Bundesministerium
für Verkehr,
Innovation und Technologie

NACHHALTIGwirtschaften
konkret

Auswirkungen des Klimawandels auf den thermischen Komfort in Bürogebäuden

T. Berger, H. Formayer,
R. Smutny, C. Neururer, R. Passawa

Berichte aus Energie- und Umweltforschung

7/2012

Dynamik mit Verantwortung

Impressum:

Eigentümer, Herausgeber und Medieninhaber:
Bundesministerium für Verkehr, Innovation und Technologie
Radetzkystraße 2, 1030 Wien

Verantwortung und Koordination:
Abteilung für Energie- und Umwelttechnologien
Leiter: DI Michael Paula

Liste sowie Downloadmöglichkeit aller Berichte dieser Reihe unter
http://www.nachhaltigwirtschaften.at

Auswirkungen des Klimawandels auf den thermischen Komfort in Bürogebäuden

DI Tania Berger, DI Rudolf Passawa
Donau-Universität Krems
Department für Bauen und Umwelt

Mag. Dr. Herbert Formayer
Universität für Bodenkultur
Department für Wasser, Atmosphäre und Umwelt
Institut für Meteorologie

DI Roman Smutny, DI Christoph Neururer
Universität für Bodenkultur
Department für Bautechnik und Naturgefahren
Institut für Konstruktiven Ingenieurbau

Wien, Mai 2011

Ein Projektbericht im Rahmen des Programms

HAUS der Zukunft

im Auftrag des Bundesministeriums für Verkehr, Innovation und Technologie

Vorwort

Der vorliegende Bericht dokumentiert die Ergebnisse eines Projekts aus dem Forschungs- und Technologieprogramm *Haus der Zukunft* des Bundesministeriums für Verkehr, Innovation und Technologie.

Die Intention des Programms ist, die technologischen Voraussetzungen für zukünftige Gebäude zu schaffen. Zukünftige Gebäude sollen höchste Energieeffizienz aufweisen und kostengünstig zu einem Mehr an Lebensqualität beitragen. Manche werden es schaffen, in Summe mehr Energie zu erzeugen als sie verbrauchen („Haus der Zukunft Plus“). Innovationen im Bereich der zukunftsorientierten Bauweise werden eingeleitet und ihre Markteinführung und -verbreitung forciert. Die Ergebnisse werden in Form von Pilot- oder Demonstrationsprojekten umgesetzt, um die Sichtbarkeit von neuen Technologien und Konzepten zu gewährleisten.

Das Programm *Haus der Zukunft Plus* verfolgt nicht nur den Anspruch, besonders innovative und richtungsweisende Projekte zu initiieren und zu finanzieren, sondern auch die Ergebnisse offensiv zu verbreiten. Daher werden sie in der Schriftenreihe publiziert und elektronisch über das Internet unter der Webadresse **http://www.HAUSderZukunft.at** Interessierten öffentlich zugänglich gemacht.

DI Michael Paula
Leiter der Abt. Energie- und Umwelttechnologien
Bundesministerium für Verkehr, Innovation und Technologie

Inhaltsverzeichnis

1. Präambel / Preamble

Der im Wortsinne globalen Bedeutung des bearbeiteten Themenfeldes entsprechend, wurde die vorliegende Forschungsarbeit im Hinblick auf die anzustrebende, breit angelegte internationale Verbreitung von Beginn an in englischer Sprache verfasst. Daher sind auch die themenbezogenen Kapitel für die Schriftenreihe der Programmlinie Haus der Zukunft plus durchwegs in Englisch abgefasst.

Die inhaltliche Berichtstruktur richtet sich nach den Vorgaben für die FFG-Schriftenreihe. Die inhaltliche Aufbereitung der Arbeit findet sich aufgrund des äußerst umfangreichen, komplexen und detaillierten Untersuchungsgegenstandes in vollem Umfang im Anhang (II. Appendix – Research Documentation)

Den über den Inhalt der Forschungsarbeit hinausgehenden speziellen Fragestellungen für die Schriftenreihe wurde separat und en bloc in deutscher Sprache entsprochen.

Due to the truly global relevance of this report, the specific topics of this research project are generally worked out in English. This comes with the fact, that this report shall be used as a basic work for international dissemination.

This report is structured following the guidelines for the FFG Schriftenreihe. Because of the very complex and detailed subject of the research topic, the complete technical documentation of the research done is enclosed as appendix at the end of this report (II. Appendix – Research Documentation).

2. Kurzfassung

2.1. Ausgangssituation/Motivation

Folgende Zusammenhänge und Auswirkungen des Klimawandels für bestehende und zukünftige Bürogebäude sind bekannt bzw. absehbar:

- Der Klimawandel wird den thermischen Komfort in Bürogebäuden durch erhöhte Außentemperaturen massiv beeinträchtigen.
- Die Produktivität am Arbeitsplatz Büro wird von erhöhten Innentemperaturen nachweislich negativ beeinflusst.
- Durch mangelnden thermischen Komfort im Büro entstehen demnach Kosten. (Personalkosten stellen den größten Budgeteinzelposten in der Mehrheit der Unternehmen dar.)
- Um gegenzusteuern, wird mechanische Kühlung großflächig eingesetzt werden, die von der Verfügbarkeit elektrischen (Spitzen)stroms abhängig ist.
- Durch die drastisch erhöhte Nachfrage wird diese Verfügbarkeit tendenziell nicht mehr flächendeckend und dauerhaft gewährleistet sein.
- Gleichzeitig ist die erforderliche Energiebereitstellung mit weiteren Klima schädigenden Emissionen verbunden, die ihrerseits den Klimawandel weiter zu beschleunigen drohen.

2.2. Inhalte und Zielsetzungen

Am Beispiel mehrerer Bürogebäude in Wien (Bestand und Neubau) wurde exemplarisch eine Untersuchungsroutine entwickelt für die Auswirkungen des Klimawandels auf den thermischen Komfort in Bürogebäuden. Augenmerk wurde dabei auch auf zu erwartende Veränderungen des Nutzerverhaltens und Möglichkeiten zur positiven Beeinflussung desselben gelegt.

2.3. Methodische Vorgehensweise

Das gegenständliche Projekt schließt vor diesem Hintergrund Forschungslücken und betritt Neuland:

- Im Projekt wurden halbsynthetische Klimadatensätze für die thermische Simulation von Zukunftsszenarien geschaffen.
- Die Auswirkungen des Klimawandels auf das thermische Verhalten von Bürogebäuden werden durch exemplarische Simulationen an neun Wiener Bürogebäuden untersucht. Dabei wurden Effekte des urbanen Mikroklimas berücksichtigt. Diese können Größenordungen erreichen, die die Auswirkungen des Klimawandels noch deutlich

übersteigen. Simulatorisch ausgetestete Kühlstrategien könnten sich dadurch in der Praxis als unwirksam erweisen. Dies gilt insbesondere für energetisch optimierte Plusenergiegebäude, die erhöhten, nicht prognostizierten Bedarf nicht durch großzügige Reserven puffern können.

- Der Einfluss der NutzerInnen wird häufig unterschätzt. Im vorliegenden Projekt wurden qualitative Abschätzungen aufgestellt, wie sich die BüronutzerInnen angesichts veränderter Klimabedingungen verhalten werden, und wie dieses Verhalten positiv beeinflusst werden kann.

2.4. Ergebnisse

Auswirkungen des Klimawandels:

Klimadatensimulation:

Die Klimadatensimulationen zeigen, dass der Kühlbedarf künftig steigen wird, während der Heizwärmebedarf sinken wird. Dabei ist festzustellen, dass der Trend beim Endenergie- und Primärenergiebedarf stark abhängt von den Gebäudeeigenschaften: Bürogebäude aus dem letzten Jahrzehnt haben jetzt schon einen höheren Kühl- als Heizwärmebedarf. Ihr Endenergiebedarf wird im untersuchten Zeitraum stagnieren oder allenfalls leicht steigen. Ältere und historische Bürobauten werden sich weiterhin durch einen hohen Heizwärmebedarf auszeichnen, auch bei der prognostizierten Klimaerwärmung im Modell 2050. Der Gesamtenergieverbrauch dieser Gebäude wird in den nächsten Dekaden abnehmen, wiewohl er in absoluten Zahlen sehr hoch bleiben wird.

Komfortmodelle:

Es zeigen beide verwendeten Komfortmodelle „Fanger“ und „Adaptive“, dass die Definition des sommerlichen Komforts in Bürogebäuden sehr stark von ihrer Kühlanforderung anhängt. Dabei ist zu unterscheiden zwischen technisch konditionierten Gebäuden (für die das „Fanger“-Modell anzuwenden ist), und solchen ohne technische Einrichtungen für Frischluftversorgung und sommerlichen Temperaturausgleich (für die das „Adaptive“-Modell anzuwenden ist).

Urbane Wärmeinsel:

Gebäude in innerstädtischen Lagen haben heute schon einen höheren Kühl- als Heizwärmebedarf als solche in Standrandzonen. Daher weisen die Innenstadtzonen den kleinsten Endenergiebedarf aus.

Optimierung der Gebäudehülle:

Auch in Hinblick auf Klimaerwärmung liefern opake Gebäudehüllen mit außenliegender Wärmedämmung die besten Ergebnisse in Bezug auf den Gesamtenergiebedarf, da diese den Heizwärmebedarf erheblich senken.

2.5. Schlussfolgerungen zu Adaptions- und Verbesserungsmaßnahmen:

Autoren: Christoph Neururer, Roman Smutny,, BOKU Wien; Alexander Keul, Universität Salzburg

Der Klimawandel wird das durchschnittliche urbane Mikroklima ebenso beeinflussen wie die Dauer von Hitzeperioden und damit Ertüchtigungsmaßnahmen am Gebäude selbst und bei den gebäudetechnischen Anlagen erfordern. Die Ergebnisse der Simulationen an bestehenden Demonstrationsbauten in wärmeren Klimaszenarien und die Resultate der entsprechenden Komfortuntersuchungen liefern Ansatzpunkte für Verbesserungs- und Adaptionskonzepte.

Die wichtigsten Erkenntnisse sind:

- Die besten Daten zur thermischen Behaglichkeit werden dort erreicht, wo die NutzerInnen selbst die Parameter ihrer Innenraumumgebung entsprechend ihrer Komfortbedürfnisse bestimmen können.
- Die besten Daten zur thermischen Behaglichkeit werden erreicht, wo ein aktives Kühlsystem von passiven Systemen zur Temperierung begleitet wird. Dabei ist festzuhalten, dass Verbesserungen und Nachrüstungsmaßnahmen von Bürogebäuden in mitteleuropäischen Breiten auf aktive Gebäudekühlung verzichten sollen, um den Energiebedarf zu minimieren. Adaptionen mit ausschließlich passiv wirkenden Kühlkonzepten sind besonders sorgsam zu planen, um die Komfortansprüche zu erfüllen. Daraus folgt, dass Simulationen zur bestmöglichen Energieeffizienz und zum thermischen Komfort neben der Betrachtung zukünftiger Klimaszenarien und deren Auswirkungen auf Mikroklimate (z.B. urbane Wärmeinseln) auch Veränderungen des optimalen NutzerInnenverhaltens umfassen müssen (Gebrauch von Beschattungseinrichtungen, elektrischer Beleuchtung und Fensterlüftung).

Wichtige Maßnahmen zur passiven Kühlung sind:

- Außenliegende Verschattungseinrichtungen mit effektiver Beschattung und Windresistenz.
- Beleuchtungskonzept: Energieeffiziente Leuchtmittel, Tageslichtkonzepte, Kunstlicht nur dann und dort, wo gerade gebraucht.
- Elektrische Ausrüstung: Energieeffiziente Geräte (Computer, Bildschirme, Drucker, Kopierer, etc.), Reduktion des Standby-Betriebs elektrischer Geräte.
- Gebrauch von Decken- und/oder Tischventilatoren.
- Nachtlüftung
- Konditionierung der Frischluft oder Bauteilkühlung mittels Erdwärmetauscher.

Bundesförderungen für thermische Verbesserungen an Gebäuden sollen diese Maßnahmen zur passiven Gebäudekühlung explizit in die entsprechenden Förderprogramme integrieren.

Voraussetzung dafür soll grundsätzlich der Wirkungsnachweis mittels einer dynamischen thermischen Gebäudesimulation sein. Diese Simulation ist aus Vergleichsgründen grundsätzlich mit standardisierten Eingangsparametern für das Mikroklima (Urbaner Wärmeinseleffekt), für das Klimawandelszenario (Länge von Hitzeperioden) und für nicht-optimales NutzerInnenverhalten (Bedienung von Beschattungen, elektrischer Beleuchtung, Fensterlüftung) durchzuführen.

2.6. Ausblick

Autoren: Christoph Neururer, Roman Smutny,, BOKU Wien; Alexander Keul, Universität Salzburg

Der Klimawandel beeinflusst die innerstädtischen Mikroklimazonen (urbanen Wärmeinseln) ebenso wie die Dauer von Hitzeperioden. Bestehende und künftige Bürogebäude, die keine Kapazität besitzen, zusätzliche Kühllasten infolge höherer Außentemperaturen abzupuffern, werden Probleme hinsichtlich des thermischen Komforts bekommen. Das bedeutet, dass die Produktivität der in diesen Gebäuden Werktätigen (Arbeitnehmer, Schüler, etc.) abnehmen wird. Genauso sind Rückgänge der Mieterträge infolge sinkender Nachfrage für im Sommer unbehagliche Büroflächen zu erwarten. Bereits jetzt haben viele Bürogebäude diese Probleme, und diese werden sich mit dem fortschreitenden Klimawandel noch verstärken. Besonders betroffen sind Büro- und Verwaltungsbauten, Schulen, Universitäten u. dgl. In innerstädtischen Lagen.

Low tech passive Kühlsysteme erscheinen als angemessene thermische Verbesserungs- und Adaptionsmaßnahmen. Die Effektivität betreffend Behaglichkeit und Energieeffizienz muss im Vorfeld systematisch für die verschiedenen, anwendbaren Kombinationen passiver Kühlsysteme analysiert werden.

Konzepte für nachhaltige Bürogebäude in wärmer werdenden gemäßigten Klimazonen können aus Untersuchungen und Berichten über Gebäude in tropischen Klimazonen abgeleitet werden. Dabei ist eine umfassende systematische Analyse notwendig, an Stelle der bisherigen europäischen oder angloamerikanischen Baukultur und Konzeptionierung. Die klimatische Adaption ist nicht nur eine technische, sondern auch eine kulturelle Innovation.

<u>Marktpotential</u>

Autor: Rudolf Passawa, Donau-Universität Krems

Zur Verbreitung in der Wirtschaft ist das „klimawandeltaugliche Bürogebäude“ durch Beschreibung und Definition von universell verwendbaren, einfachen Berechnungsgrundlagen und Effizienzkriterien (in technischen Normen, gesetzlichen Vorschriften und Förderungsrichtlinien) als eigene Marketinglinie zu propagieren. Es hat damit ähnliches Zukunftspotential wie die Passivhaustechnologie, bei deren Anwendung und Verbreitung die österreichische Wirtschaft bis dato europa- und weltweit federführend ist.

3. Hintergrundinformationen zum Projektinhalt

3.1. Beschreibung des Standes der Technik

Das Projekt konzentriert sich auf folgende vier Teilaspekte notwendiger Anpassungsstrategien gegenüber dem Status Quo von Planungsstrategien für innerstädtische Bürogebäude:

Klimadatensätze

Es gibt derzeit für Österreich keine Klimadatensätze, die die zukünftige Entwicklung im Gefolge des Klimawandels abbilden. Diese Datensätze werden aber für den Einsatz in der thermischen Gebäudeauslegung dringend benötigt. Thermische Simulationen an komplexen Gebäuden, die eigentlich deren zukünftige, thermische Tauglichkeit vorab testen sollen, werden in Ermangelung derartiger Klimadatensätzen derzeit mit Daten durchgeführt, die die klimatischen Verhältnisse der Vergangenheit abbilden und somit für Aussagen über kommende Verhältnisse ungeeignet sind. Die Schaffung dieser wichtigen Grundlage wird mit dem gegenständlichen Projekt für den Großraum Wien in Angriff genommen.

Wärmeinsel

Darüber hinaus bleiben die Effekte urbaner Wärmeinseln derzeit in der thermischen Gebäudeauslegung weitgehend unberücksichtigt – und dies, obwohl diese städtischen Erwärmungen bereits heute die Dimension der für den Klimawandel prognostizierten Temperaturerhöhungen annehmen können. Die bekannten Aufheizprozesse städtischer Mikroklimate werden von der Klimatologie weltweit seit Jahrzehnten in ihrer extrem komplexen Ausprägung beforscht, haben aber bisher kaum Eingang gefunden in die planerische Praxis der Gebäudekonditionierung. Daher werden im Projekt Abschätzungen für die simulatorische Berücksichtigung dieser Erwärmungen am Standort Wien geschaffen.

Kühlbedarf

Wenige qualitative Aussagen wurden bisher getroffen zu verändertem Kühlbedarf und zu erwartenden Leistungsspitzen durch erhöhte sommerliche Außentemperaturen. Weiters liegt bisher wenig vor über die für die Bestimmung des thermischen Komforts und der Kühllasten erforderlichen Überschreitungshäufigkeiten sommerlicher Grenztemperaturen. Diese differenzierten Aussagen treffen zu können, ist erklärtes Ziel des gegenständlichen Projektes. Auch werden diese Aussagen zu unterschiedlichen Bürogebäudetypen (Bauart, Bauepoche) gemacht.

Nutzerverhalten

Wenige Forschungsergebnisse sind verfügbar über Nutzerverhalten in sommerlichen Hitzeperioden, insbesondere bezogen auf unterschiedliche Gebäudetypen und –nutzungs-arten. Darüber hinaus ist damit zu rechnen, dass sich dieses Nutzerverhalten mit steigenden Außentemperaturen verändern und neue Ansprüche an Gebäude stellen wird.

3.2. Beschreibung der Neuerungen sowie ihrer Vorteile gegenüber dem Ist-Stand (Innovationsgehalt des Projekts)

Fußend auf den Forschungsergebnissen werden für Behörden und Immobilienwirtschaft grundlegende Empfehlungen für Anpassungsstrategien formuliert. Behörden und Immobilienwirtschaft verfügen derzeit nicht über Handlungsempfehlungen zur Anpassung des Bürobestands an den Klimawandel, und auch nicht für richtungsweisende Konzepte für künftige Büroprojekte, die entsprechend langfristiges Agieren ermöglichen.

3.3. Vorarbeiten zum Thema

Das gegenständliche Projekt baut auf zahlreichen nationalen wie internationalen Forschungsarbeiten im Bereich der Meteorologie und der Bauphysik sowie auf umfangreichen soziologischen Untersuchungen auf, die in unterschiedlicher Form genutzt werden bzw. über deren Ergebnisse in der dargestellten Form hinausgegangen wird. Die maßgebenden Arbeiten sind im Anhang I. angeführt.

4. Detailangaben zu den Zielen des Programms und Schlussfolgerungen

4.1. Einpassung in das Programm

Der Vision der Programmlinie Haus der Zukunft plus wird in zweifacher Linie optimal entsprochen:

1.

Gerade Bürogebäude haben nicht nur nennenswerten Energiebedarf für die Beheizung, sondern vor allem auch für die Kühlung im Sommer, z.B. infolge großzügiger Verglasungen, die gerade in der zeitgenössischen Architektur immer mehr Verbreitung gefunden haben, und wegen der Notwendigkeit, vermehrt Wärme aus internen Quellen (Bürogeräte, wie Computer und Bildschirme, Drucker; künstliches Licht, u. dgl.) abzuführen. Konventionelle energieintensive technische Lösungen, wie z.B. mit Klimaanlagen, verursachen zunehmende CO_2-Emissionen und sind daher nicht zukunftsfähig.

2.

Bei künftigen längeren und wärmeren Sommerperioden in europäischen Breiten reichen heutige konstruktive und technische Planungsgrundsätze, Normen, Richtlinien und Bauvorschriften für Bürobauten nicht mehr aus, um sowohl die gesetzlichen Zielvorgaben zur Energieeffizienzsteigerung als auch die sich im Zuge des Klimawandels verschärfenden Anforderungen an den Nutzerkomfort (Vermeidung der sommerlichen Überwärmung in Innenräumen) zu gewährleisten. Hier wird künftig nicht nur geänderten bautechnischen, sondern auch verschärften Komfortanforderungen zu begegnen sein.

