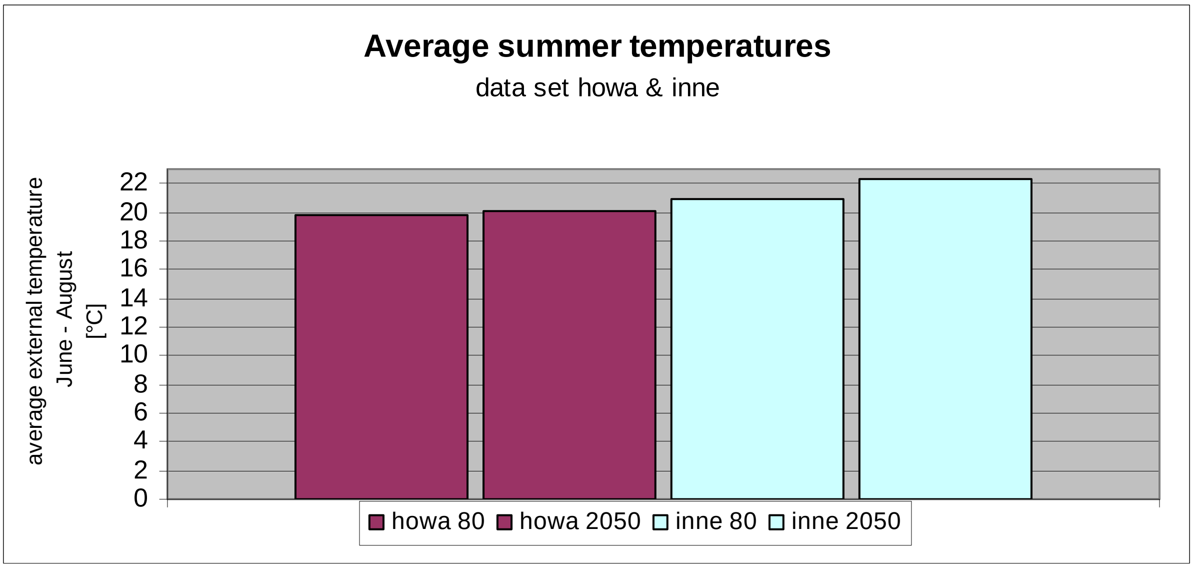
2.3 Results of comparative Analysis of climate data sets

Average external temperature (year, summer):

The comparison of air temperatures of the employed data sets display a difference in mean monthly temperatures between data sets 80 and 2050 respectively of nearly 2K on a yearly basis. The situation is slightly less uniform for the summer months: while data set howa shows an increase of roughly 1K, data set inne's temperatures are averagely augmented by 2K.



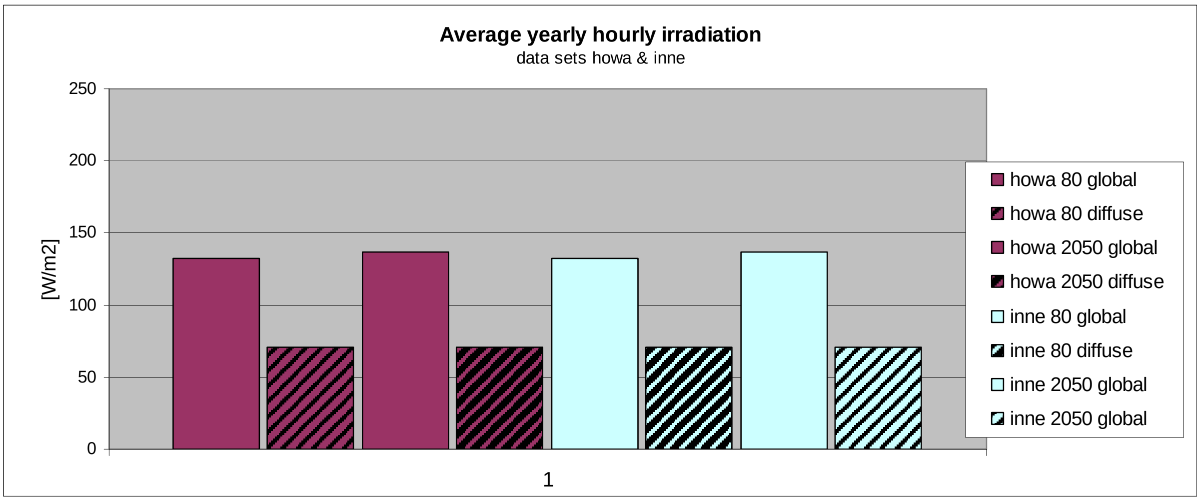
Graph 1: Comparison of average yearly external temperatures



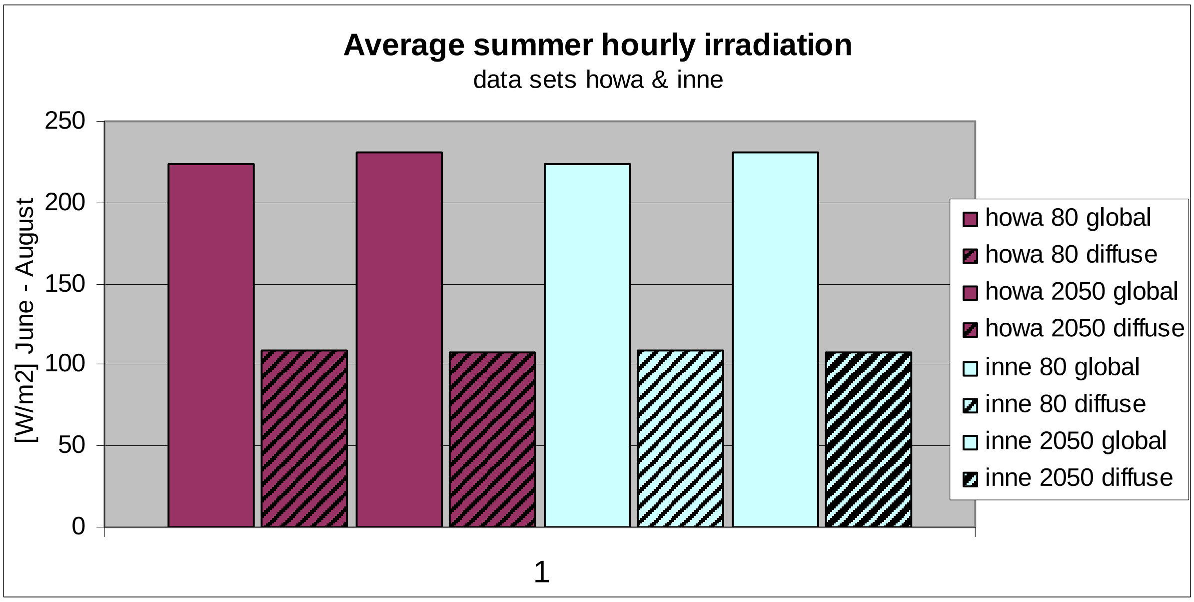
Graph 2: Comparison of average summer external temperatures

Average hourly irradiation (year, summer):

The comparison of solar irradiation of these data sets displays differences for both absolute amounts of global radiation and it's diffuse fraction; While global radiation increases between data sets howa and inne for 80 and 2050 by 3%, the fraction of diffuse irradiation remains effectively unchanged, which means, that direct irradiation is on the rise. Meteorologists attribute these effects to improved air quality due to enhanced filtering and consequently to the effects of a reduction in global dimming. Furthermore, recent weather records reveal that stable weather conditions with significant irradiation tend to appear earlier in the turn of the year, thereby causing both higher absolute irradiation sums as well as averaged hourly values all year round. This effect is attributed to global warming.



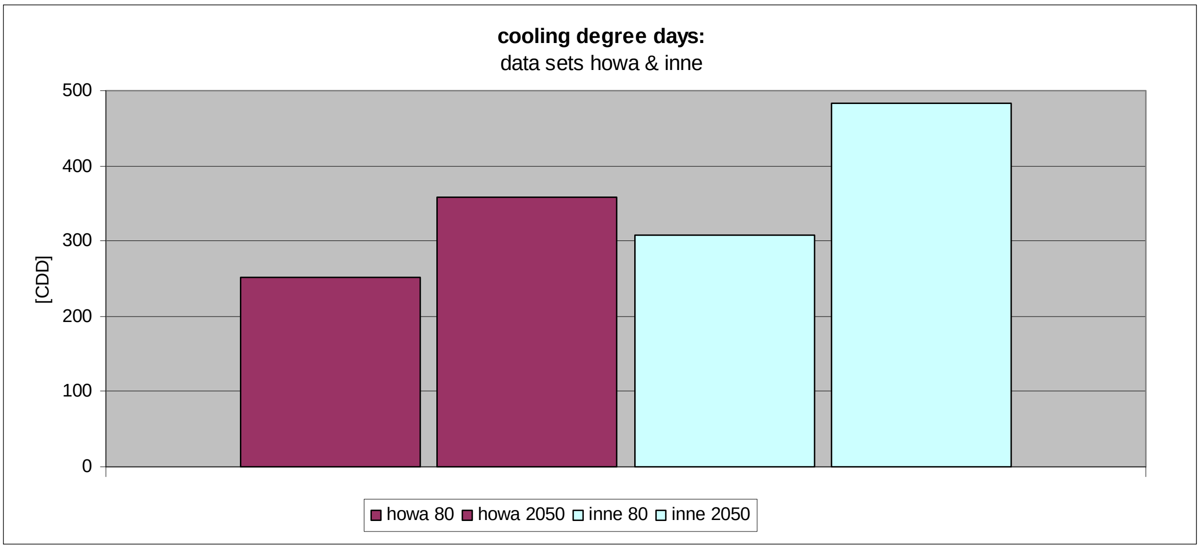
Graph 3: Average yearly irradiation



Graph 4: Average summer irradiation

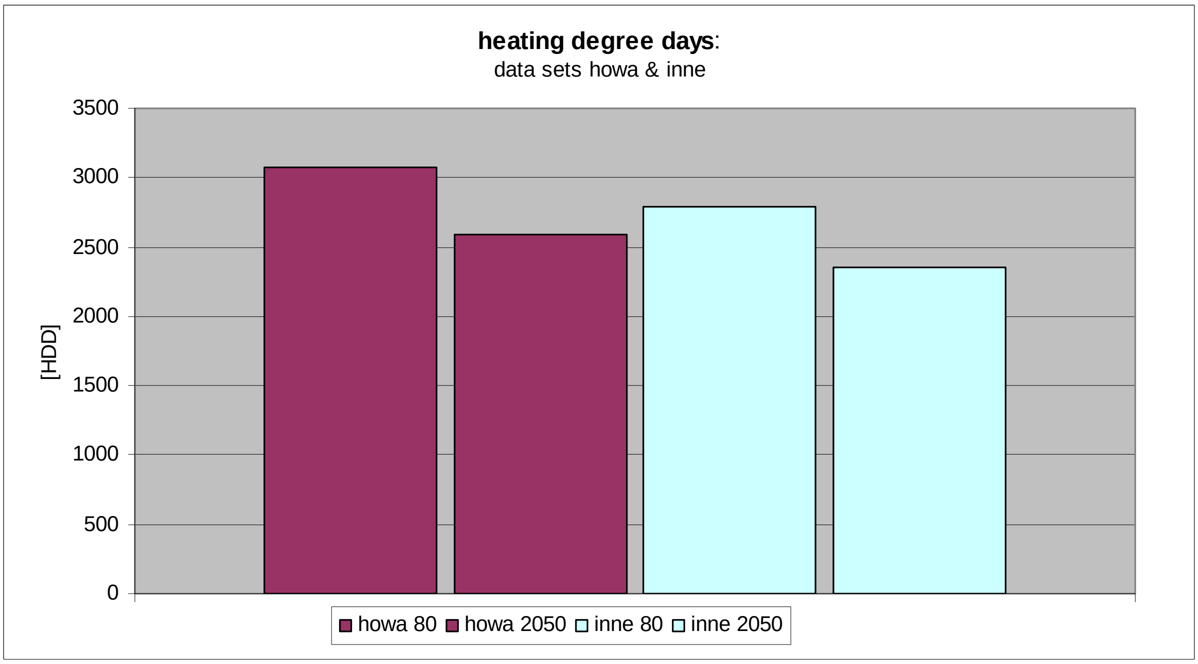
Cooling degree days

Nearly as striking as the differences between data sets 80 and 2050 is the difference between the locations howa and inne: this amounts to approximately 50 CDD in data sets 80 and further increases to almost 200 CDD in data sets 2050 portraying the location inne as clearly more overheating – prone (and more sensible to global warming) than the main weather station howa.



Graph 5: Cooling Degree days of data set "howa 80" and "howa 2050 (Main Weather Station) and "inne 80" and "inne 2050" (CBD)

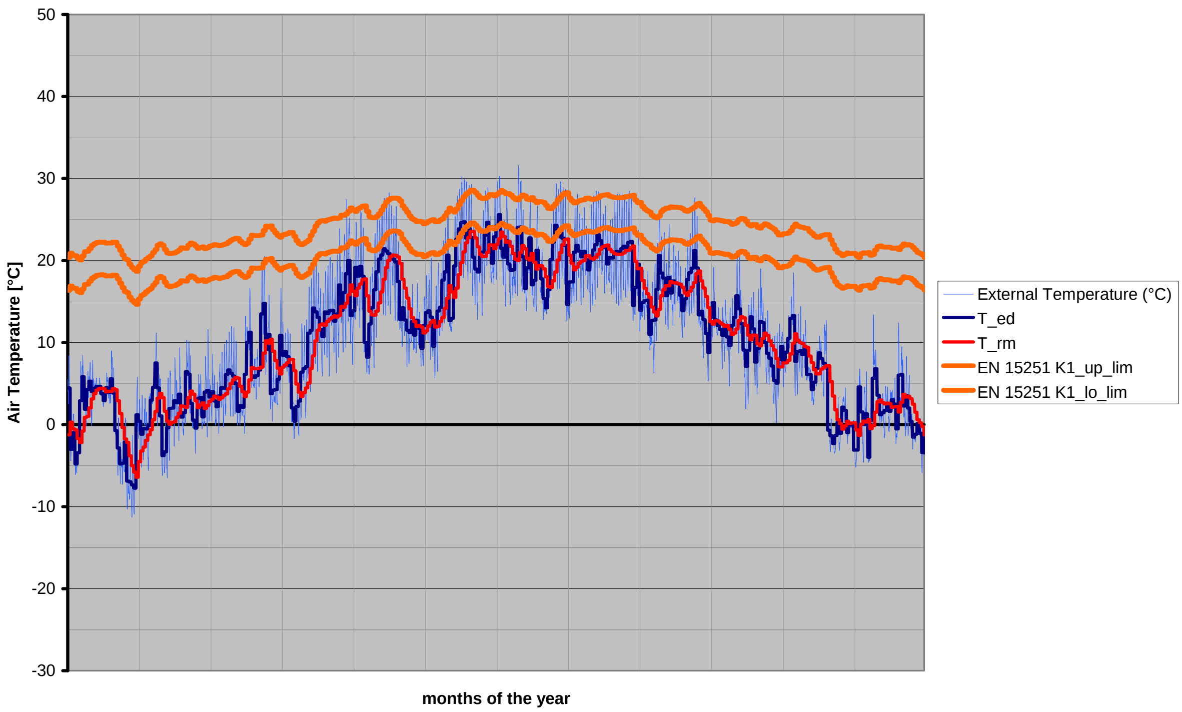
Heating degree days
An almost mirror – inverted situation is found for heating degree days, although on a much higher level and less pronounced in its differences; data set "howa" displays higher levels in heating degree days for both "80" and "2050". The difference between "80" and "2050" however is nearly the same for both data sets.



Graph 6: Heating Degree days of data set "howa 80" and "howa 2050" (Main Weather Station) and "inne 80" and "inne 2050" (CBD), Fehler! Verweisquelle konnte nicht gefunden werden.

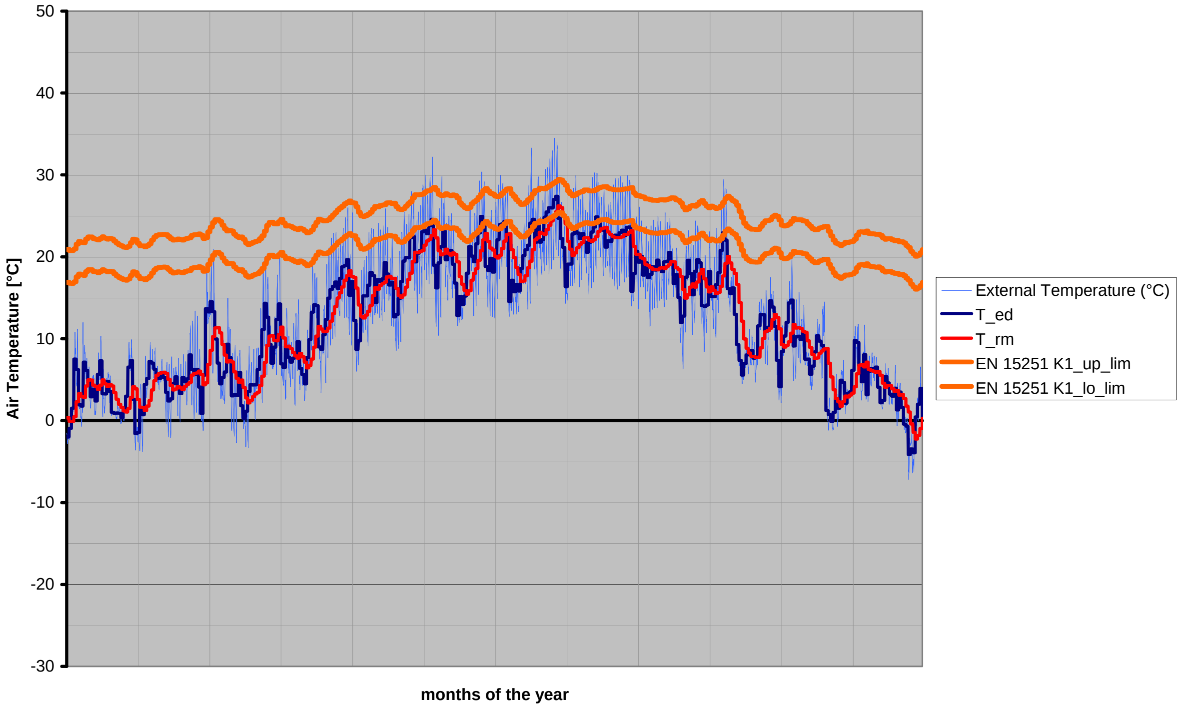
Comfort limit temperatures acc. EN 15251 (adaptive comfort model):

The comfort temperature belt closely follows the swing of outdoor temperatures during summer months (winter comfort conditions are not investigated here). Th highest acceptable temperatures range remarkably under 30°C for data sets 80. A slight raise in upper temperature limits is visible in data sets 205, however 30°C remain untouched here too.



Graph 7: Comfort limit temperatures acc. EN 15251 for data set "howa 80"

T_ed depicts daily means while T_rm constitutes the roling mean external temperature. The limit temperatures EN 15251 K1_up_lim and temperatures EN 15251 K1_lo_lim border the comfort temperature belt according the adaptive comfort model for building category 1 (best out of 3) acc. EN 15251.



Graph 8: Comfort limit temperatures acc. EN 15251 for data set "howa 2050"

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 and published climate scenarios do not foresee relevant difference 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.

3 Sample Buildings' Constructive Configuration

This study investigates four 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, divers 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.

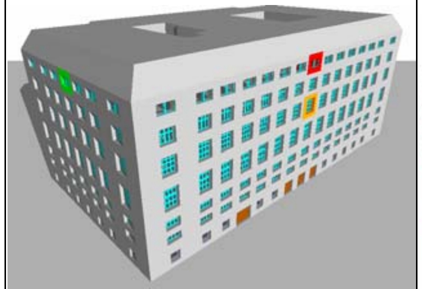
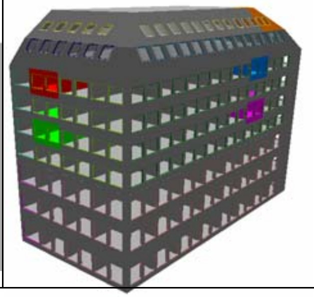
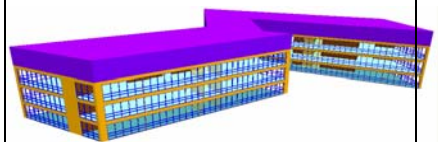
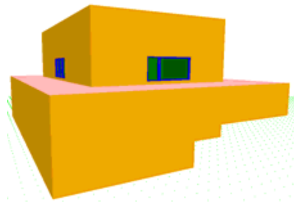
3.1 Description of sample buildings

Originally, four Viennese office buildings, fairly representative for the city's three most relevant construction periods in terms of quantity of buildings in the present building stock, should be investigated. However, close inquiry revealed, that hardly any consistent statistics are available as for the determination of "typical" office buildings in the city. Unlike for residential buildings the central Austrian bureau for statistics does not separately register data on office buildings in general and for the capital city of Vienna in particular. Hence, informal information from single potent holders of real estate portfolios, developers of business locations and major real estate broking consultants form the exclusive source available.

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. For example, the municipality's building stock in terms of offices barely displays any building dating from after the 1960ies.

On the other hand side, major real estate broking consultants do not normally deal with buildings built earlier than 1990, and they affirm, that office bildings 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 get.

It turned out to be nearly impossible to assess a statistically founded typology of Viennese office buildings. Alternatively, recurrence was taken to the generally most common division of building epochs in the country, which in turn is determined by 20th century history; the chosen sample buildings therefore represent three main building epochs and the comparatively new passive house building standard:

				
Denomination	**ONB**	**BNG**	**Strabag**	**SOL 4**
Year of construction	1913 – 1925	1950 – 1956	2001 - 2003	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 Unit
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				

Graph 9: General description of sample buildings, including representation of the applied geometric model

In all these buildings several (two to eight) single office rooms were investigated. These rooms cover all orientations; 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 (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 further room types frequently encountered in office buildings such as meeting rooms, lounges, cafeterias or server rooms as these types of rooms experience such a broad range of possible variations that generally applicable statements as to their thermal behaviour can't be seriously given here. However, as the double office room form the single most frequent room type in most medium to large office buildings, the envisaged simulation results allow for a bottom up assemblage which in turn facilitates first insights into the expectable thermal behaviour of the overall complex.

