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

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Content

Kurzfassung

Diese Studie untersucht Strategien zur Minimierung des Kühlenergiebedarfs in Bürogebäuden bei gleichzeitiger Gewährleistung von ausreichendem thermischem Innenraumkomfort. Analysiert wurden Strategien am und im Gebäude sowie im Bereich innovativer Haustechnik.

Gebäudebezogene Optimierung

Die **Reduktion interner Wärmelasten** von elektronischen Arbeitshilfen und künstlicher Beleuchtung ist in der Lage Reduktionen des Kühlbedarfes zu zeitigen, die größer sind als die durch den Klimawandel zu erwartenden Bedarfsteigerungen.

Nutzerprofile: Die tendenzielle Verschiebung von Nutzeranwesenheiten – welche stets mit Abwärme der Nutzer selbst sowie der von ihnen benutzten Geräte verbunden sind – aus den heißesten Stunden des Tages ebenso wie eine verminderte Anwesenheit durch Teleworking können Bedarfsreduktionen ermöglichen, sind aber in ihrer praktischen und sozialen Umsetzbarkeit zu diskutieren.

Fensterlüftung: In natürlich belüfteten Büros kann nächtliche Fensterlüftung tendenziell Komfortverbesserungen bewirken; zur verlässlichen Bewertung dieser Kühloption in der haustechnischen Auslegungspraxis fehlen noch robuste Berechnungswerkzeuge für die Bestimmung lokaler Außenwind- und Innenluftströmungsverhältnisse.

Haustechnische Optimierung

Die Kombination aus radiativen und evaporativen Systemen zur Erzielung einer maximalen Kühlleistung als Ergänzung zu herkömmlichen Kühltechnologien hat sich zur Abdeckung des Kühlleistungsbedarfs für Bürobauten als Zielführende Lösung erwiesen.

Abstract

This study investigates strategies to minimize cooling energy demand in office buildings while simultaneously striving to safeguard thermal comfort. Both strategies focusing at the buildings as well as those dealing with HVAC technology are scrutinized.

Building related optimization

Reducing internal heat loads of electronic devices and artificial lighting facilitates reductions in cooling energy demand which score in the order of magnitude of the increases in demand to be expected due to climate change.

Usage profiles: the presence of users is always interlaced with heat loads from the users themselves and the devices and lighting they use. Thus, shifting users' attendance from the hottest hours of the day as well as reducing their presence by means such as teleworking in theory reduces cooling demand likewise. However, practical and social limitations have to be taken into account.

Natural ventilation: in naturally ventilated office rooms, optimizations in thermal comfort are feasible by means of intelligent ventilation strategies. Precise and validated software tools for exact calculation of external wind and internal air velocities are to be developed.

HVAC related optimization

The combination of radiative and evaporative systems for the extortion of maximum cooling loads as a complement to conventional cooling technologies was identified as feasible.

E-1 Introduction

E-1.1 Context

During the past years, a general understanding has taken place throughout the scientific community that, besides mitigation measures, additional adaptation will be required to compensate 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.

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.

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.

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.

E-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.

Two general points of intervention are addressed here:

- <u>Reductions in heat gains</u>: 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"[1]. Whilst the use of ground, ground water and activated thermal mass has already been extensively investigated and is increasingly employed in mainstream construction 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.

E-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 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 documentation was undertaken here.

E-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, four semi synthetic climate data sets[2] 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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[1] In contrast, systems are labelled "active" when they "withdraw warmth by means of refrigeration machines". (See Zimmerman, Mark (2003, S. 11)

[2] s. Krec, K. Halbsynthetische Klimadaten für Wien. Erläuterungen zum Klimadatensatz, 2010.

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.

E-1.3.2 Sample buildings’ constructive configuration

Four Viennese office building, fairly representative for the city’s three main construction periods[3], 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:

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.

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[3] Main construction periods in a quantitative sense: in the present building stock, those dating from either (a) 1880 to 1920, (b) 1945 to app. 1980 or (c) from 1990 onwards make up form the vast majority.

Table 2: General description of sample buildings, including representation of the applied geometric model

				
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

E-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[4] 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 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.[5]
- **real**: this simulation mode depicts the present day situation without respectively with little cooling in 2 of the sample buildings. Consequently, large discrepancies in comfort conditions (frequency of overheating) are observed.

E-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.

E-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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[4] 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.

[5] 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 the 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.

E-1.3.6 Results

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.

E-2 Results: Investigation of optimization strategies

E-2.1 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 buildings 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 E-2.2 “*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.

E-2.1.1 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.

E-2.1.2 Investigated sample buildings, applied simulation mode

All four sample buildings were investigated under simulation mode Standard.

E-2.1.3 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 (occupancy, IT-equipment and artificial lighting) and solar gains prevail and have to be compensated for by cooling. 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” 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[6]. More efficient IT – equipment and lighting thus represents a means of reducing cooling loads and demands.

Four different levels of efficiency were defined.

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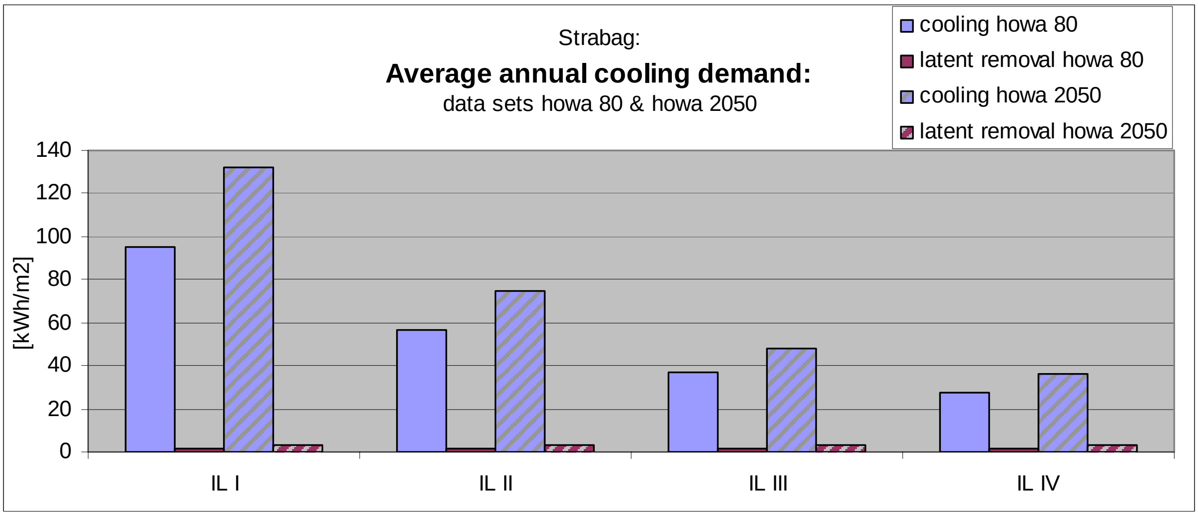
[6] At the same time, however, the overall appliance of IT and communications tool has continuously increased as well, hence compensating for efficiency gains. Prognoses for the further developments are discordant, but tend to the estimation of a slight flattening of the trend curve.

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

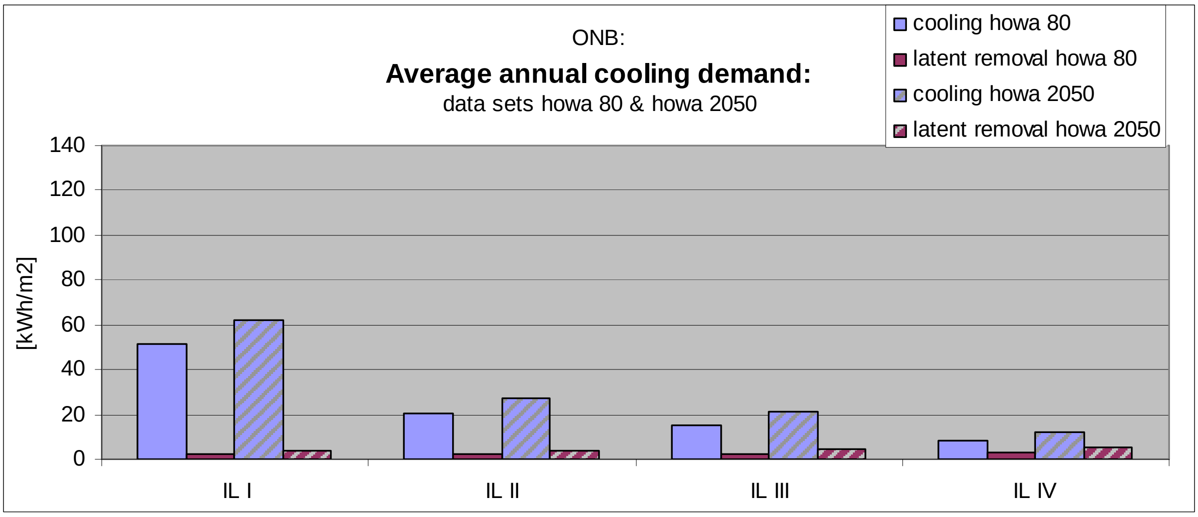
Efficiency level denomination	**Description**
IL I	very low efficiency; seldom but yet still encountered in offices, representing a worst case situation
IL II	average efficiency frequently encountered in offices; in further investigations this level is applied as Standard
IL III	high efficiency according 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.

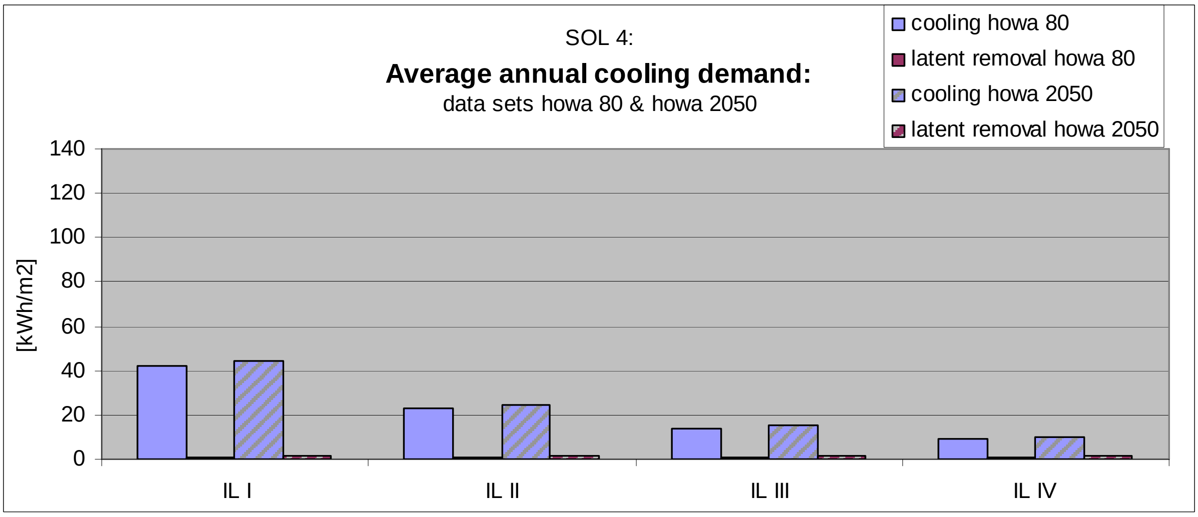


Graph 1: Strabag: annual cooling demand for "howa 80" and "howa 2050" under different levels of internal load

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.