4.2. Beitrag zum Gesamtziel des Programms

Aus Vorgenanntem folgt, dass Konzepte für Bürogebäude, die nicht nur bei der Beheizung, sondern vor allem im Sommerbetrieb CO_2-Emissionen verringern, unbedingt notwendig sind.

Auch wird deutlich, dass die zu erwartenden, intensiveren Hitzeperioden Einbußen in der Produktivität der in den Büros Beschäftigten zur Folge haben werden.

Der vorliegende Forschungsbericht zeigt hier neue Wege auf, zum einen als Hilfestellung für die Immobilienwirtschaft und als Planungsansatz für Architekten und Planer, zum anderen als Richtschnur für Gesetzgeber und Behörden zur Erarbeitung neuer gesetzlicher Vorschriften und Förderungsmodelle. Er liefert Empfehlungen zur Anpassung von Bürogebäuden an den Klimawandel, sowohl in technischer als auch in funktionaler Hinsicht.

4.3. Einbeziehung der Zielgruppen

Die Ergebnisse und Schlussfolgerungen aus der Forschungsarbeit sind für alle Zielgruppen relevant, die für die Optimierung der Energieeffizienz von Bürogebäuden und für den notwendigen Nutzerkomfort verantwortlich sind:

Immobilienwirtschaft: Interesse an funktionalen, wirtschaftlichen Gebäuden, die optimale Produktivität der NutzerInnen gewährleisten.

Architekten, Fachplaner, Baugewerbe: Verantwortlich für die sachgemäße Planung und Umsetzung.

Gesetzgeber, Behörden: Verantwortlich für die Gestaltung transparenter, wirkungsvoller Vorschriften und Anreize (Förderungen).

NutzerInnen: Die wichtigste Zielgruppe, da diese es sind, die die Leistungen in den Unternehmen erbringen. Zum Erhalt der optimalen Leistungsfähigkeit müssen daher ihre physiologischen Bedürfnisse (adäquate sommerliche Innenraumtemperaturen, Tageslicht, praktikable Bedienungs- und Steuerungs-möglichkeiten, etc.) in die Konzepte für Bürogebäude einfließen.

4.4. Beschreibung der Umsetzungspotenziale

Die Umsetzung und Verbreitung der im Bericht erarbeiteten Erkenntnisse und Empfehlungen ist grundsätzlich sehr kurzfristig möglich und auch nötig:

<u>Direkte Anwendung durch einschlägig ausgebildete Planer und Firmen:</u>

Schon jetzt besteht Nachholbedarf an Bürogebäuden, die im Sommer angemessenen Innenraumkomfort bieten. Die im Bericht formulierten Planungsgrundsätze lassen sich unmittelbar in der laufenden Tätigkeit derjenigen Architekten, Fachplaner, Baufirmen und Professionisten, die bereits einschlägiges Fachwissen hinsichtlich energieeffizienter Planung und Ausführung besitzen, umsetzen, um dem schon bestehenden Bedarf nachzukommen.

<u>Weiterbildung:</u>

Die Verbreitung von Grundlagenwissen zur Thematik energieeffizienten Planen und Bauens in der Bauwirtschaft ist nach den Erfahrungen des Projektteams immer noch ein notwendiges Ziel. Architekten, Fachplaner und Vertreter des Baugewerbes sind in zielgruppenspezifischen Seminaren und Workshops weiterzubilden, und zwar durch die eigenen Interessensvertretungen selbst, und durch Universitäten und Fachhochschulen sowie anderen Bildungseinrichtungen. Bundes- und Landesbehörden können hier mit Vortrags- und Workshop-Reihen, Veranstaltungen, Förderungsanreizen, u. dgl. einen unterstützenden Beitrag leisten (z. B. nach dem Vorbild des Disseminationsprojektes für

Bauträger „Passivhaus der Zukunft-Akademie“ des Bundesministeriums für Verkehr, Innovation und Technologie)

Ausbildung:

Direkte Einbeziehung der Forschungsergebnisse in die Lehrpläne von Fachschulen, Fachhochschulen und Universitäten, sowohl in der Grundlagenausbildung, als auch in der Weiterbildung. Die beteiligten Projektpartner (Donau-Universität Krems, BOKU) integrieren laufend die Erkenntnisse ihrer Forschungen in ihren Lehrgängen (Weiterbildung an der DUK), bzw. in ihrer Grundfachausbildung (Studenten an der BOKU).

Marktpotential:

Zur Verbreitung in der Wirtschaft ist das „klimawandeltaugliche Bürogebäude“ durch Beschreibung und Definition von massentauglichen, einfachen Berechnungsgrundlagen und Effizienzkriterien (in technischen Normen, gesetzlichen Vorschriften und Förderungsrichtlinien) als eigene Marketinglinie zu propagieren. Es hat damit ähnliches Zukunftspotential wie die Passivhaustechnologie, bei deren Anwendung und Verbreitung die österreichische Wirtschaft bis dato europa- und weltweit federführend ist.

4.5. Fachliche Einschätzung des Projektteams der aus dem Projekt gewonnenen Erkenntnisse

Für die Verfasser bestätigend war das Ergebnis aus den Simulationen, dass im Zuge des Klimawandels der Energiebedarf für Heizen in Bürogebäuden in der Gesamtbilanz an Bedeutung verlieren wird, gegenüber dem zu erwartenden Kühlbedarf bei wärmeren Klimaszenarien. In den Simulationen bestätigte sich die Annahme, dass der Effekt der Klimaerwärmung noch verstärkt wird durch die Ausbildung innerstädtischer Wärmeinseln, die durch versiegelte Flächen, Ansammlung wärmespeichernder Massen und wärmereflektierender Oberflächen in Stadtzentren gebildet werden. Ebenso bestätigte sich die Annahme, dass der Energiebedarf für die Gebäudekühlung, falls sich der Trend der Anwendung herkömmlicher, technischer Kühlmethoden (z.B. Klimaanlagen) wie bisher fortsetzt, den Energiebedarf für Heizen an Bedeutung stark übertreffen und somit der Erreichung der gesetzlichen Klimaschutzziele entgegenstehen wird.

Neben schon etablierten Planungsgrundsätzen, wie passive Methoden zur Vermeidung des solaren Wärmeeintrags in Gebäude und haustechnischen Lösungen, die regenerative Energien sowohl zur Gebäudeheizung als auch –kühlung nutzen (z.B. solar cooling, Nutzung von speicherwirksamen Massen, Nutzung der Erdwärme zur Bauteilkühlung, u. dgl.) sind als nächster Schritt auch Bau- und Betriebsmodelle für Bürogebäude aus tropischen und subtropischen Regionen auf ihre Transformationseignung in mittlere Breiten zu untersuchen.

5. Ausblick und Empfehlungen

Die Ergebnisse dieser Arbeit zeigen auf, dass mit der Anwendung und Integration der gewonnenen Erkenntnisse in Bauordnungen, Normenwerke und Lehrinhalte an Fachschulen, Fachhochschulen und Universitäten unmittelbar begonnen werden kann und muss.

Zur Dissemination in die Wirtschaft (Bauwirtschaft, Architekten, Immobilienwirtschaft, u. dgl.) und schnellen Umsetzung sind kurzfristig vertiefende Workshops notwendig; hier sind aus Sicht der Verfasser sowohl schulische und universitäre Lehreinrichtungen angesprochen, als auch Landes- und Bundesgesetzgeber. Strukturierte, zielgruppenorientierte und wissenschaftlich begleitete Workshopserien könnten nach dem Vorbild des Forschungsprojekts „Passivhaus der Zuklunft-Akademie“ der Programmlinie Haus der Zukunft plus des Bundesministerium für Verkehr, Innovation und Technologie durchgeführt werden.

Weiters wird empfohlen, dass Bundes- und Landesbehörden die Forschungsergebnisse als Grundlage für Förderungsrichtlinien und –gesetze für thermische Verbesserungen an Gebäuden heranziehen, und darauf aufbauend konkrete Maßnahmen zur passiven Gebäudekühlung explizit in die entsprechenden Förderprogramme integrieren. Voraussetzung dafür soll grundsätzlich der Wirkungsnachweis mittels einer dynamischen thermischen Gebäudesimulation sein. Diese Simulation ist aus Vergleichsgründen grundsätzlich mit standardisierten Eingangsparametern für das Mikroklima (Urbaner Wärmeinseleffekt), für das Klimawandelszenario (Dauer von Hitzeperioden) und für nicht-optimales NutzerInnenverhalten (Bedienung von Beschattungen, elektrischer Beleuchtung, Fensterlüftung) durchzuführen.

Zur weiteren wissenschaftlichen Aufbereitung erscheinen den Verfassern vertiefende Studien über die mögliche Transformation erfolgreicher energieeffizienter Gebäudekonzepte unter Behaglichkeitskriterien aus dem tropischen Raum für die Adaption in mitteleuropäische Breiten sinnvoll.

Diese weiterführenden Forschungen sollen neben den gebäudetechnischen Schwerpunkten – in Erweiterung des Erkenntnishorizonts – auch städtebauliche Aspekte umfassen. Beispielhaft seien hier Untersuchungen über den Einfluss von Wasserflächen und Vegetationsinseln auf das Mikroklima dichtbebauter städtischer Umgebungen empfohlen.

Es wird vorgeschlagen, im Rahmen der Programmlinie „Haus der Zukunft“ sowohl einen eigenen Schwerpunkt zur Entwicklung und Verbreitung verbesserter, sommertauglicher gewerblicher Bauten, als auch eine Schiene für Grundlagenstudien zur Transformation von Gebäude- und Städtebaumodellen aus dem tropischen Raum in Europa bzw. Österreich einzurichten.

6. 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 in summer
- 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 in the decades to come.
- 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 nine existent Viennese office buildings, this project aimed to investigate the magnitude of problems arising in this kind of buildings due to climate change. Herein, emphasis was placed upon parameters of thermal comfort and energy consumption. Furthermore, effects of increases in cooling demand and CO_2 emissions were investigated. As impacts of urban heat islands are assumed to further aggravate the above mentioned climate change aftermath, these impacts too formed a point of analysis. Potential of improvements in the buildings' envelop were assessed in a concluding step of investigation. As a result, the following conclusions are at hand:

Impacts of climate change

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

Impact of different comfort models: The definition of what is regarded as "uncomfortable" according to the two existing comfort models ("Fanger" and "Adaptive") remarkable impacts

upon cooling requirements. Care has to be taken to distinguish between conditioned buildings (which call for the application of the "Fanger" model) and free running buildings (to be assessed according to the "Adaptive" model).

Impact of urban heat island: Already today, locations in CBDs generally display higher cooling and lower heating demands than outside sites. This leaves inner city locations as those with the least overall final energy demand.

Possible measures for reduction of energy demand

Impact of optimization of buildings' envelops: Even in view of climate change, external thermal insulation of opaque buildings' surfaces yields bests results in terms of overall final energy requirements due to significant reductions in heating demand.

Prospects and outlook

Authors: Christoph Neururer, Roman Smutny of BOKU Vienna; Alexander Keul of University Salzburg

Climate change affects the urban microclimate (heat island effect) as well as the duration of heat-waves. Existing buildings and new buildings with no capacity to buffer the increasing cooling load will have problems with thermal comfort. This reduces the productivity of office workers (and pupils) and might reduce as well rental incomes. Many existing buildings already have these problems and the number of buildings as well as the negative impacts will increase due to climate change. Especially concerned are office buildings, administration buildings, schools, universities etc. in urban areas.

Low tech passive cooling solutions seem to be an appropriate thermal retrofit measure. The effectiveness for comfort and energy efficiency should be systematically analysed for different combinations of passive cooling solutions.

Concepts for sustainable office buildings in changing climate can be derived by observations and reports from buildings in warmer to tropical countries. A systematic analysis should be performed instead of a conservative extension of Euro- or Americocentric building practices and concepts. Climatic adaptation is a technical, but also a cultural achievement.

Marketing prospects

Author: Rudolf Passawa, Danube University Krems

The concept for the "Climate Change-Proof Office Building" is fitted with similar prospects for success, as the passive house-concept for residential buildings. If simple and effective measures for building design and energy efficiency are established by legislative authorities, this concept has marketing prospects comparable to the passive house, where Austrian enterprises are actually leading in Europe and worldwide.

7. Introduction

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.

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

Urban heat islands are well known to generally display climatic conditions quite distinct from surrounding areas, most pronouncedly detectable in higher ambient temperatures. It is most likely that climatic conditions in urban areas will generally further deteriorate due to climate change.

Offices 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. Offices are especially prone to overheating and consequently to active cooling requirements;

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

A high degree of attention has to be attributed to users' acceptance of thermal indoor conditions as this directly triggers reactions on their side. Which degree of influence are users provided upon their own environment? How do they tend to handle competing requirements of, say, day lighting and shading? Will users' behaviour change under climate change's influence? If so, in which way and to which extend? This study tried to find some preliminary answers to concerns of users' behaviour.

Goals

This study aimed to investigate impacts of climate change on energy consumption and thermal comfort in office rooms. Conventionally, these two factors are directly linked:

Interdependencies between elevated indoor temperatures and reductions in office workers' performance have been accounted for in several investigations[1].

Thermal comfort - herein understood as the compliance with normative indoor temperature limits - is safeguarded by means of mechanical cooling. A general rise in outdoor temperature due to global warming thus results in increased energy demand for cooling which induces an increase in CO_2 – emissions for the allocation of energy. By this vicious cycle, climate change threatens to be further aggravated.

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

[1] 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.

8. Methodology

In this study, thermal building simulation of up to nine representative Viennese sample buildings is employed to assess impacts of climate change on energy demand and thermal comfort.

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

8.1. 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[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, derived from the REMO-UBA[3] regional climate model.

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

Table 1: Climate data set description

Climate data set denomination		description
Temporal resolution	61	Semi synthetic data set from weather observations for the period of 1961 to 1990
	80	Semi synthetic data set from weather observations for the period of 1980 to 2009
	2025	Semi synthetic Scenario for the period of 2025
	2050	Semi synthetic Scenario for the period of 2050
	2003	weather observations from 2003 (extreme summer)
Spatial resolution	howa	Abbr. "Hohe Warte", main weather station
	inne	Abbr. "Innere Stadt", CBD
	dona	Abbr. "Donaustadt", urban location

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

[3] Jacob, D., Göttel, H., Kotlarski, S., Lorenz, P., Sieck, K., 2008: Klimaauswirkungen und Anpassung in Deutschland – Phase 1: Erstellung regionaler Klimaszenarien für Deutschland. ISSN 1862-4359

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

Weather observations of the year 2003 which displayed an extremely hot summer are included to allow reference to such extremes.

8.2. Sample buildings construction

Nine Viennese office buildings, fairly representative for the city’s three main construction periods[4], were selected 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 SPZ RHS SCP	Built from before World War 1
BGN FAS LES	Built after World War 2
Strabag	Built 2003, entirely glazed façade
SOL 4	Built 2005, passive house standard

Legend:

ONB	Headquarter of the Austrian National Bank, 1st district
SPZ	Communal building, Am Spitz 1, 21st district
RHS	Communal building, Rathausstraße 14-16, 1st district
SCP	Communal building, Schlesinger Platz 2-6, 8th district
BGN	Office Unit of the Austrian National Bank, 1st district
FAS	Communal building, Favoritenstraße 18, 10th district
LES	Communal building, Lerchenfelder Straße 4, 8th district
Strabag	Headquarter of an Austrian Construction Group, 22nd district
SOL 4	Individually inhabited Office Unit, Passive house standard, Mödling

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

- In all these buildings several (two to eight) single office rooms were investigated.
- These rooms cover those two orientations most vulnerable to overheating: South and West; 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.

8.3. 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 cause buildings to react differently to climate change.

Therefore, two different modes of simulation were distinguished:

- Simulation mode “Standard”: in this simulation mode care was taken to maintain comfort conditions acc. Austrian standards[5] 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 regardless of the actual situation in each building. 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.[6]
- Simulation mode “real”: this simulation mode depicts the present day situation without respectively with little cooling in two of the sample buildings (ONB, BGN). Lighting

[5] ÖNORM EN 7730 requires a resultant temperature of 27°C not to be exceeded for more than 5% of working hours per year in the building types in question.
[6] Additionally, in some cases it turned out to be necessary to closely investigate the buildings’ thermal behaviour and its mutual interdependencies with shading, ventilation and cooling regimes by means of the simulation of one single recurring Design Day which was modelled with allusion to the applied climate data sets. Herein, the determinations of the Standard simulation mode were kept.

and ventilation regimes in each building were modelled according to the actual situation in each building. With energy demand for cooling equally ranging at 0, resulting thermal conditions in the buildings are investigated.

8.4. Employed tools of investigation

Dynamic thermal simulation on hourly basis was applied for the close depiction of thermal conditions in single office rooms. This allows for the assessment of impacts of prolonged summer heat waves as well as of increased peak temperatures.

The precise depiction of the buildings' respective construction and consequent thermal properties is an indispensable prerequisite for such investigations.

8.5. Variants and Assessment parameters

Only some of the nine sample buildings were analysed in detail; For in – depth investigations, emphasis was laid on two to four "leading buildings" which represent their respective building epoch in terms of construction[7]. For either all buildings or these leading buildings energy demands under present and future conditions were assessed for cooling, heating and overall final and primary energy. CO_2 emissions were deduced from these demands. Likewise, demands were simulated for varying locations within the urban fabric to assess urban heat island's impact.

Impacts of improvement in the buildings' outer shell (u-, g-, F_c- values) on the resulting energy demand were calculated. Except for the comfort model discussion, all investigations were done under the assumption of equal indoor conditioning in all sample buildings.

Modular configuration of investigation

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

[7] Those sample buildings for which most detailed information was available regarding construction were selected as „leading buildings".

9. Conclusions and Further Research

As a conclusion, it has to be stressed that, due to the standardized nature of the sample buildings' conditioning (under simulation mode "Standard"), results cannot be directly applied to an existent building. Instead, these results' main indications are to be analysed and understood.

9.1. Impacts of climate change

Impact of different climate data sets:

Future climate data sets yield increasing cooling energy demands, while heating demands shrink. Trends for overall final and primary energy demand evolve differently, depending on buildings' properties: recently constructed buildings tend to yield higher net cooling than heating demands already today; their overall final energy demand will stagnate or slightly increase over the years. Historic buildings constructed before WW1 and after WW2 even by the year 2050 are clearly dominated by high net heating demands. Hence, overall final energy demand of these buildings decreases over the decades to come due the decrease in heating requirements. Notwithstanding, these overall demands remain high in absolute terms.

The picture is slightly less uniform for the development of maximum cooling loads; Even though they, too, will increase, this increase is less pronounced and its trend over the course of time is less consistent.

It has to be kept in mind, that both simulated demands and maximum loads are based on averaged climate data sets which do not necessarily include possible extremes.

Impact of different comfort models:

The definition of what is regarded as "uncomfortable" according to the two existing normative comfort models ("Fanger" and "Addaptive") remarkable impacts upon cooling requirements and consequent energy demand. Care has to be taken to distinguish between conditioned buildings (which call for the application of the "Fanger" model) and free running buildings (to be assessed according to the "Adaptive" model). Users' ability to adjust to outdoor climatic conditions should be harnessed in free running buildings by giving them control over their direct indoor environment. When doing so, potential for reductions in cooling demand can be harnessed.

Impact of urban heat island:

Locations in CBDs generally display higher cooling and lower heating demands than sites to the city outsides already today. Annual differences range in the order of magnitude of up to 5 kWh//m^2 for cooling and about 10kWh/m^2 for heating in Vienna. In consequences, both net and final energy demand is lower in inner city locations than on the outskirts. This relation appears consistent over the course of time, leaving inner city locations as those with least overall final energy demand.

9.2. Possible measures for reduction of energy demand

Impact of optimization of buildings' envelops:

Even in view of climate change, external thermal insulation of opaque buildings' surfaces yields bests results in terms of overall final energy requirements due to significant reductions in heating energy demand. This is especially true for old buildings which are dominated by their heating demand. Changes in quality of windows rather aim at decreasing cooling demand and therefore run second in the consideration of overall final energy demand.