3.2 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

[m^2/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 residing within the same area, the more heat is generated. Depending on the buildings' time of erection, 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 envelop 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, depending, however, strongly 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

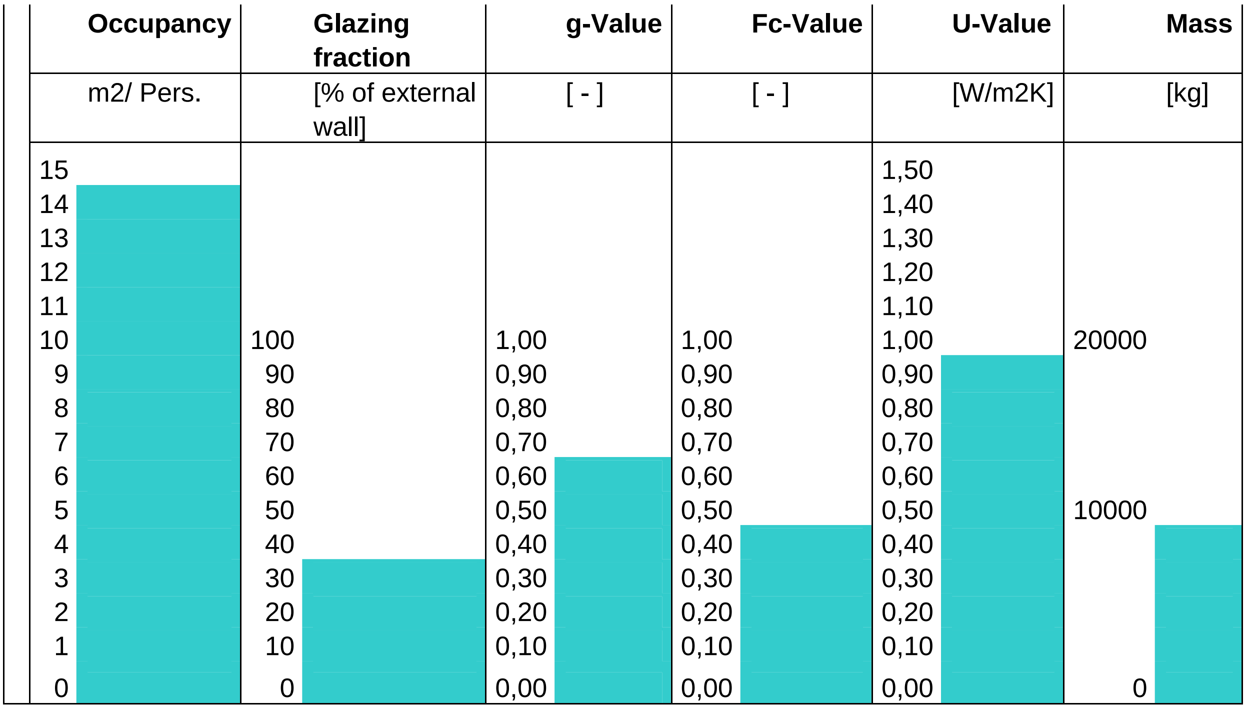
[W/m^{2}K] acc. EN 673
Heat transmission between indoors and outside both via opaque and glazed parts of the exterior wall may occur in either direction, depending on which side the temperatures are high. While during winter, it will always be colder outside than inside, the situation may vary during the summer months, allowing for cooling 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

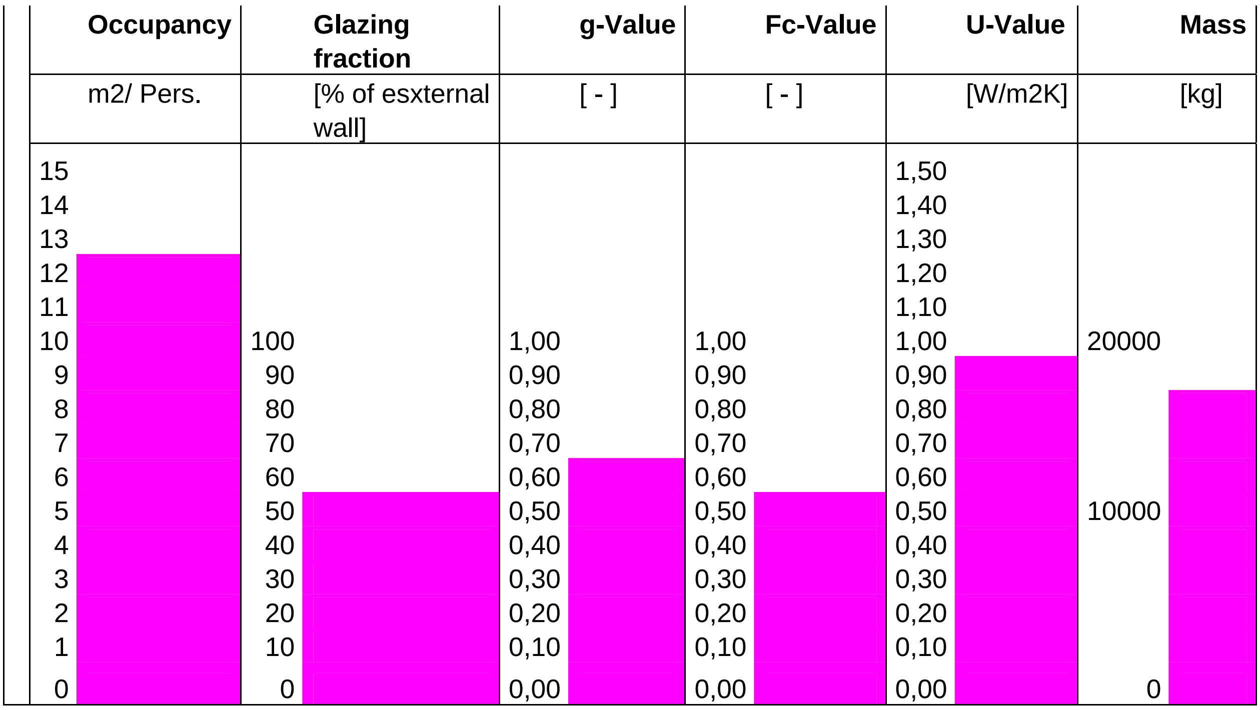
[kg] acc. ÖNORM B 8110-3
The thermal mass of the enclosing wall and ceiling elements characterizes a room's thermal inertia. The occurring heat is stored in this mass thereby dampening/ postponing heat peaks. This ability to store heat though is limited to the uppermost centimetres of the construction's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

3.3 Results of comparative building analysis

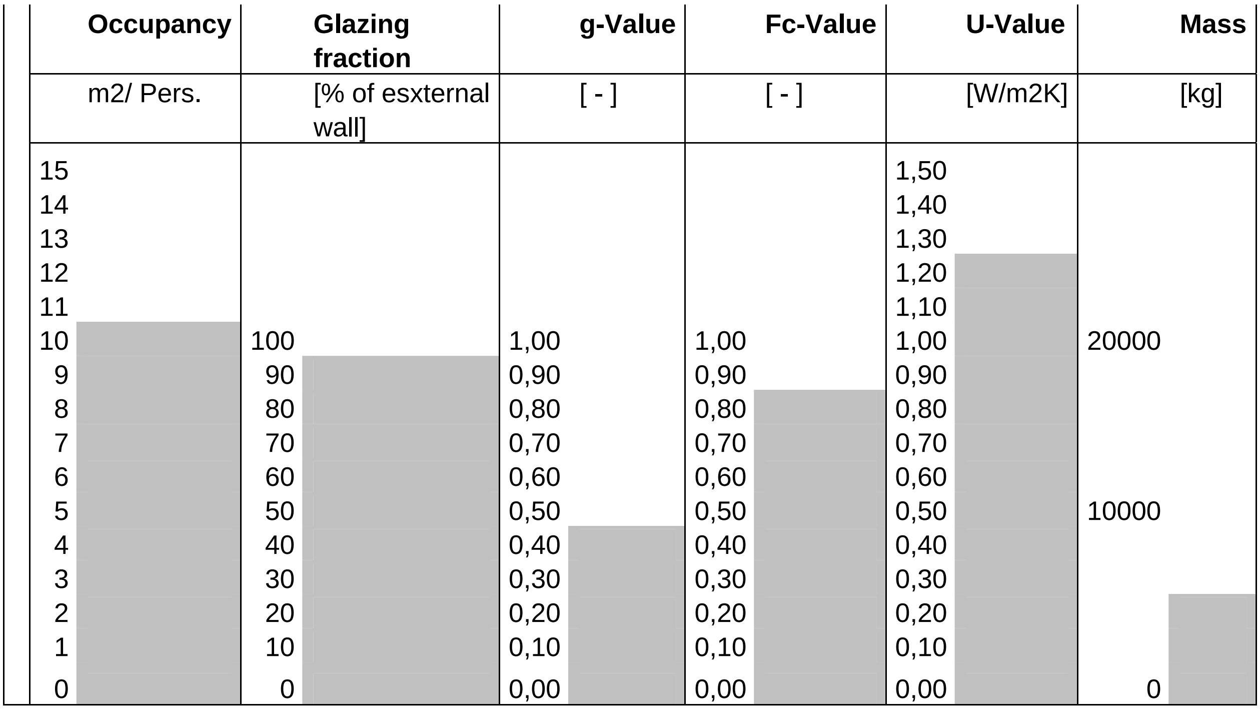
The following graphs aim at a graphical comparability of building properties in respect to the concerned building's predisposition to overheating.
The sequence of categories is arbitrary but equal for all buildings.



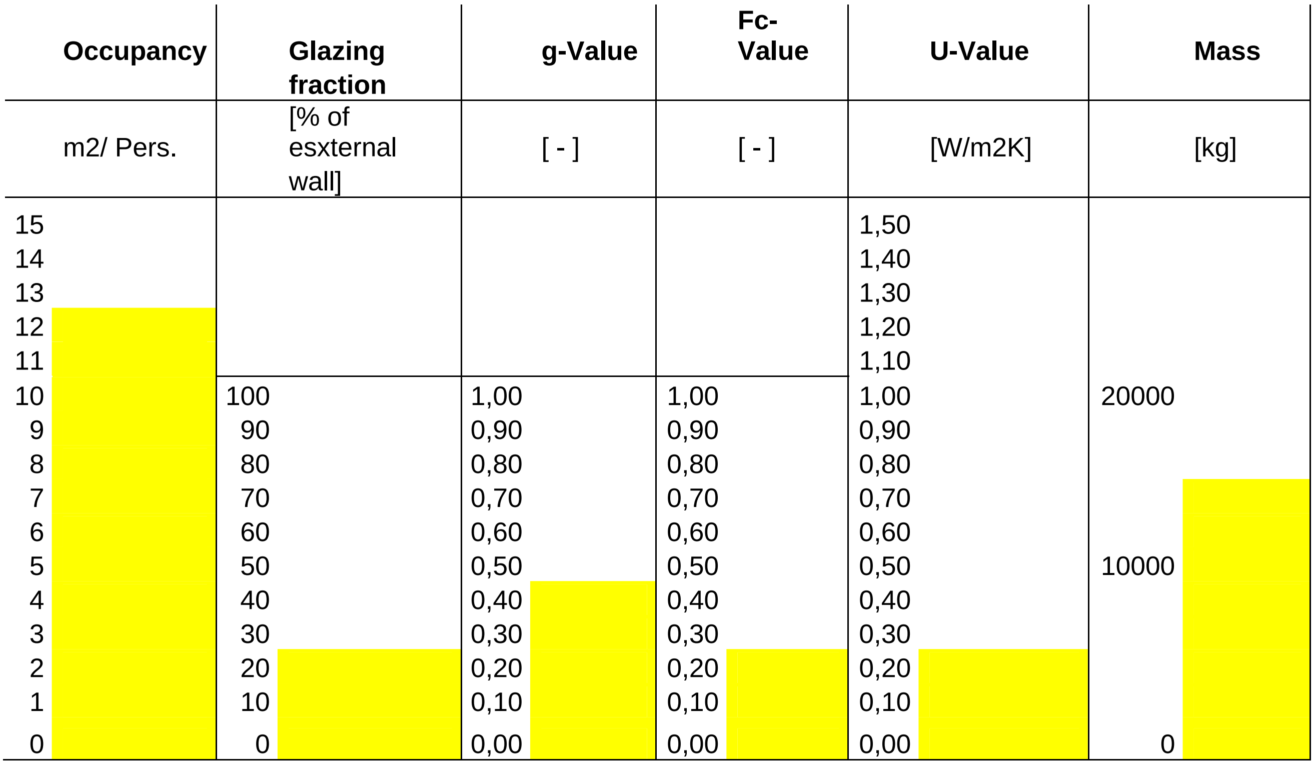
Graph 10: Building properties ONB



Graph 11: Building properties BGN



Graph 12: Building properties Strabag



Graph 13: Buildings properties SOL 4

Based on this analysis the sample buildings’ constructions can be characterized as follows (comparative terms refer to the other sample buildings only do not represent absolute assessments, they):

- ONB

Big volume due to big net area and room height

Comparatively low occupancy rate = comparatively large area per person[11]
Minor proportion of glazing in the external wall
Rather high g – value, satisfying Fc – value (exterior shading, supposedly due to later back fitting)
Rather low U – value
Restricted thermal mass,

- BGN

Small volume due to reduced room height
Medium occupancy rate
Medium proportion of glazing in the external wall
Rather high g – value, moderate Fc – value (inter pane shading)
Rather low U – value
Big thermal mass,

- Strabag

Medium size volume
High occupancy rate
Glazing fraction reaching nearly 100%
Low g – value (anti-sun glass), moderate Fc – value (inter pane shading)
Comparatively high U – value
Restricted thermal mass

- SOL 4

Medium size volume
Medium occupancy rate
Minor proportion of glazing in the external wall
Low g – value (anti-sun glass), satisfying Fc – value (exterior shading)
Extremely low U – value

[11] This statement is only true in comparison with the other sample buildings, which display even minor net areas per person. In more general terms, literature indicates significantly higher net areas per person up to 20 – 25 m^2/ person. It has to be assumed that these discrepancies are caused by differences in the definition and hence the calculation of "office area".

4 Sample buildings' Conditioning

As has been mentioned in chapter 3: *Sample Buildings' Constructive Configuration,* page 22, this study investigated four sample buildings' thermal behaviour, which is due to 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 and optimization strategies. The simulation mode operating on this basis is thus denominated as "Standard".

In some cases, nevertheless, it appeared 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 optimization strategies.

4.1 Description of simulation modes

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

Mode "Standard"

- This simulation mode aims at obtaining 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 to those of other sample buildings all buildings were simulated under equal framework conditions. These conditions and the thermal conditioning applied might therefore not comply with real conditions; the choice of the building technology applied might 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 upscale able to the entire building's performance as 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 optional amount of office places.

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 existent comfort conditions in theses sample buildings by applying existent 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 in detail under simulation mode “real”

Mode “Design Day”

At some points, selective investigations were run for 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 otherwise generally used for the sizing of heating and cooling plant rooms[12]. The applied design day was generated on basis of the climate data sets portrait above (see chapter 2.1 *Description of climate data sets*, page 15) using a sinusoidal swing[13] of outdoor temperatures and semi synthetically generated, corresponding values for further climate parameters.

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[12] See VDI 2078
[13] Acc. ÖNORM B 8110 -3

4.2 Key figures for conditioning in mode "Standard"

Ventilation
Ventilation is assumed to be provided both manually and mechanically; For outside temperatures during office hours 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 14: ventilation regime simulation mode Standard

Shading
Different shading devices as depicted in chapter 3.3: *Results of comparative building analysis*, page 26, are 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 15: shading regime simulation mode Standard

Internal Loads

Internal 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. Considerable effort was thus undertaken within the framework of this study to assess assumable levels of internal loads. Reference is made to literature[14], professionals' experiences[15] 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[16] which in turn extensively draws upon corresponding German and Swiss normative guidelines[17].

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	***)

*) flurescent 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 copymachine (2 hrs. Power, 6 hrs stand by) all /20m2
****) Depending on resp. situation in the sample building — See chapter 3.2 *Key figures for analysis*, page24

Graph 16: 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 16: *Internal Loads simulation mode „Standard"*, page 32.

[14] Zimmermann, Mark; Glauser, Heini (2003); ÖNORM B 8110-5, ISO EN 7730 (1994), VDI 2078 (1996)
15 Berger, Tania (Juni 2010): Interne Lasten in herkömmlichen Bürobauten. praktische Erfahrungen eines Haustechnikers. Interview mit Siegfried Manschein. Am Juni 2010 in Krems.
[16] Project„Standard Energieeffiziente Bürogebäude", completion due by April 2011
[17] 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 17: Internal Loads simulation mode „Standard“, different levels of internal loads for lighting and equipment

As can be seen in Graph 16: *Internal Loads simulation mode „Standard“*, time profiles were assumed for the actual usage of IT equipments, respectively for the portion of office hours during which these are run in stand by 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 might 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 I			19,3	0,4	0		
IL II			16,3	0,1	0		
IL III			6,6	0,3	0		
IL IV			5,6	0,1	0		

***) 2 PCs (4 hrs. Power, 4 hrs stand by)/
1 printer (4 hrs. Power, 4 hrs stand by)/
0,5 copymachine (2 hrs. Power, 6 hrs stand by)
all /20m2

Graph 18: Internal Loads simulation mode „Standard“, elevated levels of internal loads for lighting and equipment for the determination of cooling loads only

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 configuration in modern Strabag and post war BGN are most tightly designed to house the required furniture, equipment and open space on least area (also s. gloss Nr. 11, page 28). This fact was depicted in the simulation models by appliance of accordingly varied loads.

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 19: Occupancy Loads simulation mode „Standard“

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 20: Cooling simulation mode „Standard“

All sample rooms are assumed to be adiabatic in regard to their neighbouring rooms.

Heating

Winter conditions in the sample rooms are not within the focus of this study. However, for the assessment of impacts of different levels of internal loads 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.
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 21: Heating simulation mode „Standard“

5 Employed tools of investigation

As has been demonstrated in chapter 1.3.4 *Employed tools of investigation*, page 12, 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 which both provide a crucial 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 entirely covered the obtained results represent a magnitude of possible values rather than exacts figures.

TAS

The employed software tool for thermal simulation is TAS (Thermal Analysis System), Version 9.1.4.1, provided by the British EDSL[18].
TAS builds upon two basis input data files: one contains the structural 3D model of the sample building; the second one allocates thermal properties and usage profiles to the mapped building. In conjunction both generate a large results' file containing hourly values for all parameters of interest.

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[19]) recourse was taken in the framework of this study to simplified single room analysis tools.

Within the present study the AIOLOS software, developed by the University of Athens's Department of Applied Physics, served this purpose. AIOLOS is a 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[20]. 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

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[18] TAS – Thermal Analysis System XYZ by EDSL – Environmental Design Solutions Ltd., Milton Keynes, GB, 2007

[19] Computational Fluid Dynamics

[20] Ghiraus, Cristian; Germano, Mario (2005): Urbvent. Natural ventilation in urban areas - Potential assessment and optimal façade design. Software Guide. Herausgegeben von European Commission: the Fifth Framework. Université de La Rochelle. La Rochelle.

climate data sets which were used throughout this study's investigation. Results obtained by URBVENT therefore are of rather informative nature only.[21]

BKI

For the assessment of the economic feasibility of different strategies the mechanisms provided by VDI 2067 were followed. Thereby, the extensive data base of construction costs BKI[22], edited by Baukosteninformationszentrum Deutscher Architektenkammern, provided the basic elements of calculation.

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[21] Berger, Tania (April 2010): Correct appliance of URBVENT software (Project Nr.NNE5-2000-00238). specifications on implemented wind data and accuracy of results. Interview mit Mario Germano. Am April 2010 in Krems.

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

6 Variants and Assessment parameters

Apart from the division (described in chapter 1.2 *Goals*, page 7) between the simulative part of this study and the detailed literature review on potentials of innovative cooling strategies, a further differentiation is done by grouping the findings in modules; The following sections give an overview of the different simulation variants applied in the respective modules.

6.1 Definition of Simulation variants

- **Module 1: Cooling energy demand and load of sample buildings under different levels of internal loads and different climate data sets**

In this module, all 4 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 17: Internal Loads simulation mode „Standard", different levels of internal loads for lighting and equipment* , page 33). Both cooling energy demands and maximum cooling loads were calculated, the latter based on elevated levels of internal loads (see Graph 18: *Internal Loads simulation mode „Standard", elevated levels of internal loads for lighting and equipment for the determination of cooling loads only* , page 33).
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 (see 6.2.1 *Primary parameters*, page 39 and 6.2.2 *Comparative parameters*, page 42).

- **Module 2: Cooling energy demand and load of sample buildings under different usage modes and different climate data sets**

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 present situation ("howa 80") was applied.
Results were assessed in terms of primary and comparative parameters on energy demand.

- **Module 3: Impacts of different natural (and mechanical) ventilation regimes on thermal comfort in sample buildings**

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. Results were assessed in terms of primary and comparative parameters on thermal comfort (see 6.2.1 *Primary parameters*, page 39 and 6.2.2 *Comparative parameters*, page 42).

The following table provides a summary of the sample buildings investigated in each module and the applied simulation modes and climate data sets:

Module	Sample Building	Mode	Climate Data Set
1 Internal Loads	Strabag ONB BGN SOL 4	"Standard"	"howa 80" "howa 2050"
2 Usage Modes	Strabag	"Standard" "Design Day"	"howa 80"
3 Natural Ventilation	ONB BGN	"real" "Design Day"	"inne 80"

Graph 22: Summary on investigation modules: module number and content, investigated sample buildings, applied simulation mode and applied climate data sets

6.2 Assessment parameters for simulation results

6.2.1 Primary parameters

Energy demand

Monthly Cooling Demand (incl. load break down)
[kWh/m^2]

- The monthly Load break down displaying all loads which contribute to a sample buildings conditioning demand: Conduction (split for opaque and glazed fractions of the external wall), ventilation, solar gain, internal loads.
- Calculated on basis of a 2 persons' office 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 constructive configuration only;
- This figure includes net energy demand only, not covering system losses and auxiliary electricity for mechanical ventilation and cooling

- This figure is averaged over all reference rooms which are investigated in a particular building.

Summer Cooling Demand
[kWh/m^2]

- Cumulated energy demand for cooling and latent removal load *during summer (June – August)* required for thecooling of a double office of specific size, simulated under documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode "Standard"); Hence, the cooling demand 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 and cooling
- This figure is averaged over all reference rooms which are investigated in a particular building.
- Summer cooling demand as compared to yearly cooling demand indicates performance during hot summer periods.

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 and cooling;
- This figure is averaged over all reference rooms which are investigated in the particular building.
- Yearly cooling demand as compared to summer cooling demand indicates the performance year round, including transitional seasons and eventual winter cooling demand.

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 and cooling.
- This figure is averaged over all reference rooms which are investigated in a particular building.
- As maximum loads occur under summer conditions no additional yearly maximum cooling load is computed.

- 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 cooling 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 and heating;
- This figure is averaged over all reference rooms which are investigated in a 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 and heating.
- This figure is averaged over all reference rooms which are investigated in a particular building.

Thermal Comfort

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

- Cumulated amount of working hours during which the resultant indoor temperature surpasses 26°C, 27°C, 28°C and 29°C respectively
- This figure depicts summer comfort conditions in the investigated rooms
- It is averaged over all reference rooms which are investigated in a particular building.
- 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

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

- Amount 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.
- This figure is averaged over all reference rooms which are investigated in a particular building.

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

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

6.2.2 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
- This figure is averaged over all reference rooms which are investigated in a particular building.
- 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
- 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

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
- This figure is averaged over all reference rooms which are investigated in a particular building.

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
- This figure is averaged over all reference rooms which are investigated in a particular building.

Thermal Comfort

Decrease in Amount of working hours surpassing limit operative temperatures
(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
- This figure is averaged over all reference rooms which are investigated in a particular building.
- It depicts changes in cooling demand brought about by an optimization strategy

Decrease in Amount 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

7 Results: Investigation of optimization strategies

7.1 Module 1: Cooling energy demand of sample buildings under different levels of internal loads

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

While the presence of office workers is regarded as an indispensable necessity here (the impacts of different presence patterns are discussed in chapter 7.2 *"Module 2: Cooling energy demand of sample buildings under different usage ")* 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.

7.1.1 Investigated climate data sets

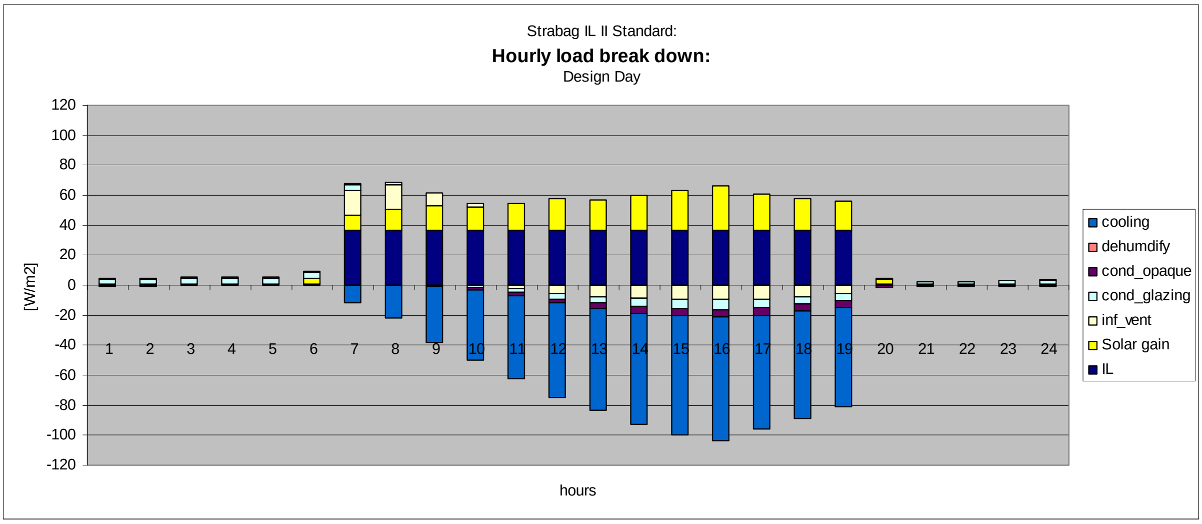
For this module the climate data sets "howa 80" and "howa 2050" were applied.
For a first glimpse of the driving factors for cooling demand an hourly load break down under a steady state Design Day was performed.

7.1.2 Investigated sample buildings, applied simulation mode

All four sample buildings were investigated under simulation mode Standard.

7.1.3 Results

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.



Graph 23: Hourly cooling load break down in Strabag Fehler! Verweisquelle konnte nicht gefunden werden.

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 effectual starting point for optimization. By the selection of energy efficient devices such reduction has become increasingly feasible during the last years[23]. More efficient IT – equipment and lighting thus represents a means of reducing cooling loads and demands.