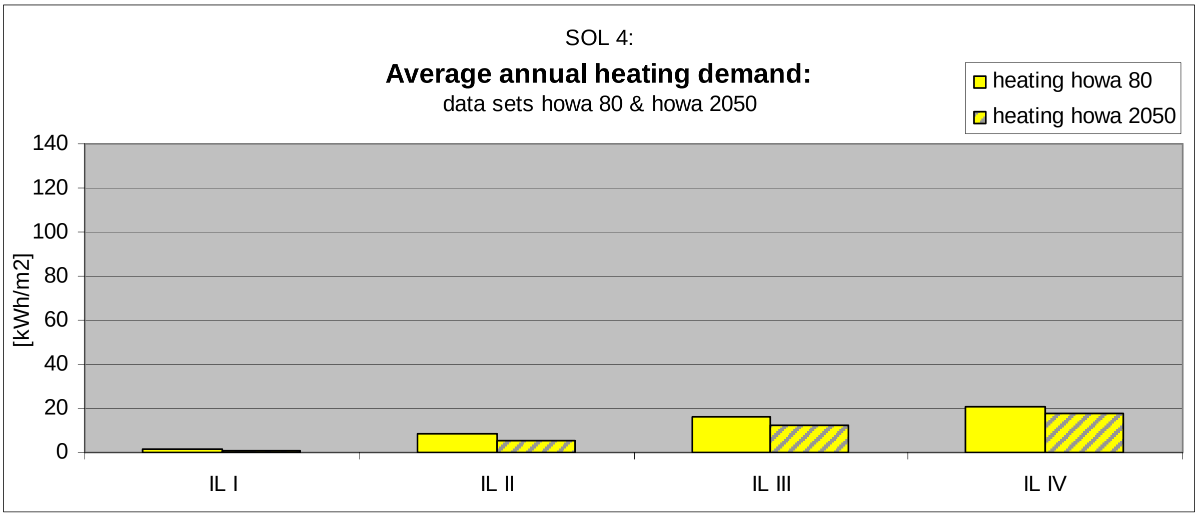
Graph 2: ONB: annual cooling demand for howa 80 and howa 2050 under different levels of internal load



Graph 3: SOL 4: annual cooling demand for “howa 80” and “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” a building 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.



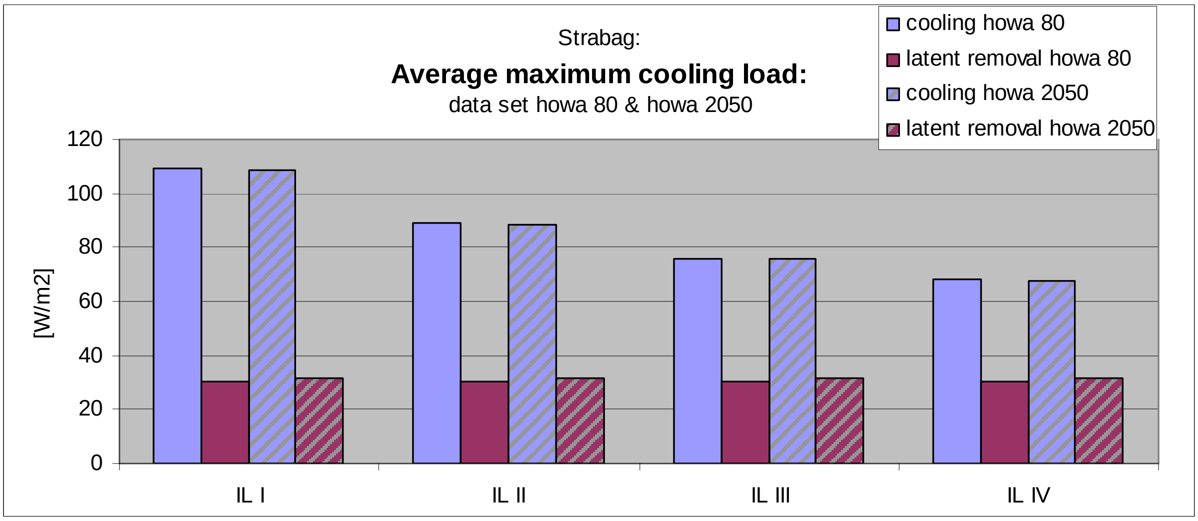
Graph 4: SOL 4: annual heating demand for "howa 80" and "howa 2050" under different levels of internal load

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.

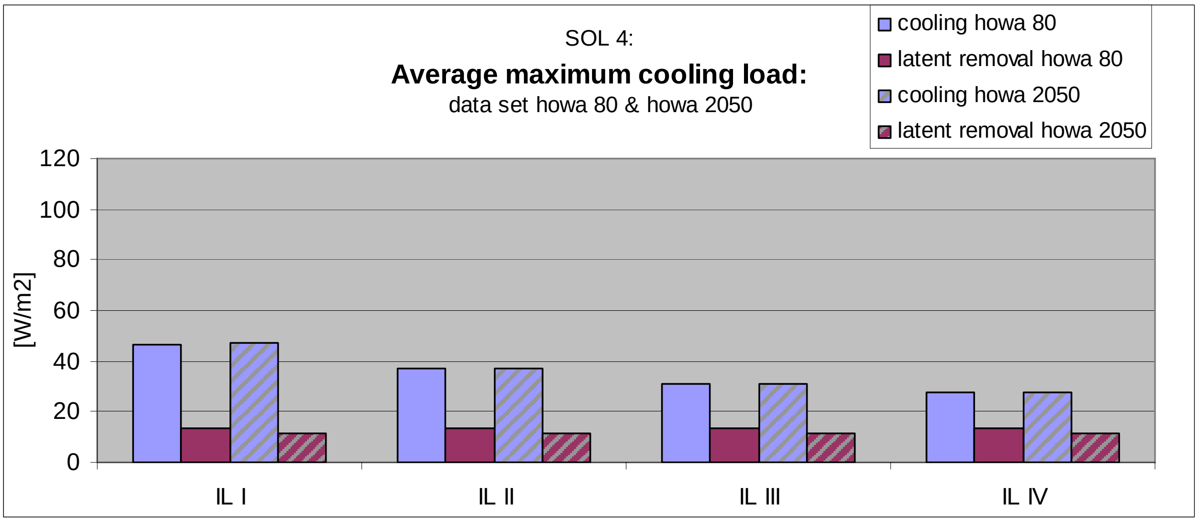
Lower internal loads may also result in lower maximum cooling loads, which are crucial for the dimensioning of the respective plant. Therefore the sample buildings were additionally simulated under the elevated levels of internal loads for lighting and equipment.

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 1, page 7).
- Although overall cooling demand has been shown in Graph 1 to increase due to climate change, maximum cooling loads remain generally unchanged, hence thresholds in plant size may not be surpassed.



Graph 5: Strabag: maximum cooling loads for "howa 80" and "howa 2050" under different levels of internal load



Graph 6: SOL 4: maximum cooling loads for "howa 80" and "howa 2050" under different levels of internal load

E-2.1.4 Conclusions

Internal loads are demonstrated to be the single most influential drivers for cooling demand. Therein, IT equipment and lighting form two out of three 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.

E-2.2 Module 2: Cooling energy demand of sample buildings under different usage modes

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.

E-2.2.1 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.

E-2.2.2 Investigated sample buildings, applied simulation mode

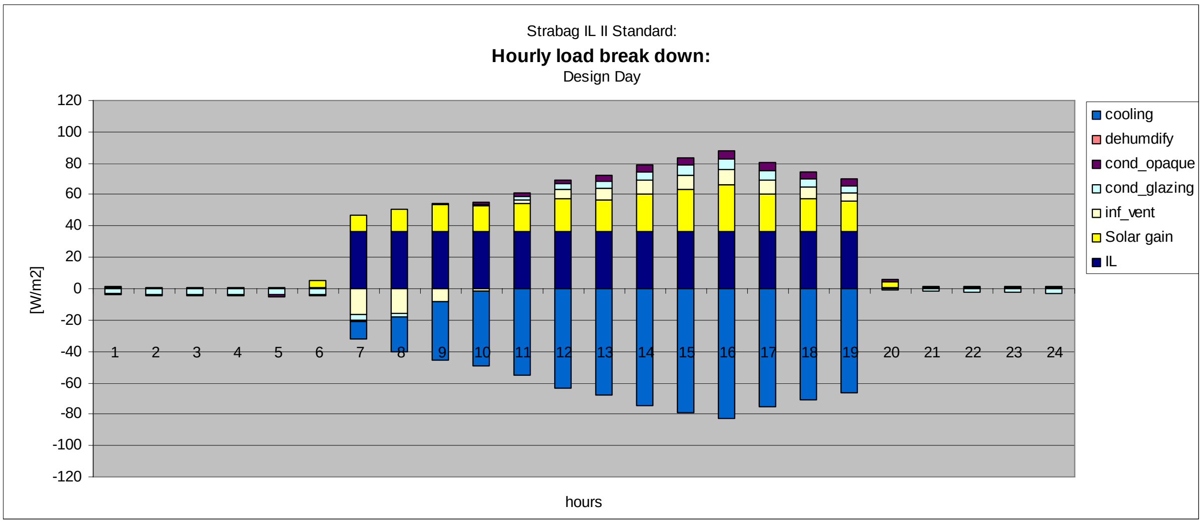
As Strabag has been shown to display comparatively high cooling demands and loads in Module 1: *Cooling energy demand of sample buildings under different levels of internal loads* (and hence a high potential for improvement is assumed here), this sample building was investigated under simulation mode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