Further Research

This present study assessed the impacts of climate change to be expected for office buildings in urban areas such as Vienna. Several fields for further investigations evolve logically from the conclusions drawn here:

- Impacts upon energy supply and market (including estimations for conversion factors to be applied under changing conditions) as well as for mitigation and adaptation policy.
- Additional economic assessments in the area of comfort models and the influence of users' satisfaction with indoor comfort on buildings' return on investment.
- Smart technology for conditioning for indoor comfort with least energy consumption, robust and easy access to climate control for single building users
- Appliance of hybrid and passive cooling systems under conditions of climate change.
- Implications of climate change for several zero emission- and plus energy – concepts which are currently intensively discussed in endeavours to further reduce building stocks' green house gas emissions and energy demands.
- Influence of climate change on live in residential buildings, especially in densely populated urban areas, including investigations on impacts of increased night time temperatures for human sleep and regeneration.
- Options for the appliance of traditional passive cooling strategies in hot climate regions in modern context.

10. User behaviour

Authors: Christoph Neururer, Roman Smutny of BOKU Vienna; Alexander Keul of University Salzburg

10.1. Recommendations for thermal simulation and analysis of user comfort:

- Natural lighting was an issue in all analysed buildings. Selective artificial lighting was often coordinated with natural lighting to achieve the desired amount of Lux at minimal electrical energy consumption. Therefore it could be interesting to investigate different lighting concepts for thermal simulation.
- The desire to open windows in summer is obviously stronger than the reasonable consideration that it would remain cooler with closed windows [Plesser et al., 2008]. Therefore it is suggested to take into account the share of occupants, who use the shading devices and windows properly.
- The findings of the best practise database and future usage profiles in the context of telework were not inconsistent with the simulation scenarios in Table 4 and Table 5 in Berger & Pundy [Berger & Pundy, 2009 p.17 and p.27].
- The percentage of permanently absent occupants in the simulation scenarios “Tele” and “Tele Siesta” of Berger & Pundy is significantly higher than the values from literature (see chapter “future usage profiles in the context of telework“).
- A suggestion regarding ventilation schedules for Table 5 in Berger & Pundy is to add a scenario based on the difference between external and internal temperature. Most ventilation concepts in the best practise buildings weren’t based on time schedules but rather on temperature differences.
- The simulation of thermal comfort should take a scenario with ceiling fans into account.
- Surveys to evaluate productivity have to take into account what type of social milieu, interaction and distraction is involved in „normal office work” and how much mental workload (e.g. concentration) is actually needed to fulfil the specific work task.

- For non-air-conditioned office buildings in summer the PMV- and PPD-figures of the classical Fanger-model (ISO 7730) have to be treated with caution. The demonstrations buildings showed good comfort values despite higher indoor air temperatures. The adaptive comfort model of Nicol & Humphreys (EN 15251) or an adaption of the Fanger-model or a combination of both seem to be appropriate. The positive impact of user intervention the indoor environment as well as of air velocity by ceiling fans should be taken into account.

10.2. Prospects and outlook

Authors: Christoph Neururer, Roman Smutny of BOKU Vienna; Alexander Keul of University Salzburg

Climate change affects the urban microclimate (heat island effect) as well as the duration of heat-waves. Existing buildings and new buildings with no capacity to buffer the increasing cooling load will have problems with thermal comfort. This reduces the productivity of office workers (and pupils) and might reduce as well rental incomes. Many existing buildings already have these problems and the number of buildings as well as the negative impacts will increase due to climate change. Especially concerned are office buildings, administration buildings, schools, universities etc. in urban areas.

Low tech passive cooling solutions seem to be an appropriate thermal retrofit measure. The effectiveness for comfort and energy efficiency should be systematically analysed for different combinations of passive cooling solutions.

Concepts for sustainable office buildings in changing climate can be derived by observations and reports from buildings in warmer to tropical countries. A systematic analysis should be performed instead of a conservative extension of Euro- or Americocentric building practices and concepts. Climatic adaptation is a technical, but also a cultural achievement.

I. Anhang – Vorarbeiten zum Thema

reclip:more:

In dieser aktuellen Studie über die künftigen Klimawandelfolgen in Österreich wurde auf Basis des globalen Emissions-Szenarios IS 92a des IPCC ein Downscaling für Österreich durchgeführt. Damit stehen erstmals regionalisierte Klimaszenarien zur Verfügung, die allerdings aufgrund der enthaltenen Unsicherheiten im gegenständlichen Projekt nur indirekt zur Bewertung der Ergebnisse herangezogen werden.

In Europa zeigen Studien einen rasanten Anstieg der mit mechanischer Kühlung versehenen Gebäudeflächen seit 1990 (Adnot et al., 2003).

An dokumentierten Fallbeispielen für die Schweiz wurde gezeigt, wie sich unterschiedliches Gebäudedesign auf die klimawandelbedingt steigenden Innenraumtemperaturen auswirken wird (Holmes und Hacker, 2007).

SEP

Nach den Erhebungen aus dem Städtischen Energieeffizienzprogramm der Stadt Wien „SEP“ (Haas et al, 2006) haben sich die Verkaufszahlen von Klimaanlagen vom Sommer 2002 auf den ungewöhnlich heißen Sommer 2003 in Wien mehr als verdoppelt. 2003 waren geschätzte 37% des gewerblich-technischen Bereichs mit Klimaanlagen und 32% mit Ventilatoren ausgerüstet. Der Anteil an Klimaanlagen im gewerblichen Bereich hat sich demnach von einem niedrigen Niveau aus zwischen 1987 und 2003 auf das 45fache erhöht. Deutlich erkennbar wird damit, dass das Thema „Klimatisierung“, das sich bis vor wenigen Jahren auf einige wenige Bürohäuser beschränkte, Potential besitzt zum Massenphänomen zu werden.

Für Österreich liegen erste Gebäudesimulationsversuche unter Einbeziehung des Klimawandels vor, die vom Antragsteller des gegenständlichen Projektes, dem Department für Bauen und Umwelt der Donau-Universität Krems durchgeführt wurden (Holzer und Hammer, 2007).

Austro Clim – Identifikation von Handlungsempfehlungen zur Anpassung an den Klimawandel in Österreich

Diese im November 2008 erschienen und im Auftrag des Lebensministeriums u.a. vom Institut für Meteorologie der Universität für Bodenkultur in Wien (Projektpartner des gegenständlichen Projektes „Büros_im_Klimawandel“) erstellte Zusammenschau von Expertenmeinungen behandelt neben Auswirkungen des Klimawandels auf Land- und

Forstwirtschaft, Tourismus, Wasserwirtschaft und Elektrizitätswirtschaft auch jene für das Bauwesen. Die hierbei geäußerten Erwartungen hinsichtlich Überhitzungstendenzen in Bürogebäuden insbesondere in urbanen Regionen decken sich weitestgehend mit den Ausgangshypothesen des gegenständlichen Projektes.

HEAT.AT bzw. „Auswirkungen des Klimawandels in Niederösterreich" (NÖ Klimastudie 2007)

Forscher des Grazer Wegener Centers befassen sich mit den Auswirkungen des Klimawandels auf den Heiz- und Kühlenergiebedarf in Österreich. Mithilfe von Referenzgebäuden wird der Zusammenhang zwischen Außentemperatur und Heiz- und Kühlenergiebedarf für unterschiedliche Gebäudetypen analysiert. Der gebäudespezifische Energieverbrauch wird mit einer im Rahmen des Projekts StartClim2006.F generierten regionalisierten Datenbasis zum derzeitigem Gebäudebestand sowie zu Heiz- und Kühlgradtagen zusammengeführt. Weiters werden in Szenarien die zukünftige Entwicklung des Klimas, des österreichischen Gebäudebestandes unter Berücksichtigung von Bevölkerungstrends, der gesetzliche Rahmenbedingungen, sowie der Gebäudetechnik beschrieben und der Einfluss des Klimawandels auf die Nachfrage nach Heizenergieträgern und dem derzeit vorwiegend eingesetzten Kühlenergieträger Elektrizität untersucht. Dieser makroökonomische Untersuchungsansatz unterscheidet sich deutlich von den Vorhaben in „Büros_im_Klimawandel", die auf die Sicht des Gebäudebenutzers fokussiert. Die in HEAT.AT ermittelten Trends der Entwicklung der Kühlgradtage bilden hierfür jedoch ein Referenzmodell.

International wurden in Sachen Klimawandelanpassung bereits weiterführende Schritte gesetzt: So hat das britische UK Climate Impacts Programme umfangreiche Studien (nicht nur über die technischen, sondern auch die sozialen Folgen des Klimawandels für Großbritannien) zu einem Report zusammengeführt, der auch bereits Empfehlungen für Anpassungsmaßnahmen enthält.

(Bengtsson et al, 2007) haben eine umfangreiche Studie über die Klimawandelfolgen und Anpassungsstrategien für den Gebäudepark Neuseelands publiziert.

„Folgen des Klimawandels: Gebäude und Baupraxis in Deutschland"

Diese vom Bundesministerium für Verkehr, Bau und Stadtentwicklung beauftragte und vom Institut Wohnen und Umwelt (Darmstadt) erarbeitete Studie listet im gesamtwirtschaftlichen Überblick die für Deutschland zu erwartenden Auswirkungen des Klimawandels hinsichtlich Hitzewellen, Starkregenereignissen, Wind und Hagel. Auf tatsächliche Entwicklungen in konkreten Gebäudetypen wird dabei nicht eingegangen.

„Raumentwicklungsstrategien zum Klimawandel“

Auch diese, ebenfalls vom deutschen Bundesministerium für Verkehr, Bau und Stadtentwicklung beauftragte und von der Technischen Universität Dortmund erstellte Studie befasst sich mit allgemeinen Betroffenheitskategorien deutscher Regionen und geht daher auf bauliche Aspekte nur am Rande ein.

„Bauen, wenn das Klima wärmer wird“

Zu sehr konkreten Ergebnissen im Gebäudebereich der Schweiz kommt dagegen eine vom Schweizer Bundesamt für Energie, Forschungs- und Entwicklungsprogramm „Rationelle Energienutzung in Gebäuden“ beauftragte, 2008 veröffentlichte Untersuchung. Es wurden hierbei Grundlagen für spätere normative Festlegungen erstellt und für Umbauten wurden bauliche und haustechnische Maßnahmen für Bauherrnschaften und Architekten gelistet. Ähnlich wie in „Büros_im_Klimawandel“ geplant, wurden hier bereits unterschiedliche Gebäudekategorien auf ihre Vulnerabilität hin untersucht. Darauf aufbauend wurden gesamtwirtschaftliche, aber auch konstruktive Empfehlungen für den Gebäudebestand der Schweiz formuliert. Letztere bilden mit der entwickelten Parametermatrix eine hervorragende Ausgangslage für die Entwicklung von spezifisch österreichische Anpassungsstrategien im Rahmen von „Büros_im_Klimawandel“.

Building Knowledge for a Changing Climate (BKCC)

Im UK Climate Impacts Programm wurden 9 Projekte initiiert, die die zu erwartenden Auswirkungen des Klimawandels u.a im Gebäudebereich untersuchten und für relevante Stakeholder notwendige Anpassungsmaßnahmen entwickelten. Durch die exemplarische Untersuchung zweier städtischer Agglomerationen wurden Erkenntnisse gewonnen hinsichtlich der Gefährdung durch zu erwartende, verstärkte Starkregen und – Windereignisse sowie die Auswirkungen von Hitzewellen für den städtischen Außenraum. Der Vergleich mit kontinental europäischen Klimaszenarios zeigt, dass in Großbritannien die Zunahme punktueller Niederschlagsmengen durch den Klimawandel deutlicher im Vordergrund steht als in anderen EU-Ländern, weshalb britische Erkenntnisse zu Anpassungsstrategien in Kontinentaleuropa nur bedingt anwendbar sind.

Keep Cool

Das im Rahmen der EU - Programmlinie „Intelligent Energy Europe“ geförderte Projekt Keep Cool erarbeitete 2005 eine umfangreiche Übersicht und Informationssammlung zu energieeffizienten Methoden der sommerlichen Gebäudekühlung. Im Projekt „Büros_im_Klimawandel“ kann darauf jedoch kaum zurückgegriffen werden, da hier vor allem die Erhebung des sich durch den Klimawandel ergebenden Problemumfangs im

Mittelpunkt steht. Es wird vom Projektkonsortium jedoch angestrebt aufbauend auf die hier gewonnenen Erkenntnisse in der Folge auch mögliche Optimierungsstrategien für die Haustechnik mit den von Keep Cool aufgezeigten Optionen zu untersuchen.

„Bürogebäude mit Zukunft“

In Deutschland wurden für das umfangreiche Buch „Bürogebäude mit Zukunft“ 23 energetisch optimierte Gebäude des Nichtwohnbaus v.a. durch das Frauenhofer Institut für Solare Energiesysteme (ISE) untersucht und in mehrjährigen Messprogrammen evaluiert. Als richtungweisend erwies sich bei allen diesen Gebäuden die Entscheidung, allein durch bauphysikalisch abgestimmte entwerferische und konstruktive Mittel oder durch die Nutzung von Umweltenergie ein angenehmes sommerliches Raumklima zu gewährleisten. Weitergehende Abschätzungen über die genauen Auswirkungen des Klimawandels hierauf wurden jedoch nicht angestellt. „Büros_im_Klimawandel“ kann v.a. auf die umfangreichen, hier ausführlich dokumentierten Erfahrungen mit unterschiedlichen Haustechniksystemen und –komponenten zurückgreifen sowie auf entwickelte Routinen zur Erhebung von Nutzerzufriedenheit.

Cool San

Das im Rahmen der Programmlinie „Haus der Zukunft“ geförderte Projekt COOLSAN (2005) stellt mit der durchgeführten, detaillierten Untersuchung von Sanierungsstrategien für mehrere konkrete Gebäude hinsichtlich ihrem sommerlichen Verhaltens eine wichtige Datengrundlage für das gegenständliche Projekt „Bauen_im_Klimawandel“ dar. Zu erwartende Veränderungen durch den Klimawandel und Einflüsse urbaner Wärmezellen wurden dort allerdings nicht berücksichtigt.

Aktuelle Masterthesen am Department für Bauen und Umwelt, Donau-Universität Krems

Zwei derzeit am Department für Bauen und Umwelt der Donau-Universität Krems in Arbeit befindliche Masterthesen widmen sich ebenfalls den Auswirkungen des Klimawandels auf den sommerlichen Komfort in Bürogebäuden. Neben einer Zusammenschau aktueller Entwicklungen nationaler und internationaler Regelwerke in diesem Themenbereich (z.B. adaptive Komfortmodelle) werden dabei auch erste Studien an konkreten Wiener Bürogebäuden durchgeführt, deren Ergebnisse direkt für das Projekt „Büros_im_Klimawandel“ verwendet werden.

Office 21

Vom Frauenhofer Institut für Arbeitswirtschaft und Organisation (IAO) wurde bereits 1996 die Innovationsoffensive OFFICE 21® gestartet, die von rund 20 großen Unternehmen getragen wird. Im 2003 erschienen Buch „Mehr Leistung in innovativen Arbeitswelten“ wurden dabei Forschungsergebnisse zu Einflussgrößen für die Produktivität und Performance im Büro vorgelegt. Obwohl das Thema der thermischen Behaglichkeit am Arbeitsplatz nicht isoliert untersucht wurde, kann hier auf wichtige Erkenntnisse zum Nutzerverhalten einerseits und auf zukünftige bauliche Entwicklungen in der Bürogestaltung andererseits zurückgegriffen werden.

Forschungsfelder Real Estate, Donau-Universität Krems

Am Fachbereich „Real Estate“ des Departments für Bauen und Umwelt der Donau-Universität Krems läuft aktuell ein umfangreiches Forschungsprogramm zu „Sustainable Investment in Real Estate“, das sich der Frage widmet, inwiefern Nachhaltigkeitsaspekte in Anlagenstrategien einzubeziehen sind und wie die Nachhaltigkeit von Bestandsportfolios effektiv verbessert werden kann. Da die Herangehensweise hier aus dem Blickwinkel des Immobilieninvestors erfolgt und baulich – technische Themen daher nicht enthalten sind, stellen die in „Büros_im_Klimawandel“ generierten Ergebnisse hier eine wichtige komplimentäre Forschungsgrundlage dar. Dies stellt die direkte Verwertung der gewonnenen Erkenntnisse in der betroffenen Immobilienwirtschaft sicher.

II. Appendix – Research Documentation

II. Appendix

RESEARCH DOCUMENTATION

english

Superscription	Offices and Climate Change
Title	Impacts of Climate Change on the Thermal Comfort of Office Buildings
Programme	Haus der Zukunft Plus
Applicant	Donau-Universität Krems, Department für Bauen und Umwelt DI Tania Berger
Project Partners	Universität für Bodenkultur, • Institut für Meteorologie (BOKU-Met), Arbeitsgruppe Ressourcenorientiertes Bauen Mag. Dr. Herbert Formayer • Institut für Konstruktiven Ingenieurbau, Department für Bautechnik und Naturgefahren (BOKU–IKI) DI Roman Smutny, DI Christian Neururer

Content

1 Climate data sets

1.1 Background

According to IPCC[1] long term climate change scenarios have to be based on the results of coupled global circulation models (GCMs). As the resolution of this type of model is too coarse to resolve regional to local effects, further downscaling of the climate change scenarios is necessary.

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

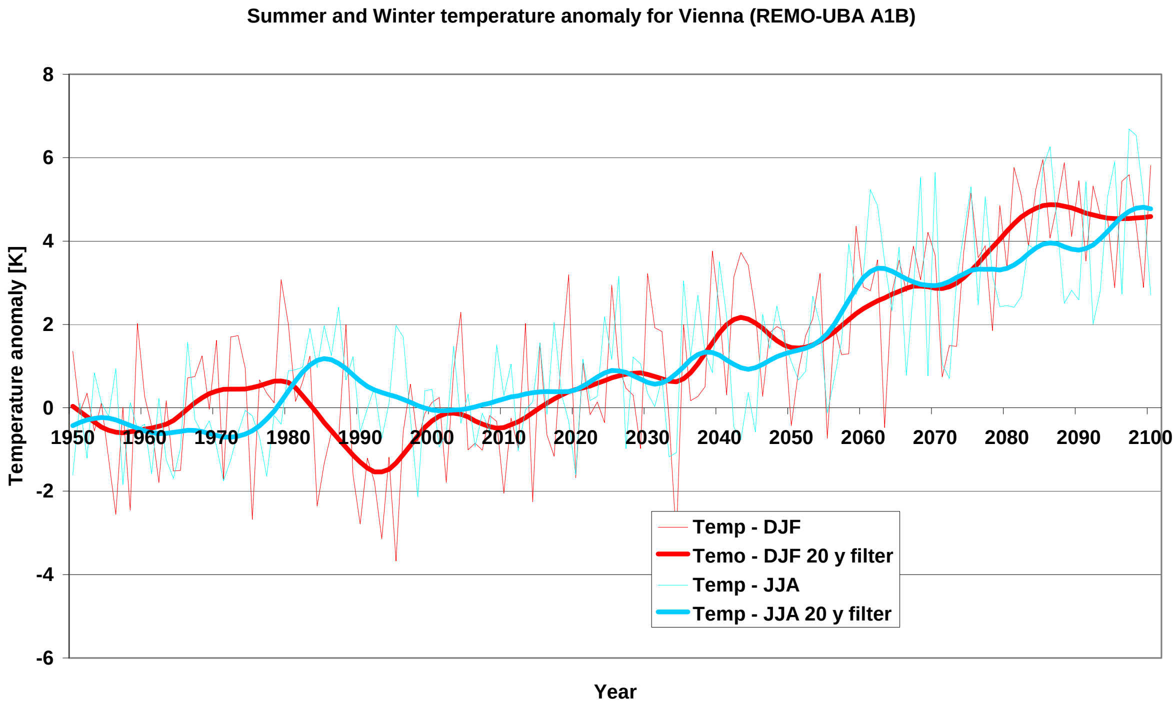
As Vienna is located at the easternmost border of the Alps, the spatial resolution of RCM might be crucial for the quality of regional climate change scenarios. Therefore we decided to use the results of the RCM REMO. REMO is the RCM of the Max Planck Institute in Hamburg and this model is also participating in the ENSEMBLES project. On behalf of the German environment agency (UBA), this model made climate change runs for the whole 21st century and the emission scenarios B1, A1B and A2 with 10 km resolution for whole Germany, but including also the largest parts of Swiss and whole Austria. This REMO-UBA [2] model results are the basis for our scenarios for Vienna. We also decided to use the results of the A1B scenario. Till the middle of the 21st century the differences between the emissions scenarios is not very high. Especially the climate change signal of A1B and A2 are quite similar. Only in B1 the climate change signal is a little bit smaller.