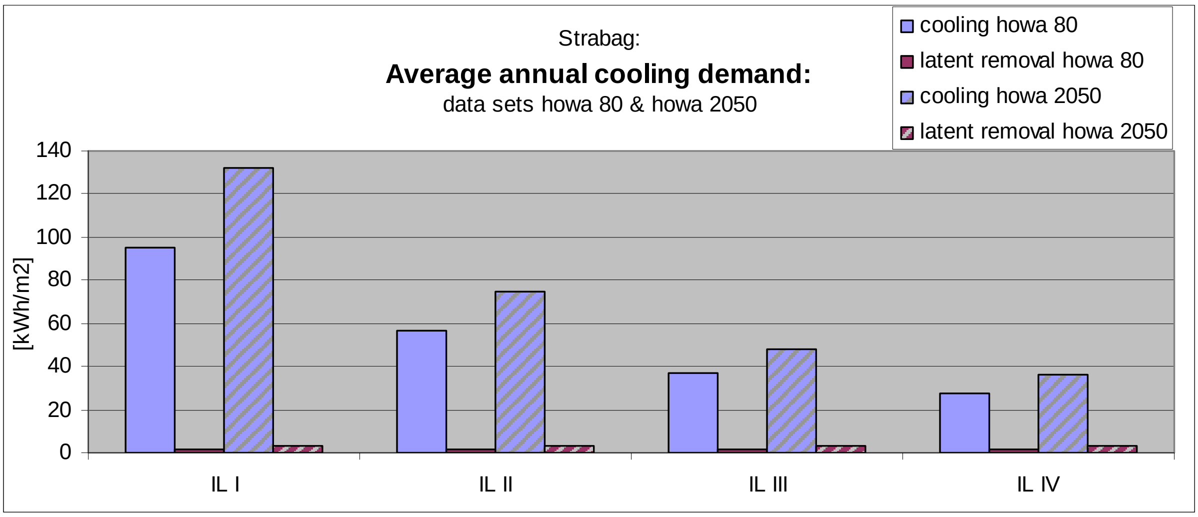
According to Graph 17: *Internal Loads simulation mode „Standard", different levels of internal loads for lighting and equipment* , page 33, four different levels of efficiency were defined.

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

Table 3: Description of investigated efficiency levels (IL stands for Internal Loads)

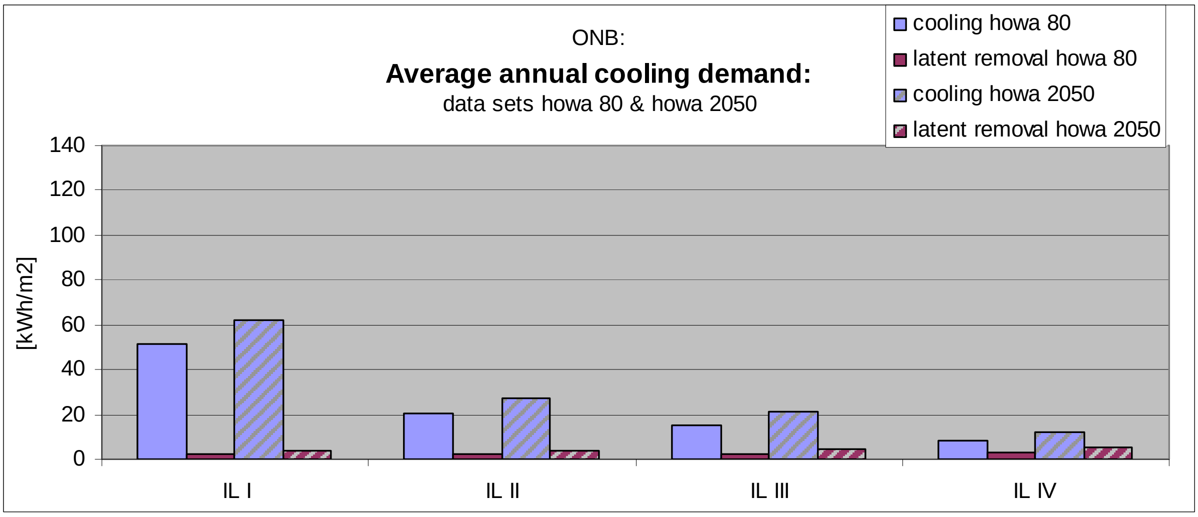
Efficiency level denomination	Description
IL I	very low efficiency; seldom but yet still encountered in offices, representing a worst case situation
IL II	average efficiency frequently encountered in offices; in further investigations this level is applied as Standard
IL III	high efficiency according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

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 out weight by differences of cooling demand for different levels of internal loads.

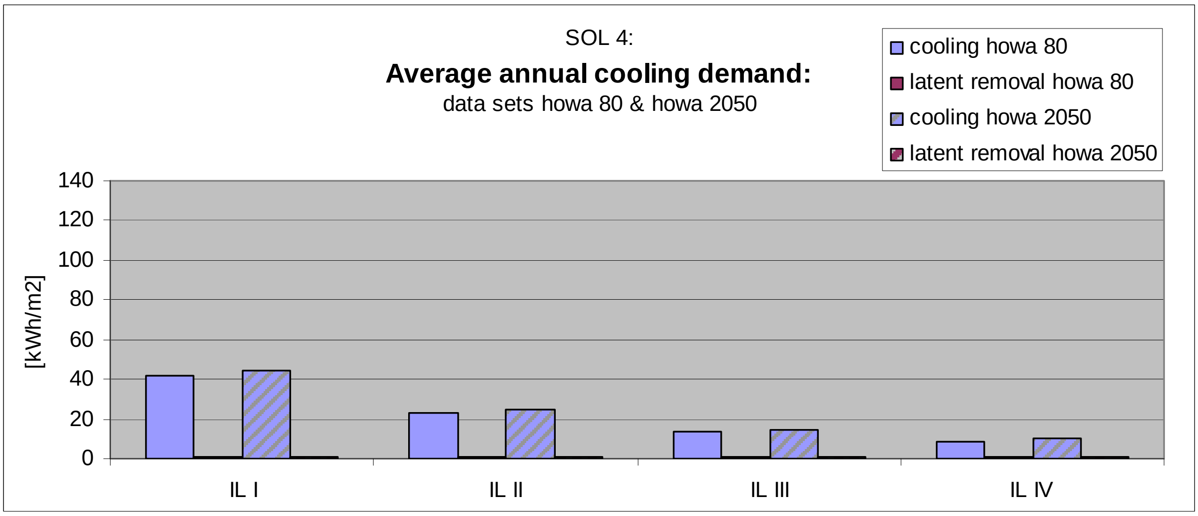


Graph 24: Strabag: annual cooling demand for "howa 80" & "howa 2050" under different levels of internal load

Furthermore, these results depict differences between sample buildings: While comparatively highly glazed and poorly shaded BGN and Strabag depict highest cooling demands, passive house SOL 4 scores lowest. It has to be stated that the applied simulation mode Standard in this building does not incorporate some distinct features which form an integral part of the passive house concept. This causes the simulation's outputs not to represent the building's real dimensioning. For example, internal loads in SOL 4 are equivalent to IL III, whereas in further investigation IL II was generally applied in compliance with all other sample buildings.



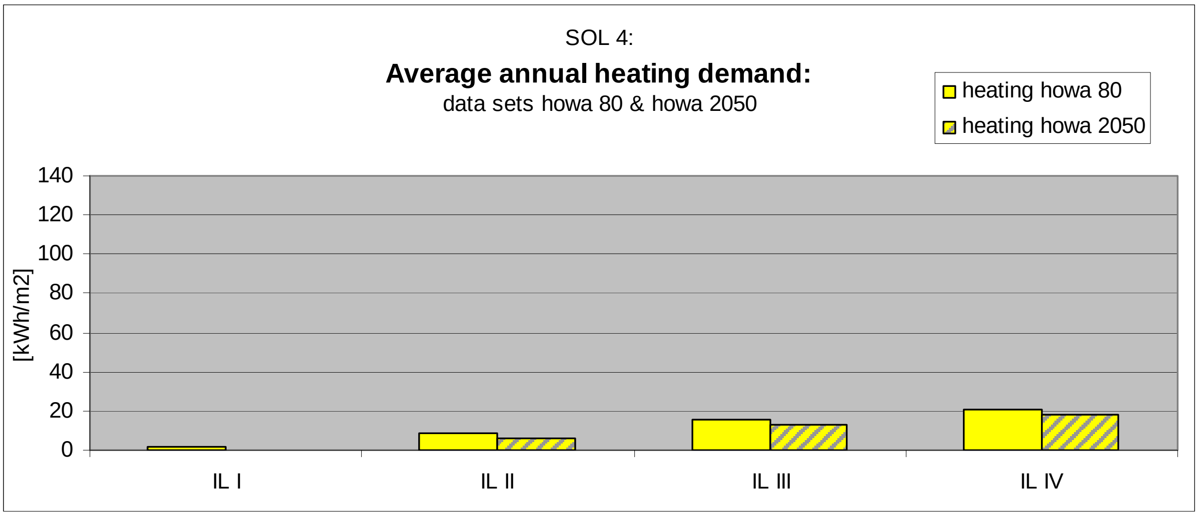
Graph 25: ONB: annual cooling demand for "howa 80" & "howa 2050" under different levels of internal load



Graph 26: SOL 4: annual cooling demand for "howa 80" & "howa 2050" under different levels of internal load

To a certain extent, internal loads compensate for heat losses during winter times 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 a near to 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 top increases in heating demand.



Graph 27: SOL 4: annual heating demand for howa 80 under different levels of internal load

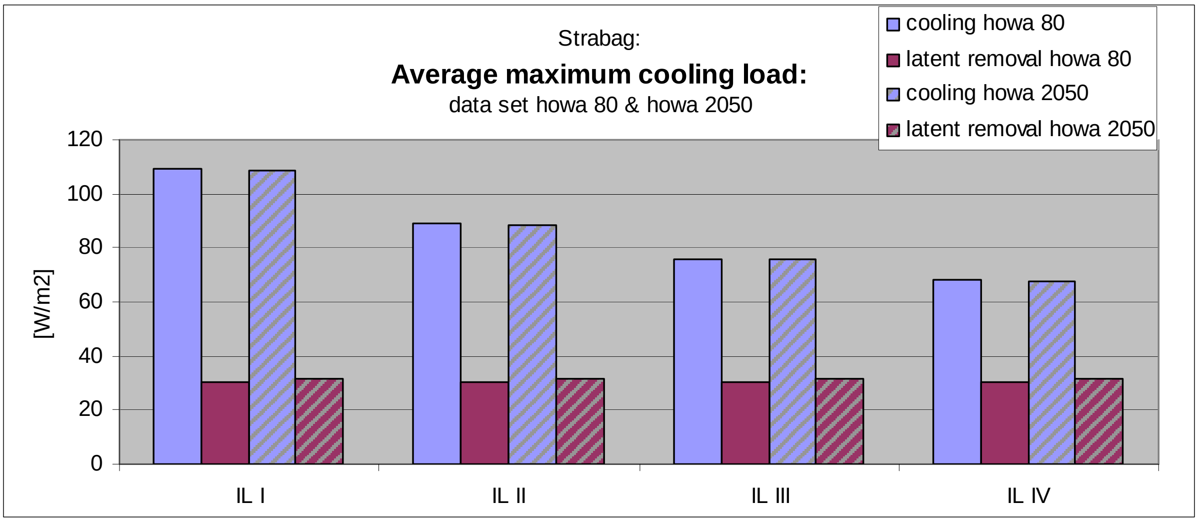
Still, for less insulated buildings this signifies that measures for increased energy efficiency in IT and communication equipment should go along with improvements of the building's thermal envelop. This would prevent reductions in cooling demand to be partly compensated for by increased heating demand in winter due to the reduction of internal heat sources.

Lower internal loads may also result in lower maximum cooling loads, which are crucial for the dimensioning of the respective plant. Therefore the sample buildings are additionally simulated under the elevated levels of internal loads for lighting and equipment depicted in Graph 18: *Internal Loads simulation mode „Standard", elevated levels of internal loads for lighting and equipment for the determination of cooling loads only* , page 33.

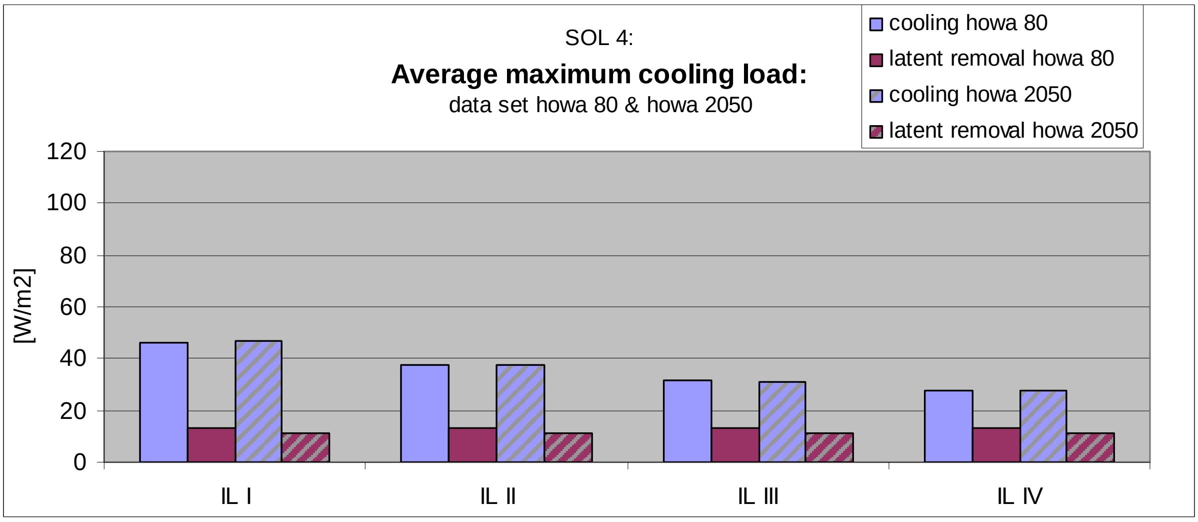
The simulation results reveal a twofold insight:

- More efficient equipment contributes in bringing down the required cooling loads, but these – with the exception of SOL 4 - still do not fall below app. 40 W/m^2. This threshold by rule of thumb represents the limit for adoption of hybrid cooling strategies (s. gloss 3, page 7).

- Although overall cooling demand has been shown in Graph 24**Fehler! Verweisquelle konnte nicht gefunden werden.** to increase due to climate change, maximum cooling loads remain generally unchanged, hence thresholds in plant size may not be surpassed.



Graph 28: Strabag: maximum cooling loads for "howa 80" and "howa 2050" under different levels of internal load Fehler! Verweisquelle konnte nicht gefunden werden.



Graph 29: SOL 4: maximum cooling loads for "howa 80" and "howa 2050" under different levels of internal load

7.1.4 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 could be demonstrated that different levels of energy efficiency in equipment and lighting influence cooling demand in the sample buildings to a more significant extent than does the influence of a changing climate, depicted here by the adoption of different climate data sets. This is still more so the case when regarding maximum cooling loads.

To a minor extent 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 envelop have to developed.

7.2 Module 2: Cooling energy demand of sample buildings under different usage modes

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 preponing 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 larger 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, 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 before mentioned social implications are not further investigated.

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.

7.2.1 Investigated climate data sets

For this module climate data set “howa 80” was applied.
For a first glimpses 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.

7.2.2 Investigated sample buildings, applied simulation mode

As Strabag has been shown to display comparatively high cooling demands and loads in Module 1: *Cooling energy demand of sample buildings under different levels of internal loads* (and hence a high potential for improvement is assumed here), this sample building was investigated under simulation mode Standard.

Different usage profiles both in terms of occupancy presence schedule and intensity were investigated. These profiles are prescribed in detail in the following chapter.

Table 4: Description of investigated usage profiles

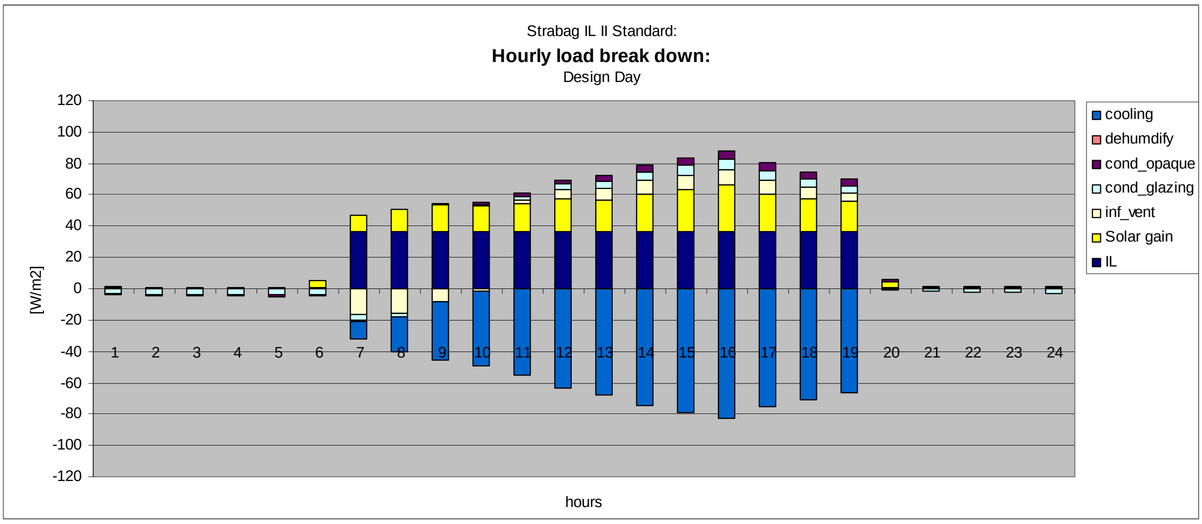
Usage profile denomination	**Description:** occupancy schedule
Standard	6:00 am to 7:00 pm
Standard real	8:00 am to 5:00 pm
early	7:00 am to 4:00 pm
Siesta	8:00 am to 12:00 am, 4:00 pm to 7:00 pm
Tele	6:00 am to 7:00 pm, 30% of occupants permanently absent
Tele Siesta	8:00 am to 12:00 am, 4:00 pm to 7:00 pm 30% of occupants permanently absent
Shade	6:00 am to 7:00 pm shading closes at irradiation of150W/m^2 [24]

7.2.3 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

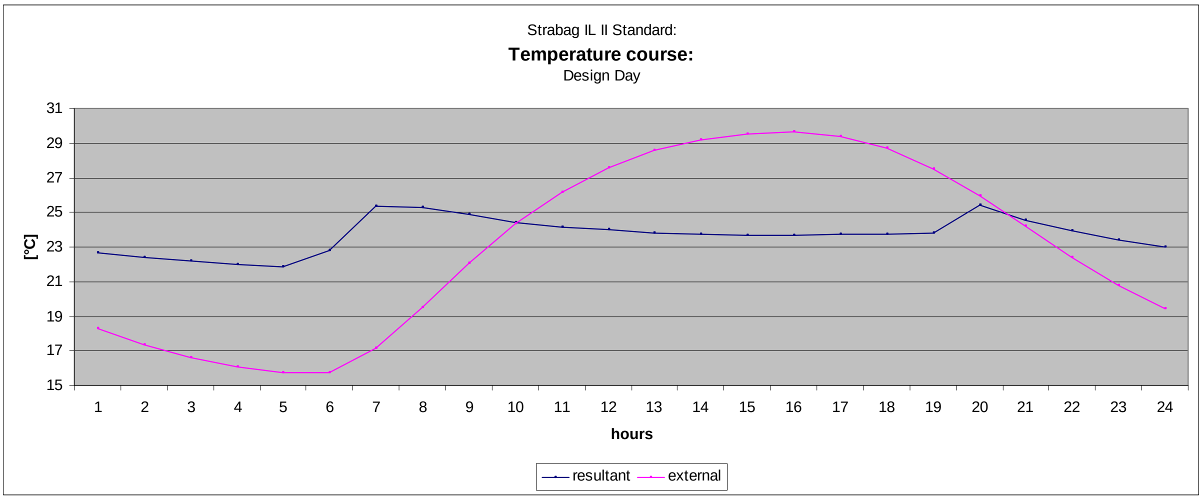
[24] on vertical window pane

cooling, as the incoming outdoor air is mostly hotter than the cooled indoor environment.



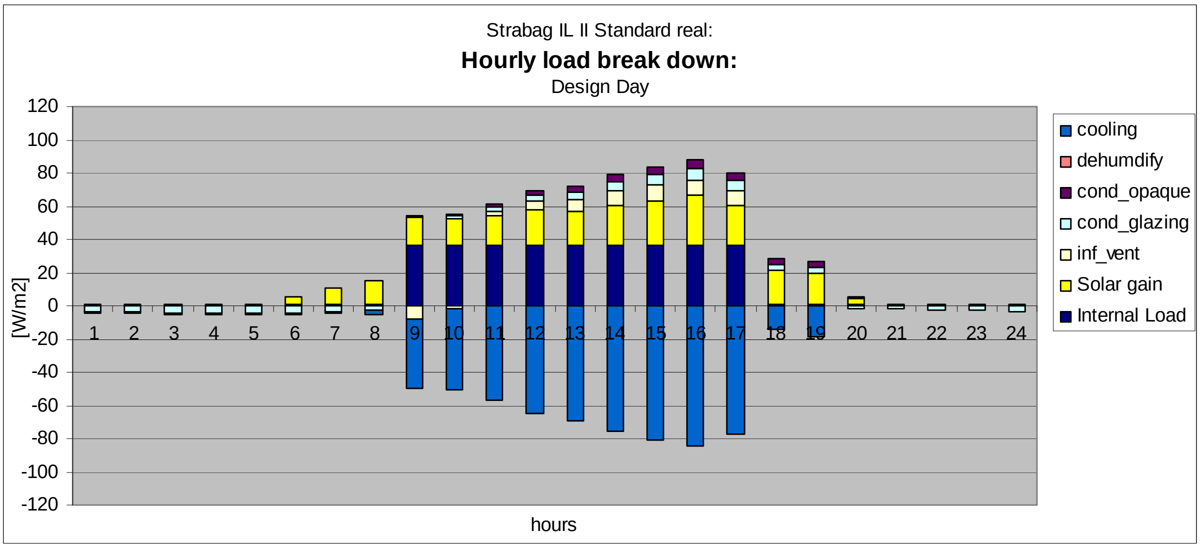
Graph 30: Hourly load break down in Strabag mode "Standard" Fehler! Textmarke nicht definiert. **(same as. Graph 23)**

The corresponding temperature swing documents how 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 31: Temperature course in Strabag mode "Standard"

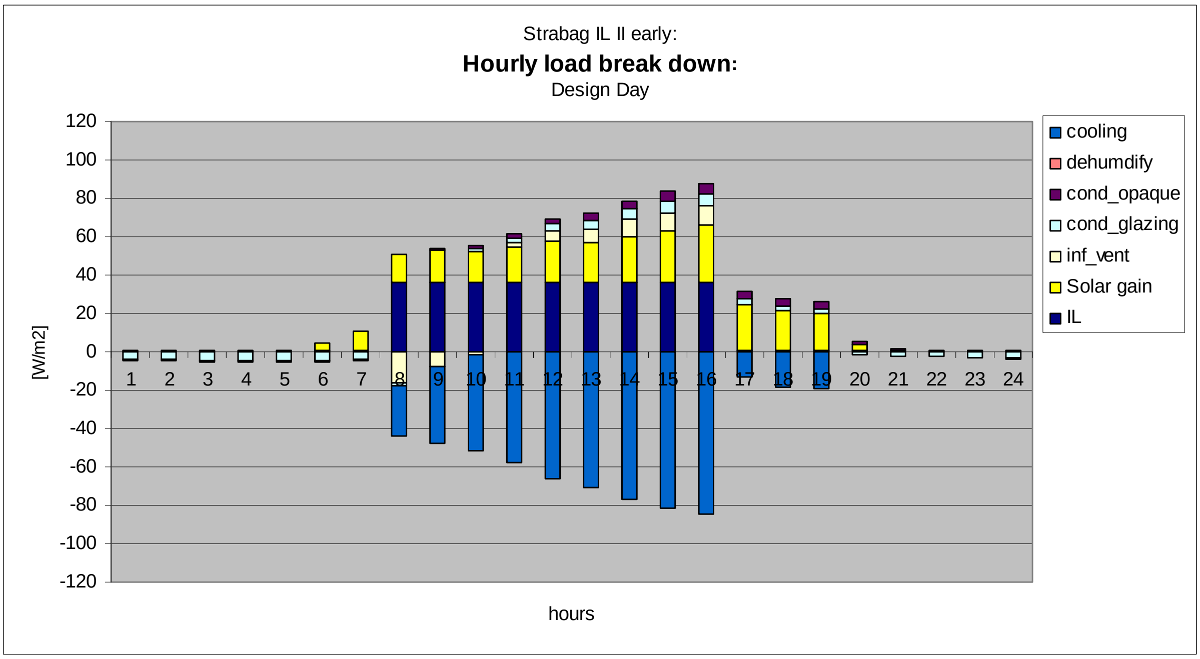
While simulation mode "Standard" accounts for 13 office hours (6:00 am to 7:00 pm), most office workers are present for eight hours and less. Applying a tighter time scheme "Standard real" (8:00 am to 5:00 pm) would already decrease cooling demand by 16%. For those workers, however, who come earlier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



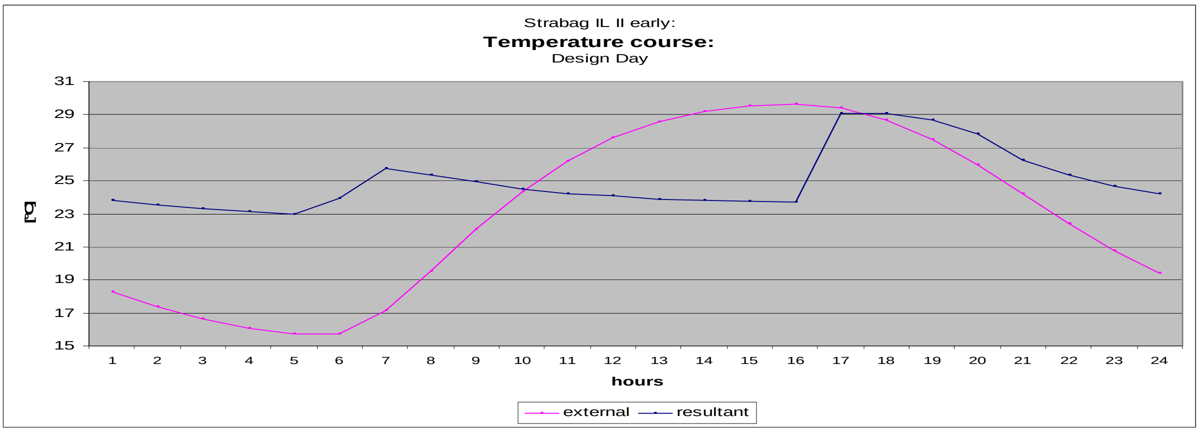
Graph 32: Hourly load break down in Strabag mode "Standard real"

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.