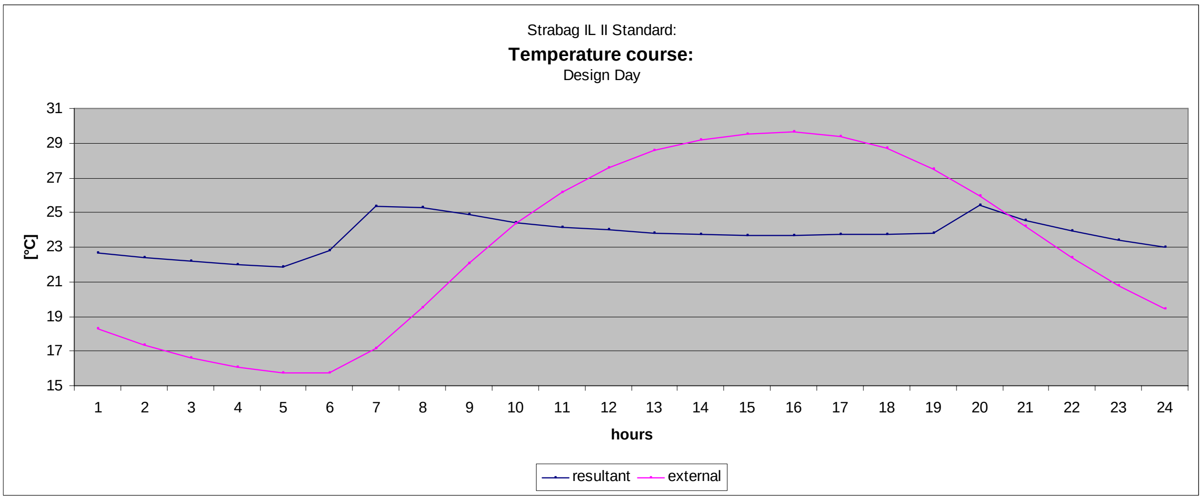
E-2.2.3 Results

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



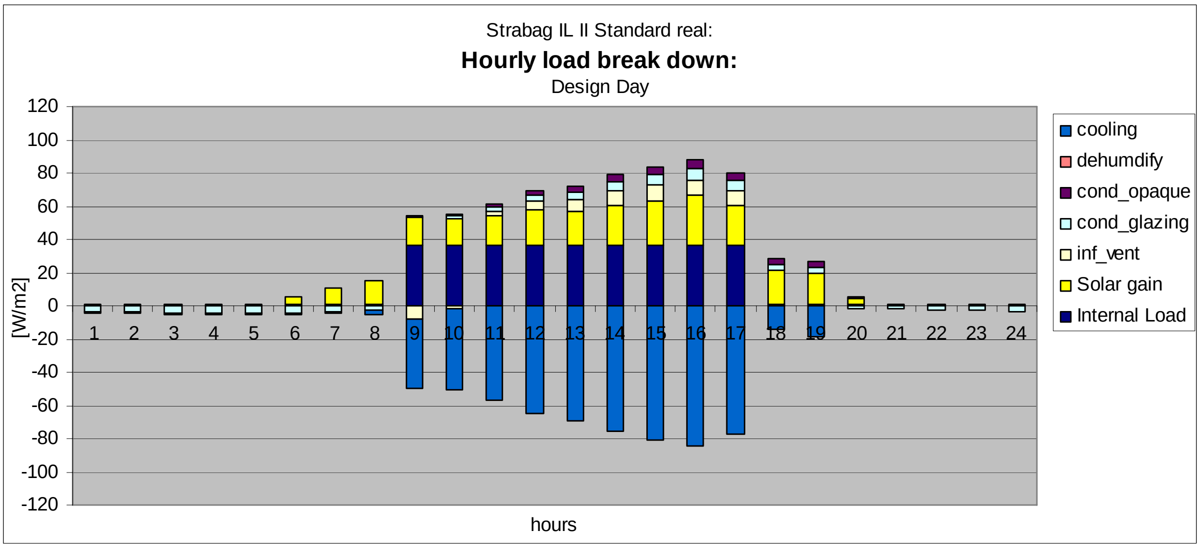
Graph 7: Hourly load break down in Strabag mode "Standard"

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.



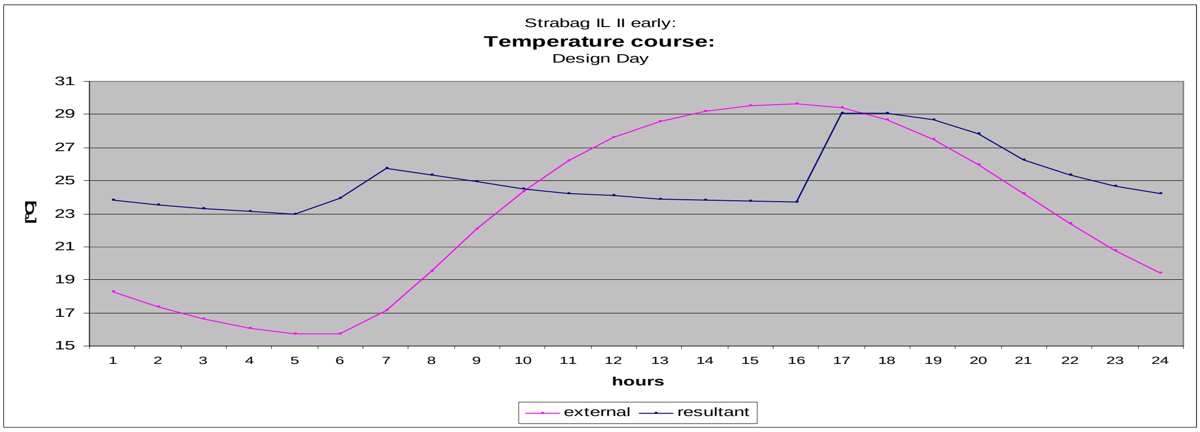
Graph 8: Temperature course in Strabag mode "Standard"

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.



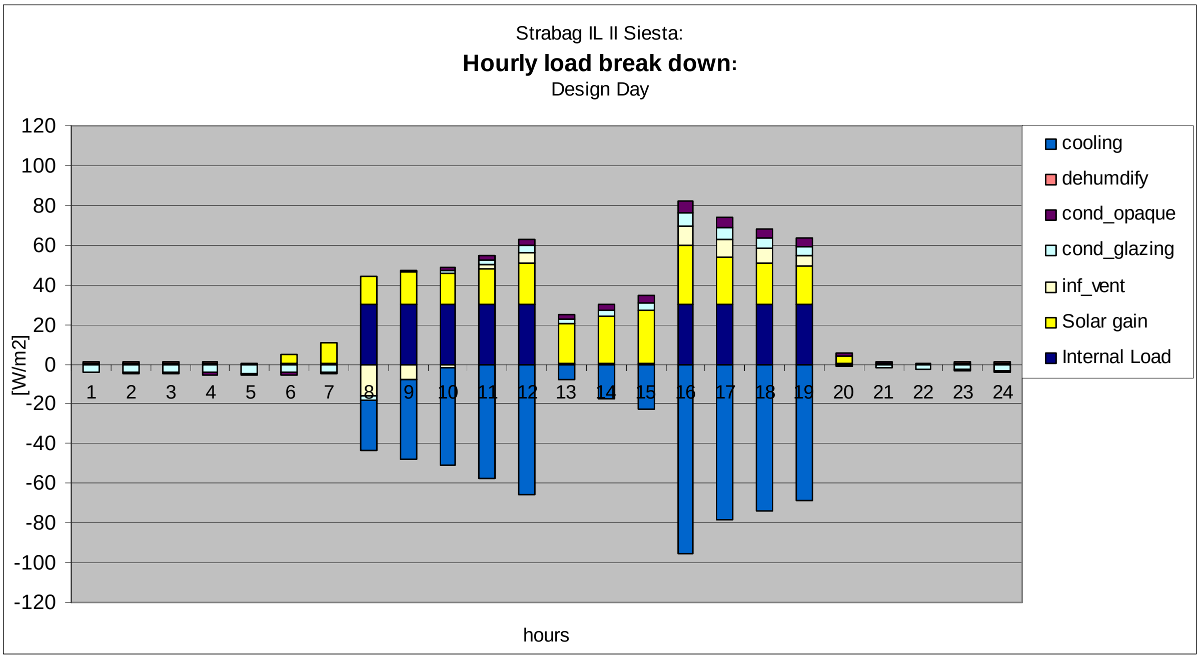
Graph 9: Hourly load break down in Strabag mode “Standard real”

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 10: 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 11: Hourly load break down 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[7].

In conclusion, rough estimates based on simulations under Design Day 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.

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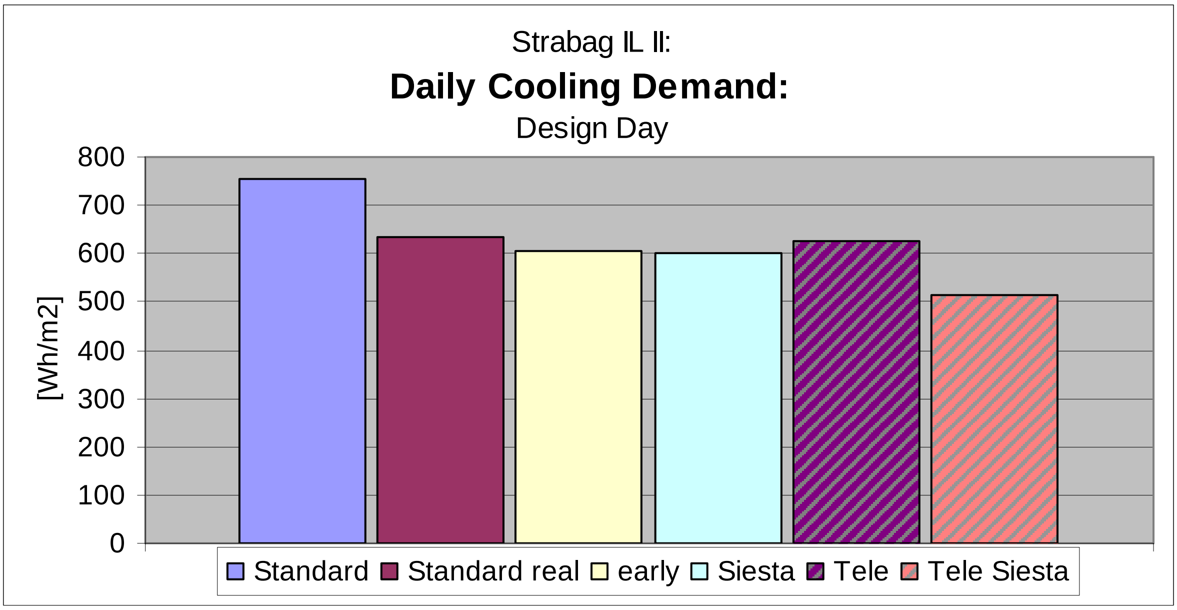
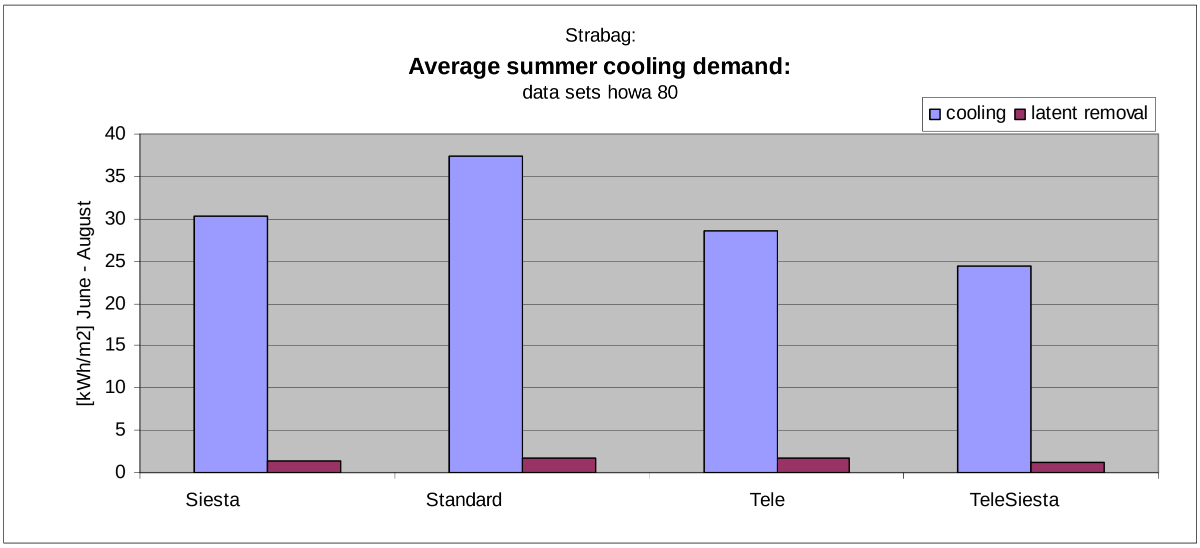
[7] It may be brought forward, that internal loads of both workers and their equipment and lighting are only displaced to other locations by teleworking. This location most probably will be a working desk in the employee's home, which might not normally be equipped with cooling devices. The issue of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