In graph 1 the transient development of the summer (blue) and winter (red) temperature anomaly relative to the period 1961-1990 of the used climate change scenario (REMO-UBA) for Vienna is shown. The thin line show the values of single years and the bold lines a 20 year Gauss filter is shown. Both seasons show a more or less linear increase of the temperature starting around the year 2010. The increase reaches in both seasons the order of 5 degrees till the end of the 21st century. It can also be seen, that this linear trend is modified by decadal fluctuation of the model with the magnitude of ± 0.5 degrees. This is important for the construction of climate change signals for specific time periods. When we look on the climate change signal for 2025 or 2050 we always take a 30 year time frame around this dates (2011-2040 for 2025 and 2036-2065 for 2050) to smooth out the decadal fluctuations.

---

[1] IPCC (2007): Climate Change 2007: Impacts, Adoptions and Vulnerability - Summary for Policymakers.

[2] Jacob, D., Göttel, H., Kotlarski, S., Lorenz, P., Sieck, K., 2008: Klimaauswirkungen und Anpassung in Deutschland – Phase 1: Erstellung regionaler Klimaszenarien für Deutschland. ISSN 1862-4359.

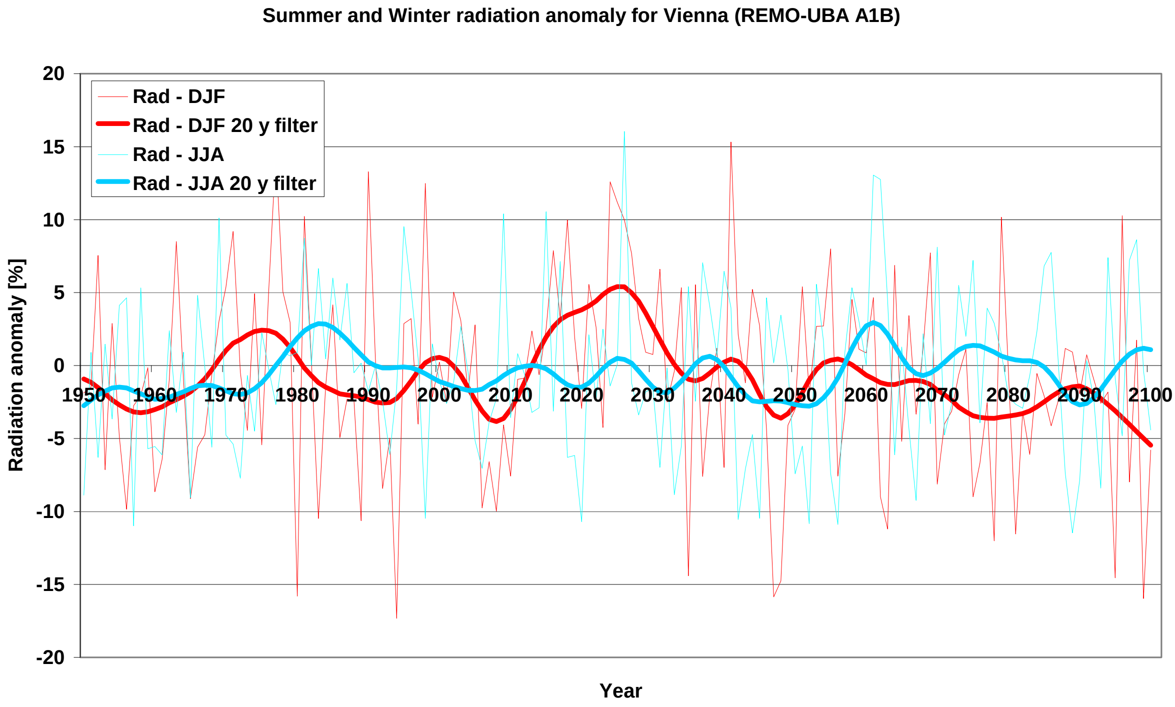


Graph 1: Temperature scenario (JJA = summer, DJF = winter) for Vienna derived from the regional climate model REMO-UBA forced with the emission scenario A1B.

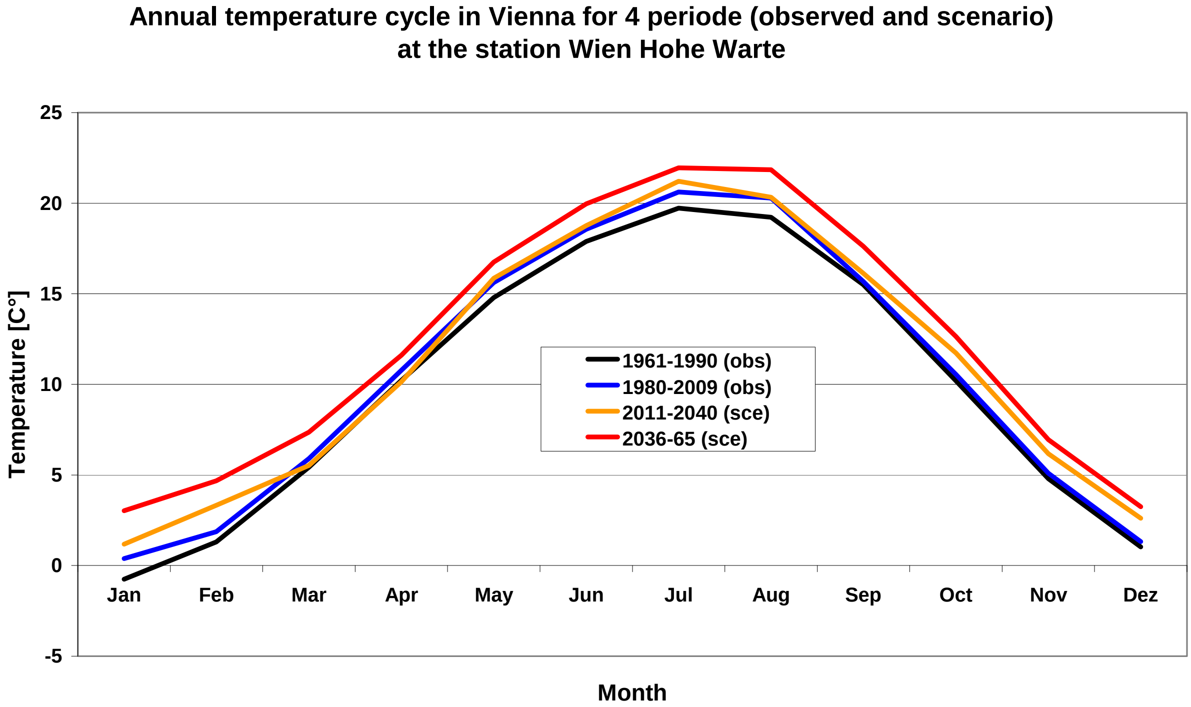
For this study additional to temperature we also need the parameter relative humidity, wind speed, global radiation and diffuse radiation. All these variables showed now significant trend in the REMO-UBA A1B scenario for the 21st century in Vienna. In graph 2 as an example the development of the global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

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

In graph 3 the average annual cycle of the monthly mean temperature for the two observational periods (1961-1990 and 1980-2008) and the scenario periods (2011-2040 and 2036-2065) is shown for the weather station Wien Hohe Warte. The high temperature increase within the last decades can be seen in the difference between the black line (1961-1990) and the blue line (1980-2009). Temperature increase was most pronounced in January and February and from May to August. No warming was observed in autumn within the last decades. The warming in the last decades was higher than in the used climate scenario, that especially in spring and summer no difference between the last observation period (1980-2008) and the first scenario period (2011-2040) for temperature occur. Between the first and the second scenario period (from 2025 to 2050) a further continuous warming appears, with maximum warming from January to April. The average warming from the first observational period (1961-1990) till the second scenario period (2036-2065) is 2.35 degree with increased warming in winter and spring and slightly lower warming in spring and autumn.



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



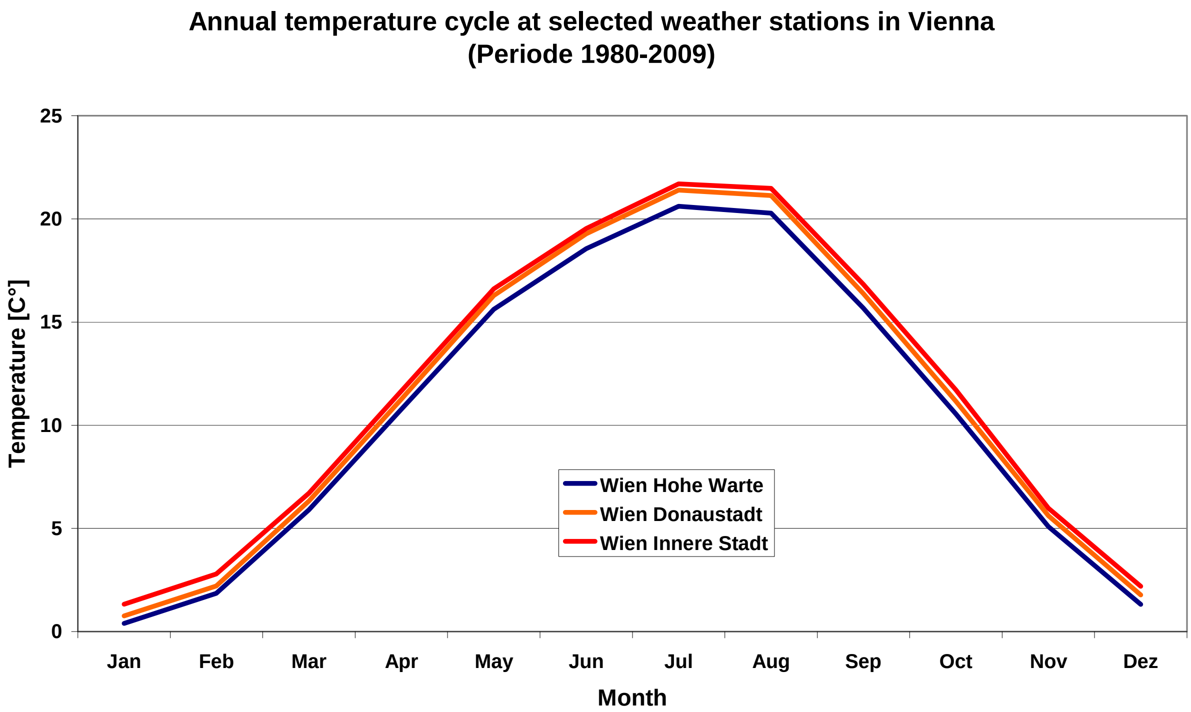
Graph 3: Annual cycle of the monthly mean temperature for four different periods (observations and scenarios) in Vienna at the weather station Wien Hohe Warte

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

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

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

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



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

1.2 Generation of climate data sets

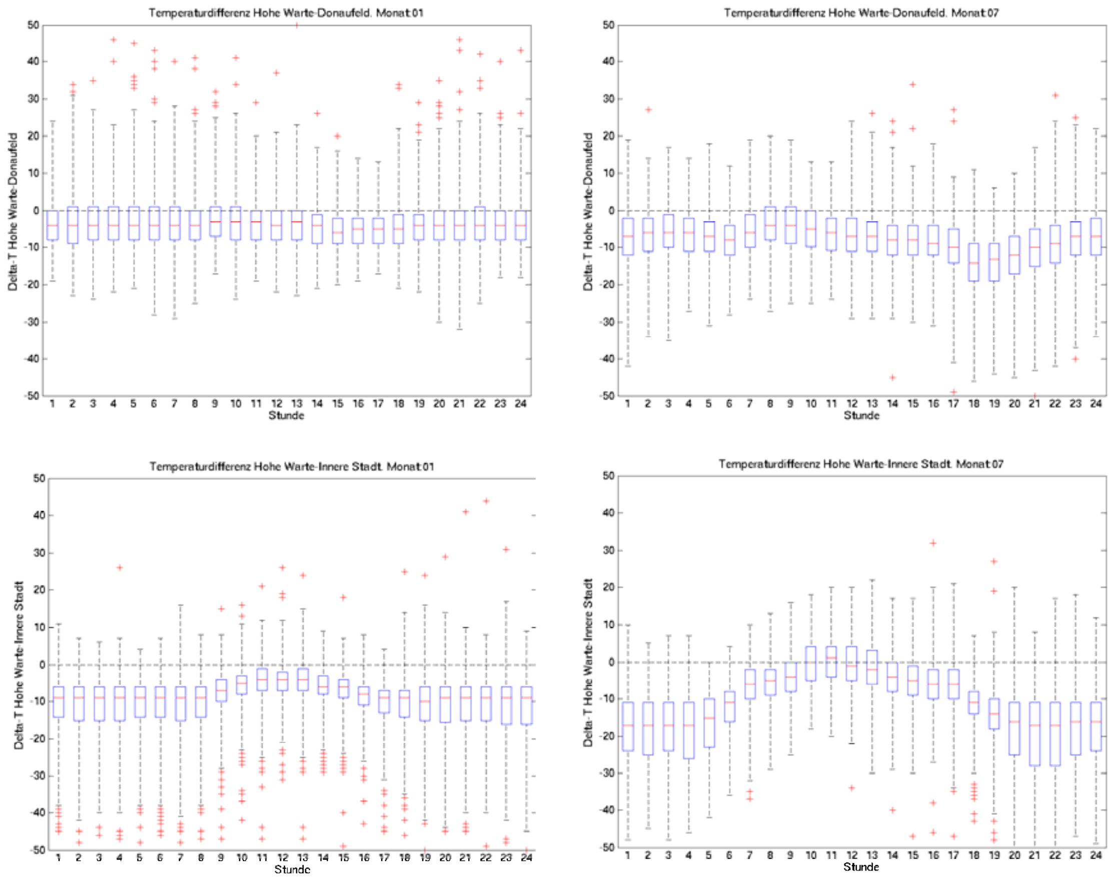
Bases for the construction of the synthetic climate data sets are the hourly observations of the three meteorological stations Hohe Warte, Donaufeld and Innere Stadt. The synthetic climate data sets should be able to represent the observed climate change in Vienna, as well as further scenarios. So we decided to use the WMO – standard period 1961-1990 and the last available observational thirty years 1980-2009 for the observations. For the scenarios we use two period not too far in the future, 2011-2040 for the near future and 2036-2065 for mid–century and the climate change signals for temperature are derived from the REMO-UBA model, based on the A1B emission scenario.

Following meteorological parameter are used for constructing synthetic climate data sets on hourly bases:

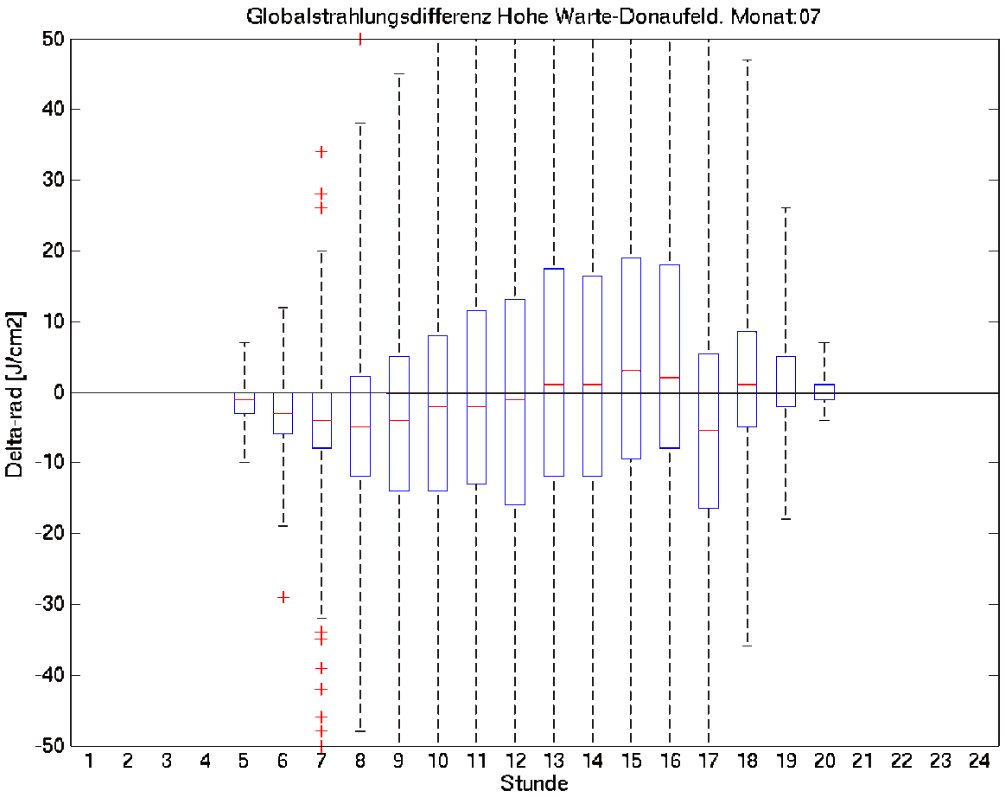
- Air temperature [°C]
- Relative humidity [%]
- Wind speed [m/s]
- Global radiation [W/m²]
- Diffuse radiation [W/m²]

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

For this, an analyses of the differences of the hourly values within months was applied. In graph 5 the distribution of the hourly differences between Hohe Warte and Donaufeld (upper panel) and Innere Stadt (lower panel) for the month January (left) and July (right) is shown. In January Donaufeld (upper left) is constant 1 degree warmer than Hohe Warte. Innere Stadt however shows a slight diurnal range. Arround noon (9 am to 3 pm) Innere Stadt is only half a degree warmer than Hohe Warte, the rest of the day also 1 degree. In July both stations show a diurnal range in temperature differences. In Innere Stadt the warming is most pronounced during night time with temperature 2 degree higher than Hohe Warte. During daytime the differences decreases and vanish totally during noon. This is in good agreement with the urban head island effect. In Donaufeld the situation is not so clear. The station is general half a degree warmer than Hohe Warte and the difference is most pronounced from 5 to 8 pm. This seems to be related different insolation around 5 pm (see graph 6) and in general different temperature conversion of the solar radiation in the surrounding of the weather station and this part of town.



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



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

1.3 Description of climate data sets

For the modelling of climatic conditions semi synthetic data sets[3] 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 58 years of hourly weather observations these data sets depict characteristic weather situations including the typical diurnal range of the location, the variability from day to day and moderate extreme winter and summer conditions. As the construction uses monthly blocks of observations as basis, the physical correlation between the different parameter is conserved. The construction method complies with the regulation ÖNORM EN ISO 15927-4. This method is also suitable for use with climate change scenarios, as long as the climate change signal is within the range of the observed range of variability on monthly base of the differend meteorological parameters. This is the case for this investigations.