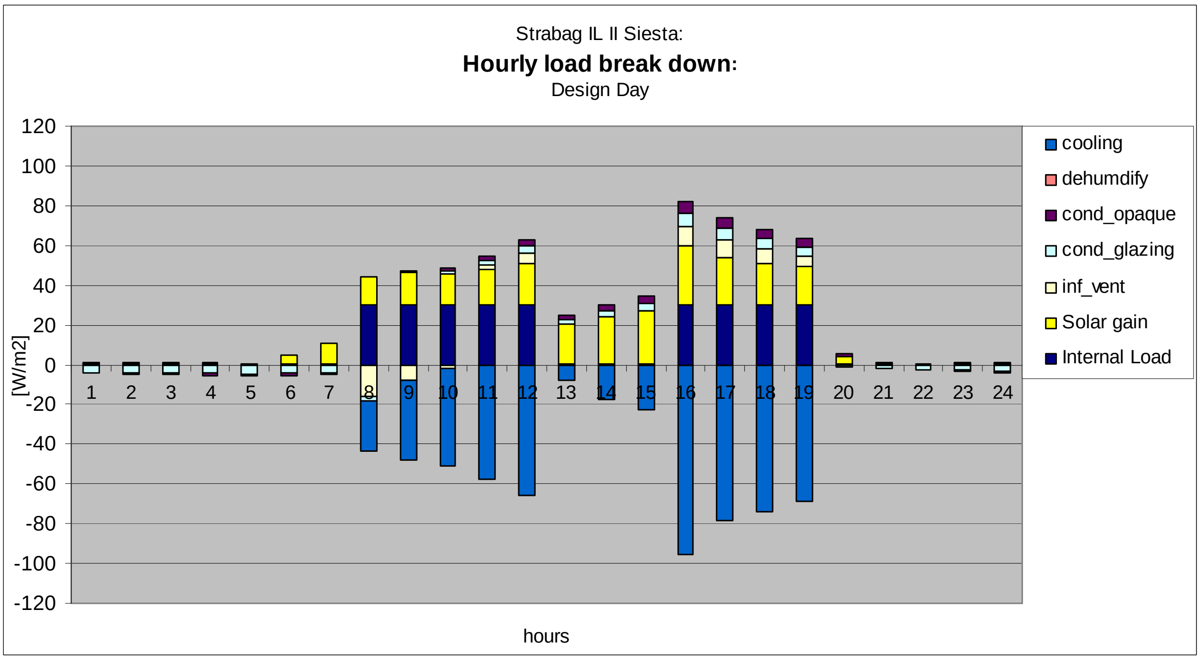


Graph 33: Hourly load break down in Strabag mode "early"

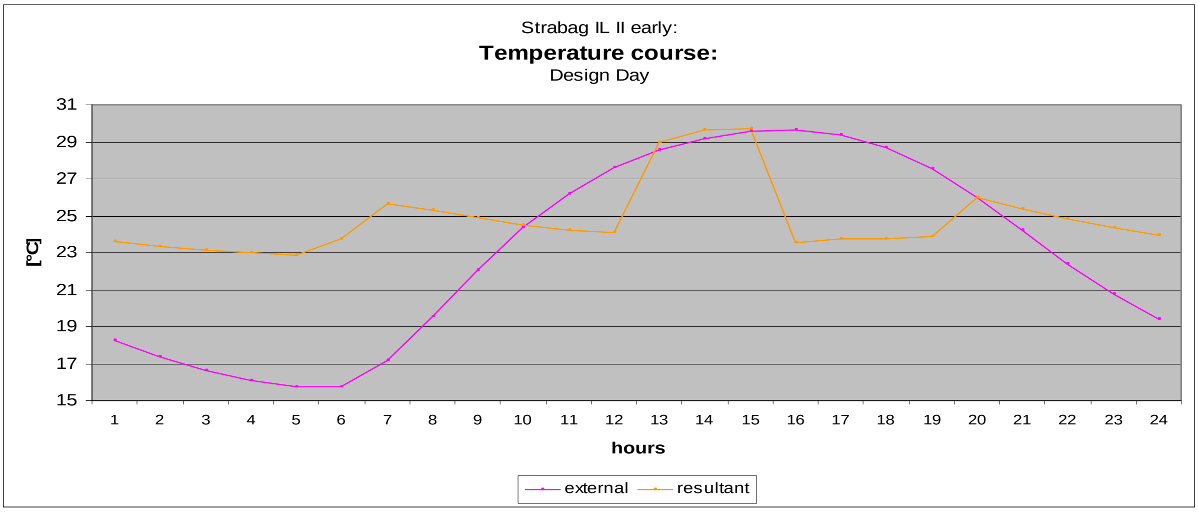


Graph 34: Temperature course in Strabag mode "early"

The traditional concept of a midday Siesta strives to avoid working during the hottest hours of day. In terms of energy consumption, this only makes sense, if equipment and light are switched off for the lunch break and higher temperatures are allowed for 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".



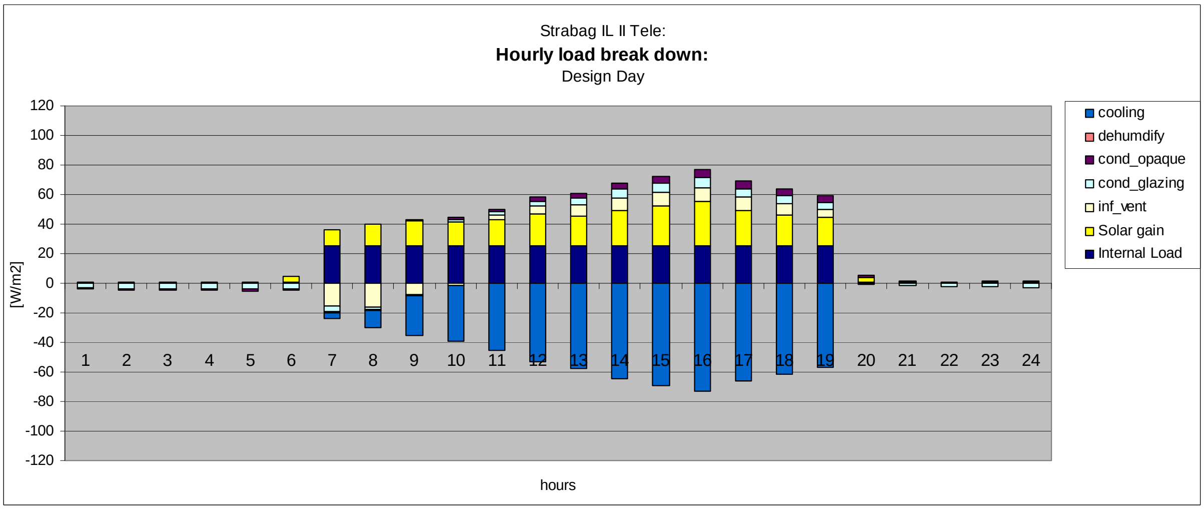
Graph 35: Hourly load break down in Strabag mode "Siesta"



Graph 36: 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[25].



Graph 37: Hourly load break down in Strabag mode "Tele"

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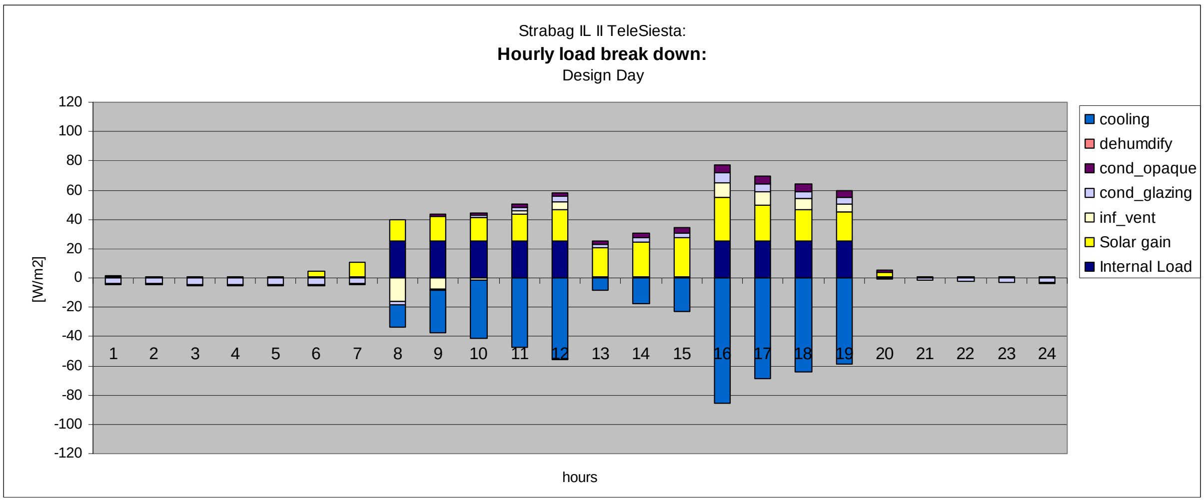
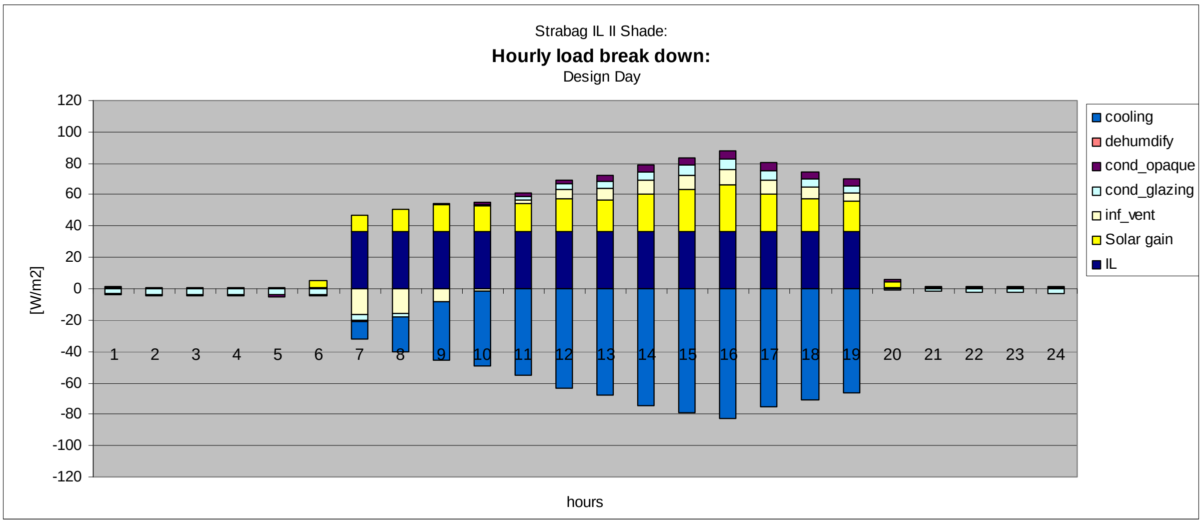
[25] It may be brought forward, that internal loads of both workers and their equipment and lighting are only displaced to other locations by teleworking. This location most probably will be a working desk in the employee's home, which might not normally be equipped with cooling devices. The issue of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



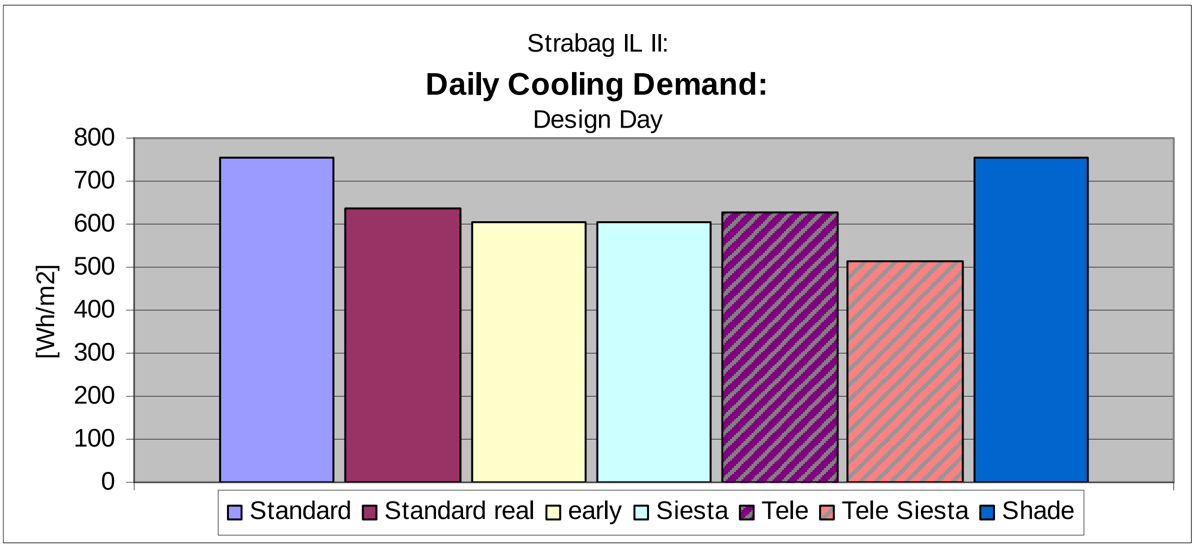
Graph 38: Hourly load break down in Strabag mode "TeleSiesta"

It has been indicated above that the shading regime implemented in mode "Standard" already illustrate 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. The simulation results for mode "Shade" demonstrate that 180 W/m^2 is a reasonable target already: in this mode the threshold has been decreased to 150 W/m^2 only. But this does not result in any cooling demand reduction due to the fact, that all significant irradiation is covered for by a threshold of just 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.



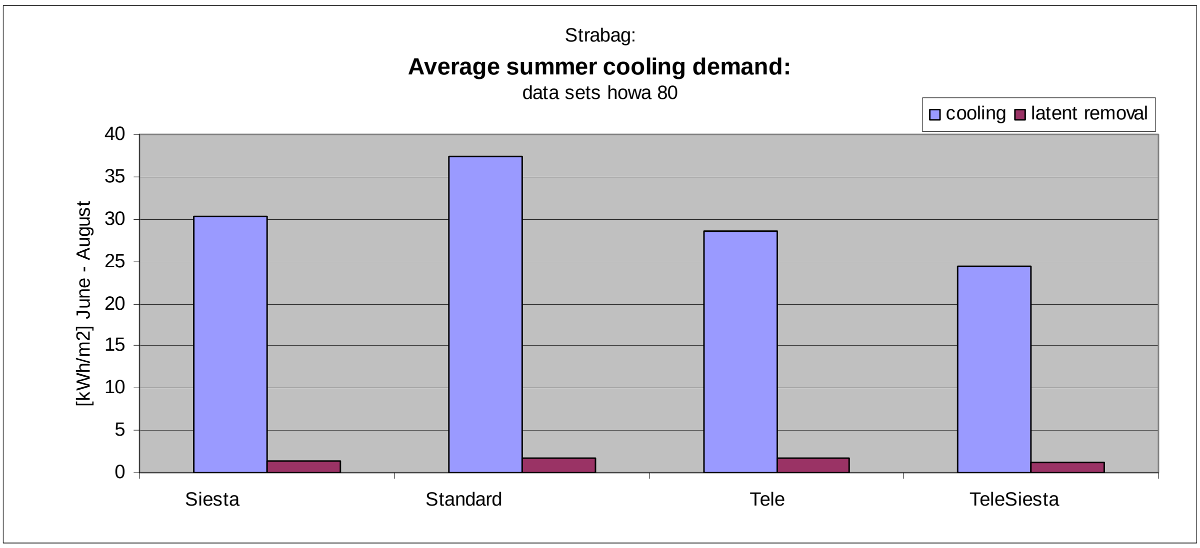
Graph 39: Hourly load break down in Strabag mode "Shade"

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



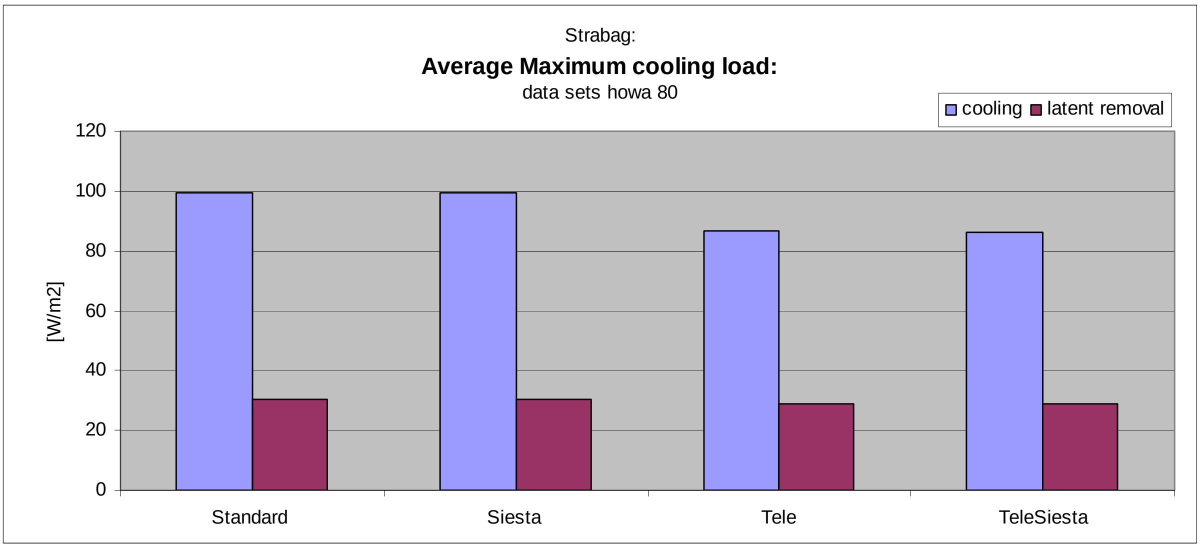
Graph 40: Daily cooling demand of different usage profiles

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



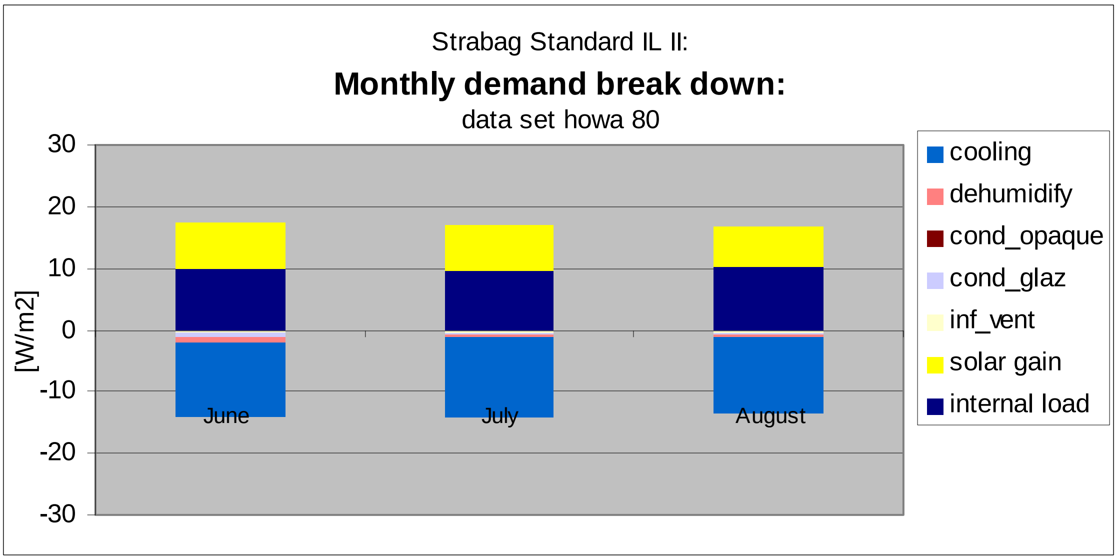
Graph 41: Summer cooling demand of different usage modes

An investigation of maximum cooling loads forwards the fact 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.

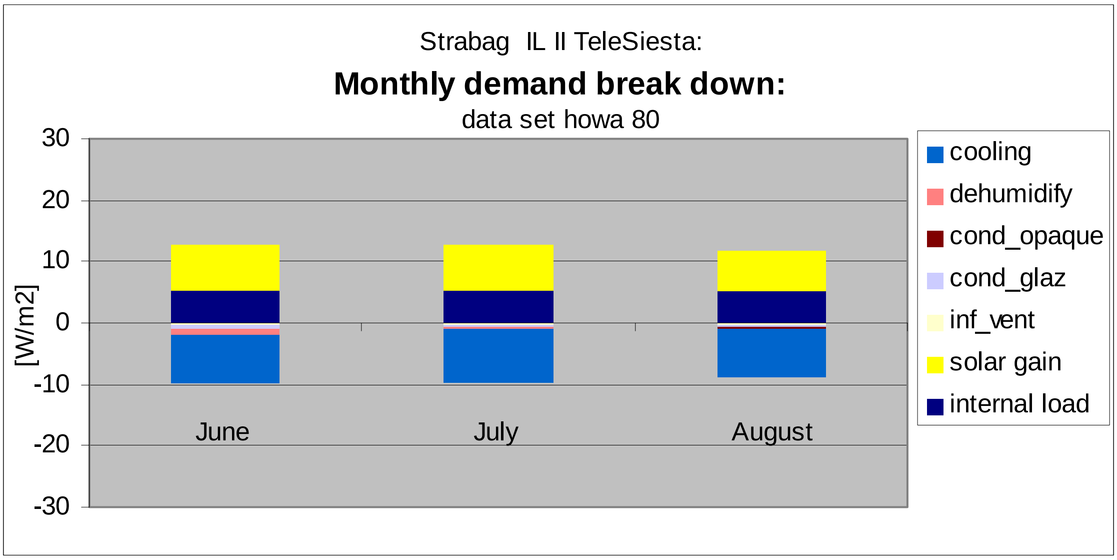


Graph 42: cooling load of different usage modes

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.



Graph 43: Summer load break down for Strabag mode "Standard"



Graph 44: Summer load break down for Strabag mode "Tele Siesta"

7.2.4 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 quiet 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 to cope with the impacts of climate change.

7.3 Module 3: Impacts of different natural (and mechanical) ventilation regimes on thermal comfort in sample buildings

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 turns open windows into security issues.