Graph 12: Daily cooling demand of different usage profiles

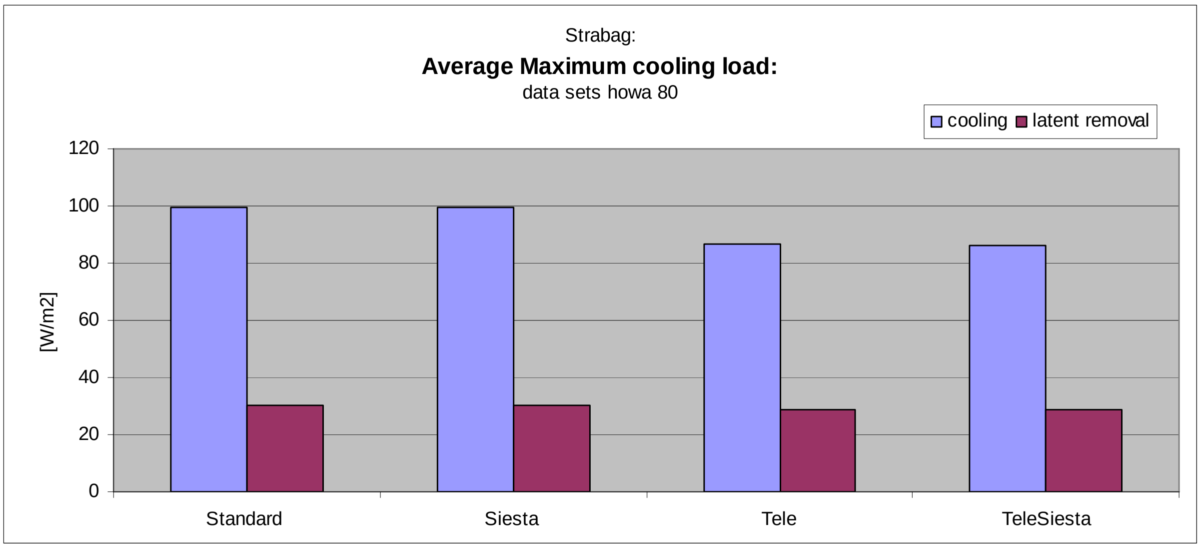
The appliance of these optimized modes under long term conditions of a whole summer period reveal that this potential can in fact be harnessed; Especially, the twofold approach of mode “TeleSiesta” with reduced workers’ presence and shifted office hours results in saving of up to 35%. This makes the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



Graph 13: Summer cooling demand of different usage modes

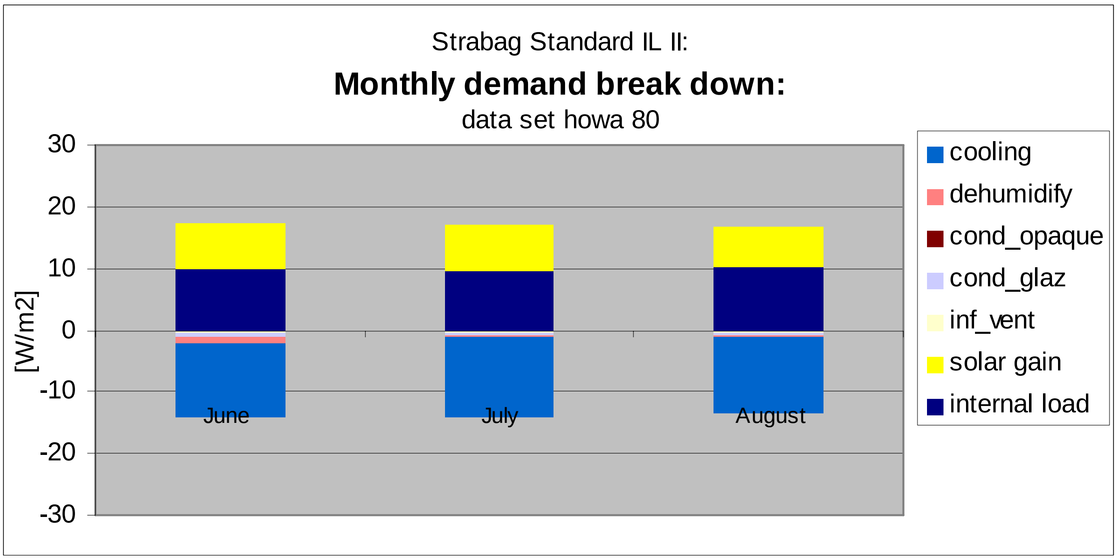
An investigation of maximum cooling loads forwarded the fact that shifted working hours do not allow for more modest cooling plants as high loads can still occur.

Reducing internal loads by means of teleworking also reduces maximal cooling loads, though to a minor extent.

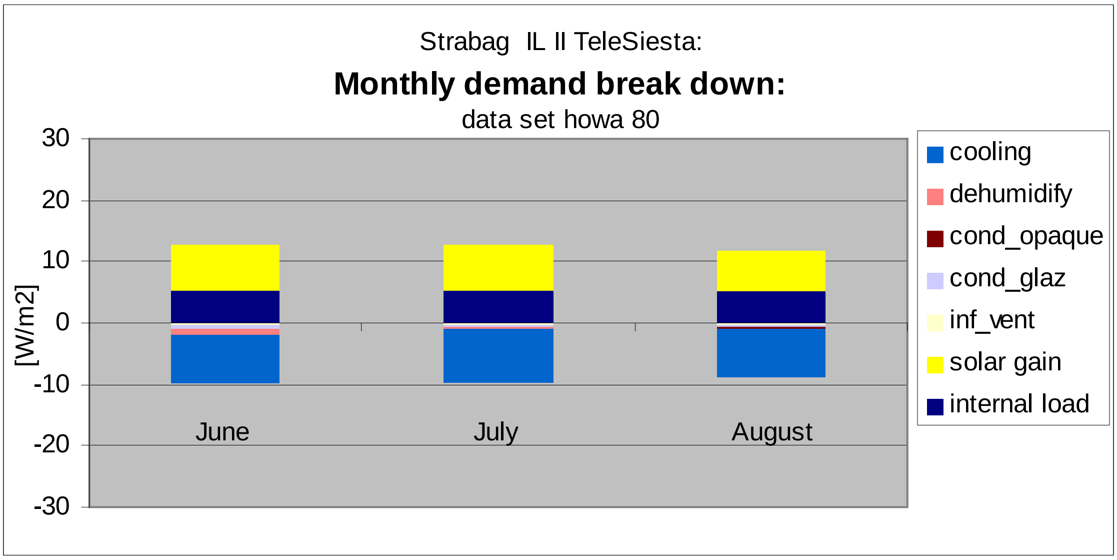


Graph 14: cooling load of different usage modes

These findings were 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 15: Summer load break down for Strabag mode “Standard”



Graph 16: Summer load break down for Strabag mode “Tele Siesta”

E-2.2.4 Conclusions

Simulations run in this module demonstrated 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.

E-2.3 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.

E-2.3.1 Investigated climate data sets

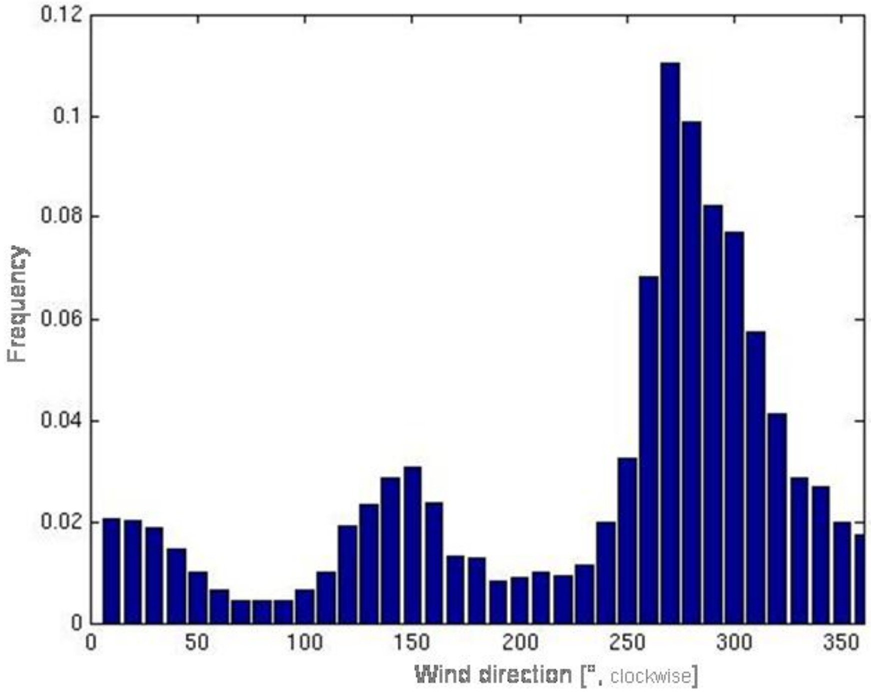
All investigations in this module were run under the conditions of climate data set “inne”: As has been described, the envisaged ventilation strategies should be tested under the assumption of urban conditions. Would data sets be used, which represent conditions at main weather stations only – which 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” was applied for investigations. Assessments of future situations still lack 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.

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 17: statistical distribution of wind directions (indication of degrees clockwise) for 6:00 p.m.

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

E-2.3.2 Investigated sample buildings, applied simulation mode

Two of the sample buildings – ONB and BGN – are already facing severe comfort deficits under present conditions. 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.

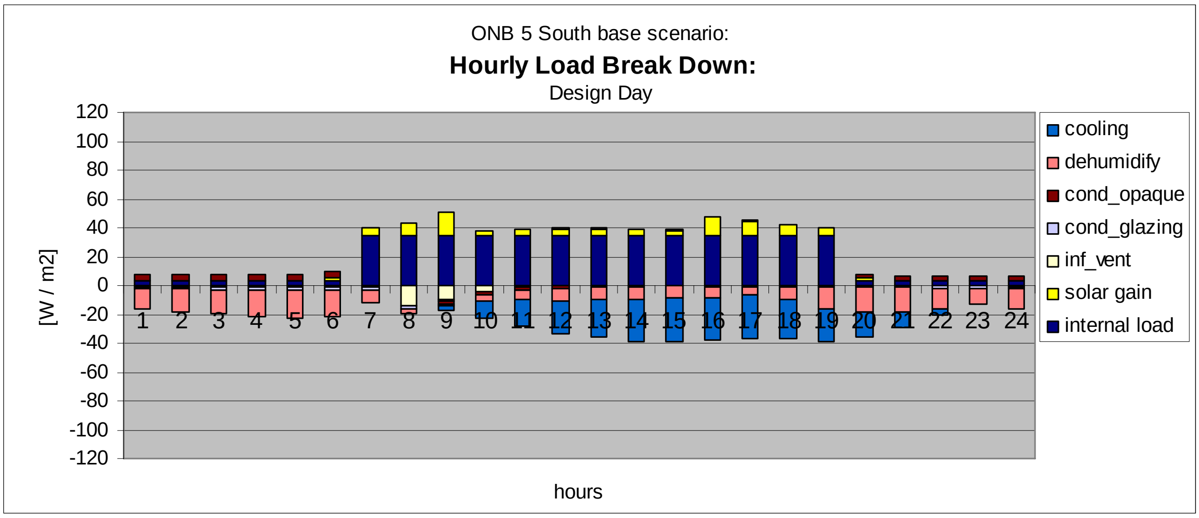
E-2.3.3 Results

ONB

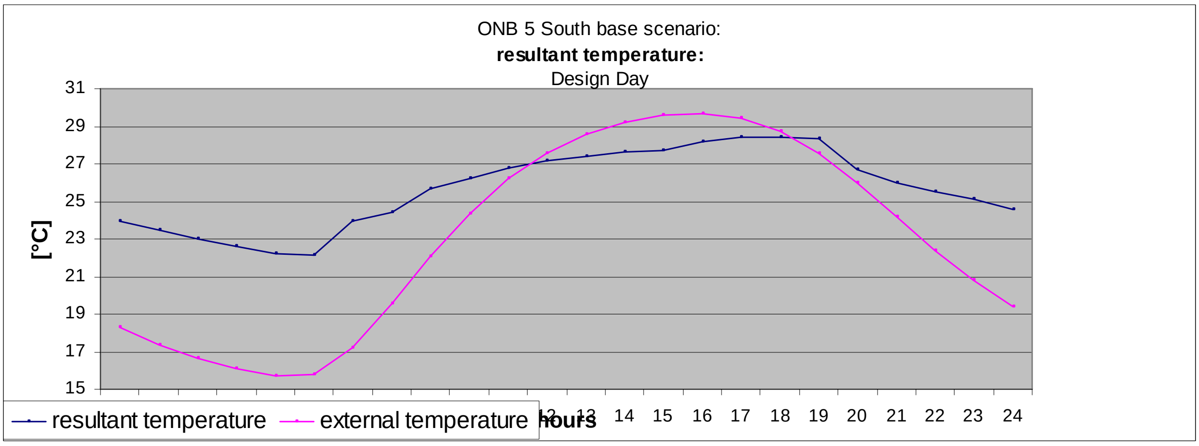
One single reference room (5th floor, facing South) was investigated in this sample building. The present day situation in this room served as base scenario for optimization hereafter: The room today is served by mechanical ventilation, which induces fresh air on a constantly low temperature level (21°C)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