[3] 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 (ZI. NC 23-1988/1989, Wien (1990)

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

- "howa 61": semi synthetic data set covering the observation period 1961 – 1990 for the location of Vienna's main weather station
- "howa 80": semi synthetic data set covering the observation period 1980 – 2009 for the location of Vienna's main weather station
- "howa 2025": semi synthetic data set depicting future climate conditions in 2025, for the location of Vienna's main weather station; based on localized climate scenarios
- "howa 2050": semi synthetic data set depicting future climate conditions in 2050, for the location of Vienna's main weather station; based on localized climate scenarios

- "Inne 61": semi synthetic data set covering the observation period 1961 – 1990 for Vienna's CBD
- "Inne 80": semi synthetic data set covering the observation period 1980 – 2009 for Vienna's CBD
- "Inne 2025": semi synthetic data set depicting future climate conditions in 2025, for Vienna's CBD, based on localized climate scenarios
- "inne 2050": semi synthetic data set depicting future climate conditions in 2050, for Vienna's CBD, based on localized climate scenarios

- "dona 61": semi synthetic data set covering the observation period 1961 – 1990 for an urban location within Vienna
- "dona 80": semi synthetic data set covering the observation period 1980 – 2009 for an urban location within Vienna
- "dona 2025": semi synthetic data set depicting future climate conditions in 2025, for an urban location within Vienna
- "dona 2050": semi synthetic data set depicting future climate conditions in 2050, for an urban location within Vienna; based on localized climate scenarios

1.4 Key figures for analysis of climate data sets

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

- Average external temperature (year, summer):

[C°]
Yearly or summer average 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 temperature which indicates whether a data set displays especially hot summer months (June – August).

- Average hourly irradiation (year, summer):

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

- Cooling degree days:

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

- Heating degree days:

[HDD]
Although winter conditions are not a focus in this study, all year round assessment parameters are nonetheless charted in order to check possible interdependencies. Therefore, the applied climate data sets are likewise analysed as to their respective heating degree days. Analogue to cooling degree days, these indicate 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.4 Therefore, the yearly swing of the rolling mean external temperature was depicted.

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

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

[4] two limitations of the adaptive comfort model acc. to EN 15251 have to be kept in mind:
1) the determination of comfort limits above 25°C relies on reduced statistic data
2) users' subjective comfort judgements were taken independently of their actual working performance under the documented conditions

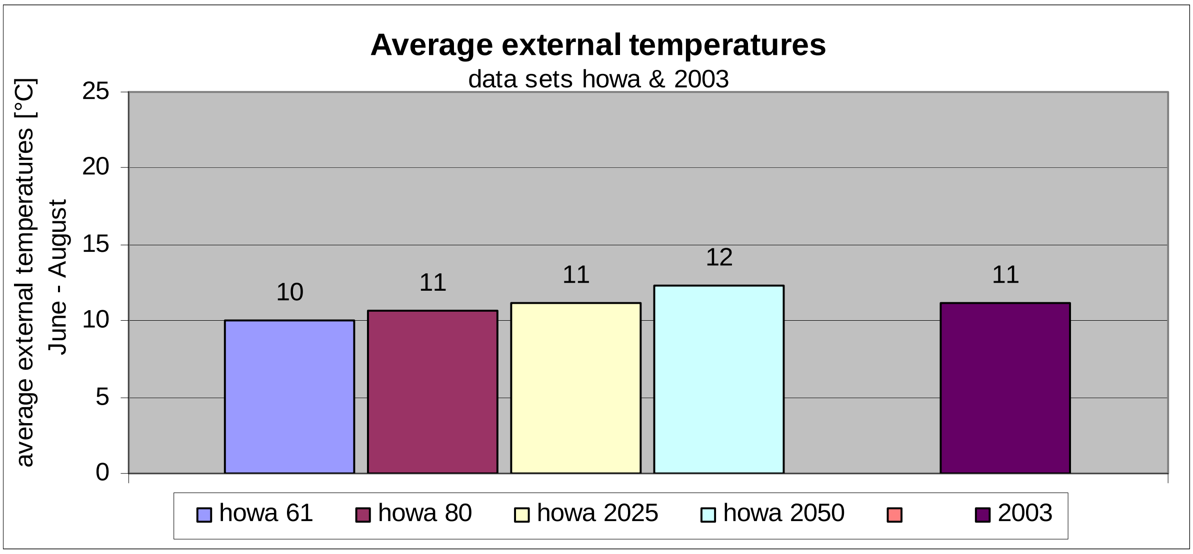
1.5 Results of Analysis of climate data sets

1.5.1 Average external air temperature

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

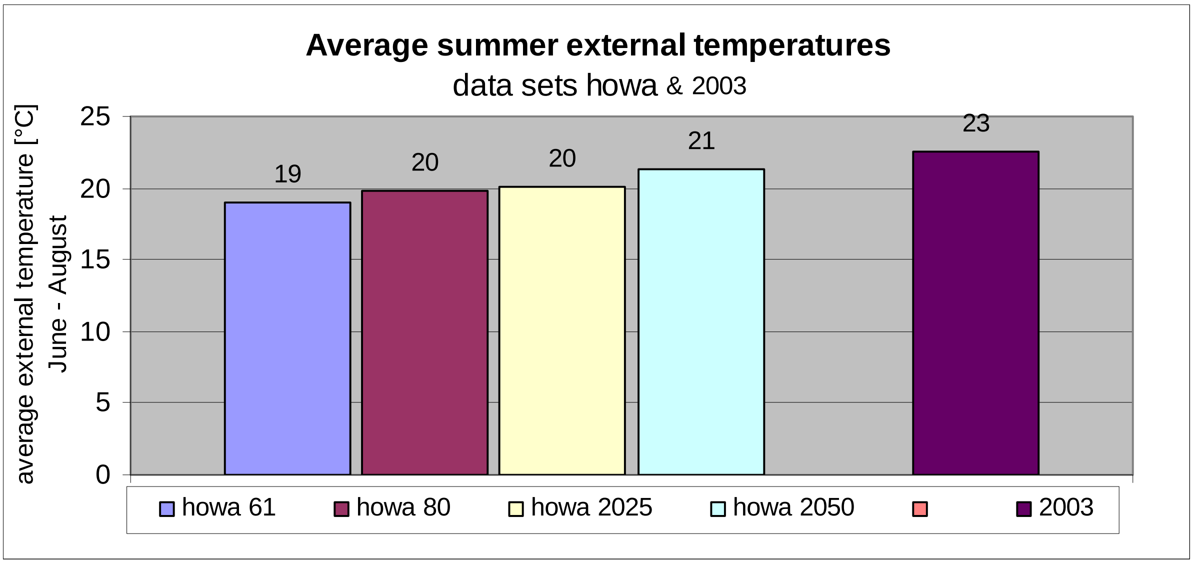
It has to be kept in mind that various climate data sets frequently in use today in thermal simulations for sizing of cooling and heating plants in newly to be build office blocks roughly date to the period of “howa 61”. Herein lays a considerable danger: while energy requirements under the use of such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

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



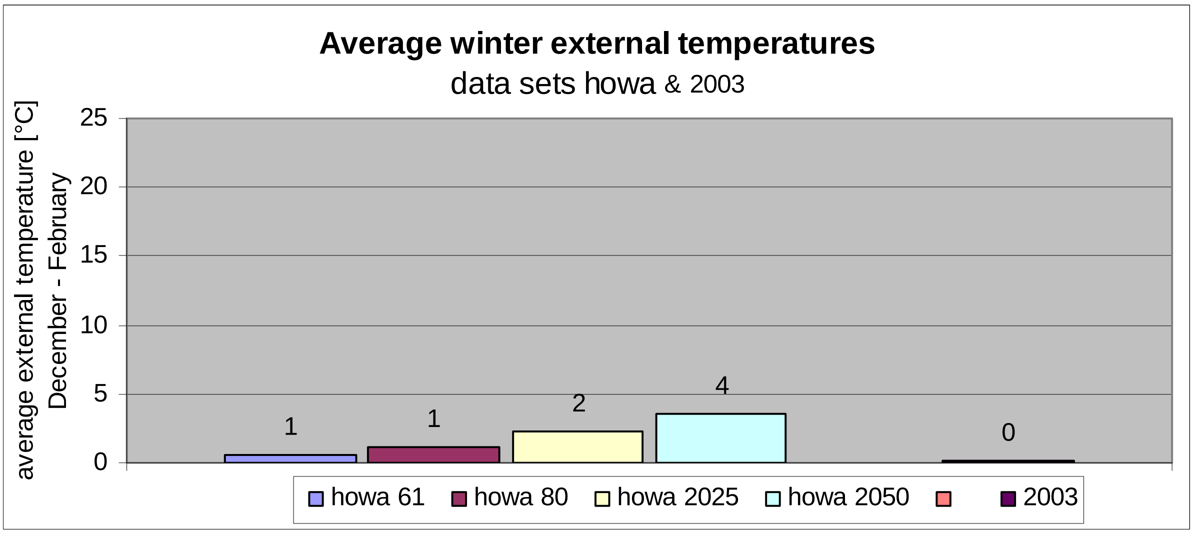
Graph 7: Average Annual external temperatures for different temporal resolution of howa

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



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

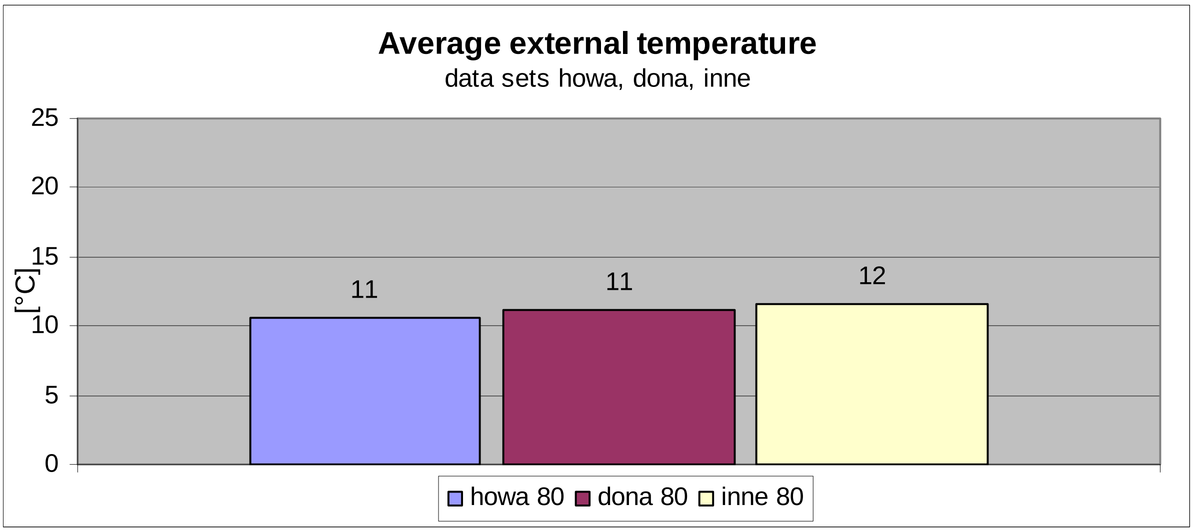
Winter average temperatures reveal that hot summers like those of 2003 are not necessarily linked to warm winters as well: this year's winter mean ranges below those of all long – lived averages of the "howa" data sets.



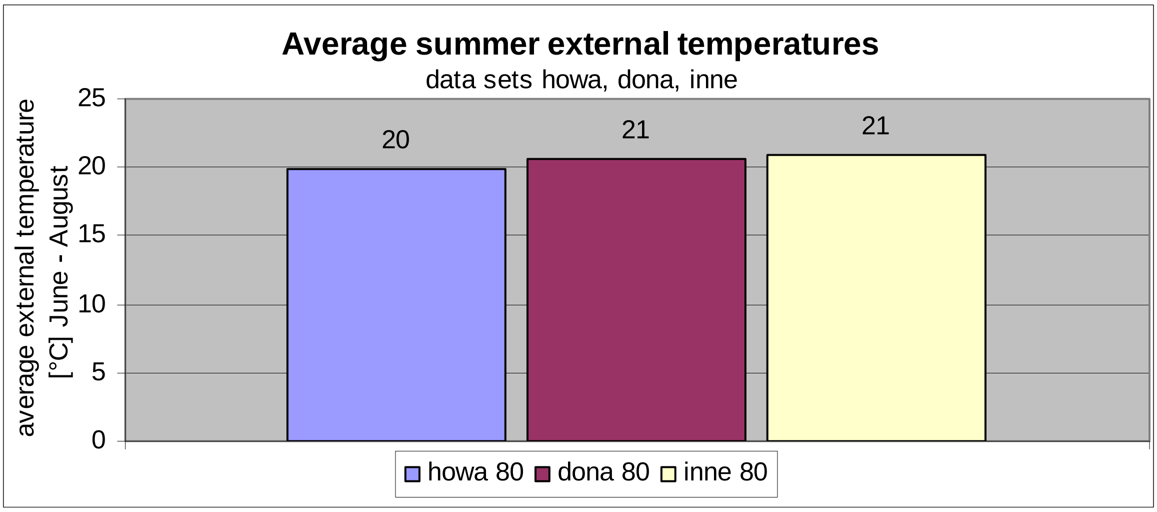
Graph 9: Average winter eternal temperatures for different temporal resolution of howa

Spatial resolution of climatic conditions within the city area of Vienna is exemplarily displayed here for the temporal setting of "80": while annual temperature average scores lowest for "howa" in the green city outskirts, the highest value is obtained for the location "inne", even though differences are minor. This goes in line with general literature indications[5] that Vienna is a well ventilated city which in consequence does not display harsh urban heat island intensity.

This proposition holds true even for summer month; calm nights which generally favour the built up of consistent temperature difference between core cities and cooler surroundings are seldom here.



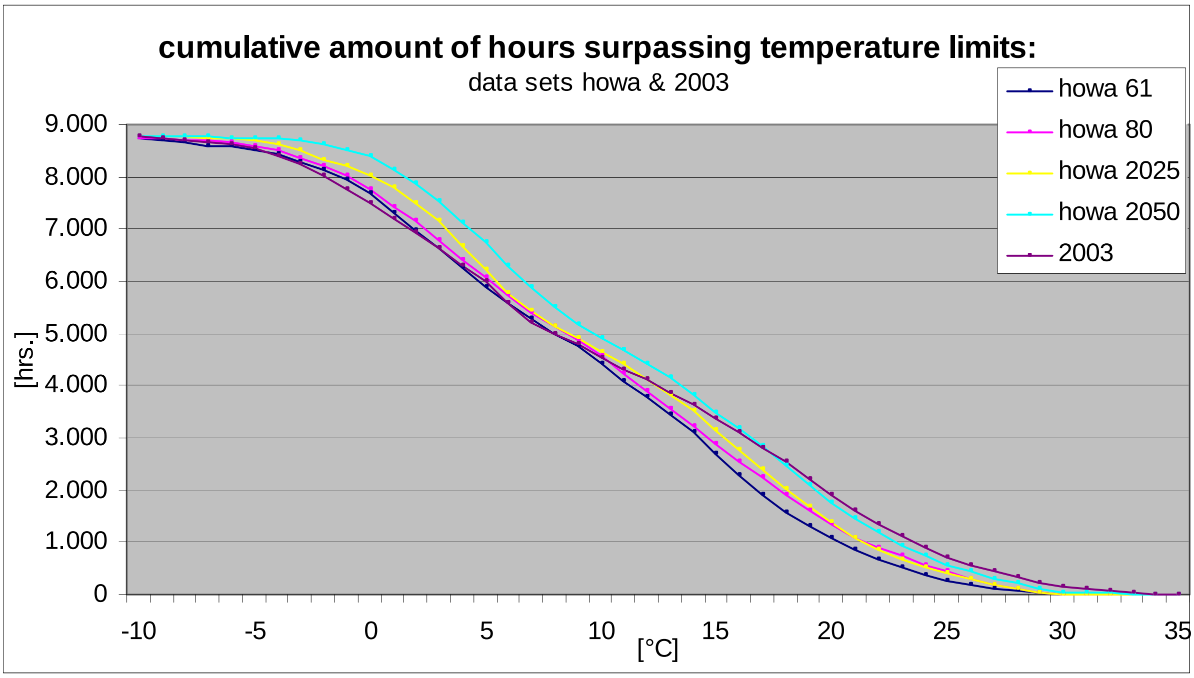
Graph 10: Average external temperatures for different spatial resolution



Graph 11: Average Summer external temperatures for different spatial resolution

[5] Mursch-Radlgruber, Erich; Trimmel, Heideline (2009)

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

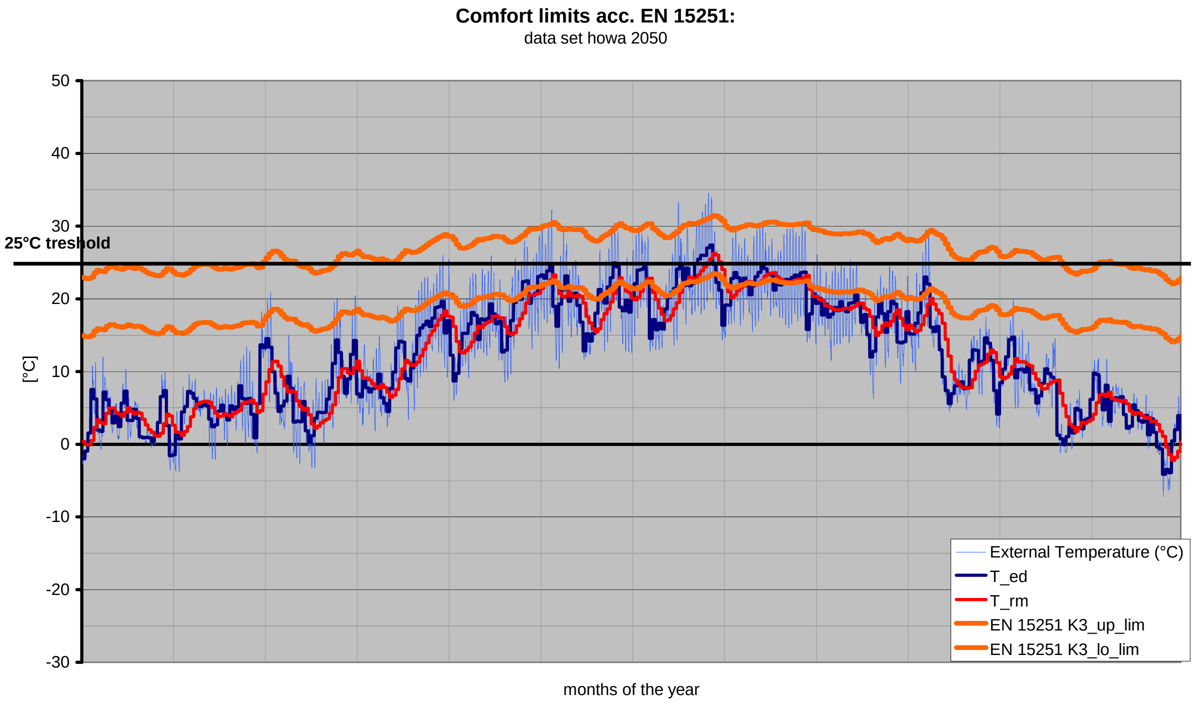


Graph 12: Amount of hours surpassing continuous temperature limits for different temporal resolution of howa

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

The comfort temperature belt established on base of rolling mean outdoor temperature[6] closely follows the swing of outdoor temperatures during summer months (winter comfort conditions are not investigated here). The highest acceptable temperatures touch values well beyond 30°C for data set “howa 2050”.