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

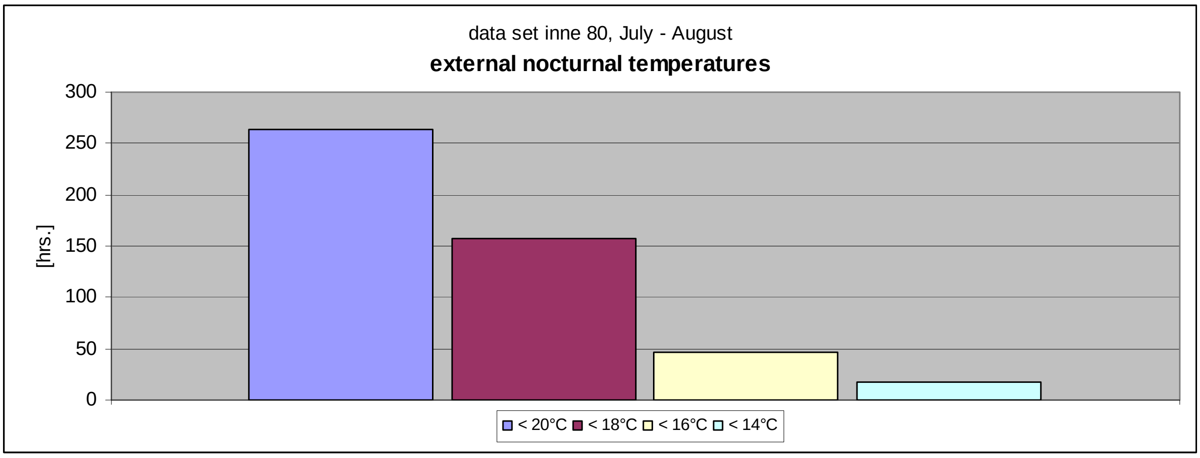
7.3.1 Investigated climate data sets

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, which 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.

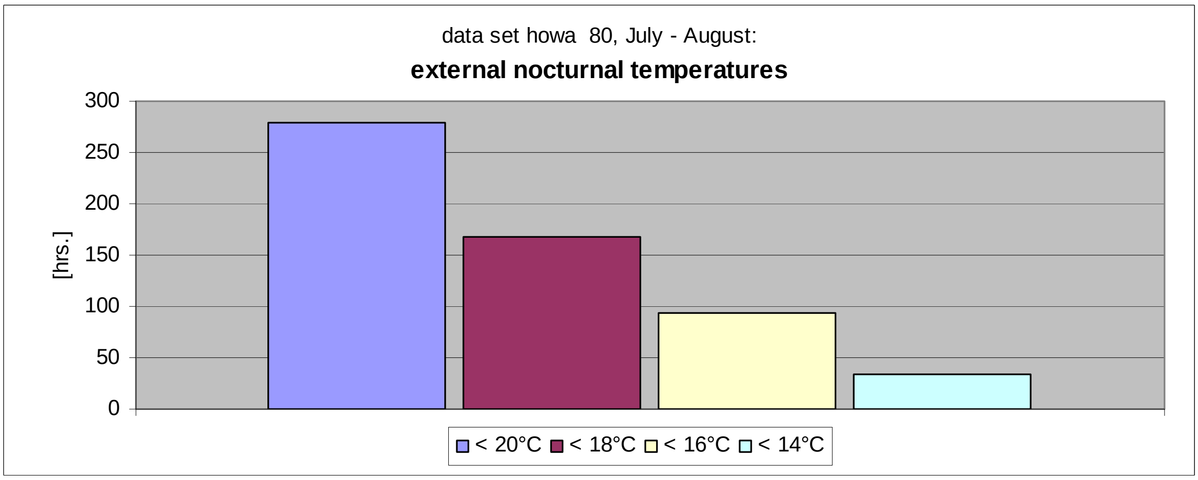
Therefore, one single summer month out of “inne 80” is applied for investigations. Assessments of future situations still lake sound basis as localized climate scenarios, so far, make no allusions as to what wind environments will be like in the decades to come.

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 first is directly influenced by outdoor temperature and hence subject to implicit changes as outdoor temperatures are generally on the rise, the latter one 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) amounts of 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 45: Amount of hours with external nocturnal temperatures under-running various limits, data set "inne 80"

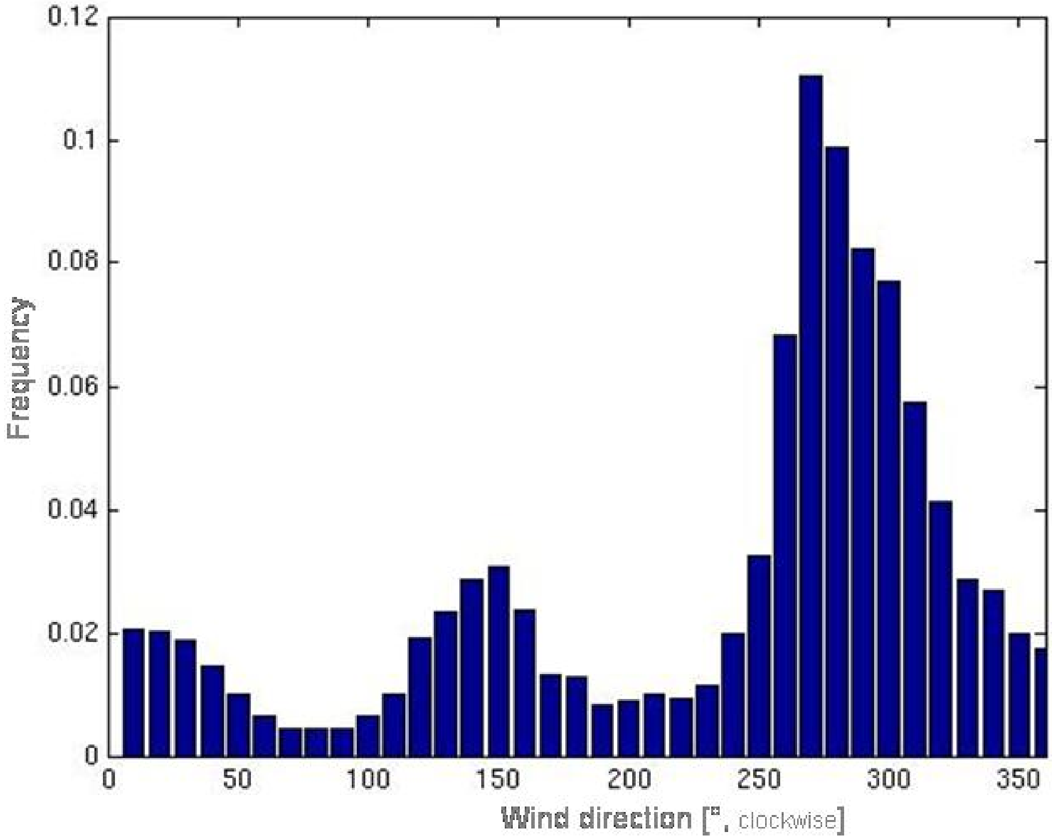


Graph 46: Amount of hours with external nocturnal temperatures under-running various limits, data set "howa 80"

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.

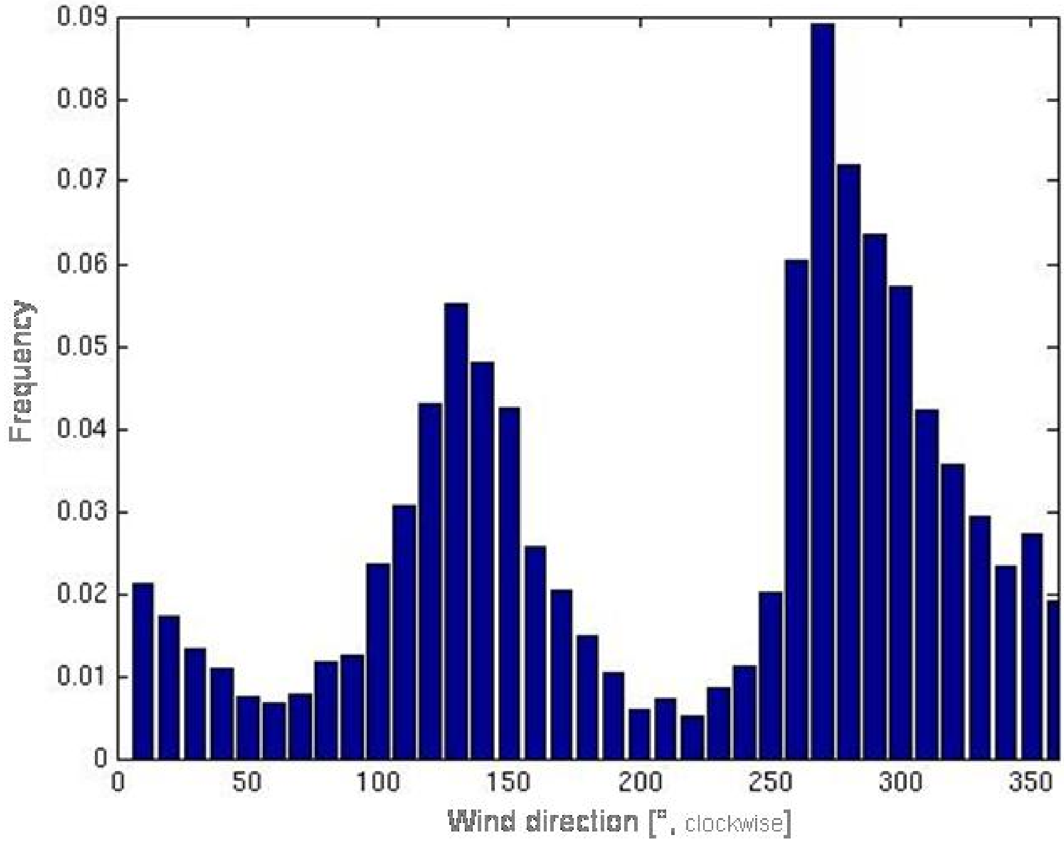
For detailed analysis of ventilation processes, the sample buildings were investigated under steady state conditions of climate design days in order to reveal independencies of loads, gains and losses. 15 preconditioning days were assumed therefore.

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, Southern ones (130°) are often encountered likewise, especially during daytime. Highest wind speeds occur under West wind conditions, fainter winds from South are to be expected on hot days. This means that wind speeds tend to be limited when most needed during hot periods.



Graph 47: statistical distribution of wind directions (indication of degrees clockwise) for6:00 p.m.

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



Graph 48: statistical distribution of wind directions (indication of degrees clockwise) for6:00 a.m.

7.3.2 Investigated sample buildings, applied simulation mode

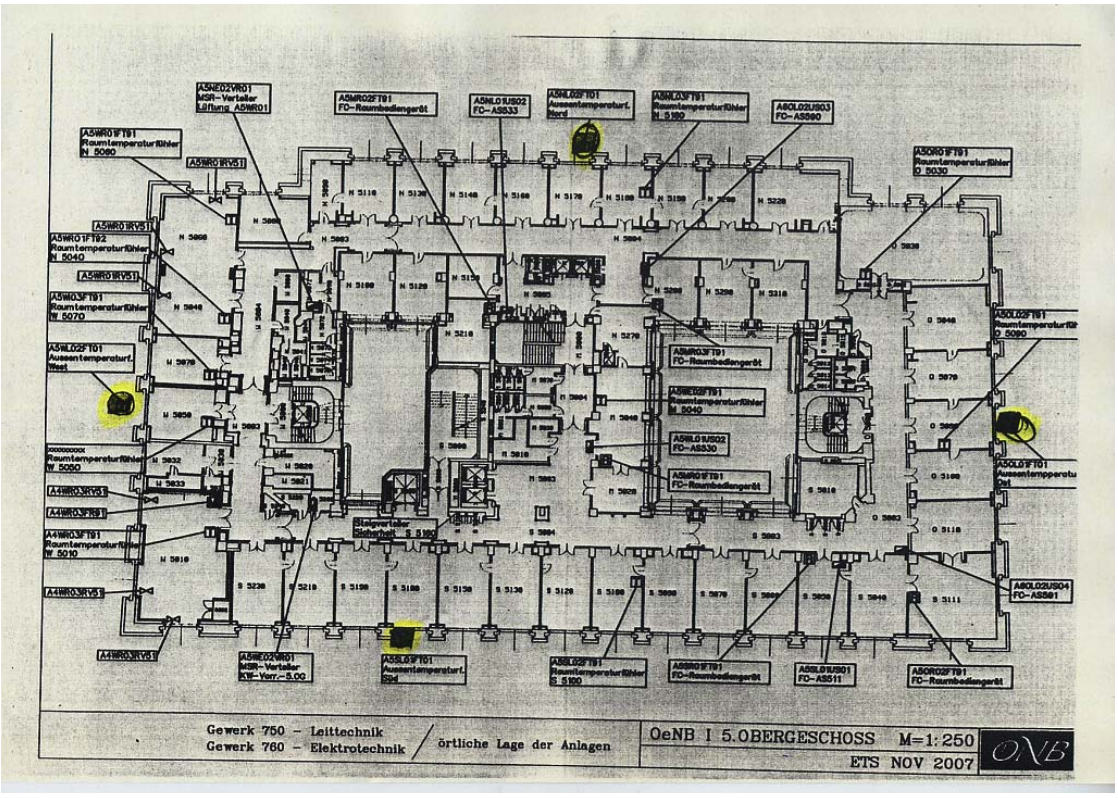
Two of the sample buildings – ONB and BGN – are already facing severe comfort deficits under present conditions (simulation mode "real"). Both historic buildings command hardly any or no cooling at all at present day. This fact has been taken as a starting point for the quest of directly applicable optimization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

7.3.3 Validation of simulated indoor temperatures

In order to obtain reliable results about the viability of natural ventilation it was necessary in 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 would it yield sound results if alternative options were implemented in the simulation model.

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 façade respectively.

All these sensors are mounted in front of the external walls, with only a few centimetres in between. This proximity of 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.

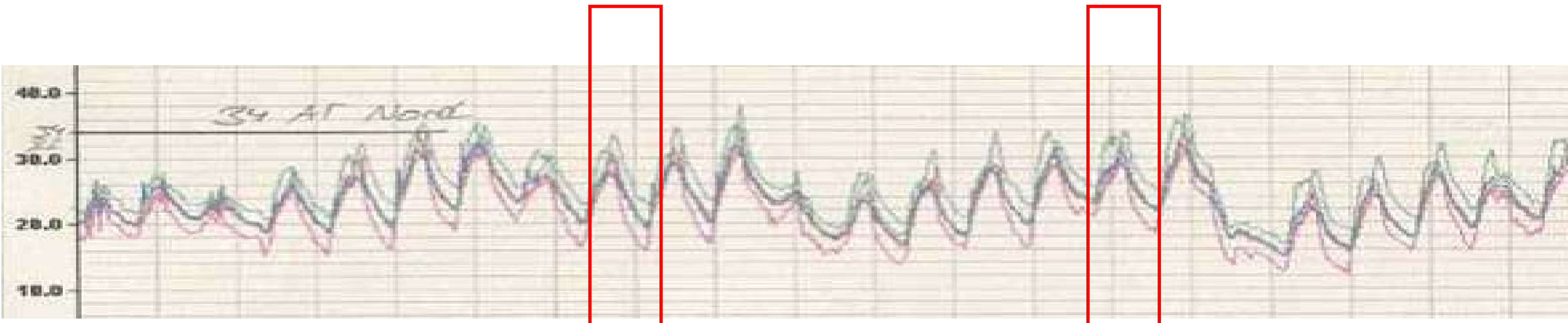


Graph 49: ONB floor plan with external temperature sensors

Graph 50: placement of temperatur sensor on west facade

Graph 51: placement of temperatur sensor on east facade

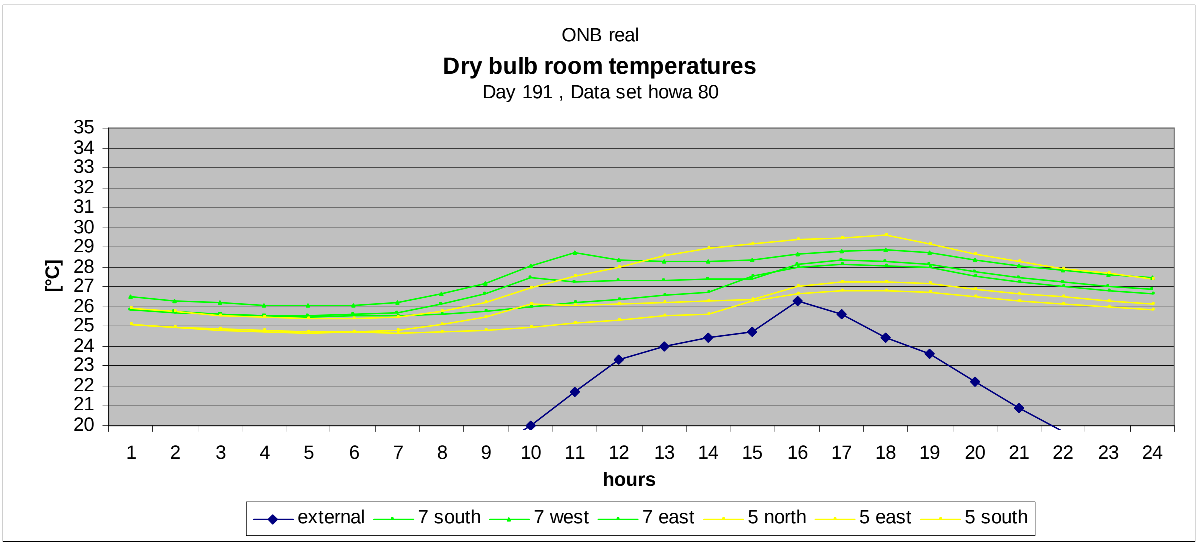
Observations of external and internal temperature sensors



External temperature readings

5th storey

Graph 52: Indoor air temperature observations (including outdoor air temperature: blue line; the red rectangles enframe the measurements of August 18 and August 27,2009, which are scrutinisded against simulation results hereafter)

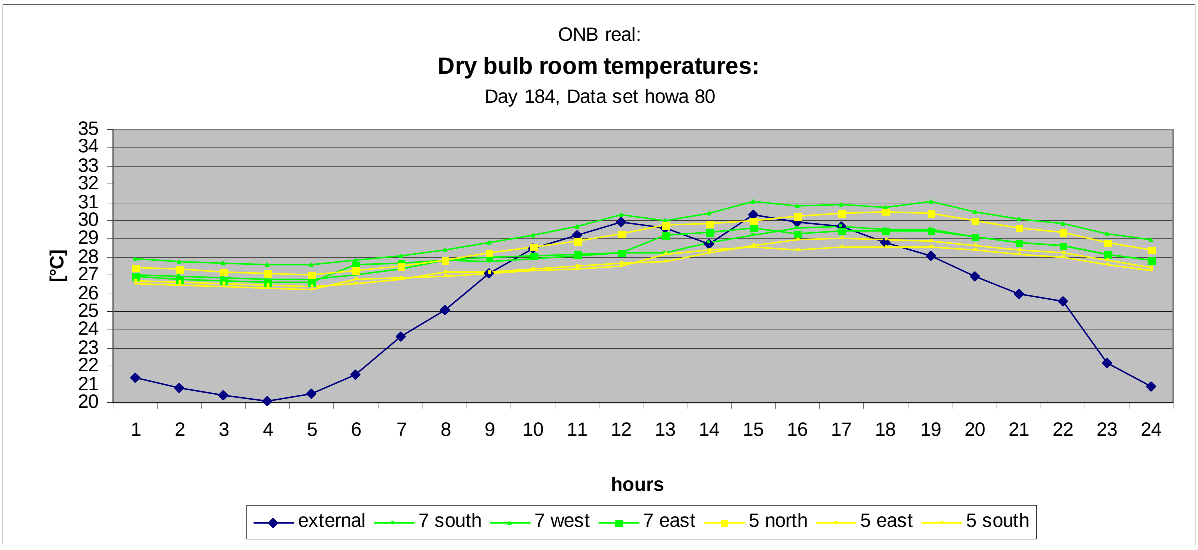


Graph 53: Simulation results for a day comparable to August 18, 2009 (in terms of external temperature reached)

<u>Temperature observations</u> August 18, 2009 displays 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 54: Simulation results for a day comparable to August 27, 2009 (in terms of external temperature reached)

Temperature observations 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.

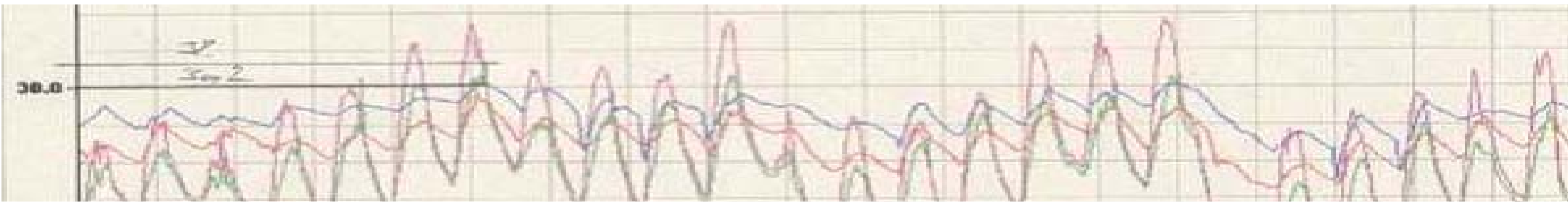
These simulation result do not exactly match with measurements in the existing building, but rather tend to be slightly higher than indoor measurements; However, it has to be taken into account that the given readings of outdoor temperature must be assumed to exaggerate the actual external air temperature 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.

However, 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 adversely 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.

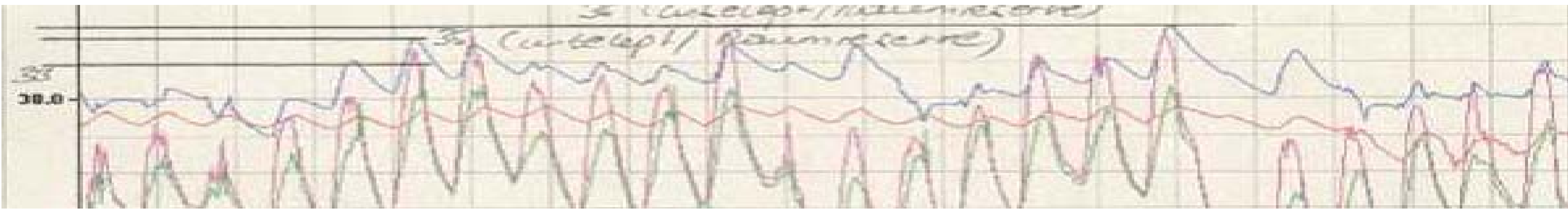
BGN: Observations of external temperature sensors

BGN

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 55: 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 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 storey 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 in the occasion of a refurbishment process). Temperature amplitudes appear smoothed here while still on high level.

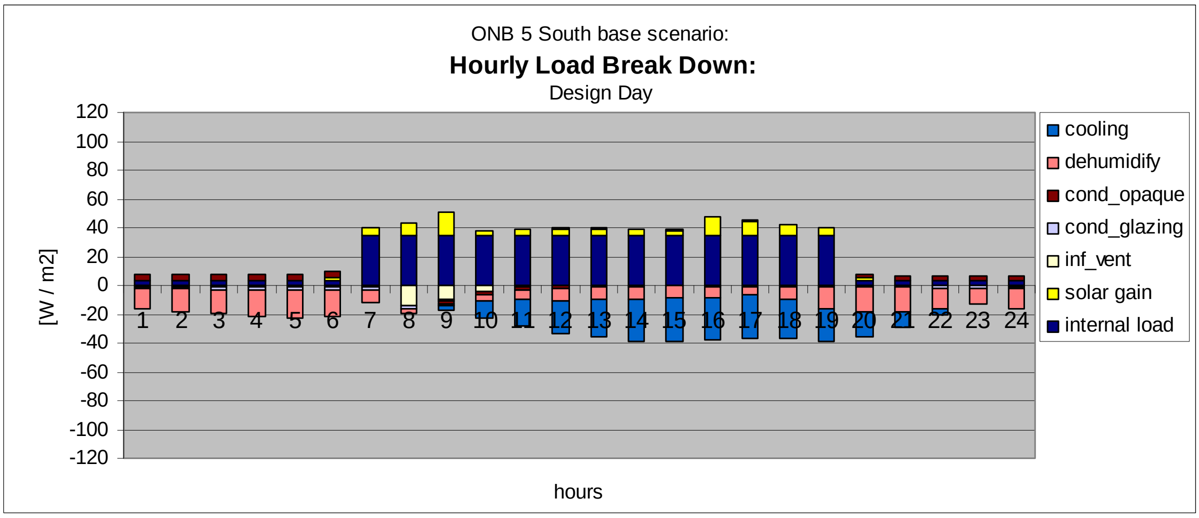
7.3.4 Results

ONB

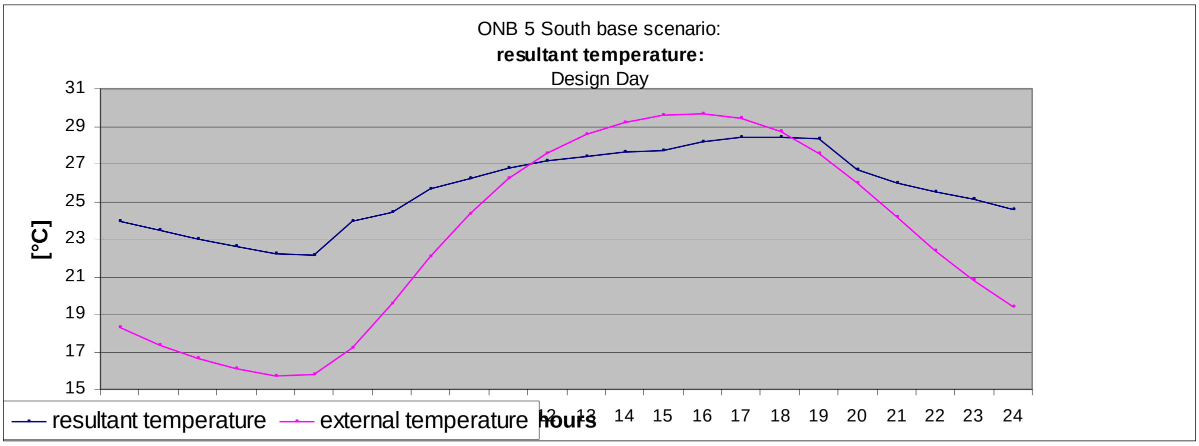
One single reference room (5th floor, facing South) has been investigated in this sample building. The present day situation in this room serves as base scenario for optimization hereafter: The room is served by mechanical ventilation, which induces fresh air on a constantly low temperature level (21°C) 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 out rule 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 56: hourly gains and losses for ONB base



Graph 57: Temperature course for ONB base

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

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, constant pressure coefficient[26] for the outside wall and discharge coefficients[27] for the opening's shape, both equally obtained from literature[28].