Additional natural ventilation by users was enabled for those hours during which external temperatures range between 18 and 26°C. Likewise, sun shading was 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 revealed driving forces for overheating: while solar gains were clearly cut to a minimum for most of the day, internal loads (lighting, occupants and equipment) during office hours out ruled cooling applied by the mechanical ventilation system. Dehumidification loads were not discharged here. Gains and losses by conductance through opaque and transparent external walls were of minor magnitude. Natural ventilation via windows was only applied during early morning.



Graph 18: hourly gains and losses for ONB base



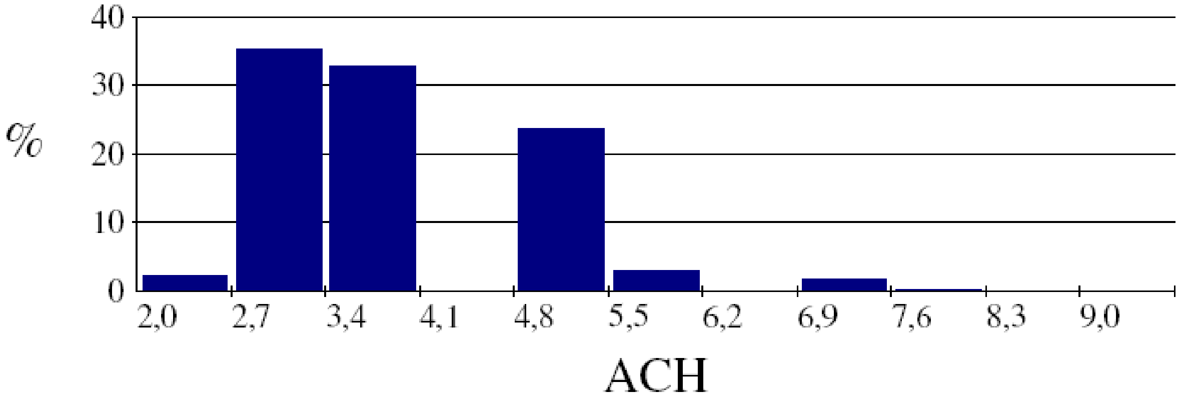
Graph 19: Temperature course for ONB base

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[8] for the outside wall and discharge coefficients[9] for the opening's shape, both equally obtained from literature[10].

The application of these framework conditions revealed that remarkable air change rates were likely to arise from outdoor wind induction. At the same time, the obtained frequency distributions also indicated 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 were some hours during the investigated month, which display minor air changes. Should they occur during hours of highest loads, these reduced air change rates were to be implicated, hence presenting a worst case scenario.



Graph 20: Frequency Distribution of achievable air change rates due to natural ventilation for ONB s12 (nocturnal ventilation), wind direction West

The above generated, nocturnal air change rates were applied to the simulation of the reference room under steady state conditions: 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.

Increased discharging of heat stored in external walls does not significantly increase these walls' capacity to dampen heat peaks during the following day. As long as ventilation is absent in the cool morning hours, indoor temperature rises quicker than in the base scenario and improvements remain insignificant.

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

The applied Design Day 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.

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[8] 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.

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

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

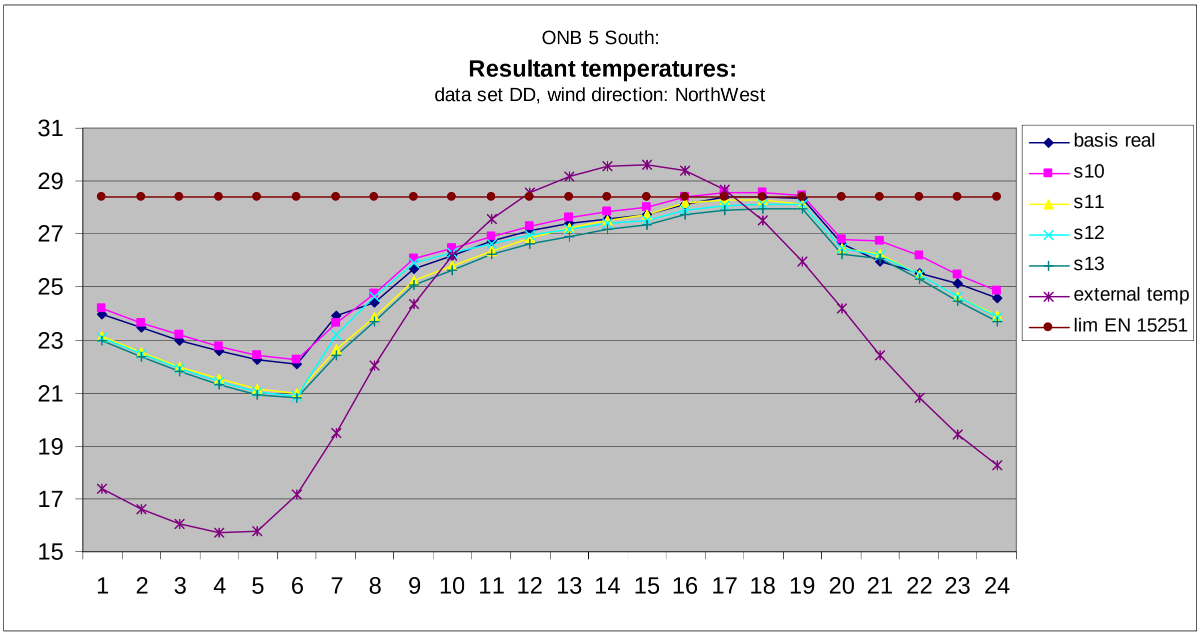
Analysis and optimization

Further ventilation schedules were simulated under Design Day 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 21: 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 – three 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 two 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.

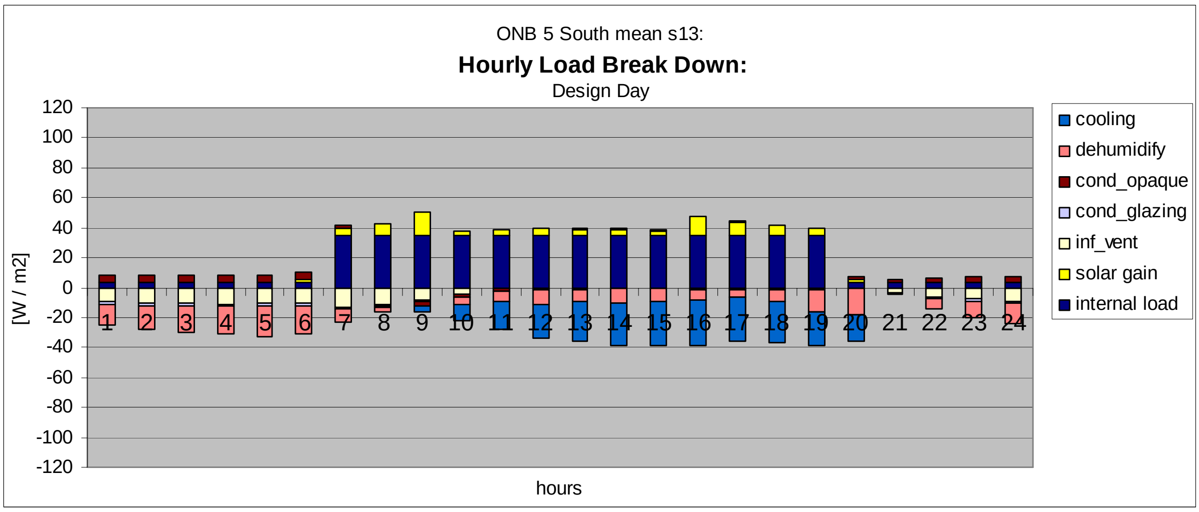
During this hour, only s11 displays open windows, resulting in its temperature course to drop to those of s12 and base scenario. In the latter one, windows remain closed as external temperature still exceeds 26°C.

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.

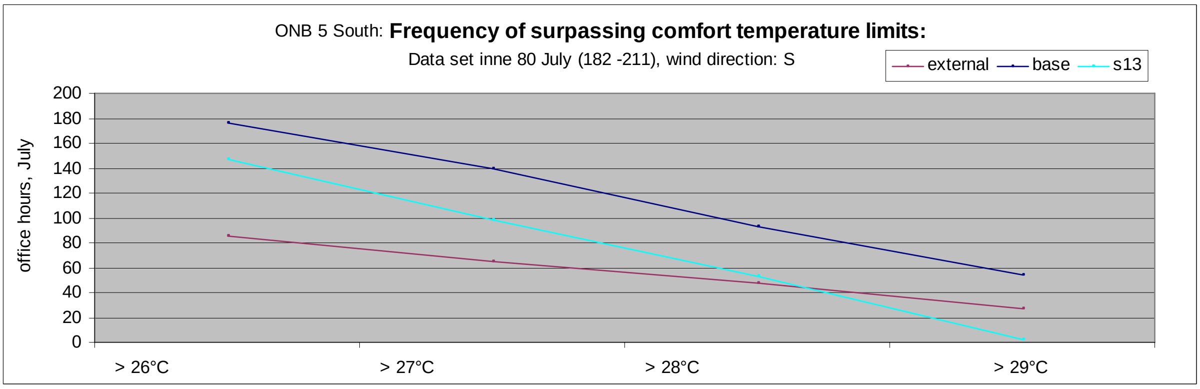


Graph 22: hourly gains and losses for ONB s13 (extended nocturnal ventilation)

The analysis of s13' hourly load break down under Design Day 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 Design Day 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

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[11] during which certain comfort temperature limits are surpassed by indoor resultant temperature.



Graph 23: 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.