[6] For detailed description of the adaptive comfort model and the notion of rolling mean outdoor temperature refer to chapter 6.2 Module 2: Discussion of comfort models, page 85



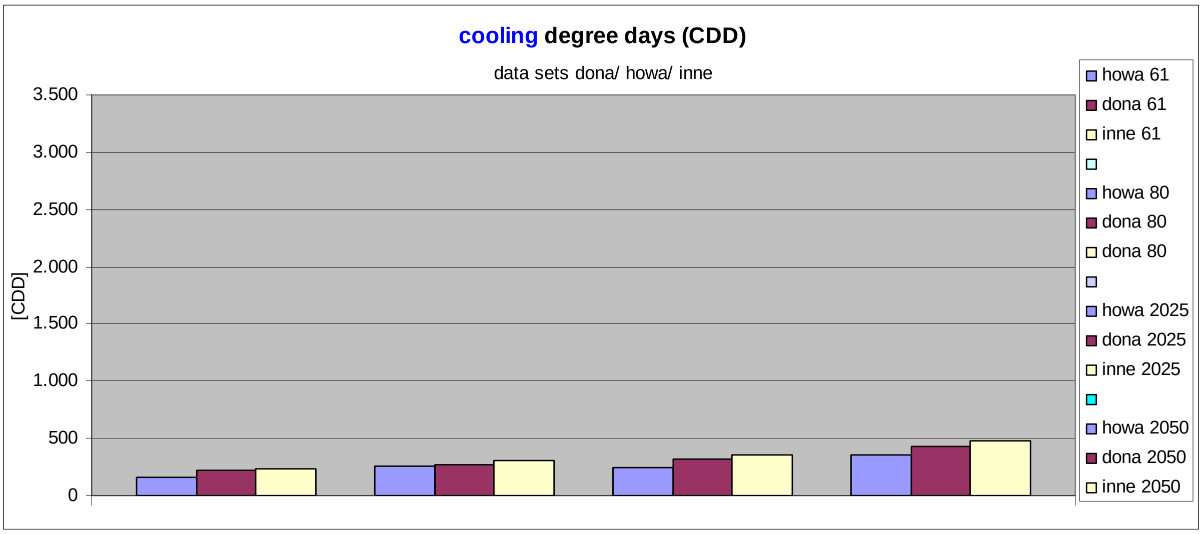
Graph 13: Annual swing of upper and lower comfort limit for climate data set "howa 2050" acc. EN 15251[7]

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

Cooling Degree Days

Nearly as striking as the differences between different temporal resolutions is the difference between the locations howa, dona and inne in terms of Cooling Degree Days (CDD): 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 than the main weather station "howa".

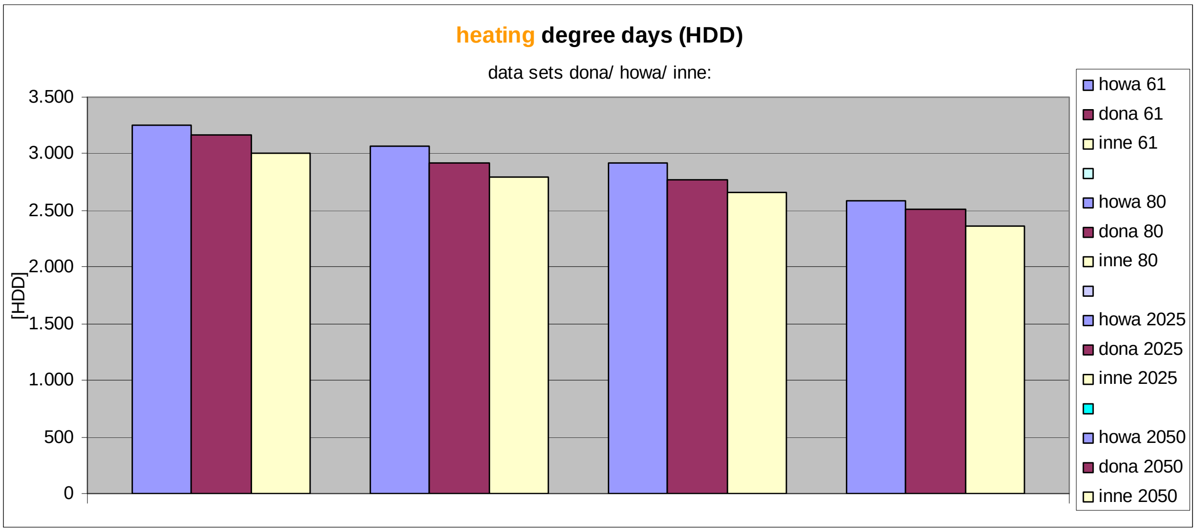
[7] adapted from: Holzer, P.: climate data wien.xls



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

<u>Heating Degree Days</u>

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



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

1.5.2 Design Day determination for cooling plant sizing[8]

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

The corresponding Austrian technical norm ÖNROM B 8110-3 (1999)[9] describes the compilation of Design Day climate data sets as follows: it takes local conditions into account and asks for a 24 hours' set of outdoor air temperatures which is not surpassed on more than 13 days in long-term mean.

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

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

1.5.3 Average hourly irradiation

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

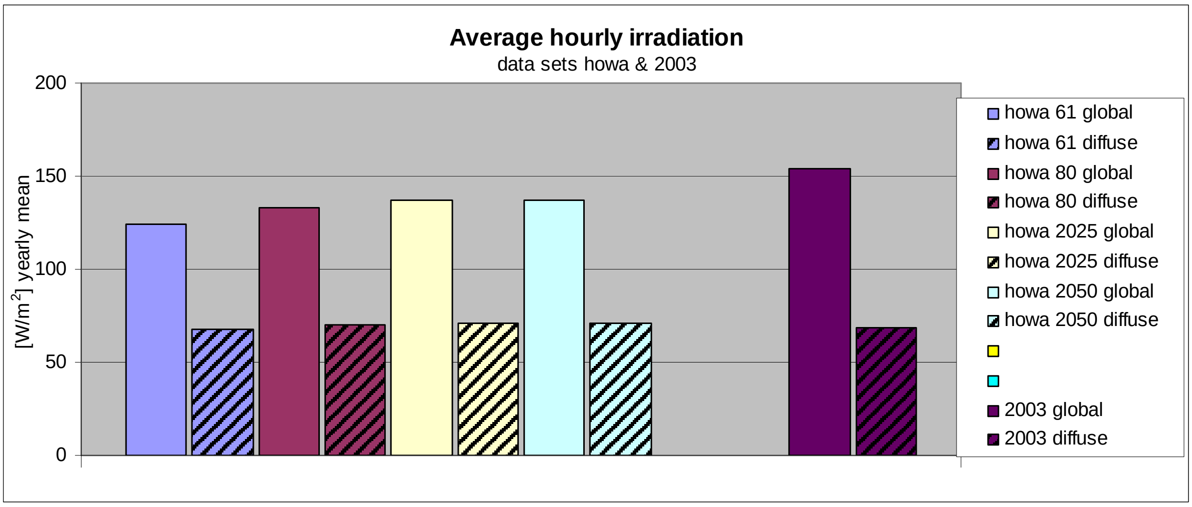
Average hourly irradiation rates of both global and diffuse fraction for the applied climate data sets demonstrate a consistent trend: global irradiation constantly increases between "howa 61" and "howa 2050" and reaches a pronounced peak in data of 2003. At the same time the diffuse fraction of this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

Global Dimming was widely observed in the 70ies and 80ies of the last century and found to be caused by massive air pollution. Aerosols of various consistencies and

[8] See also: 6.1.7 Cooling load under Design Day Conditions, page 81

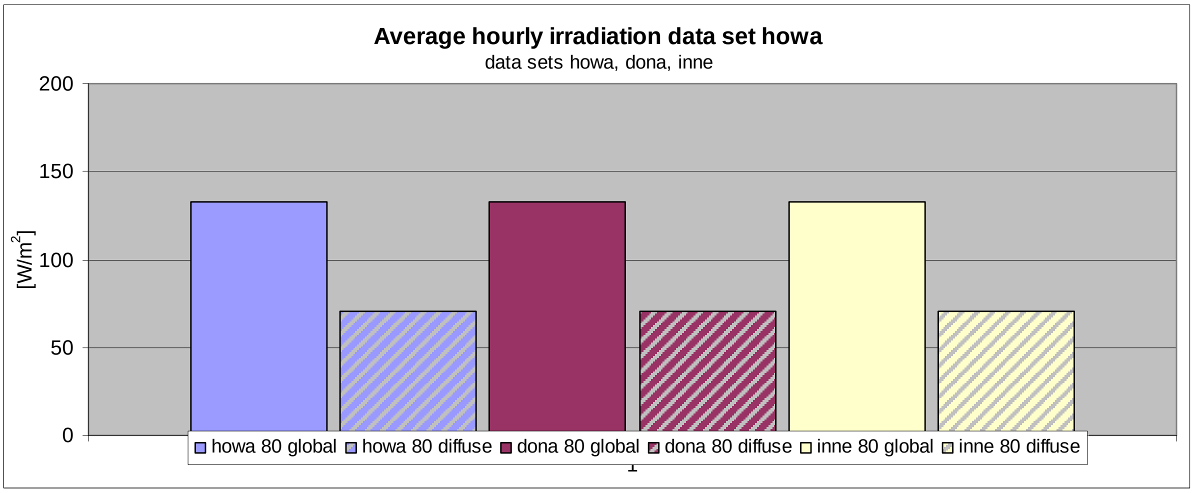
[9] ÖNORM B 8110-3 (1999): chapter 7, page 8

anthropogenic origin effectuated a clearly measureable, increasing blocking of solar irradiation. Consecutive efforts to counteract by the appliance of appropriate filtering technology are by now yielding success in terms of less blocking and raised levels of irradiation again reaching the atmosphere. The future scenarios “howa 2025” and “howa 2050” foresee remaining potential for this process while data of 2003 depicts an exceptionally hot summer rich in solar irradiation.



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

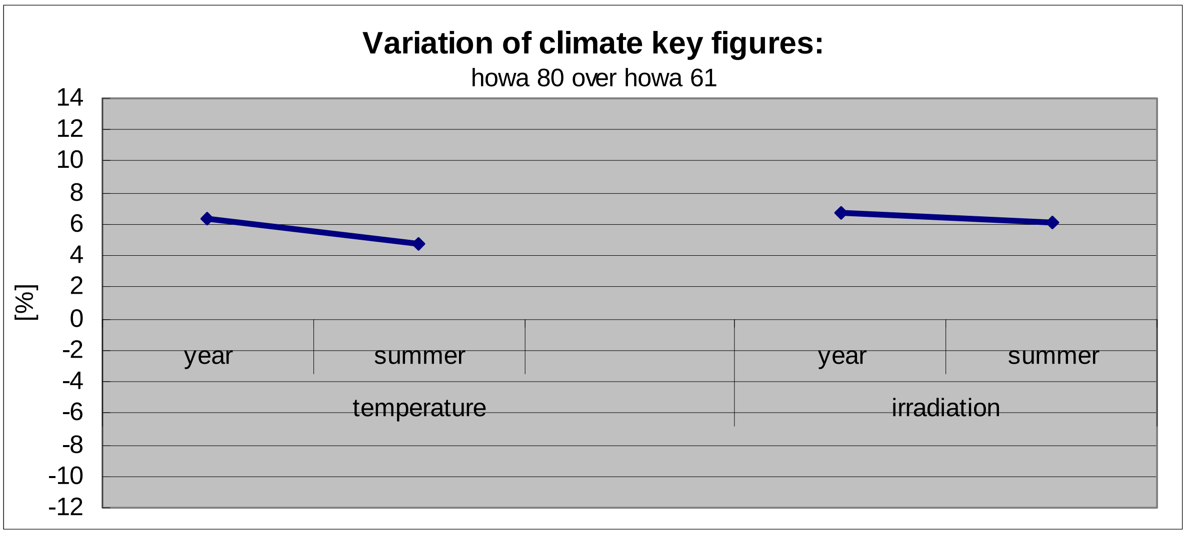
Regarding spatial resolution, however, no difference can be detected between the different Viennese locations in terms of solar irradiation.



Graph 17: Average hourly irradiation for different spatial resolution

Comparison of climate data sets

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



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

Remarks on humidity and wind

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

2 Sample buildings' Constructive Configuration

This study investigates up to nine sample buildings' thermal behaviour due to their particular constructive properties incorporated in their constructions, which in turn are strongly determined by their respective building epoch (room layout, storey height and the like). This is to stress that their constructive configuration is, what differentiates the sample buildings from each other, whereas the conditioning of their indoor climate, 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.

2.1 Description of sample buildings

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

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

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 buildings from earlier decades are nonmarketable. In general, such buildings constitute company head quarters in the companies' proper holdings (whereas nowadays such head quarters are normally leased from a provider or developer). In consequence, information on offices built between 1960 and 1980 is especially scattered and hard to 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's history; the chosen sample buildings therefore represent three main building epochs:

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

2.1.1 Leading and additional buildings

For all epochs involved at least 1 sample was chosen. For the period “before WW1” and “after WW2” additional buildings were added to the sample in order to broaden the statistical basis. However, for only 4 sample buildings the available data on constructive configuration was sufficient for in – depth investigation. This is why detailed analysis is mainly done in focus of these four buildings, hereafter denominated as “leading buildings”.

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

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

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 regarding 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 simulation results allow for a bottom up assemblage which in turn facilitates first insights into the expectable thermal behaviour of the overall complex.

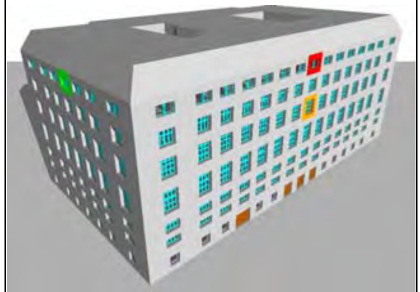
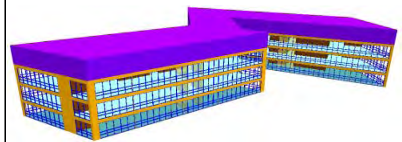
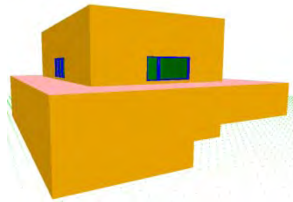
				
Denomination	**ONB**	**BNG**	**Strabag**	**SOL 4**
Year of construction	1913 – 1925	1950 – 1956	2001 - 2003	2005
Nr. of storeys	10	9	13	4
Net office area	43.255 m^2	8.107 m^2	28.000 m^2	2.221 m^2
Description	Headquarter of the Austrian National Bank	Office Unit of the Austrian National Bank	Headquarter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

Table 1: General description of leading sample buildings, including representation of the applied geometric model

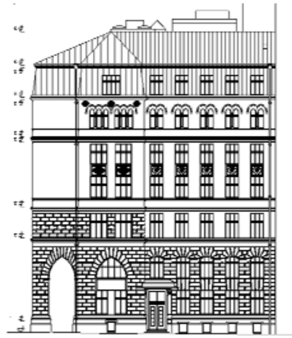
<table>
<tr><th colspan="4">Additional Buildings</th></tr>
<tr><td>Built before WW1</td><td>SPZ (20., Am Spitz Nr.1)
Municipal Building, District Administration
</td><td>RHS (1., Rathausstrasse 14–16)
Municipal Building, District Administration
</td><td>SCP (8., Schlesinger Platz 2 – 6)
Municipal Building, District Administration
</td></tr>
<tr><td>Built after WW2</td><td>FAS (10., Favoritenstr. 18)
Municipal Building, District Administration</td><td>LES (8., Lerchenfelderstrasse 4)
Municipal Building, District Administration
</td><td></td></tr>
</table>

Table 2: Additional sample buildings' representation

2.2 Key figures for analysis

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

Occupancy
[m2/pers.]; only net area of the investigated office rooms was taken into account; all sample rooms are occupied by two workers;
In thermal terms occupants represent heat sources and the more persons 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/m2K] acc. EN 673
Heat transmission between indoors and outside both via opaque and glazed parts of the exterior wall may occur in either direction, depending on which side the 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.

2.3 Results of comparative building analysis

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

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

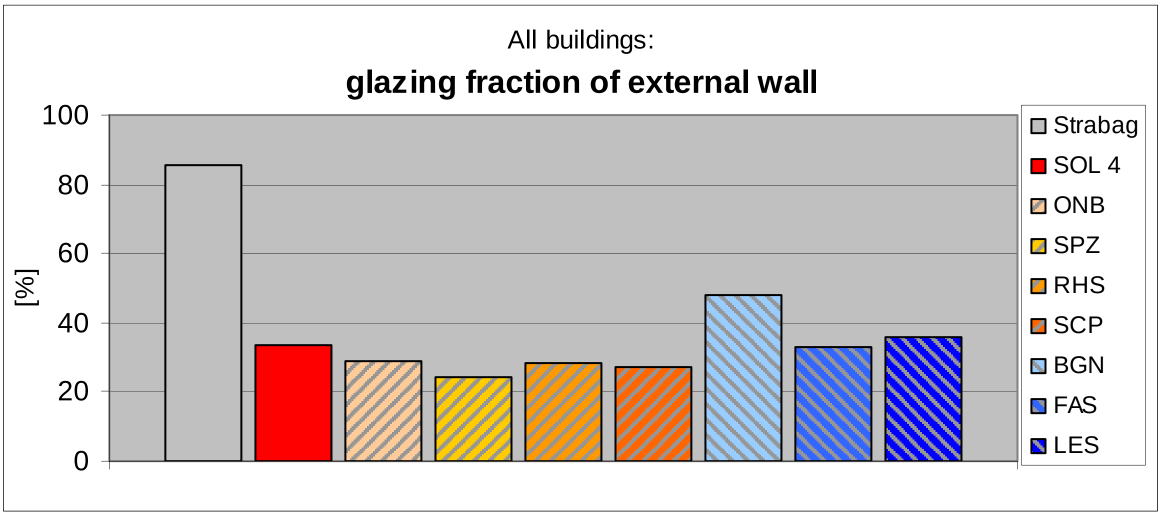
		temperature		irradiation							
		U - value		g - value	Fc - valu	g*F_c - val	glaz	glaz		occupna	mass
		[-]		[-]	[-]	[-]	[%]	[m^2/m^3]		[m^2/pers.	[kg/m^2]
Strabag		1,24		0,36	0,58	0,2	85,27	0,15		11,15	246,32
ONB		0,99		0,62	0,19	0,1	28,80	0,05		14,05	284,78
SOL 4		0,34		0,52	0,15	0,1	33,37	0,06		12,42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

Graph 19: Overview buildings' properties

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

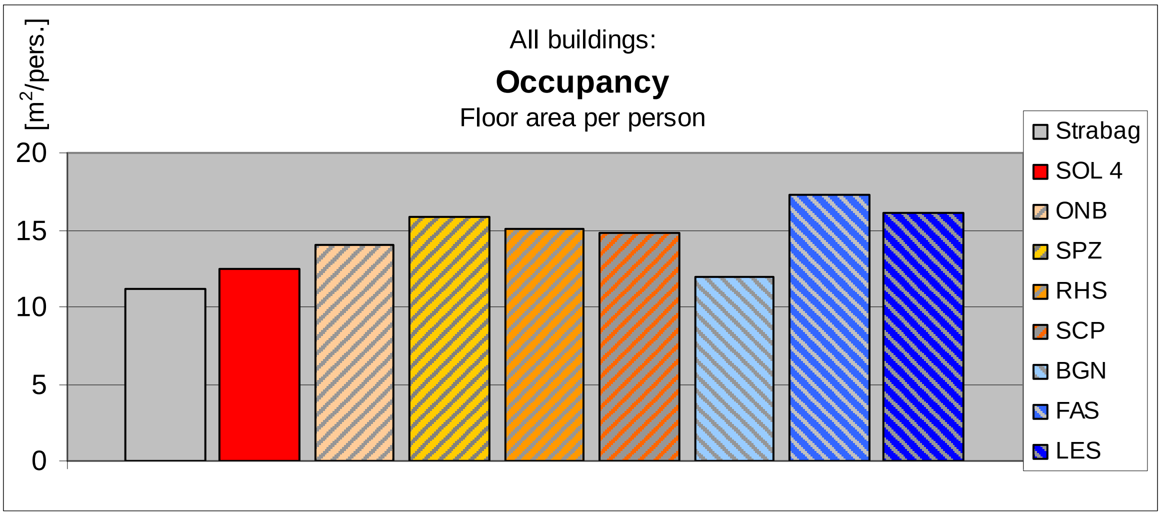
Graph 19 are represented in comparisons of the sample (leading and additional) buildings for single properties hereafter.