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

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 app. 80% of the time, there are some hours during the investigated month, which display minor air changes. Should they occur during hours of highest loads, these

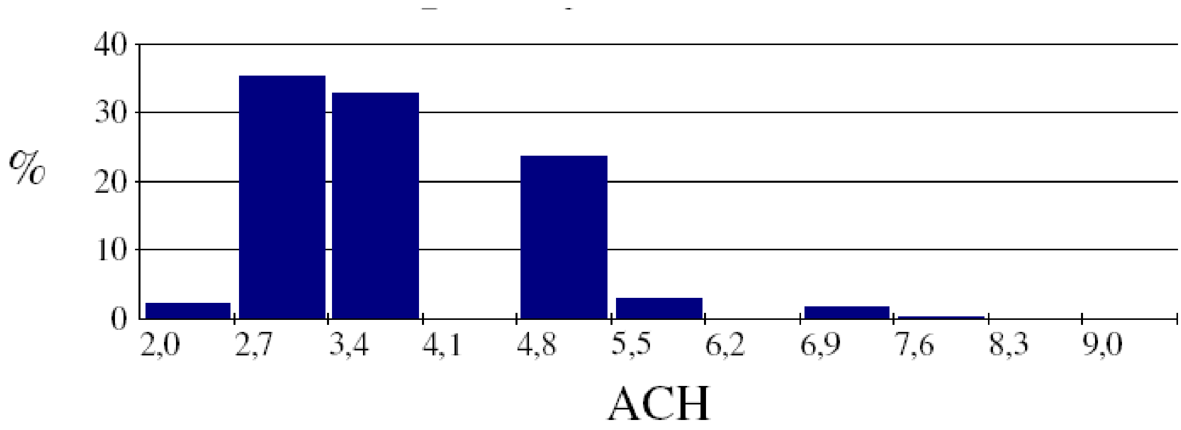
[26]The pressure coefficient in general is a dimensionless number which describes the relative pressures throughout a flow field in fluid dynamics. In the case of a flow hitting a building's façade, this coefficient varies with the flow's angle of attack and the relative position in the façade.

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

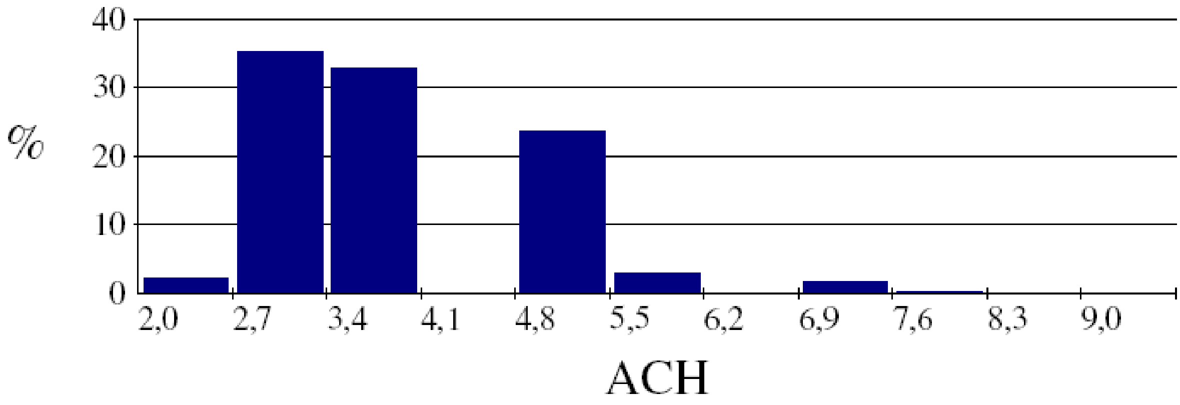
[28]Allard, Francis; Santamouris, Mat; Alvarez, Servando (2002): Natural ventilation in buildings. A design handbook. Reprint. London: James & James. . See page 53 and 100

reduced air change rates are to be implicated, hence presenting a worst case scenario.

Surprisingly, different wind directions do not generate different indoor air change rates.



Graph 58: Frequency Distribution of achievable air change rates due to natural ventilation for ONB s12 (nocturnal ventilation), wind direction West



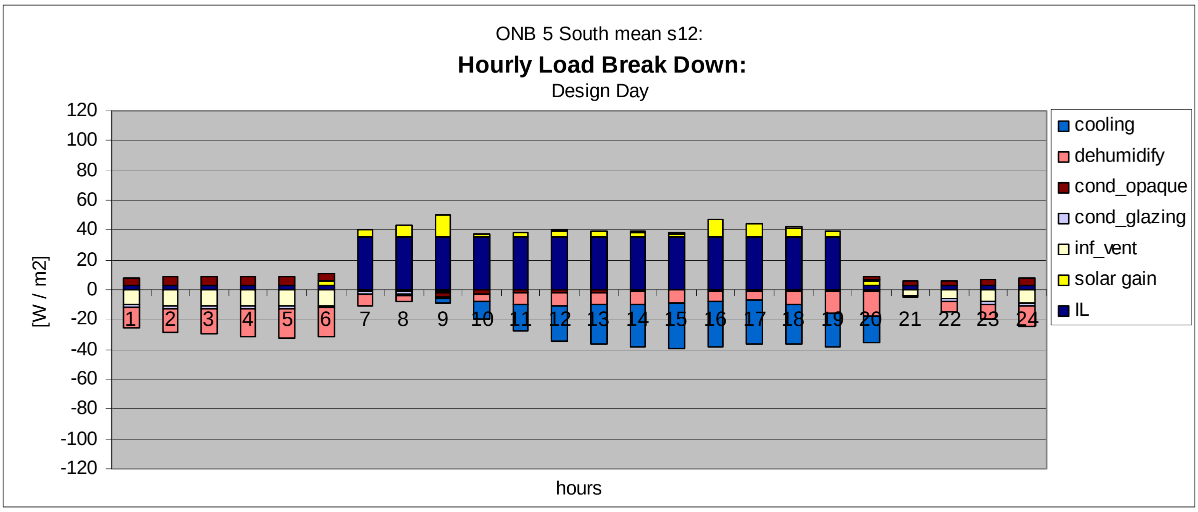
Graph 59: Frequency Distribution of achievable air change rates due to natural ventilation for ONB s12 (nocturnal ventilation), wind direction South

The above generated, nocturnal air change rates 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.

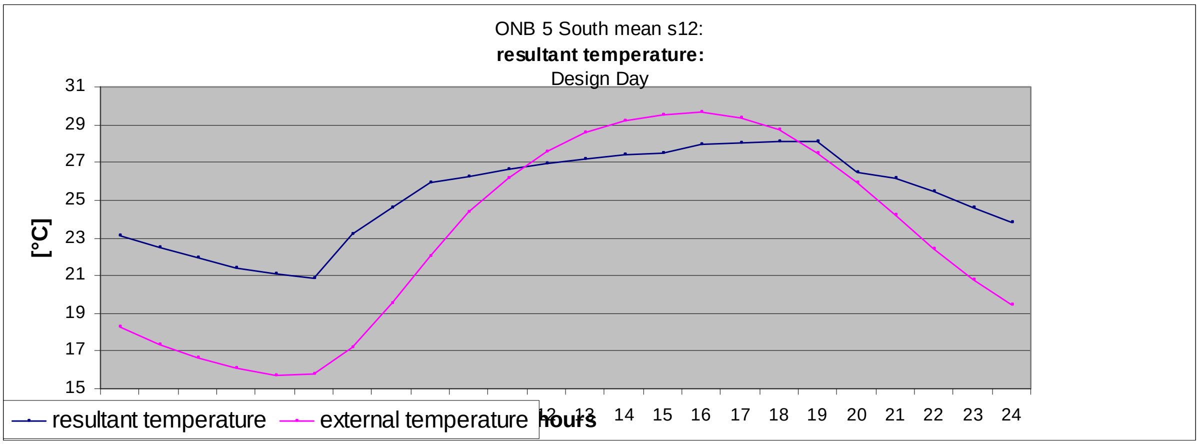
Although increased discharging of heat stored in external walls is visible in Graph 60: *hourly gains and losses for ONB s12 (nocturnal ventilation)* , page 19) as compared to Graph 56: *hourly gains and losses for ONB base* , page 72) this does not significantly increase these wall's capacity to dampen 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 out master 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 60: hourly gains and losses for ONB s12 (nocturnal ventilation)



Graph 61: Temperature course for ONB s12 (nocturnal ventilation)

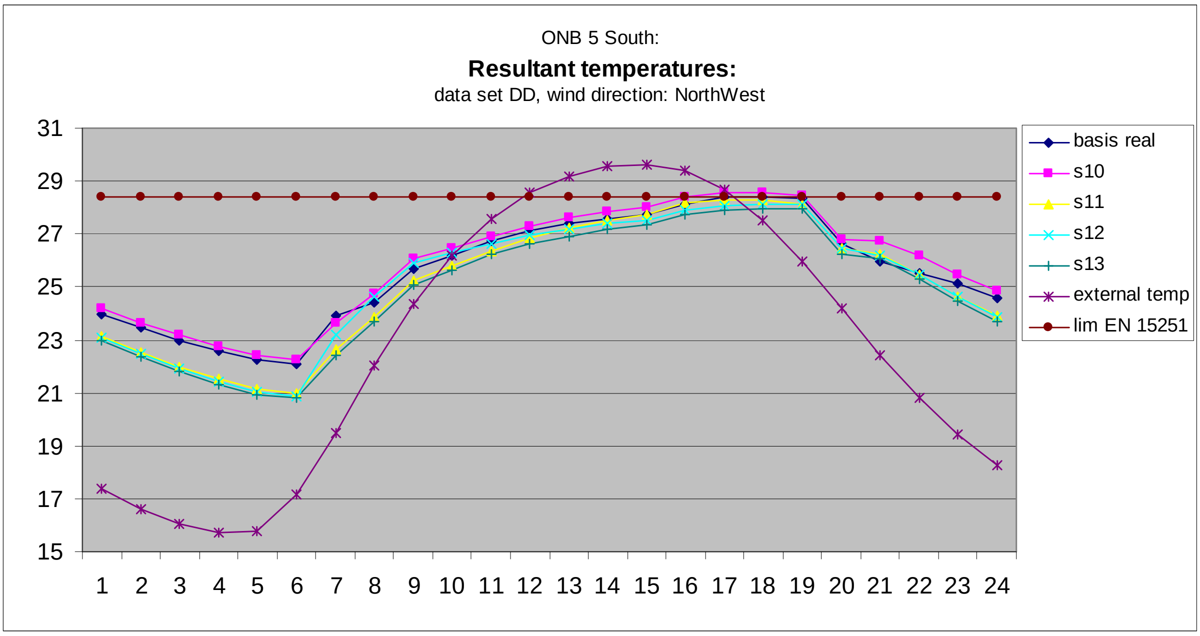
Analysis and optimization

Further ventilation schedules were simulated under steady state conditions:

Table 5: natural ventilation schedules' description

Ventilation schedule denomination	Window opening hours	description
Basis real		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

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 62: analysis of temperature courses for ONB

0:00 – 7:00 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.
7:00 – 10:00 am

Windows are opened in base scenario as outdoor temperatures range between 18 and 26°C, the indoor temperature rise 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 constantly open; starting from lower nocturnal values, this schedule's temperature course remains low due to chilly morning air.

Windows are shut in s12, 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 s12, the further ones' temperature courses 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 effects 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 acc. 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 however 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.

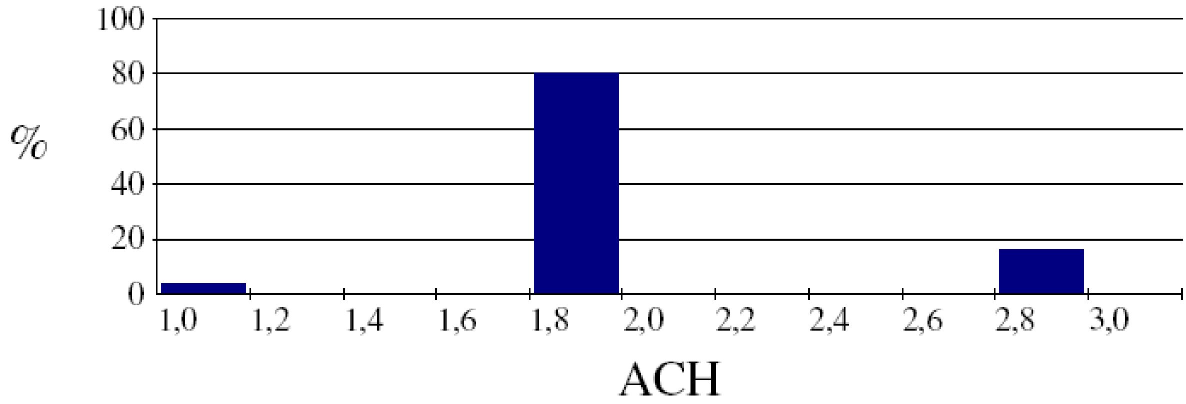
7:00 – 8:00 pm
Last users finish work and switch off equipment as well as lighting, thus causing a sharp fall in indoor temperatures below the 27°C threshold, though these still remain remarkably high. Altogether, this comfort limit is over run at least for 6 hours in all variants. In contrast, the comfort 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

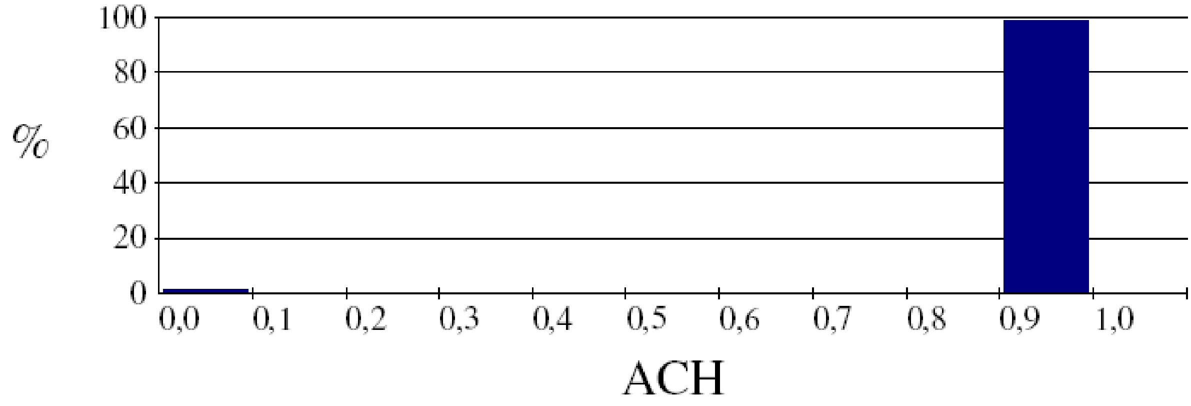
The internal temperature drop generally slows down as nearly all internal loads have already been removed. s10 is the only variant with openings closed during the whole period – a fact, which clearly effects elevated temperatures as compared to the other variants.

s13

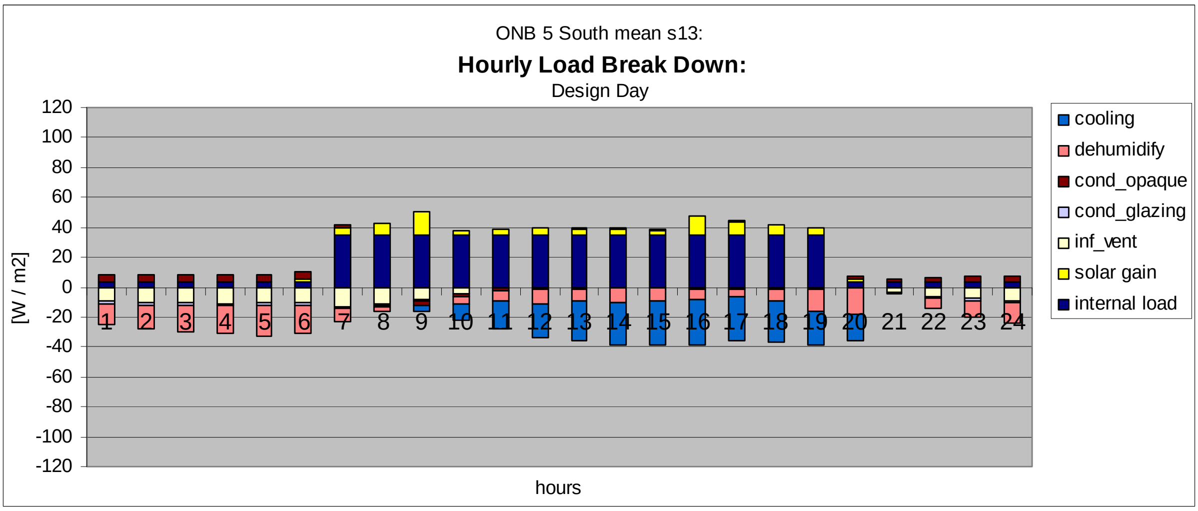
On basis of the above analysis of hourly temperature courses in dependency on ventilation strategies the schedule s13 was created. It was found that base scenario profited from morning stack effect due to chilly morning air, while s12 takes advantage of cold nocturnal outside conditions. Both slightly decrease indoor temperature by window closing during hot day time hours. s13 therefore forms a synthesis of these two approaches: it largely dwells on 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 63: Frequency Distribution of achievable air change rates due to natural ventilation for ONB s13 (extended nocturnal ventilation), wind direction West



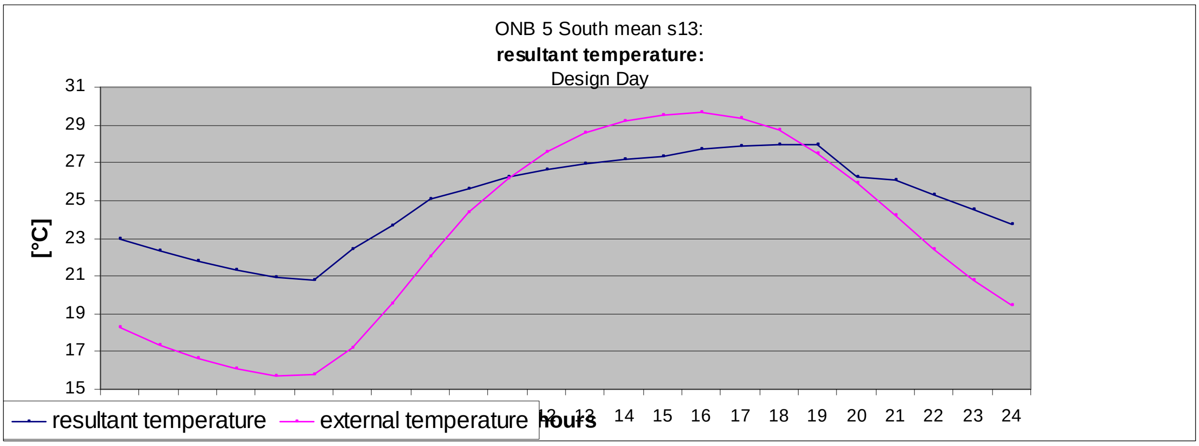
Graph 64: Frequency Distribution of achievable air change rates due to natural ventilation for ONB s13 (extended nocturnal ventilation), wind direction South



Graph 65: hourly gains and losses for ONB s13 (extended nocturnal ventilation)

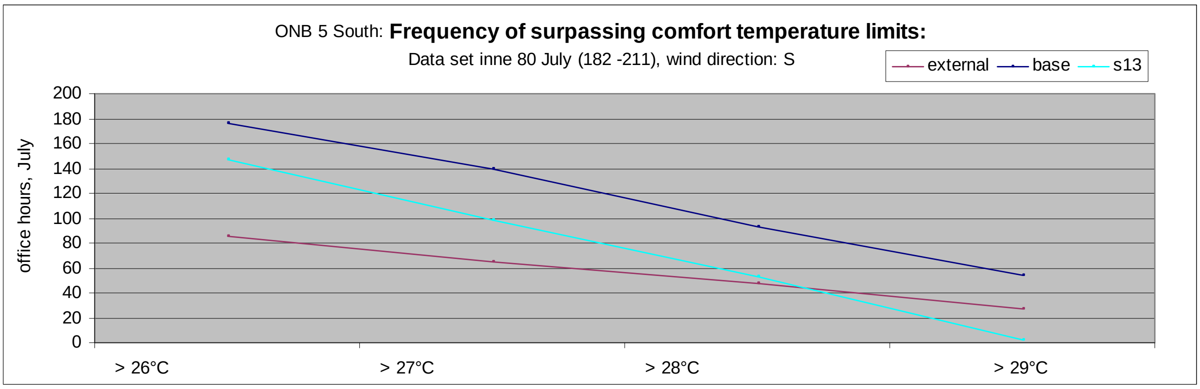
The analysis of s13' hourly load break down under steady state reveals a – though limited - potential to harness nocturnal ventilation losses for improved comfort conditions during the hottest hours. Still, it has to be kept in mind:

- 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 66: Temperature course for ONB s13 (extended nocturnal ventilation)

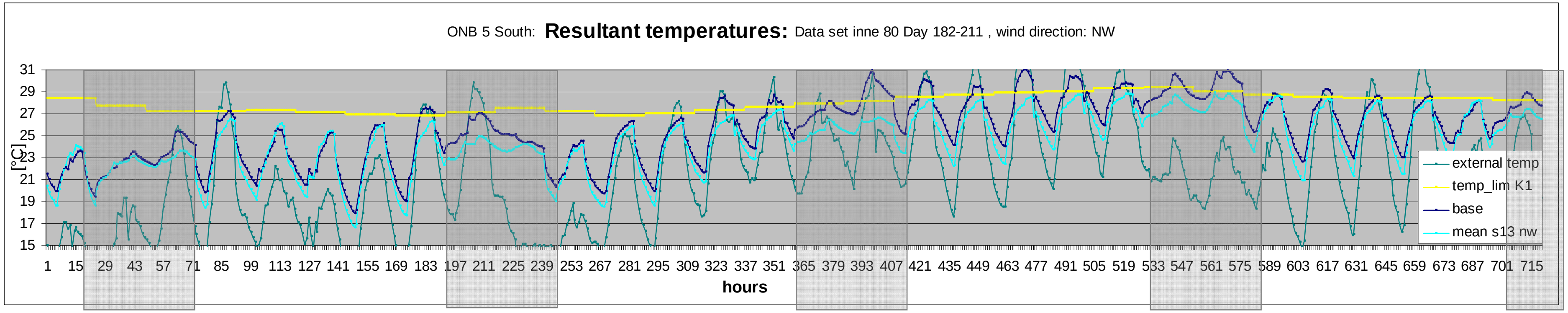
s13 has been applied to the reference room under the conditions of climate data set “inne 80” for July (day 182 – 211). In comparison with the base scenario this effects in a decrease of office hours[29] during which certain comfort temperature limits are surpassed by indoor resultant temperature.