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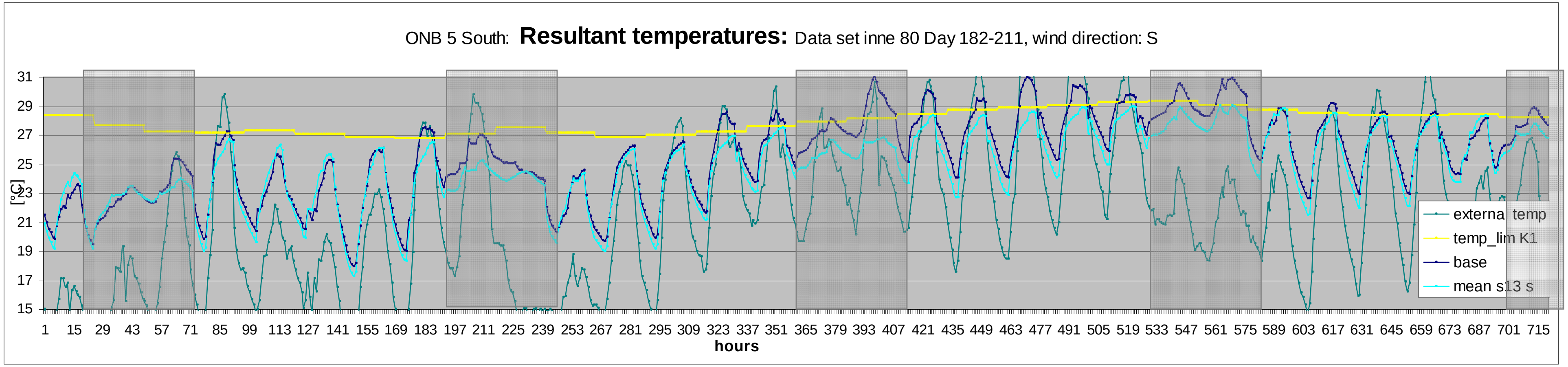
[11] weekends were not investigated at all



Graph 24: 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. While natural ventilation strongly relies on local wind environments, which are difficult to predict in detail, 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.

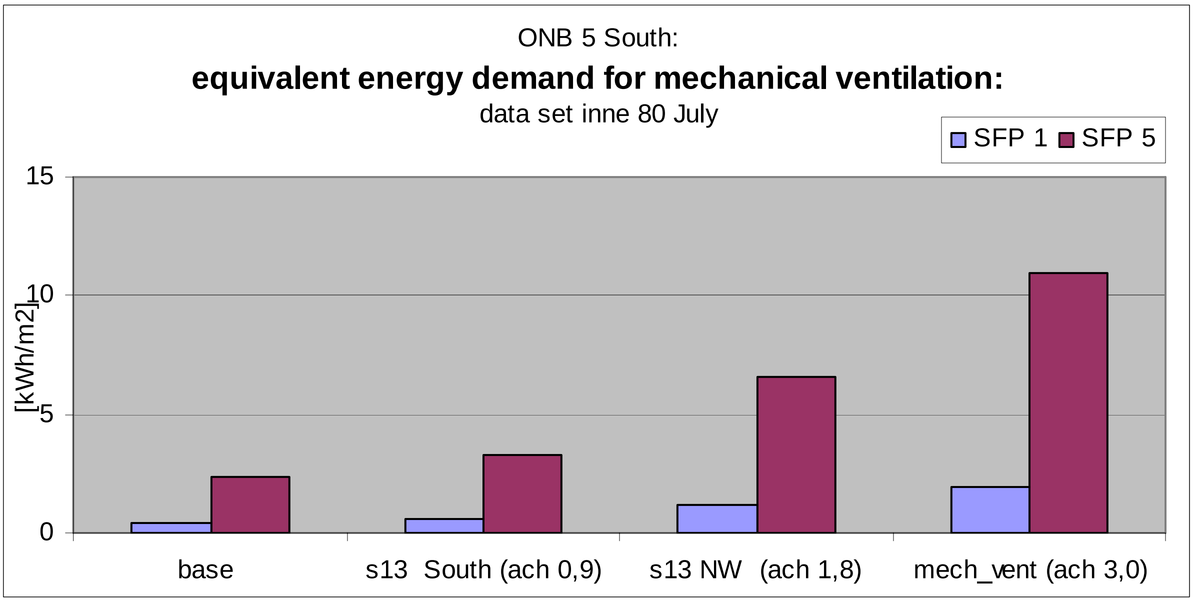
The base scenario employed as a reference here already includes mechanical ventilation, which provides hygienically determined air change rates. The variant presented hereafter constitutes of an additional air change. This air change was assumed to be 3 ach. In allusion to s13, it was applied during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

The results show that, while s13 displayes a reduction of surpassing hours (s. Graph 23) between 16 (for hours > 26°C) and 96% (for hours > 29°C), the reductions due to mechanical ventilation account for 28 to 100%.

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 5 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 savings. 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 25: Energy demand which would arise would natural ventilation be replaced by mechanical ventilation

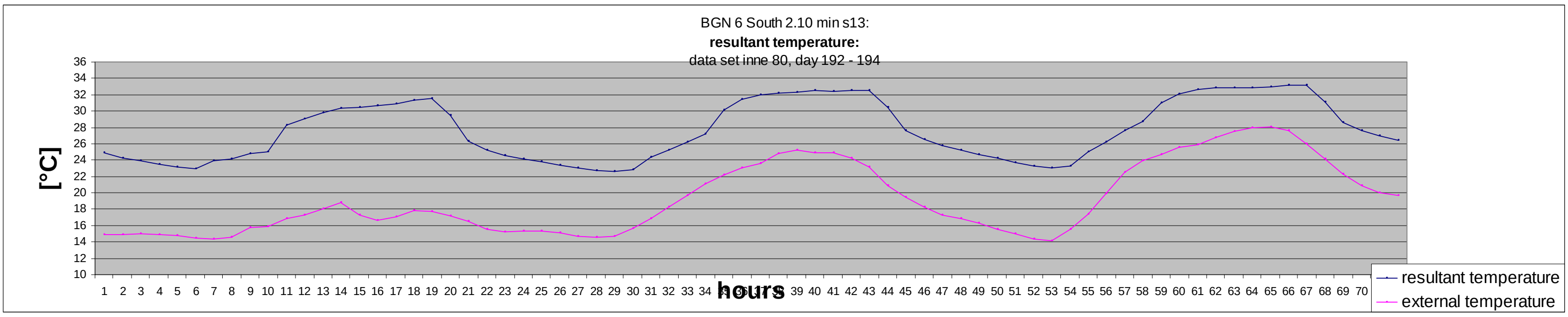
BGN

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. High internal solar gains are registered even if the shading devices are activated already during morning hours. At the same time, internal loads due to lightning, occupancy and equipment fall within usual ranges.

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.

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.

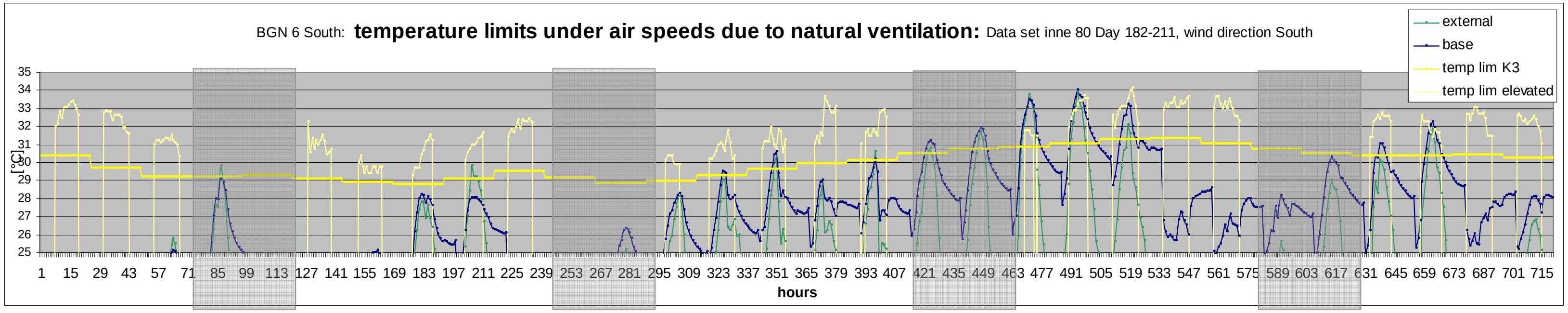


Graph 26: temperature course for BGN s13 (extended nocturnal ventilation and shut windows during daytime)

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

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).

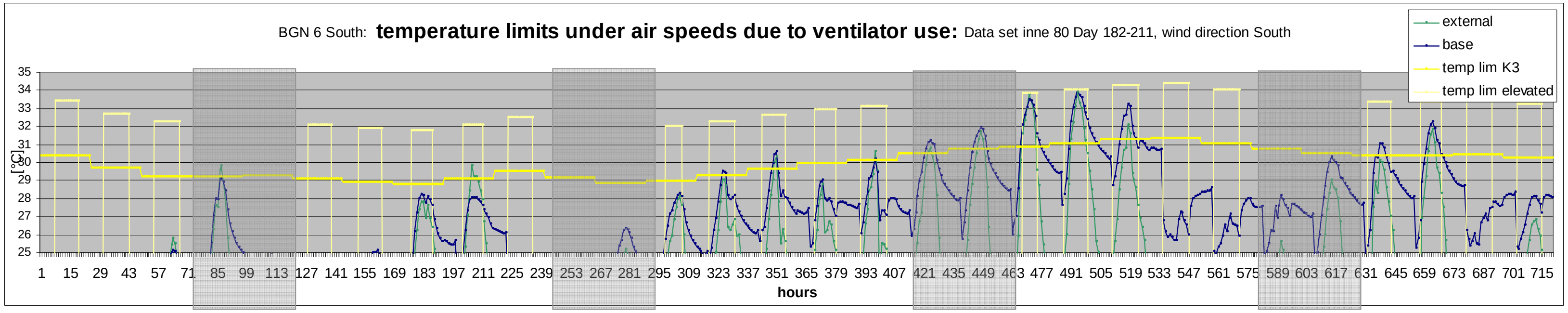
The appliance of the wind speeds thus calculated allows for the determination of an elevated comfort limit according to the indications of EN 15251 and results in the following temperature limits for July of climate data set “inne 80”xdsaq .



Graph 27: temperature limits due to wind induced air speed (acc. EN 15251) and outside temperature course

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

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

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.

E-2.3.4 Conclusion

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. It could be demonstrated that different optimization strategies are successful in different buildings in terms of comfort. 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.
- 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. 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.

E-2.4 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 was 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[12]. 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.

E-2.4.1 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.

E-2.4.2 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[13] 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. Upper and lower limits for probable investment cost were derived from BKI[14]. This data base contains processed and detailed cost data from existent, newly erected or refurbished buildings. Furthermore, an index to adapted prices to regional conditions is provided for Germany and Austria.

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[12] 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.