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



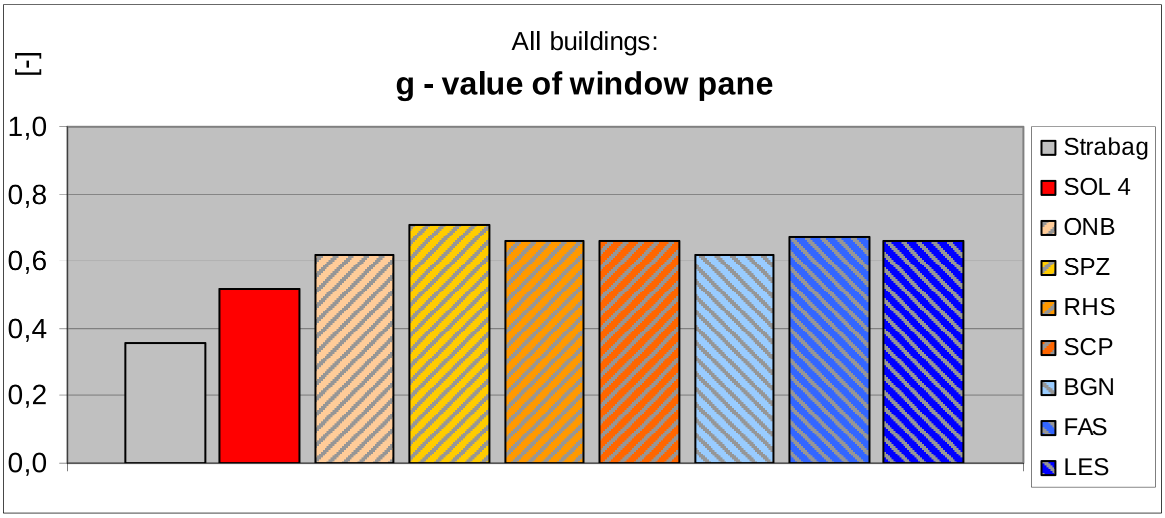
Graph 20: Glazing fraction of all buildings

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



Graph 21: Occupancy rate of office rooms in sample buildings

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

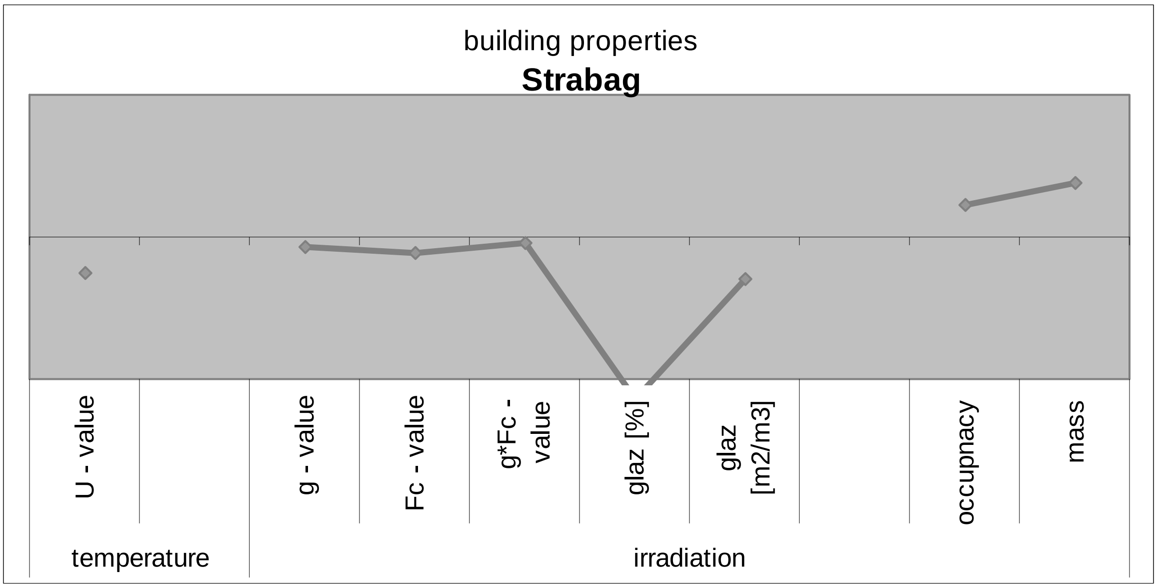


Graph 22: g – value of window panes in all sample buildings

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

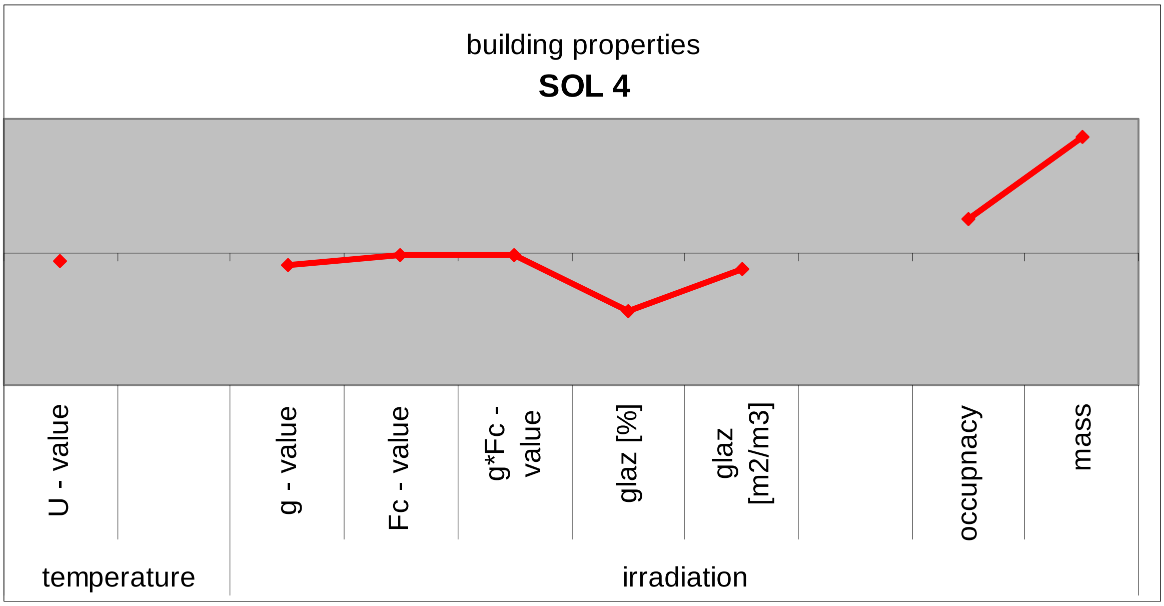
Having compared single properties over all sample buildings, it appeared likewise advisable to compare several thermal properties aver single leading sample buildings. Therefore, a graphical method was applied which definitely did not strive to reflect these properties in correct relationship to one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

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



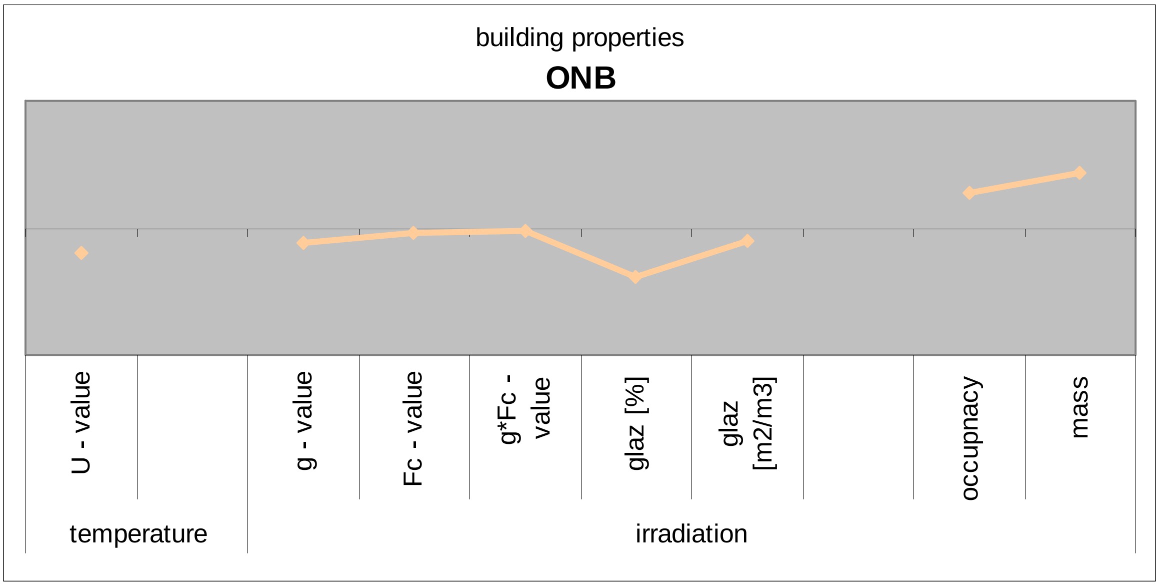
Graph 23: Strabag's building properties

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



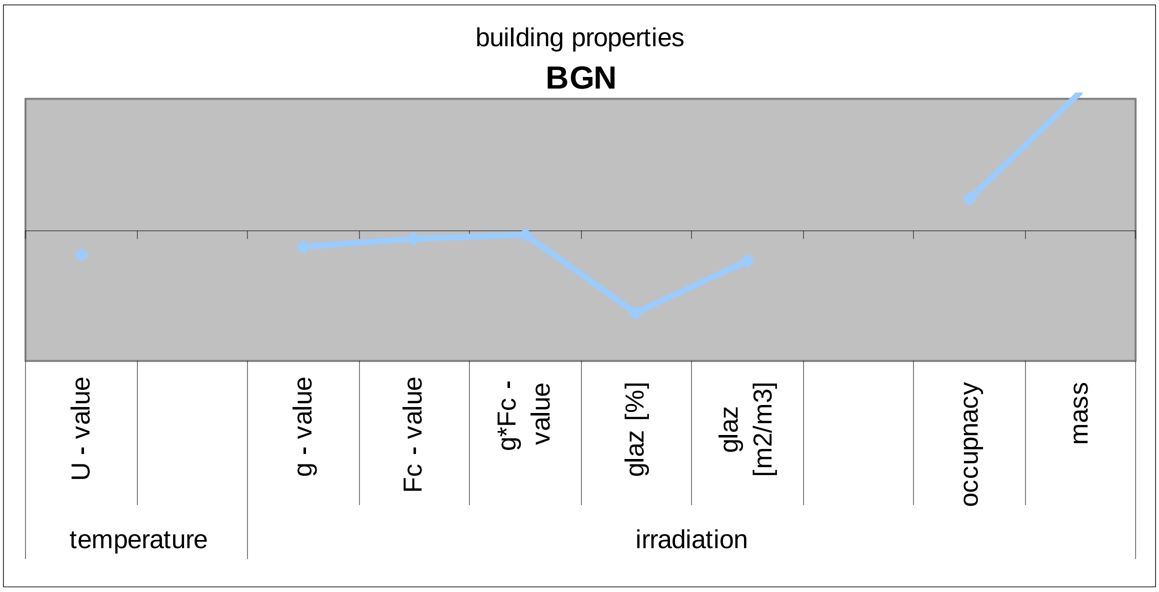
Graph 24: SOL 4's building properties

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



Graph 25: ONB's building properties

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



Graph 26: BGN’s building properties

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

3 Sample buildings' conditioning

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

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

In some cases, nevertheless, it 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 thermal comfort conditions.

3.1 Description of simulation modes

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

Simulation 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.

Simulation Mode “real”

- Several sample buildings, dating back to periods before World War One and shortly after World War Two, (partly) lack cooling devices in the actual present situation and already display precarious comfort conditions today. These comfort deficits are not displayed in the simulation mode “Standard”, which operates under documented standardized parameters regarding ventilation, shading, cooling and internal loads.
- Simulation mode “real” therefore separately addresses 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 under simulation mode “real”

Simulation 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 generally used for the sizing of heating and cooling plants[10]. The applied Design Day was generated on basis of the climate data sets portrayed above and referring to Austrian technical norm ÖNORM B 8110-3 (1999) for configuration[11].

3.2 Key figures for conditioning

3.2.1 Ventilation

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

[10] See VDI 2078

[11] see chapter 6.1.7 Cooling load under Design Day Conditions, page 79

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

Graph 27: Ventilation régime simulation mode Standard

3.2.2 Shading

Different shading devices as depicted in chapter 2.3 Results of comparative building analysis, page 27, 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 28: Shading regime simulation mode Standard

3.2.3 Internal Loads

Internal heat loads from IT equipment and lighting generally represent a significant contribution to thermal environments in offices. However, levels of employed equipment vary broadly from building to building, depending on specific types of tasks performed there. Effort was thus undertaken within the framework of this study to assess assumable levels of internal loads. Reference is made to literature[12],

[12] Zimmermann, M. et al. Handbuch der passiven Kühlung. Rationelle Energienutzung in Gebäuden (Frauenhofer IRB Verlag, Stuttgart, 2003); ÖNORM B 8110-5, ISO EN 7730 (1994), VDI 2078 (1996)

professionals' experiences[13] 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[14] which in turn extensively draws upon corresponding German and Swiss normative guidelines[15].

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

Graph 29: Internal Loads simulation mode „Standard"

As can be seen in Graph 29: *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 mode only. This is a valid approach for the simulation of cumulated energy demands for certain periods of time. For the determination of maximum loads however this may prove to be insufficiently severe: Highest cooling requirements 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:

---

[13] Berger, Tania (Juni 2010): Interne Lasten in herkömmlichen Bürobauten. praktische Erfahrungen eines Haustechnikers. Interview mit Siegfried Manschein. Im Juni 2010 in Krems.

[14] Programmlinie Haus der Zukunft (Hg.) (2010): PH Office. Standard für energieeffiziente Bürobauten. Endbericht. Unter Mitarbeit von Robert Lechner, Thomas Zelger und Felix Heisinger et al. Bundesministerium für Verkehr, Innovation und Technologie. Wien. (Impulsprogramm Nachhaltig Wirtschaften).

[15] VDI 3807, SIA 380-4

internal loads		Elevated levels					
				working days		weekends	
		Radiant Proportion	**View Coefficient**	6:00 - 19:00	20:00 - 5:00	0:00 - 24:00	**[ ]**
equipment		0,1	0,372				W/m2 ***)
	IL II			16,3	0,1	0	
***)		2 PCs (4 hrs. Power, 4 hrs stand by)/ 1 printer (4 hrs. Power, 4 hrs stand by)/ 0,5 copymachine (2 hrs. Power, 6 hrs stand by) all /20m2					

Graph 30: Internal Loads simulation mode „Standard“, elevated level of internal loads for lighting and equipment for the determination of cooling load only

3.2.4 Occupancy

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

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

Graph 31: Occupancy Loads simulation mode „Standard“

3.2.5 Cooling

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

Cooling

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

*) upper limit of the cooling control band

Graph 32: Cooling simulation mode „Standard“

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

3.2.6 Heating

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

Heating

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

*) lower limit of the heating control band

Graph 33: Heating simulation mode „Standard“

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

4 Employed tools of investigation

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

TAS

The employed software tool for thermal simulation is TAS (Thermal Analysis System), Version 9.1.4.1, provided by the British EDSL[16].

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 results' file containing hourly values for parameters of internal condition, such as air, radiant and resultant temperature, humidity, applied cooling and heating load and the like.

[16] TAS – Thermal Analysis System, Version 9.1.4.1 by EDSL – Environmental Design Solutions Ltd., Milton Keynes, GB, 2007

5 Variants and Assessment parameters

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

5.1 Definition of simulation variants

- **<u>Module 1</u>: Impacts of Climate Change**

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. Both cooling energy demands and maximum loads were calculated, the latter based on elevated levels of internal loads.
Climate data sets depicting past (“howa 61”), present (“howa 80”) and future (“howa 2025 and 2050”) situations were applied.
The results were assessed in terms of primary and comparative parameters on energy demand.

- **<u>Module 2</u>: Discussion of different comfort models**

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

- **<u>Module 3</u>: Impacts of urban heat island**

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

- **<u>Module 4</u>: Impacts of optimizations in the buildings’ envelop**

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

Module	Sample Building	Simulation Mode	Climate Data Set
1 Climate Change (Temporal resolution)	Strabag SOL 4 ONB SPZ RHS SCP BGN FAS LES	“Standard” “Design Day”	“howa 61” “howa 80” “howa 2025” “howa 2050” “2003”
2 Comfort models	ONB BGN	“real”	“howa 80”
3 Urban heat island (Spatial resolution)	Strabag SOL 4 ONB BGN	“Standard”	“howa 61” – “howa 2050” “inne 61” – “inne 2050” “dona 61” – “dona 2050”
4 Optimizations of buildings’ envelop	ONB BGN/ FAS	“Standard”	howa 80” “howa 2050”

Table 3: Overview of investigated sample buildings, simulation modes and employed climate data sets

5.2 Assessment parameters for simulation results

5.2.1 Primary parameters

Energy demand:

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

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

Maximum Cooling Load
[W/m^2]

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

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

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

Maximum Heating Load
[W/m^2]

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

Annual Final and Primary Energy Demand
[kWh/m^{2}a]

- Final and primary energy demand for cooling and heating of a double office room of specific size, simulated under the documented standardized parameters regarding ventilation, shading, cooling and internal loads (mode "Standard");

- Final energy demand is calculated based on indicated values for COP of both cooling and heating plant, not covering auxiliary electricity for mechanical ventilation;
- Primary energy demand is calculated based on indicated values for COP of both cooling and heating plant and PEI of electricity, not covering auxiliary electricity for mechanical ventilation;
- These figures are averaged over all reference rooms of the indicated orientation in the particular building.

Annual CO_2 emissions
[g/m^{2}a]

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

<u>Thermal Comfort:</u>

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
- A single south fachin room is simulated in August of data sets "howa80" and "howa 2050".
- According to EN 7730 all conditions exceeding 26° and 27°C respectively (depending on the investigated building's category) are to be regarded as uncomfortable

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.
- A single south facing room is simulated in August of data sets "howa80" and "howa 2050".

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

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

5.2.2 Comparative parameters

Energy demand:

Increase in summer/ yearly cooling demand
[%]

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

Increase in maximum cooling load
[%]

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

Decrease in heating demand
[%]

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

Decrease in maximum heating load
[%]

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

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
- 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

6 Results

6.1 Module 1: Impact of Climate Change

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

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

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

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

The following table summarizes the framework condition of these simulations:

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

Table 4: Investigated sample buildings, simulation modes and employed climate data set in Module 1

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

6.1.1 Net Cooling Energy Demand

The application of climate data sets from “howa 61” to “howa 2050” in different runs of thermal simulation is seen as a representation of the course of time from the past (“howa 61”) to far future (“howa 2050”). Accordingly, net cooling energy demand continuously increases over the course of near and far future scenarios. This increase is most distinct in two time steps: firstly between data sets “howa 61” and “howa 80” and secondly between “howa 2025” and “howa 2050”. This finding is congruent with climate data analysis[17].

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

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

This insight coincides with the fact that these two buildings display by far the highest glazing fractions in their external walls[18]. At the same time the simulated rooms are comparatively densely occupied and are therefore equipped with slightly higher internal heat loads[19]. In contrast, relatively low g-values of these buildings’ glazing do not succeed in counteracting the trend to elevated cooling demands.

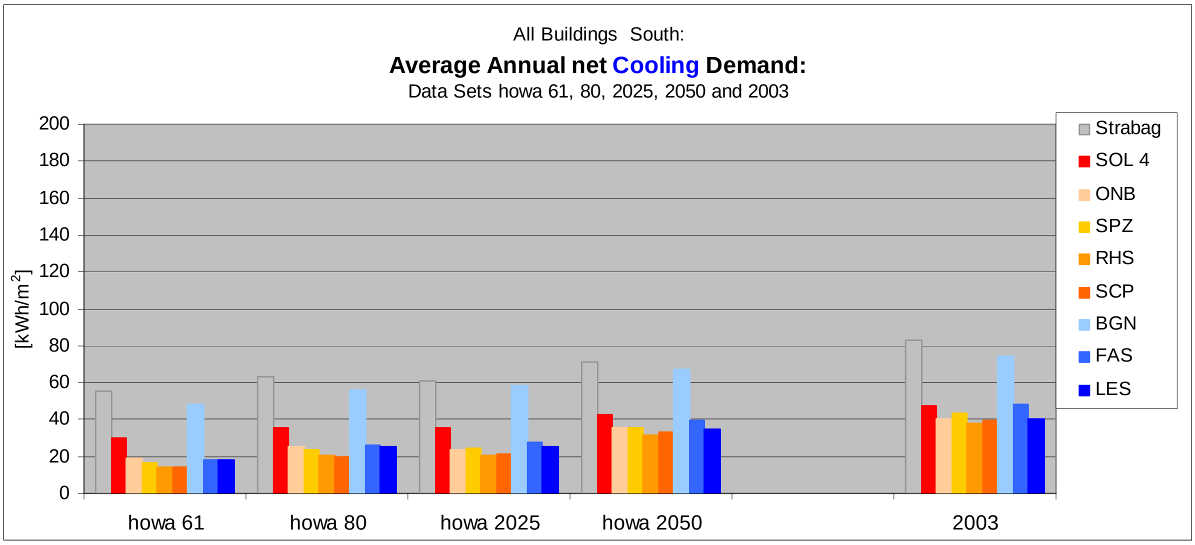
With the exception of BGN, the cohorts of buildings built before WW1 and after WW2 appear fairly uniform. It has been demonstrated for the cohort built after WW2 that available data on constructive configuration was by far most consistent in BGN[20] (even so indications on u-values seem overoptimistic). Therefore, for further investigations, BGN was regarded as leading worst case example for this buildings’ cohort.