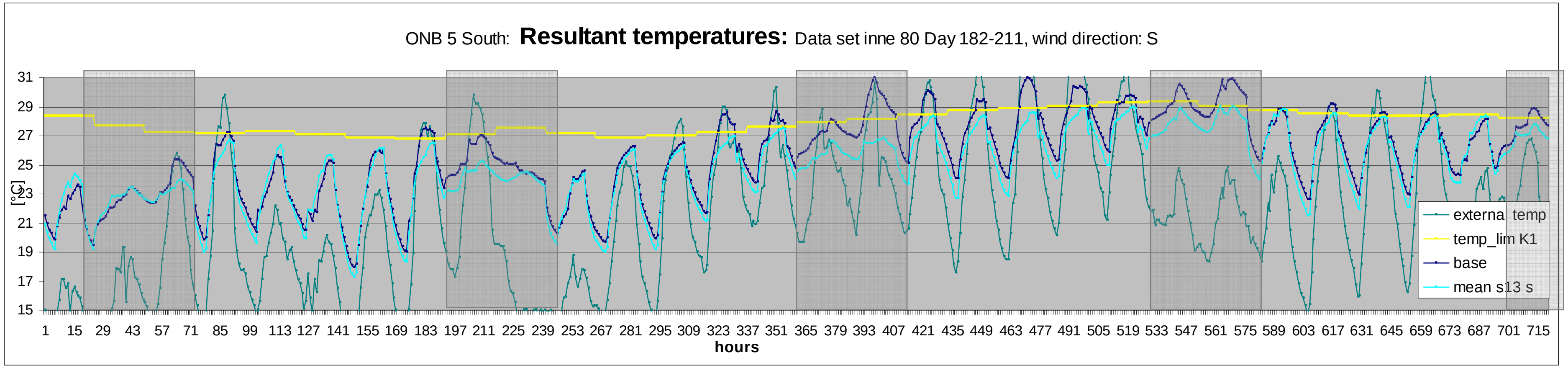
Graph 67: Amount of hours during which temperature limits are surpassed in ONB under base and s13 (extended nocturnal ventilation) respective

The temperature course of both variants documents comparatively high values, with the important distinction that those of s13 remain 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 requested.

[29] weekends were not at all investigated



Graph 68: Resultant temperature courses in ONB under base and s13 (extended nocturnal ventilation), wind direction NW; weekends are faded in grey;



Graph 69: Resultant temperature courses in ONB under base and s13 (extended nocturnal ventilation), wind direction South; weekends are faded in grey;

Mechanical Ventilation

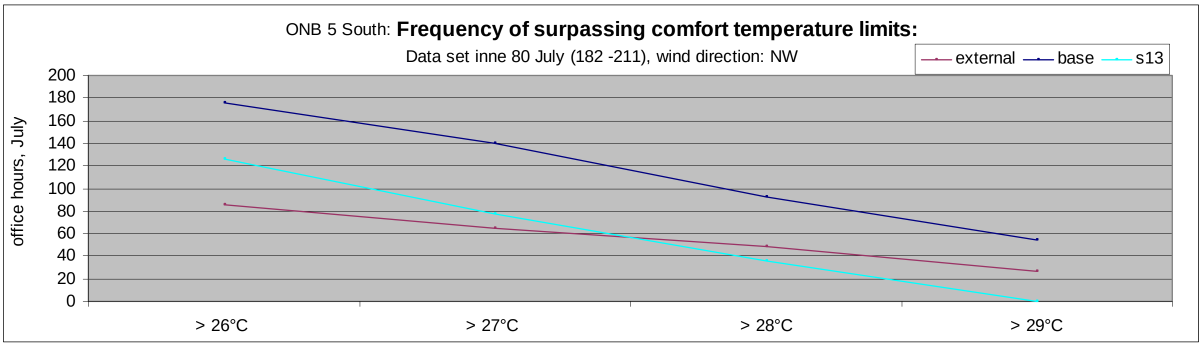
In this section, impacts of mechanical ventilation in terms of energy demand were investigated.

Natural ventilation strongly relies on local wind environments which are difficult to predict in detail. Thus, while holding the potential of comfort improvement devoid of energy demand, natural ventilation incorporates the risk of still air in 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.

Improvements in terms of comfort conditions, which would be achievable by the appliance of mechanical ventilation as compared to the above presented natural ventilation strategies, have been 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 ventilation fans were not taken into account.



Graph 70: Amount of hours during which temperature limits are surpassed in ONB under base and mechanical ventilation respective

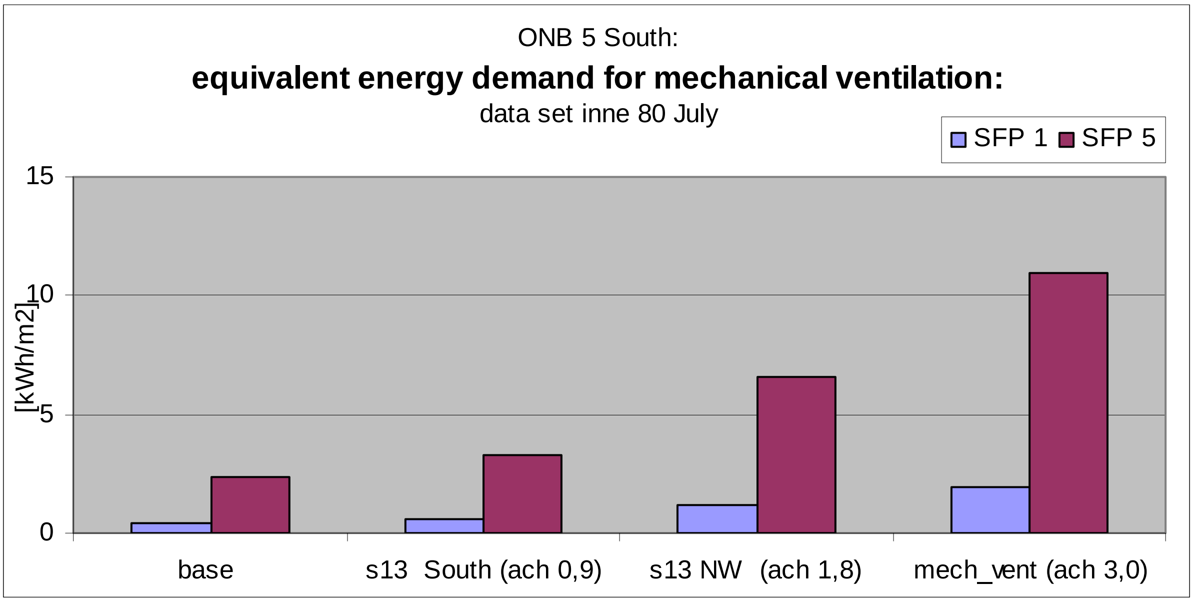
The results show that, while s13 displayed a reduction of surpassing hours (s. Graph 67) between 16 (for hours > 26°C) and 96% (for hours > 29°C), the reductions due to mechanical ventilation account for 28 to 100%.

Energy demand and savings

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

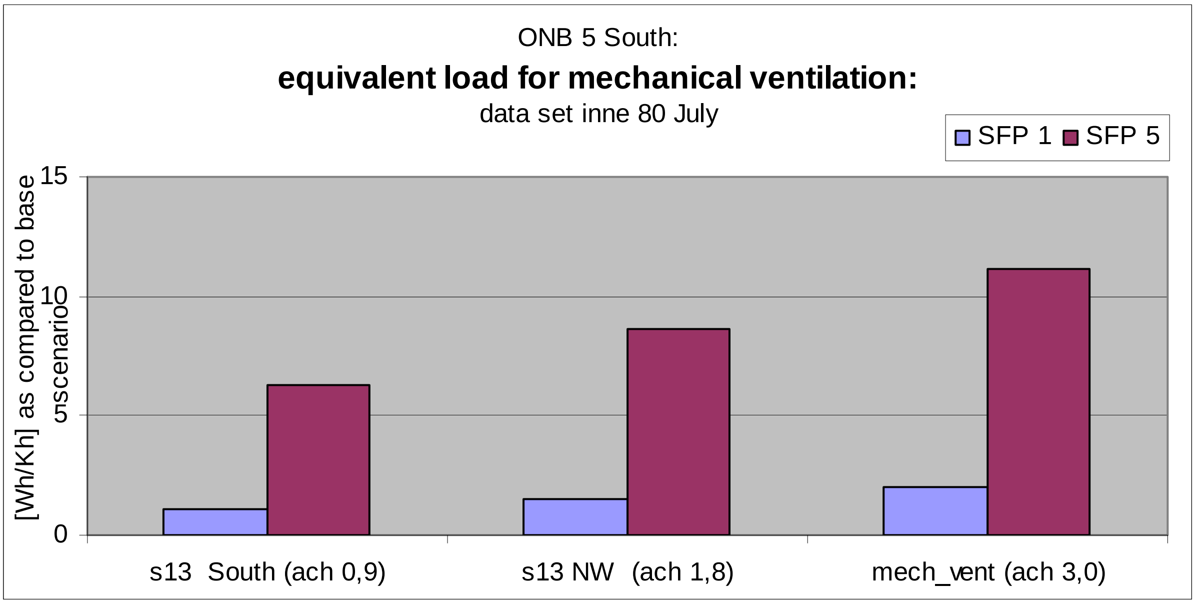
This categorization has been employed to assess the energy demand for mechanical ventilation as well as the energy savings by application of natural ventilation. Again, these calculations do not take into account the energy demand of the mechanical ventilation which provides the ventilation rate necessary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

The following graph depicts which energy demand would arise had air change rates induced by natural ventilation instead been provided by mechanical ventilation. This energy is not consumed in case of natural ventilation; 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. These values are also highest in absolute amounts as this variant uses the highest air exchange rates.



Graph 71: Energy demand which would arise would natural ventilation be replaced by mechanical ventilation

The same methodology is used to evaluate the surplus energy demand per unit of comfort improvement: as such, the indoor temperature reduction per 1K 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 72: Energy demand which would arise would natural ventilation be replaced by mechanical ventilation

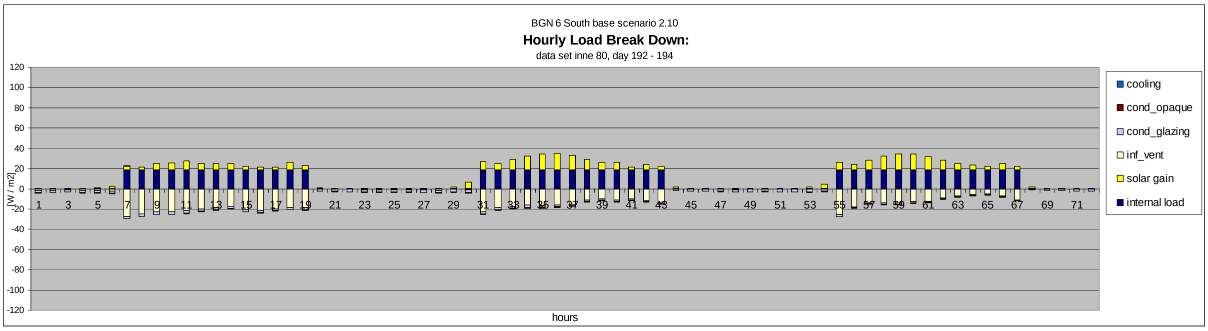
BGN

If conditions in ONB had already been near to uncomfortable they are still 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.

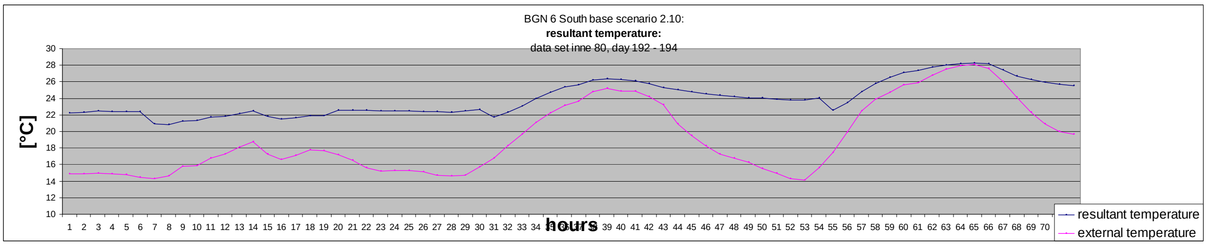
To further worsen conditions, BGN displays no external shading. Instead, blinds are installed in the twofold glazing's interspaces. At the same time internal loads due to lightning, occupancy and equipment fall within usual ranges.

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 so the shading devices are 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 open the window 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.

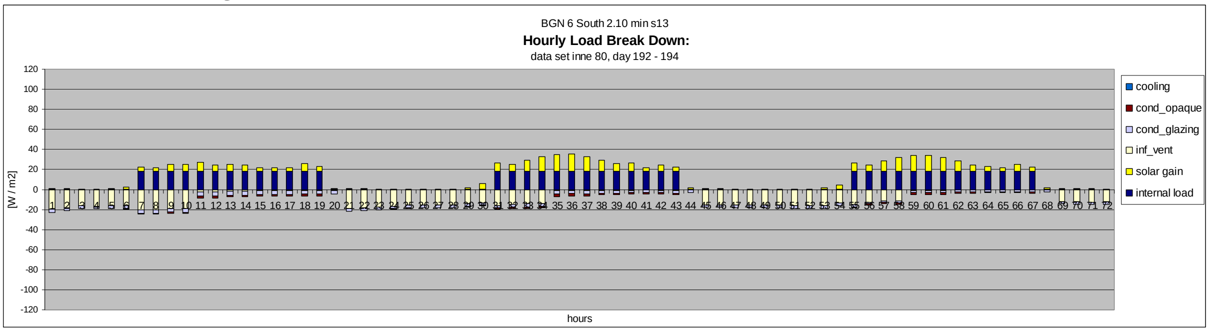


Graph 73: hourly gains and losses for BGN base

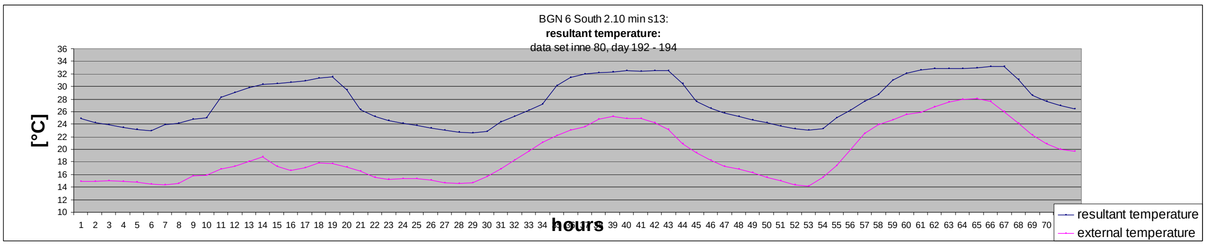


Graph 74: temperature course for BGN base

This already delivers a sound hint why nocturnal ventilation falls short of delivering alleviation of the cramped comfort condition in the building: the construction's thermal behaviour proves unapt to transfer night time heat losses to hot office hours, at the same time closed windows during day are counterproductive in terms of comfort. Indoor temperature thus dramatically increases under the application of extended nocturnal ventilation and shut windows during daytime.



Graph 75: hourly gains and losses for BGN s13 (extended nocturnal ventilation)



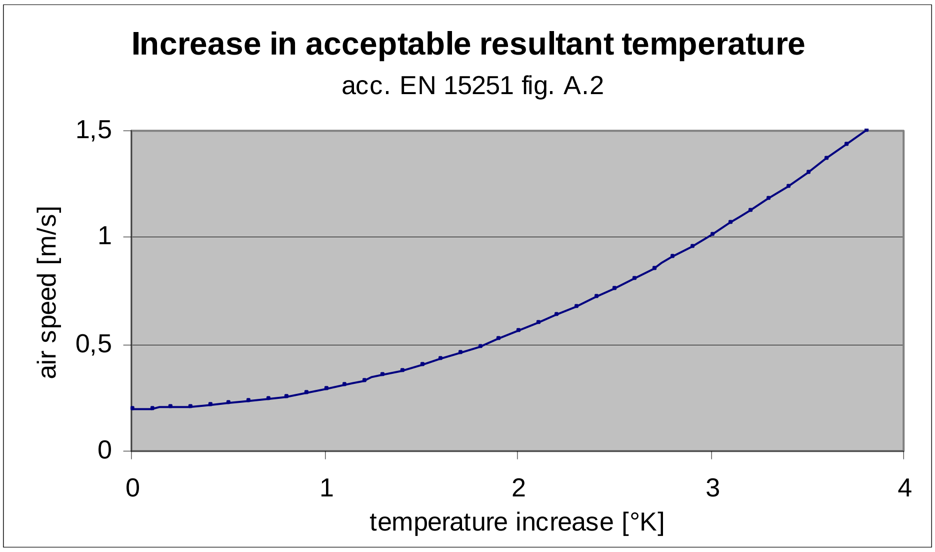
Graph 76: temperature course for BGN s13 (extended nocturnal ventilation and shut windows during daytime)

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[30] can be elevated according to the following chart because air movement increases sweat condensation on human skin and thereby reduces heat sensation.

[30] for the detailed assesment of comfort limits s. Graph 7 and Graph 8, page 21



Graph 77: 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 outside wind environment is not particularly mentioned as possible source, still, simulation of this environment allow for the consideration of wind as such a source of air movement.

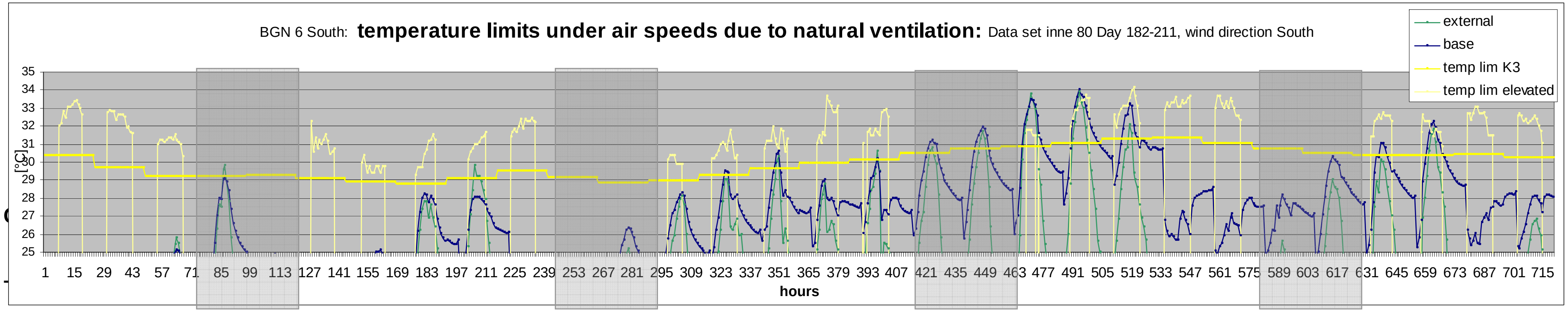
A rough estimation of possible indoor air speeds under the outside wind conditions is thus needed. This calculation was conducted according to literature indications and under the assumption of unobstructed, completely opened windows (which might prove difficult to obtain under working conditions).

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																

Graph 78: Calculation of indoor air speed acc. Melaragno[31]

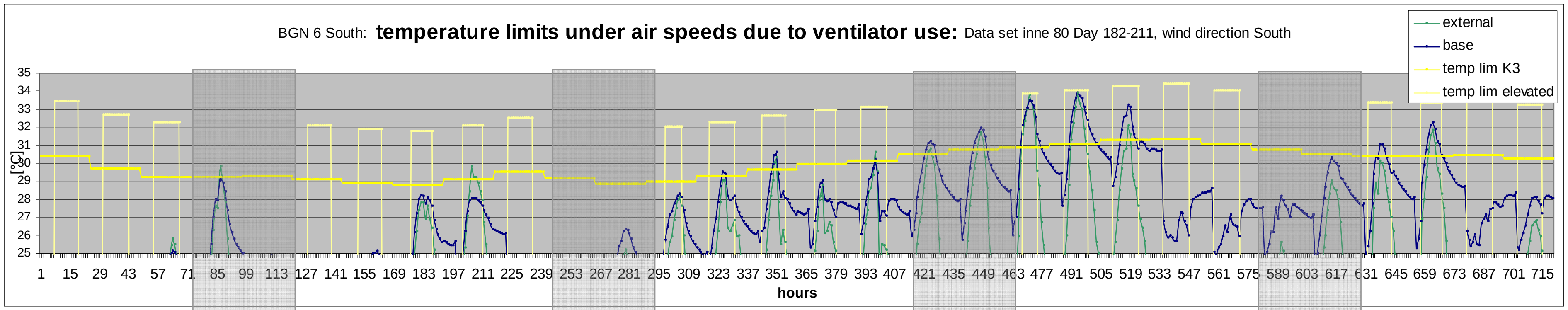
[31] Allard, Francis; Santamouris, Mat; Alvarez, Servando (2002): Natural ventilation in buildings. A design handbook. Reprint. London: James & James.

The appliance of the wind speeds thus calculated allows for the determination of an elevated comfort limit according to the indications of EN 15251 (s. Graph 77, page 87 of the present study) and results in the following temperature limits for July of climate data set “inne 80”.



surpassed only for a few working hours for the applicable building category K3 (“moderate range of expectations from users’ side, applicable for existent buildings”).

As indicated by EN 15251, indoor air speed can be provided by ceiling or desktop fans. Producers’ information on such customary products indicate 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 thus applicable 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.



Graph 80: temperature limits due to fan induced air speed (acc. EN 15251) and outside temperature course

From Graph 75 it is clearly visible that fans would be needed for restricted amounts of hours per day only. If these devices are switched on when indoor temperatures exceed outdoor ones this results in an all over energy demand of 0,04 kWh/m^2 for a double office room within the investigated month of July.

7.3.5 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 complexity of factors, ranging from 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.

7.3.6 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.

7.4 Module 4: Economic assessment on impacts of optimization strategies

Principles of sustainable building have it that constructions and equipment should not only respond to ecologic demands but also yield economic feasibility. Keeping this requirement in mind, an economic assessment of the optimization strategies discussed above has been undertaken here.

Therein, due to the nature of the results obtained in the before mentioned modules, two different approaches were applied; 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 live cycle model for a standardized cooling plant was implemented to demonstrate the 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 of this study, these impacts had been calculated in terms of reduction of working hours which display indoor temperatures beyond comfort limits.

Literature on the topic clearly reveals links between increased temperature and workers' reduced productivity[32]. 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 increases in wage payments due to overheating.

7.4.1 Investigated climate data sets & Investigated sample buildings, applied simulation modes

The described, twofold approach for economic assessment likewise influences 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 were 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.

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[32] Seppänen, O., Fisk, W. & Faulkner, D. COST BENEFIT ANALYSIS OF THE NIGHT-TIME VENTILATIVE COOLING IN OFFICE BUILDING. Lawrence Berkeley National Laboratory, University of California.

7.4.2 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[33] 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[34]. The provenience of the chosen values is documented in chapter 9.*Appendix*, page 103.

	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 81: Overview of all input parameters of life cycle model

Upper and lower limits for probable investment cost were derived from BKI[35]. This data base contains processed and detailed cost data from existent, newly

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

[34] s. 9 *Appendix*: Economic assessment – Provenience of calculation values, page 103

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

erected or refurbished buildings. Furthermore, an index to adapted prices to regional conditions is provided for Germany and Austria.

7.4.3 Results

Internal Loads: Assessment of economic impacts of reduction in energy consumption

As has been demonstrated above (s. chapter 7.1: *Module 1: Cooling energy demand of sample buildings under different levels of internal loads*, page 44), 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 pant size and thereby reduces investments. Smaller investments in turn influence operation costs because these are calculated as proportional fraction of investment.

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, resulting in no more extra expenses being generally detectable for such equipment today[36]. 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.