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

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

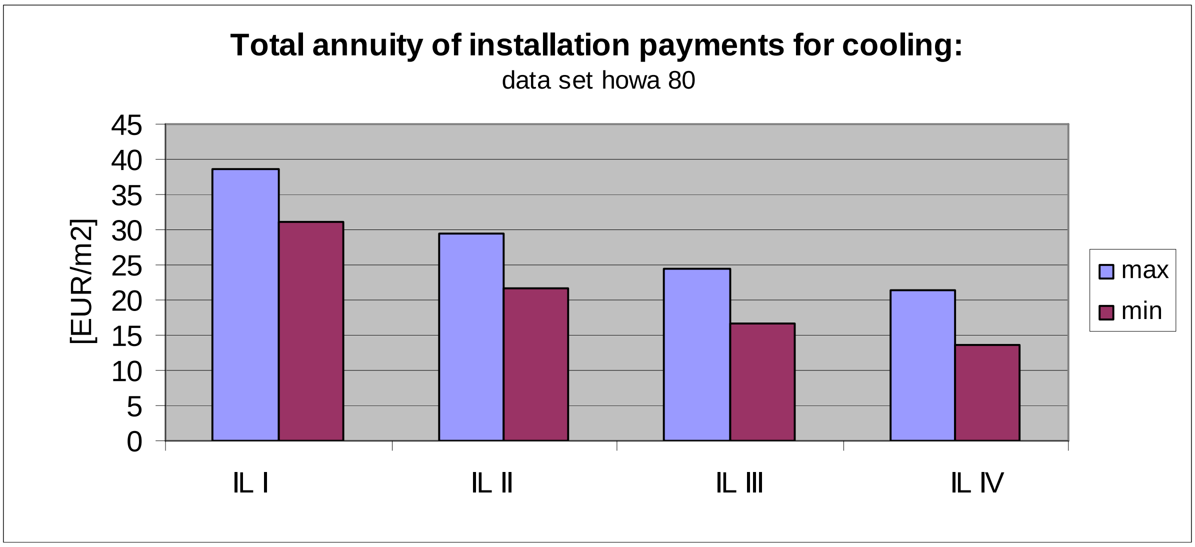
E-2.4.3 Results

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

As has been demonstrated above (s. chapter E-2.1: *Module 1: Cooling energy demand of sample buildings under different levels of internal loads*, page 12), reduced internal loads effectuate lower cooling energy demand and reduced maximum cooling load. The first effect reduces running costs for energy consumption, 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[15]. Investments for this category therefore were assumed equal for all variants investigated and could hence be neglected in the life cycle model.

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



Graph 29: 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

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.

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.

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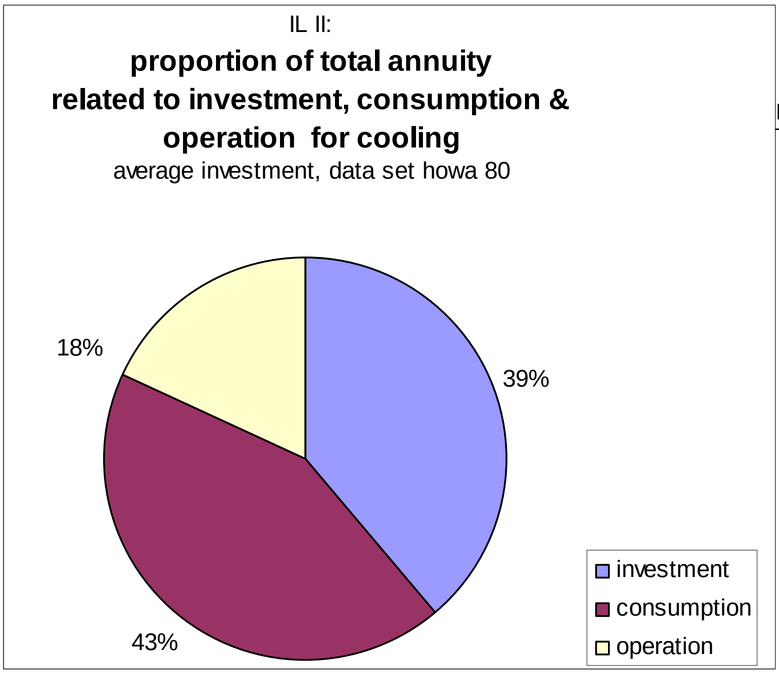
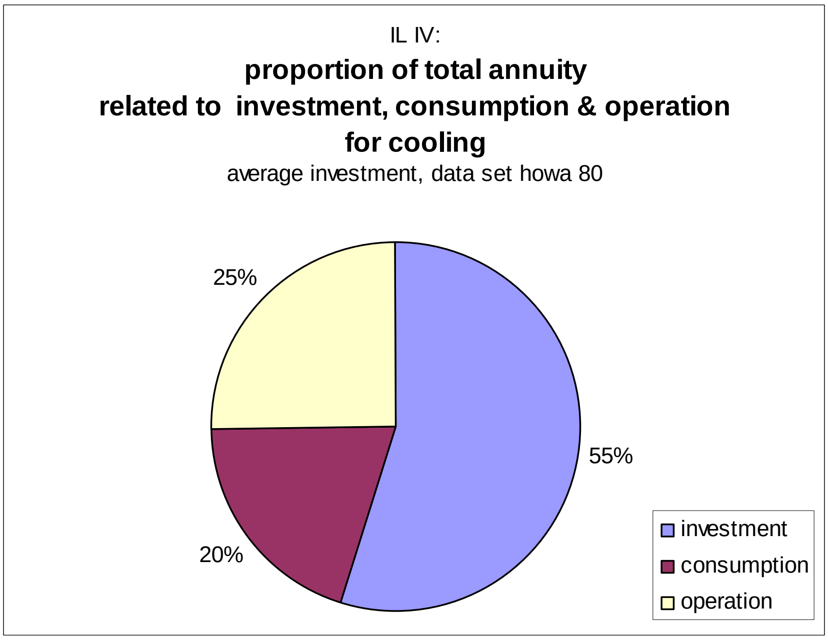
[15] *Berger, Tania (September 3, 2010): Energy Star - Energieeffiziente Bürogeräte. Mögliche Mehrkosten von energieeffizienten Bürogeräten. Interview mit Bernd Schäppi. Am September 3, 2010 in Krems*.



Graph 30: Proportion of total annuity for standard energy efficiency in internal loads (IL II), all sample buildings



Graph 31: 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.[16]

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.

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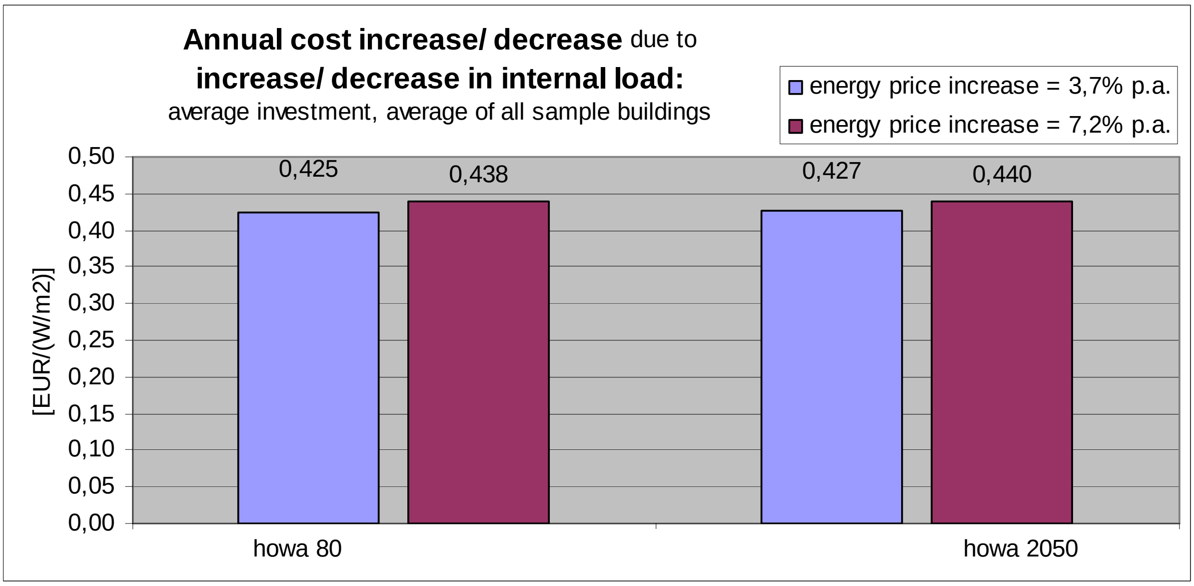
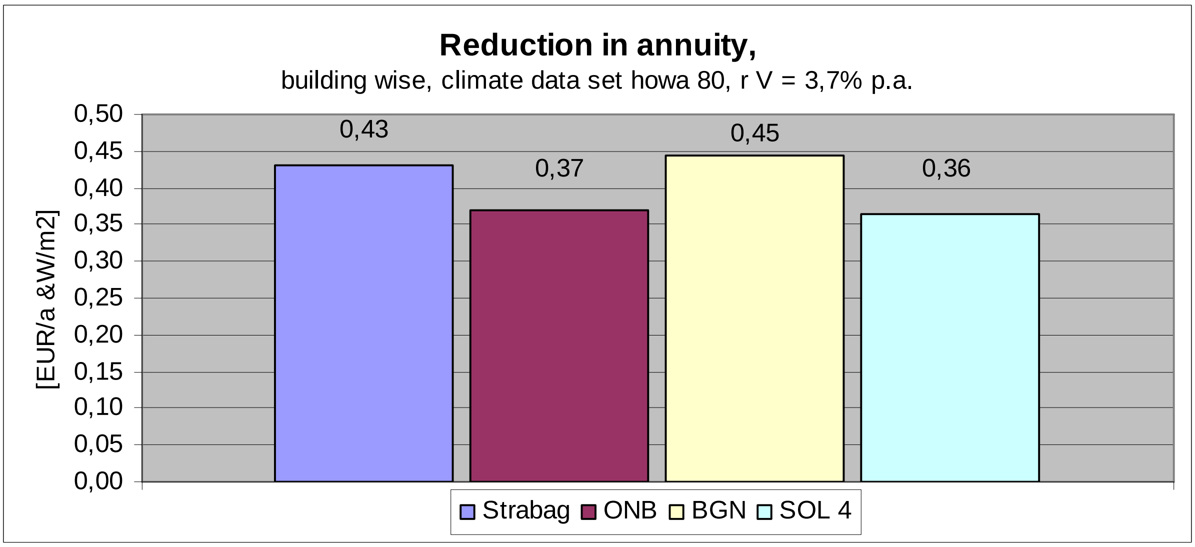
[16] Gazon, Siegfried (2010): Lebenszykluskosten: Prognosen und Kostentreiber für Mehrfamilien-Wohnhausanlagen. Untersuchung am Beispiel von Objekten der Gemeinnützigen Donau-Ennstaler-Siedlungs-Aktiengesellschaft. Master-Thesis zur Erlangung des akademischen Grades. Herausgegeben von Donau Universität Krems. Department für Bauen und Umwelt. Krems, see page 57



Graph 32: 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.

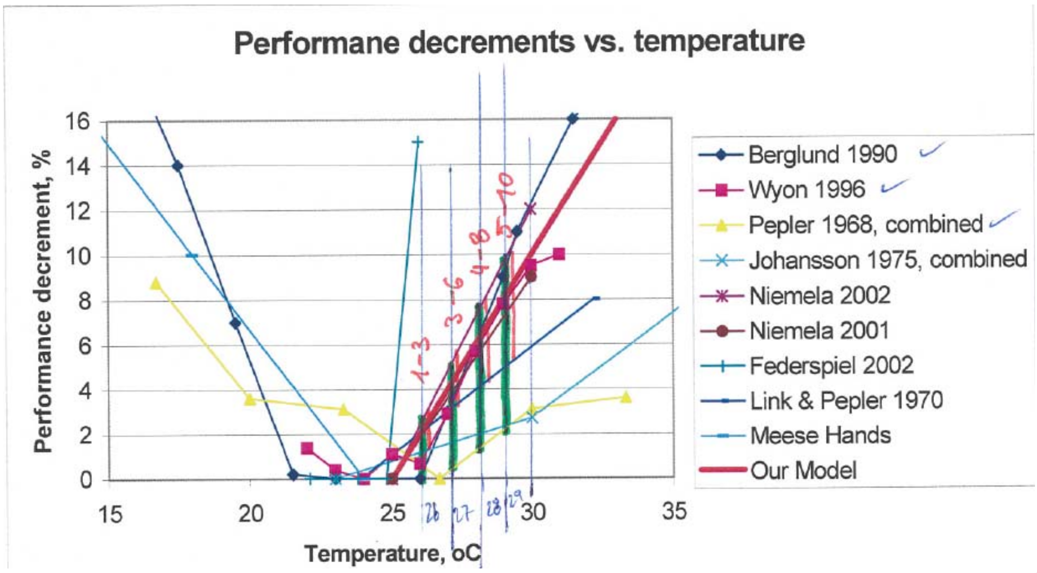


Graph 33: Reductions in annuity for sample buildings

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[17]. 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 34: summary of studies on the decrement of performance and productivity[18]

An optimum of all working hours within the limits of conformability acc. to ÖNORM 8110-3[19] 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. 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.

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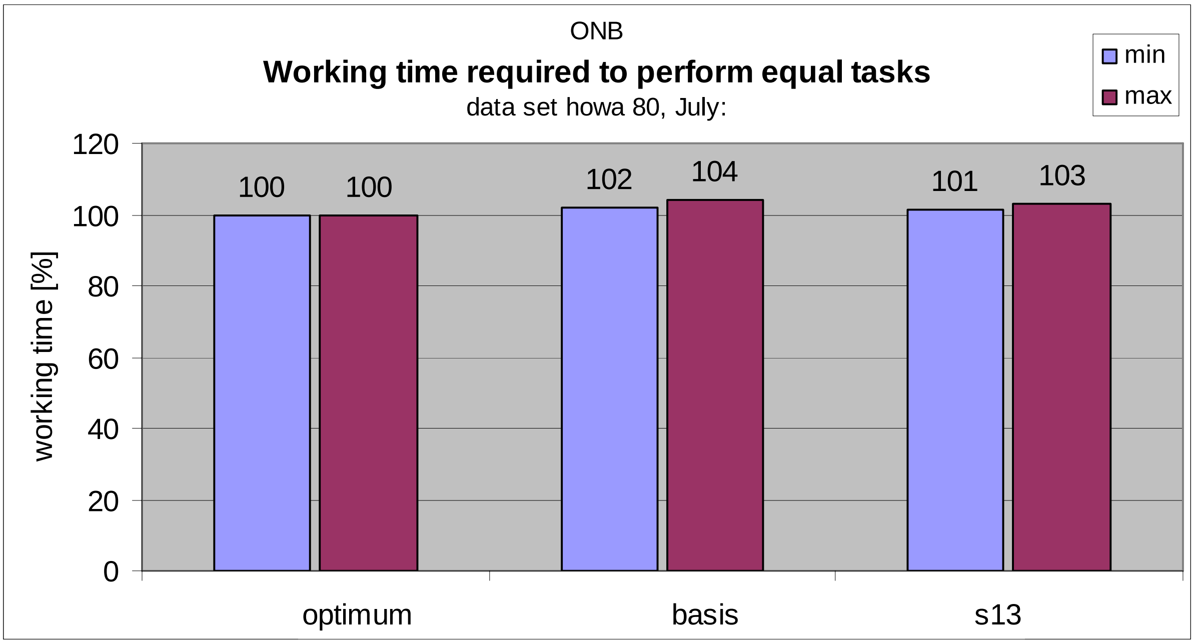
[17] Seppänen, O., Fisk, W. & Faulkner, D. COST BENEFIT ANALYSIS OF THE NIGHT-TIME VENTILATIVE COOLING IN OFFICE BUILDING. Lawrence Berkeley National Laboratory, University of California.

[18] ibidem

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



Graph 35: 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.

E-2.4.4 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.

E-2.5 Module 3: Innovative cooling systems

In this module, innovative cooling strategies for HVAC systems were investigated. These investigations focused upon highly innovative systems which in their majority are not yet available on the market. For radiative and evaporative cooling the following results were compiled:

- Status quo: experiences with the respective technology regarding applicability and limits of performance documented in related literature
- Definition of categories/ types within each technology including the description of the respective features
- Identification of those categories/ types worth of further investigation due to their obvious capability to fulfil capacity requirements
- Description of feasible areas of application of these technologies and the requirements related to these areas in terms of imput data for simulation

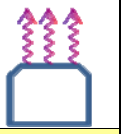
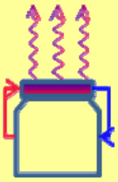
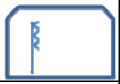
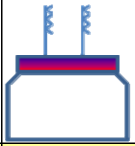
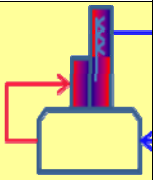
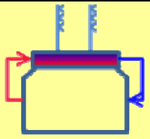
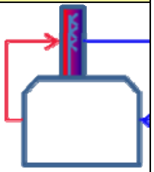
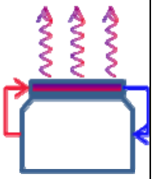
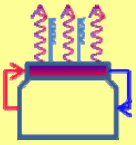
Category/ type	**Sub-group**	**Description**	**Example**	**Symbol**
Radiative	Direct/ passive	Building envelop serves as radiator for heat transfer towards the sky; heat transmission from internal to external surface of wall and roof has to be guaranteed; impact enhanced by materials of high emissivity	Heat radiated towards the sky from a concrete slab	
Radiative	Indirect/ hybrid	A medium (air or water) is circulated through the radiative cooling radiator and cooled thereby; this medium in consequence cools rooms via ventilation, chilled beams, activated concrete slabs and the like	Flat plate collector	
Evaporative	Direct/ passive/ external	External air is cooled due to the presence of water pools, plants etc. due to absorption of water and hence enters rooms with reduced temperature	Planting, ponds	
Evaporative	Direct/ passive/ internal	Internal air is cooled due to the presence of fountains, water trickling over surfaces, water sputtering etc. due to the absorption of water	Indoor fountains	
Evaporative	Indirect/ passive	Water is cooled due to condensation in roof top ponds with maximized surface; heat is transferred from hot internal space	Roof pond systems	
Evaporative	Indirect/ hybrid/ air	Mechanical ventilation system employing evaporation to cool exhaust air: by means of heat/ cool recovery supply air is cooled without increasing it's moisture content	Air washer in exhaust air duct + heat/cool recovery	
Evaporative	Indirect/ hybrid/ water	Water is cooled by evaporation in roof ponds and pumped into thermo active building elements or cooling transmitters	Roof pond system e.g. with cool water storage tank and thermo active building elements	
Evaporative	Direct/ hybrid/ air	Mechanical ventilation system employing evaporation to cool supply air while thereby increasing it's moisture content	Air washer in supply air duct	
Evaporative/ radiative	Direct/ passive	Water is cooled by evaporation in roof ponds. The pond is covered by a white metal plate which impedes the water from heating up during daytime due to it's high reflectivity and cools down due to radiation during nighttime; additionally water condensates at the cool metal plate and gets further cooled down.	Roof pond system in combination with radiative cooling by means of a metal plate	
Evaporative/ radiative	Indirect/ hybrid/	Water is cooled by evaporation in roof ponds or by nighttime radiation from water sputtered onto the roof itself. Cool water is used in thermo active building elements; either are roof ponds covered during daytime to prevent heating up or cool water is stored in ground water storage tanks	Roof pond systems: cooling by means of evaporation and radiation	

Table 6: description of the investigated innovative cooling technologies (technologies in coloured rows were investigated in detail)

The present study's findings regarding the performance and capacity of the investigated systems, the implications for their mapping in simulation and the applied tools are summed up hereafter.

The applicability of radiative systems is limited in terms of their capacity. If air is applied as carrier medium, this applicability is further diminished due to the specific heat capacity of air. If water is applied as carrier medium, the radiators' capacity ranges between 80 W/m^2 (experimental) and 160 W/m^2 (model calculation). As cooling ceilings require capacities around 70 W/m2, the cooling capacity extorted from one square meter of roof surface roughly corresponds to the load required by one square meter of office area. Similar values are to be expected from combined systems.

Hence, as a rule of thumb for both radiative systems using water as carrier medium and combined, indirect hybrid systems, the available roof area equals the office area which can be cooled. For multi-storey buildings additional cooling systems, either conventional or alternative, are indispensable. Such combinations, employing the investigated technologies for coverage of peak loads only, are especially feasible for indirect hybrid systems.

Indications of the cost effectiveness of such combinations are partly lacking. For one of the investigated cases, a doubling of investment cost as compared to those of a conventional refrigeration machine was reported[20]. Elevated investment costs are likely as algorithms of control beyond mainstream have to be implemented. This might hinder broad application as well as the fact that facility management is generally focused upon users' contentedness rather than energy efficient operation which has to be triggered by incentives. Innovative, energy efficient, but comparatively complex plants run danger of being run suboptimal.

Radiators making use of the dew point of air for the generation of cold water take advantage of the fact that relatively humid outside air, readily available in moderate, middle European zones, can be deployed as cooling water. The amounts of cold water produce vary from region to region, no indications were found for Central Europe. Hence, further investigations are required in this area.

This also applies for evaporative indirect hybrid Systems, for which information on the specific capacity in W/m2 of roof pond area are missing. The application of these systems is pinpointed by wet bulb temperature. A general disadvantage of all evaporative systems is their water demand, which can be critical in regions prone to water shortage.

Prospects

The combination of radiative and evaporative systems for the coverage of maximum cooling loads as a complement to existent technologies figure as most goal oriented strategy. The integration of storage capacities for bridging the time gap between energy generation during night hours and consumption at daytime is convenient and often necessary, be it via the building's thermal mass or in the form of water tanks. Rather elevated temperatures of the cold water produced by such systems favors the application in cooling ceilings or thermo active building elements which generally also operate on comparatively high cold water temperatures. As for now, combined systems, which could be labeled "state of the art" are not available. Such systems additionally require an according control in order to safeguard the envisaged energy savings.

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[20] Büttner, Dietrich; Kranl, Detlev; Schäfer, Matthias; Weinläder, Helmut (2003): Kühlkreislauf mit passiver Kälteerzeugung durch Strahlungskühlung. Bayrisches Zentrum für angewandte Energieforschung e.V. (Hg.).

The limited capacities of the portrayed cooling technologies commemorate the necessity to reduce cooling demand in the first place. Analogous to the passive principle in terms of heating demand, the reduced demand can then be covered easier from renewable sources.

Likewise, further research and dissemination is also required for comparisons of energy demand and green house gas emissions of these innovative technologies as well as other alternative cooling strategies such as desiccant cooling, solar cooling by means of adsorption machines or even for conventional refrigeration machines powered by photovoltaic plants.

Furthermore, it has to be acknowledged that the investigated cooling technologies are to be employed for safeguarding thermal comfort in office rooms – applications in highly sensible areas such as computer centers are not advisable due to the technologies' reliance on external climatic conditions.

E-3 Conclusion

This study investigated strategies to minimize cooling energy demand in office buildings while simultaneously striving to safeguard thermal comfort. Both strategies focusing at the buildings as well as those dealing with HVAC technology were scrutinized.

Building related optimization

Reducing internal heat loads of electronic devices and artificial lighting was found to facilitate reductions in cooling energy demand which score in the order of magnitude of the increases in demand to be expected due to climate change.

Usage profiles: shifting users’ attendance from the hottest hours of the day as well as reducing their presence by means such as teleworking in theory was shown to reduce cooling demand. However, practical and social limitations have to be taken into account.

Natural ventilation: in naturally ventilated office rooms, optimizations in thermal comfort were shown to be feasible by means of intelligent ventilation strategies. Precise and validated software tools for exact calculation of external wind and internal air velocities are to be developed.

HVAC related optimization

The combination of radiative and evaporative systems for the extortion of maximum cooling loads as a complement to conventional cooling technologies was identified as feasible.

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Tables

Graphs