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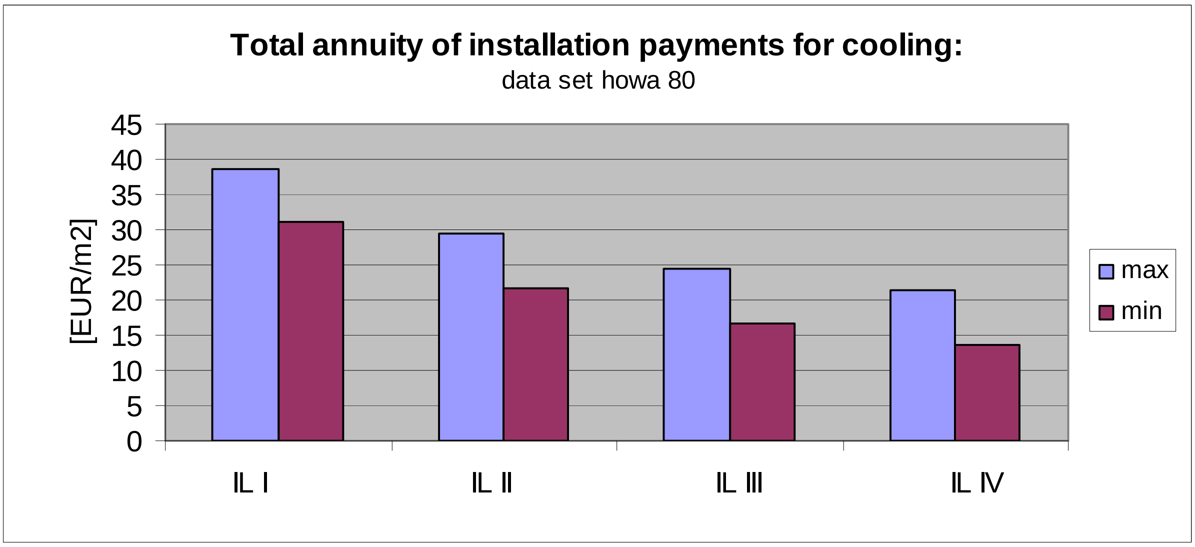
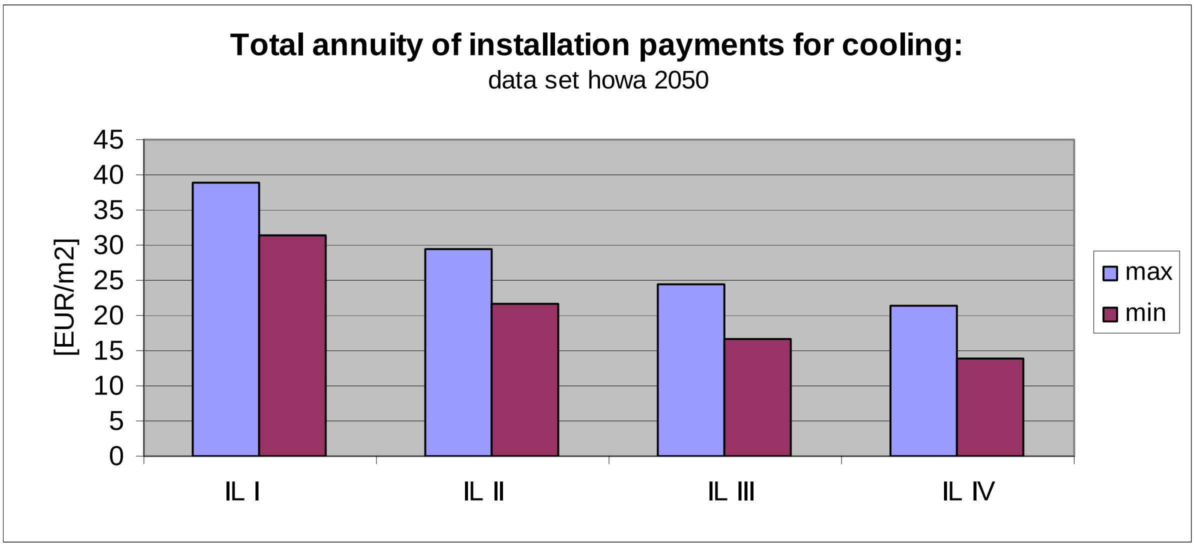
[36] Berger, Tania (September 3, 2010): Energy Star - Energieeffiziente Bürogeräte. Mögliche Mehrkosten von energieeffizienten Bürogeräten. Interview mit Bernd Schäppi. Am September 3, 2010 in Krems.



Graph 82: 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



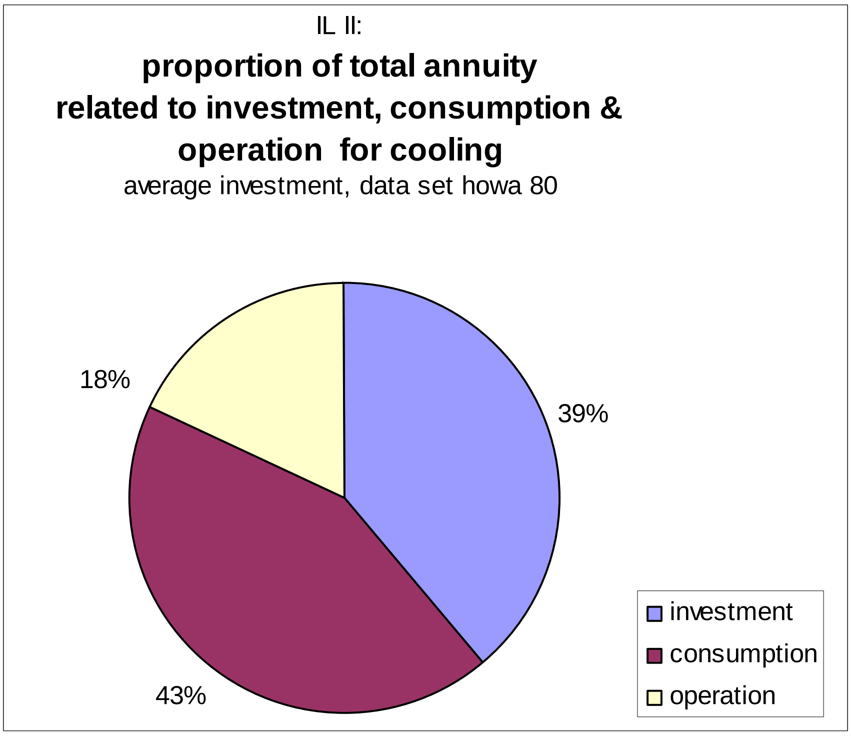
Graph 83: Ranges of total annuity of installation payments under different levels of internal load for data set "howa 2050": values include annuities for investment, consumption and operation

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 for terms of energy consumption, remains valid for economic assessment, too.

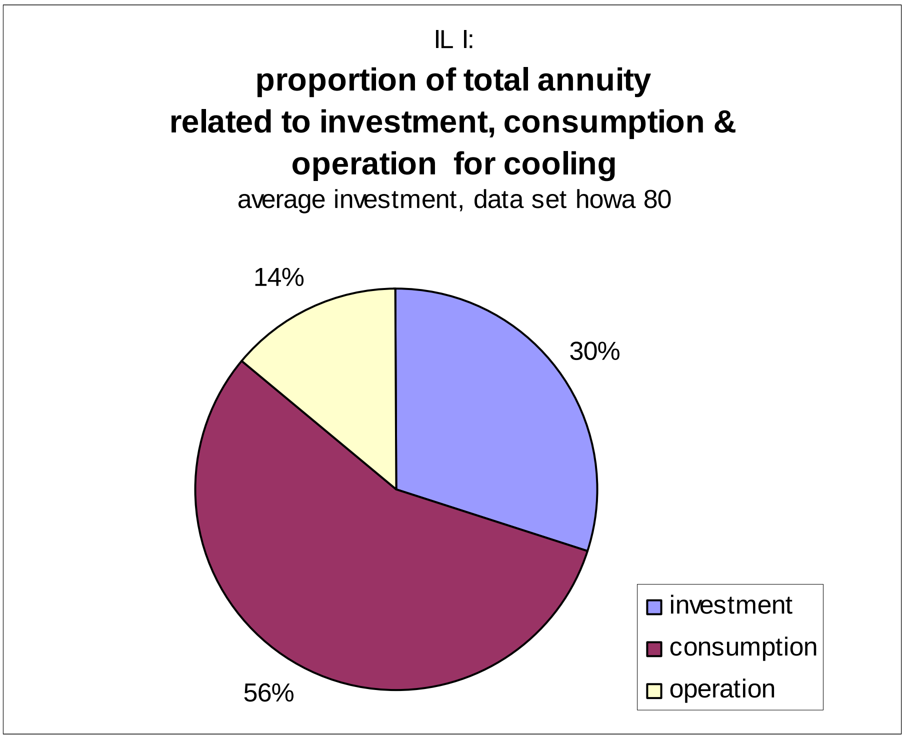
It had also been observed that climate change increases cooling energy demand rather than maximum cooling load. As the latter influences investment and operational costs differences between the two climate data sets applied are further diminished.

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

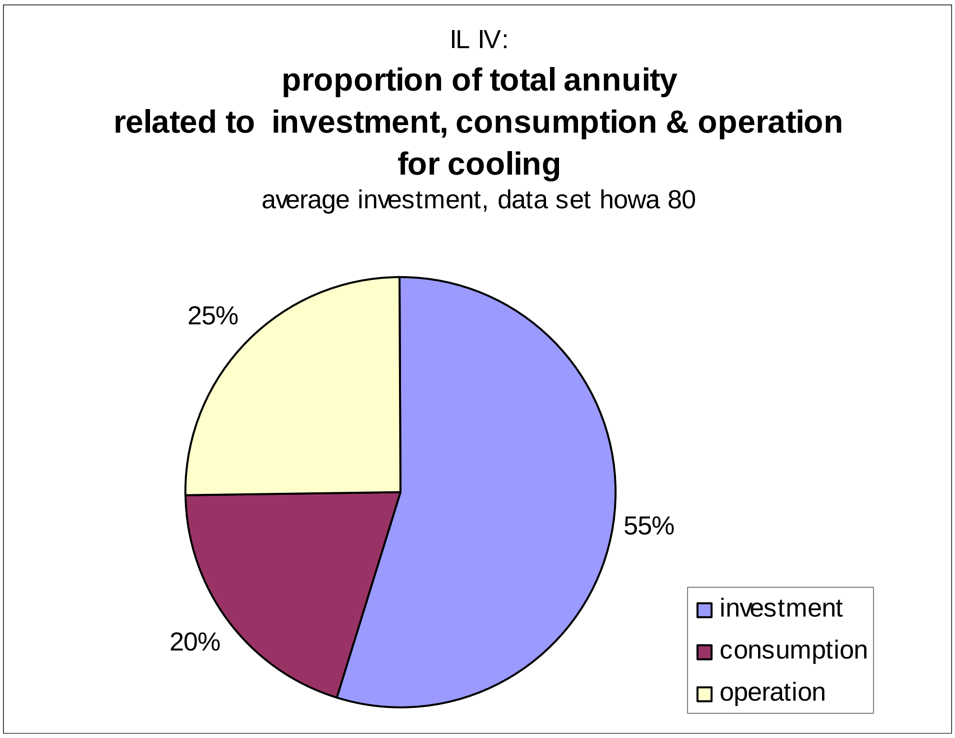
Comparing the proportions of cost fractions contributing most to the overall annuity clearly demonstrates the influence of energy efficiency in terms of IT equipment and lighting on both consumption related and over all costs: While under the standard IL II consumption related costs contribute by 52%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



Graph 84: Proportion of total annuity for standard energy efficiency in internal loads (IL II), all sample buildings



Graph 85: Proportion of total annuity for low energy efficiency in internal loads (IL I), all sample buildings



Graph 86: Proportion of total annuity for very high energy efficiency in internal loads, all sample buildings (IL IV)

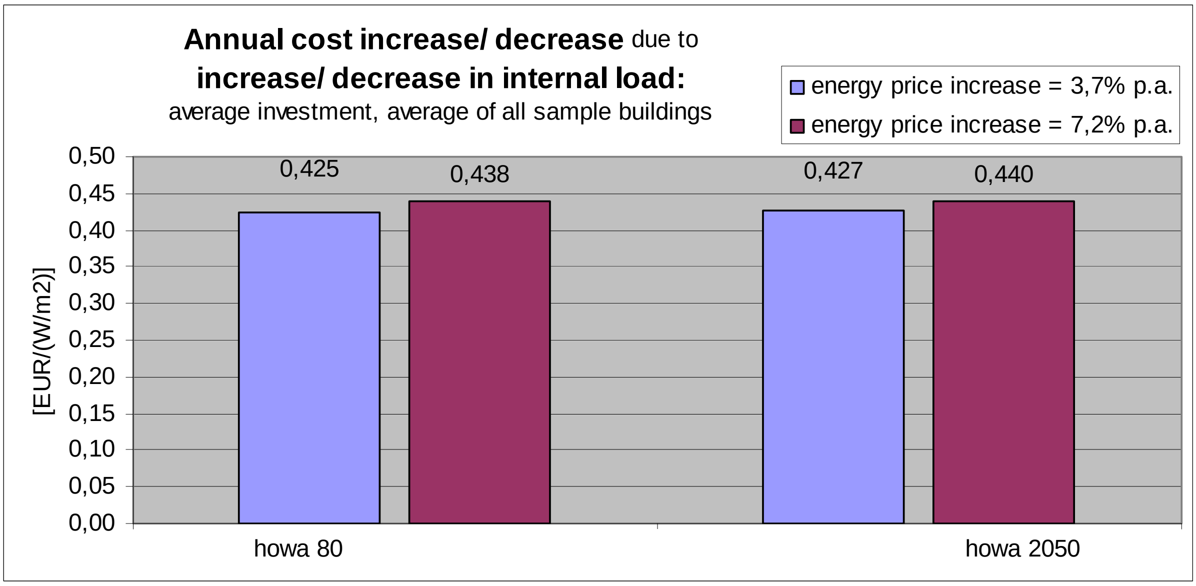
Relating differences in annuity to differences in cooling energy demand brings up figures for annuity reduction per Watt load reduction due to more efficient equipment.

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: 3,7% p.a.
Maximum assumption: 7,2 % p.a

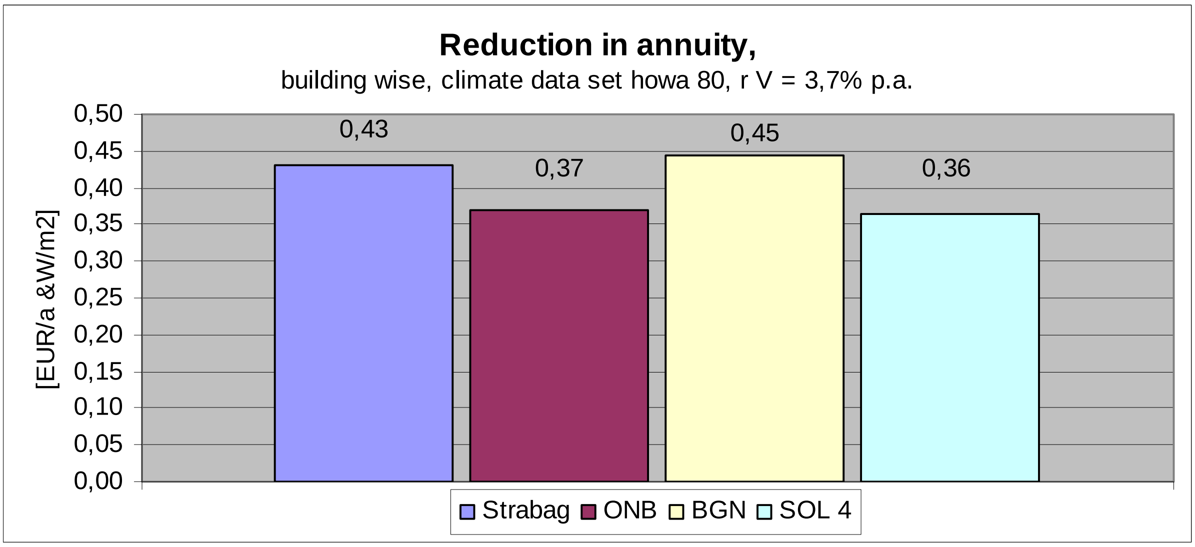
These two values were inserted for all sample buildings and climate data sets. The reductions in annuity for each climate data set and energy price index are equal, regardless whether minimum or maximum investment costs are considered.

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



Graph 87: 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 envelop and powerful shading devices, potential for feasible improvement by means of more efficient equipment is thus lowest 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.

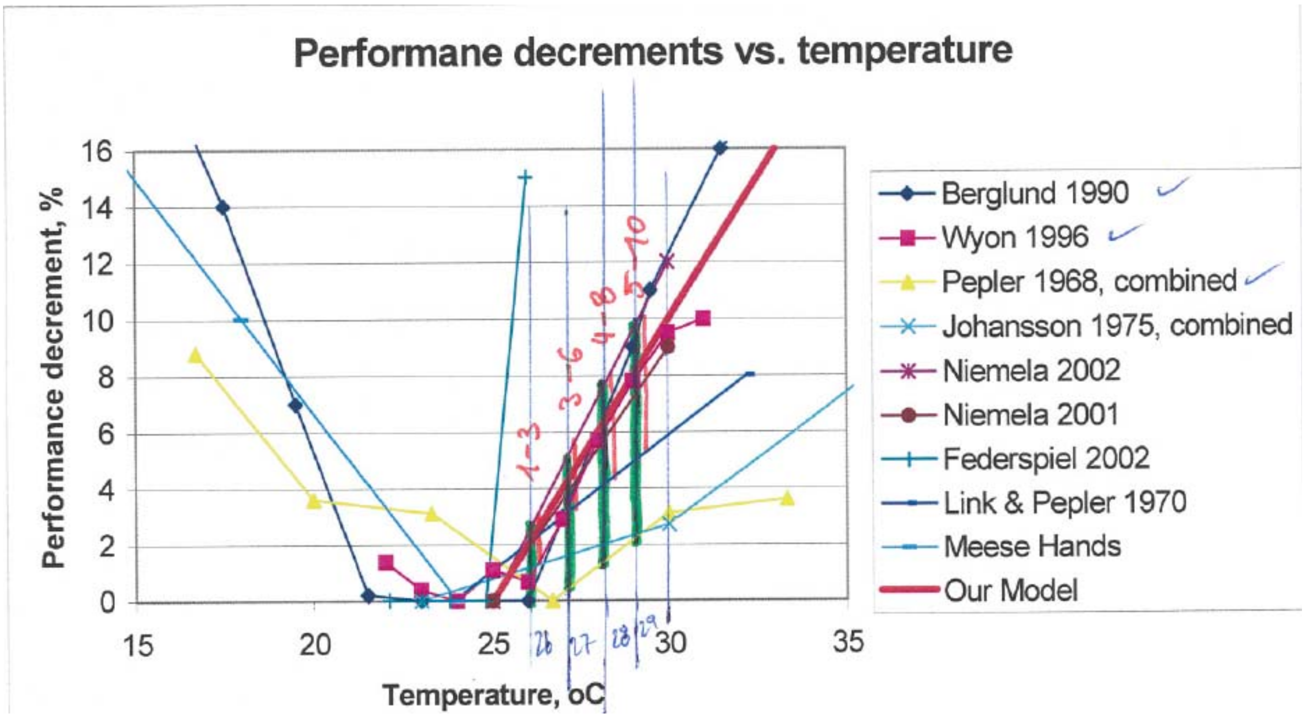


Graph 88: Reductions in annuity for sample buildings

Natural Ventilation: assessment of economic impacts of reduction in surpassing comfort limits

In the corresponding module of this study, the impacts of natural ventilation on indoor comfort had 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[37]. 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 89: summary of studies on the decrement of performance and productivity[38]

An optimum of all working hours within the limits of conformability acc. to ÖNORM 8110-3[39] 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.

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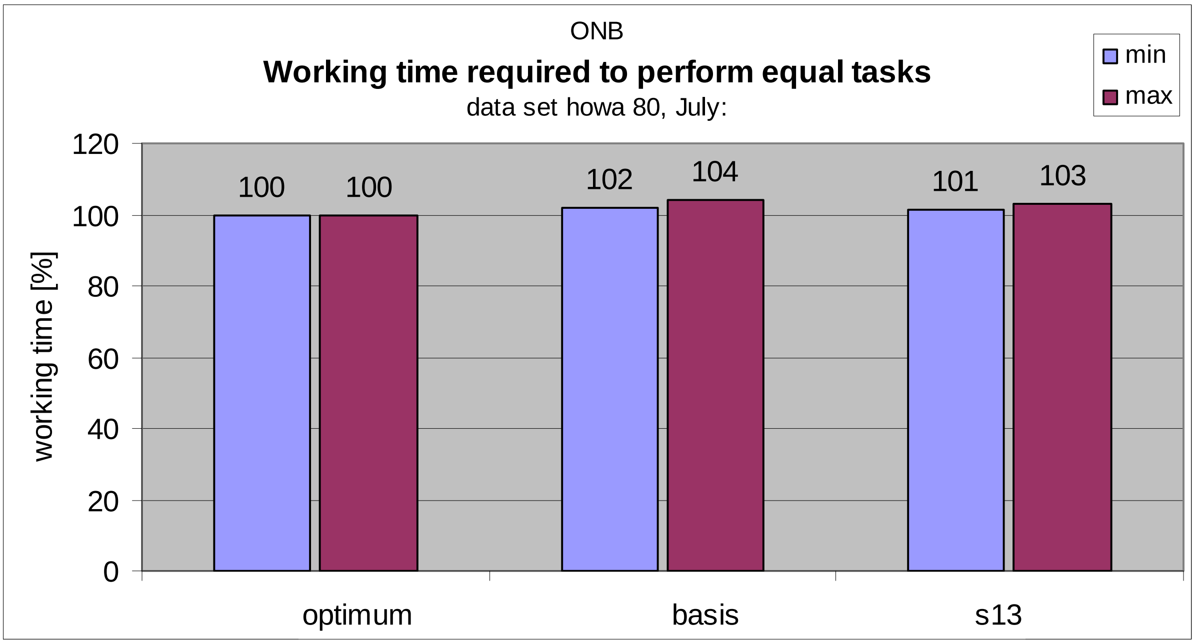
[37] Seppänen, O., Fisk, W. & Faulkner, D. COST BENEFIT ANALYSIS OF THE NIGHT-TIME VENTILATIVE COOLING IN OFFICE BUILDING. Lawrence Berkeley National Laboratory, University of California.

[38] ibidem

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

By means of times 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 an increase in wage payments.



Graph 90: : impacts of reduction in surpassing comfort limits on productivity in ONB: When comfort limits are surpassed, workers' productivity decreases, working time required to perform tasks increases.

7.4.4 Conclusion

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 displaying increases in wage cost to be expected under hot summer conditions in poorly cooled spaces. The impacts of natural ventilation were found to be limited but recognisable.

8 Conclusions

Several options of reducing cooling energy demand and/ or improving thermal comfort in offices were investigated by means of dynamic thermal simulation.

Results show considerable potentials for such optimization by reduction of internal loads due to IT equipment and artificial lighting. 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 extra expenses for energy efficient equipment tend towards zero. Care has to be take for this reduction not to be counteracted by further increases in equipment density and/ or more powerful devices.
Furthermore, it has to be taken into account that decreases in internal loads cause rises in heating demand during winter times. Therefore, improvements in energy efficiency of IT equipment and artificial lighting should be accompanied by improved thermal insulation of the building envelop in order to keep heating demand low.
Economic assessment for internal load reduction was performed by means of a simplified life cycle cost model. This revealed the economic feasibility of the measure.

Changes in the usage profiles of offices likewise influence cooling demand when aiming at removing working hours from the hottest times of the day by trend. Traditional Siesta models are effective in this sense if users' absence is coupled with complete switch off of equipment and lighting and indoor temperatures are allowed to rise above certain limits during the break.
Impacts of such usage profiles on employees' every day life are considerable and must be discussed beyond purely technical matters. The same holds true for teleworking 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 site in question. More 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. Fixed comfort limits, however, may not always be kept.
Wind induced air movement within rooms with open windows can contribute to improve comfort conditions. A similar service can be rendered by desktop fans.

9 Appendix

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&menuId=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[40], p. 57
Conservative: 3,7% (1,037)
Pessimistic: 7,18% (1,0718)

Degree of efficiency/ COP component 1
Value: 2,4
Provenience:
acc. Recknagel& Sprenger[41]
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[42], 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)

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40 Gazon, Siegfried (2010): Lebenszykluskosten: Prognosen und Kostentreiber für Mehrfamilien-Wohnhausanlagen. Untersuchung am Beispiel von Objekten der Gemeinnützigen Donau-Ennstaler-Siedlungs-Aktiengesellschaft. Master-Thesis zur Erlangung des akademischen Grades. Herausgegeben von Donau Universität Krems. Department für Bauen und Umwelt. Krems.

41 Recknagel, Hermann; Schramek, Ernst-Rudolf; Recknagel, Sprenger Schramek; Recknagel, Sprenger (2001): Taschenbuch für Heizung und Klimatechnik. Einschließlich Warmwasser- und Kältetechnik ; [2001/02]. 70. Aufl. München: Oldenbourg.

42 Gazon, Siegfried (2010)

Price-dynamic annuity factor for operation-related costs
Value: **1,01**
Provenience: acc. Floegl[43] **Fehler! Textmarke nicht definiert.**
main cooling plant: 4%, panel coolers ceiling, tubes: 0,1%, air conditioning system: 1,5%, mechanical ventilation: 1%
average 1% (1,01)

[43] Floegl, Helmut (2010): LEBENSZYKLUSKOSTENPROGNOSEMODELL. Version 2.3.08.03.2010. Krems.

9.1 Tables & Graphs

9.2 References

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