The results of passive house SOL 4 range somewhat in between Strabag and BGN on one hand side and the remaining sample buildings on the other; However, it has to be stressed that these figures have to be viewed conditionally: As has been demonstrated before[21], in SOL 4 several fundamental features have been omitted in a strive to simulated all sample buildings under comparable conditions. In

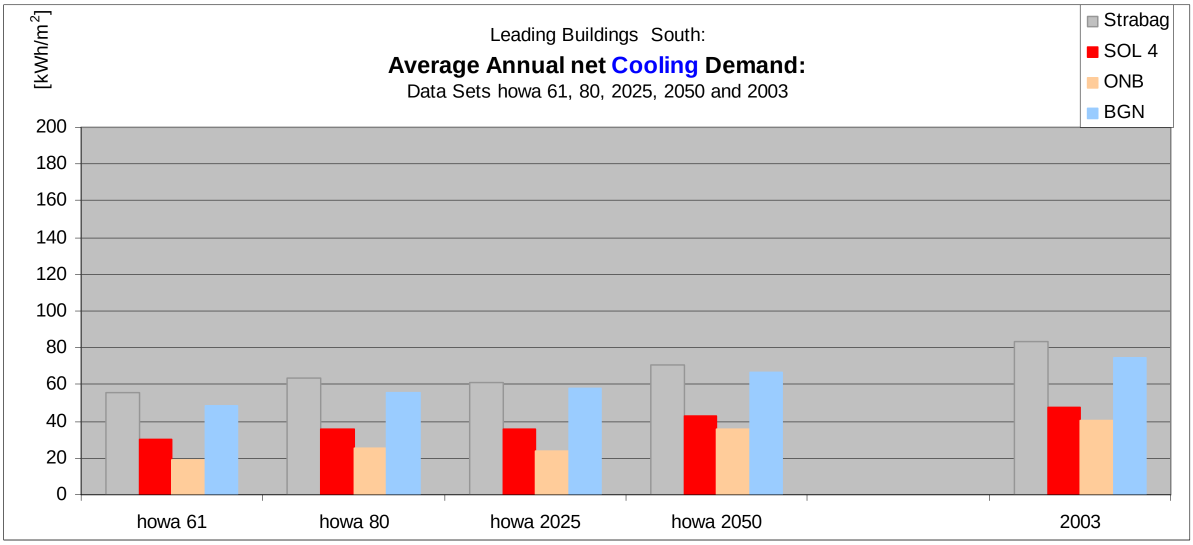
[17] see Graph 8, page 25
[18] see Graph 20, page 40
[19] see Graph 21, page 41
[20] See chapter 2.1 Description of sample buildings, page 33
[21] See chapter 3.2 Key figures for conditioning, page 42

consequence, the simulation results give an indication on the building envelope's performance only, not taking into account aspects such as reduced levels of internal loads and nocturnal ventilation by mechanical systems. Still, the case of SOL 4 reflects the fact that passive house planning, originating from the residential sector (in which heating is the crucial influence), so far has placed more emphasis on winter insulation than on prevention of overheating during summer.

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

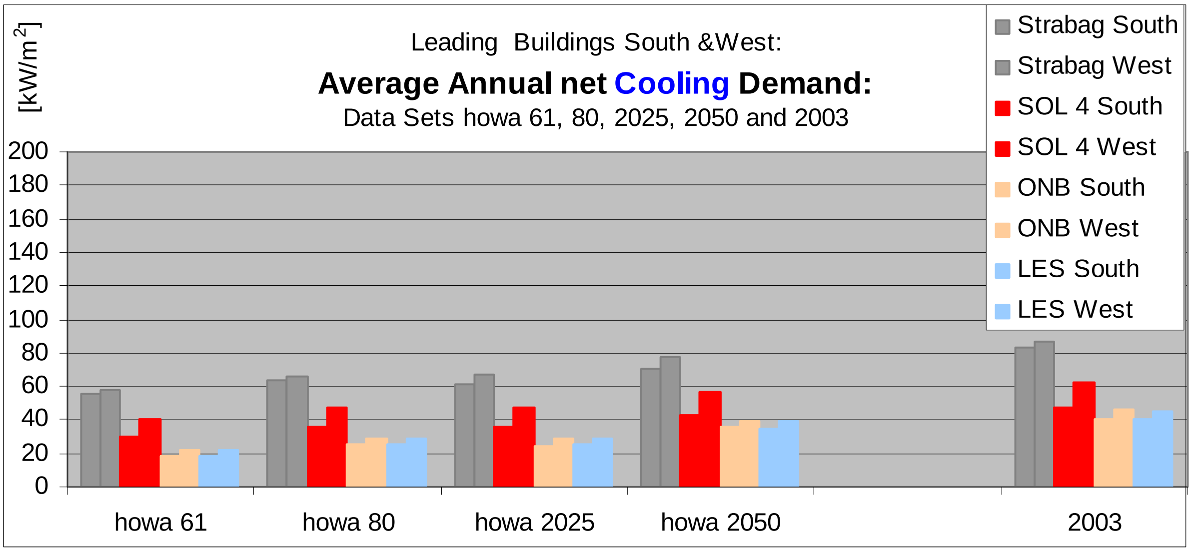


Graph 34: Cooling energy demand of all buildings (South)



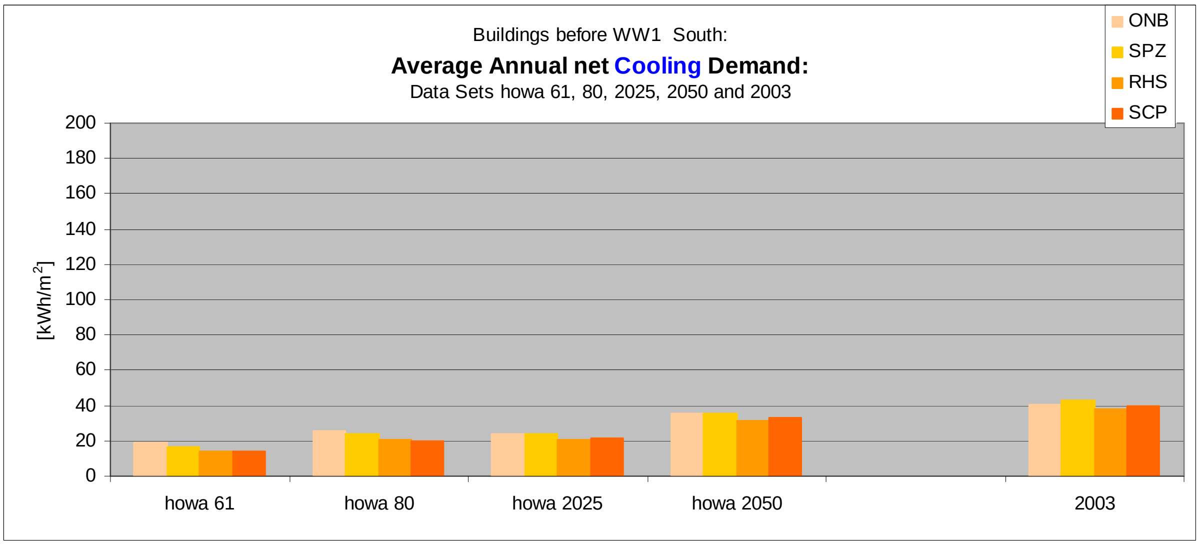
Graph 35: Cooling energy demand of leading buildings (South)

Sample rooms of different orientation have been investigated separately in the leading buildings: While South facing rooms are exposed to solar irradiation during the hottest hours of the day; these sunbeams intrude by a steep angle which makes it relatively easy to shade the room by means of adequate devices. In contrast, Western rooms are already well heated up when, by the end of the day, they are hit by low angled radiation which is hard to be kept out. As a result, Western rooms generally require more cooling than rooms facing south.[22]



Graph 36: Cooling energy demand of leading buildings (South & West)[23]

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

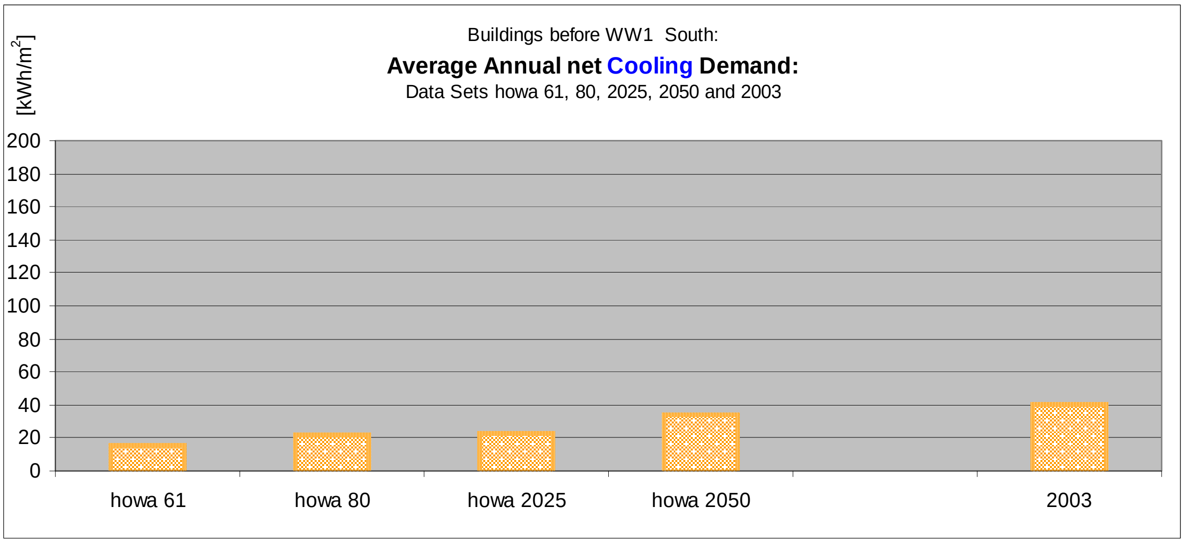


Graph 37: Cooling energy demand of buildings dating from before World War 1 (South)

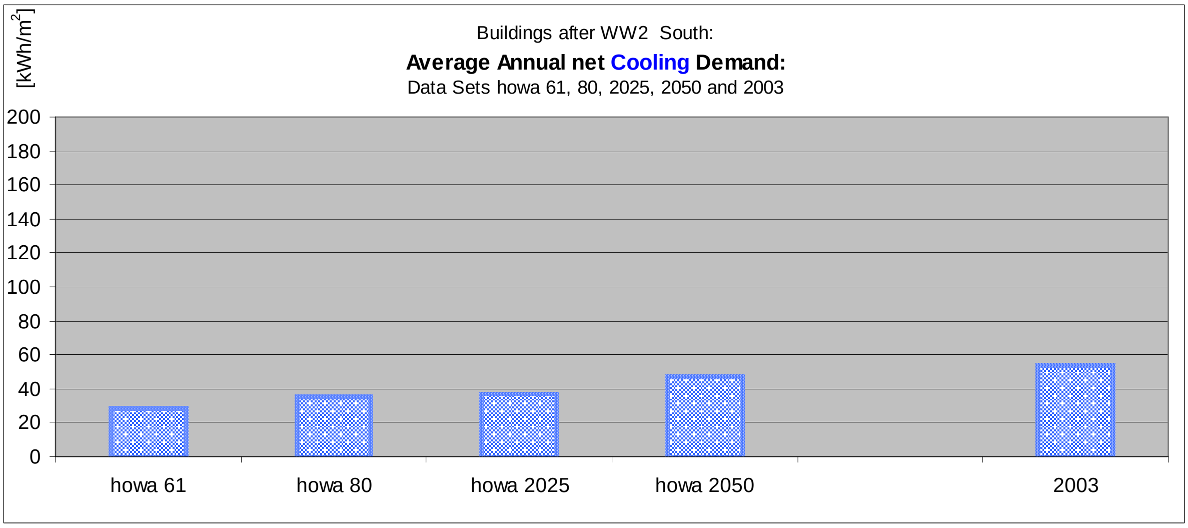
[22] For detailed load break down of annual cooling loads in the leading buildings refer to: Berger, T., Pundy, P. (2010): Adapting office buildings to climate change: optimization of thermal comfort and energy demand. Final report StartClim2009.E within StartClim2009: adaptation to climate change: contributions to the establishment of a national Austrian adaptation strategy. Awarding authority: BMLFUW, BMWF, BMWFJ, ÖBF

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

The comparison of the two cohorts displays higher values in absolute terms for the buildings dating after WW2, the overall tendency is obviously in both.

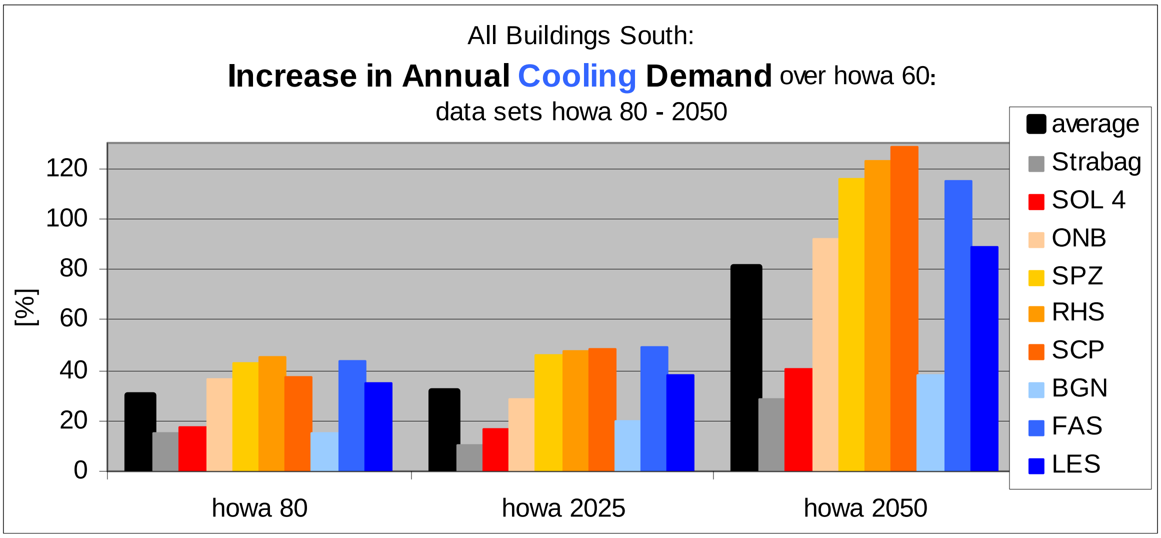


Graph 38: Average Cooling energy demand of buildings dating from before World War 1 (South)



Graph 39: Average Cooling energy demand of buildings dating from after World War 2 (South)

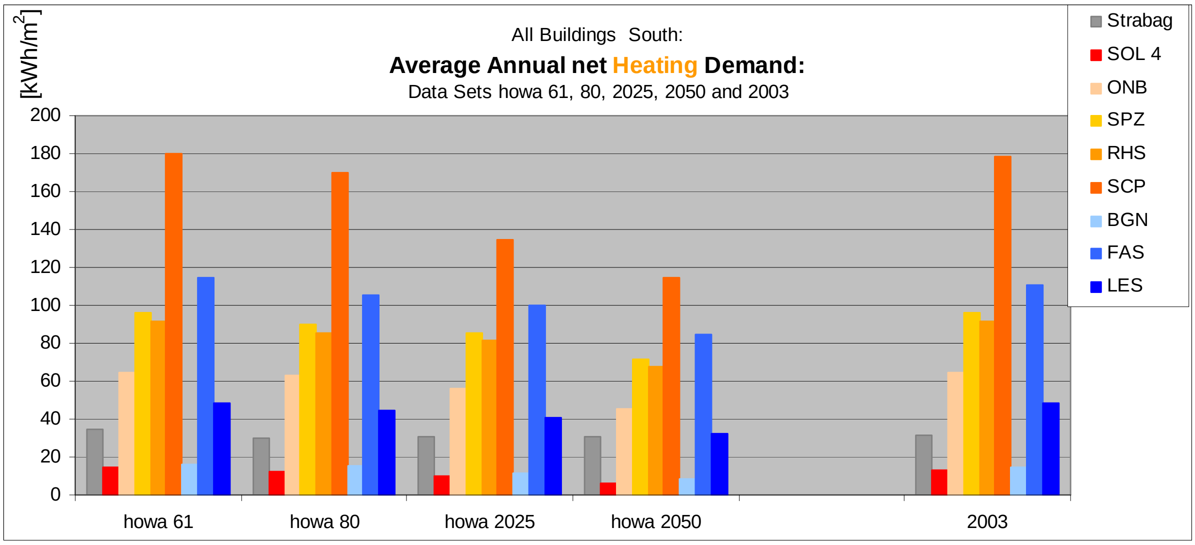
In relative terms the increase of net cooling energy demand against the baseline of climate data set “howa61” in average ranges at about 25% for all sample buildings for both climate data set “howa 80” and “howa 2025”. The increase for “howa 2050” over the baseline is more than double and nearly touches 80%. In other words: net cooling demand for “howa 2050” is almost twice the demand arising under “howa 61”.



Graph 40: Increase in net cooling demand

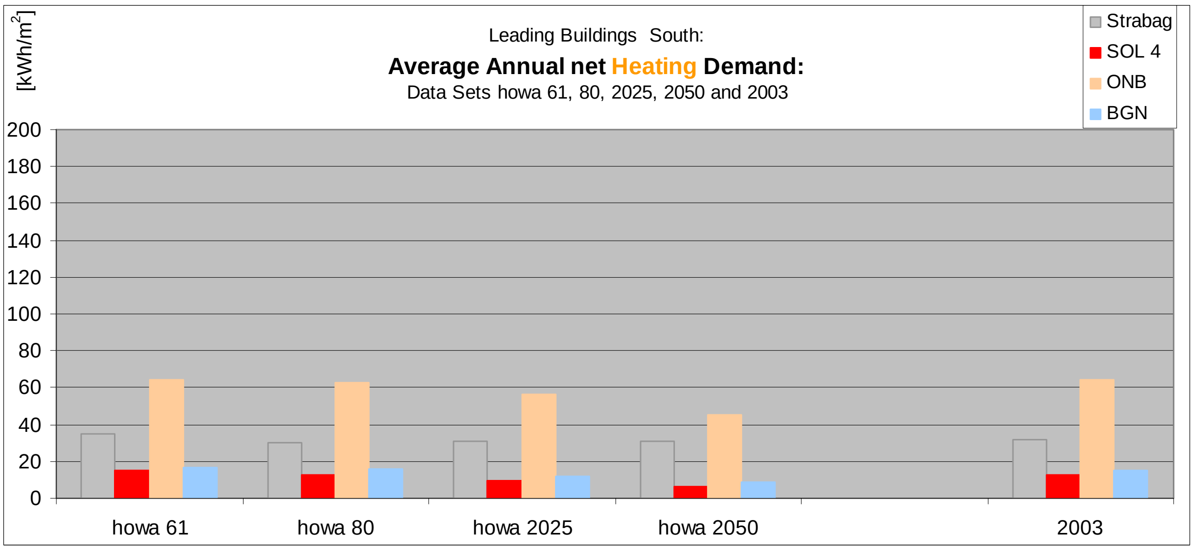
6.1.2 Net Heating energy demand

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



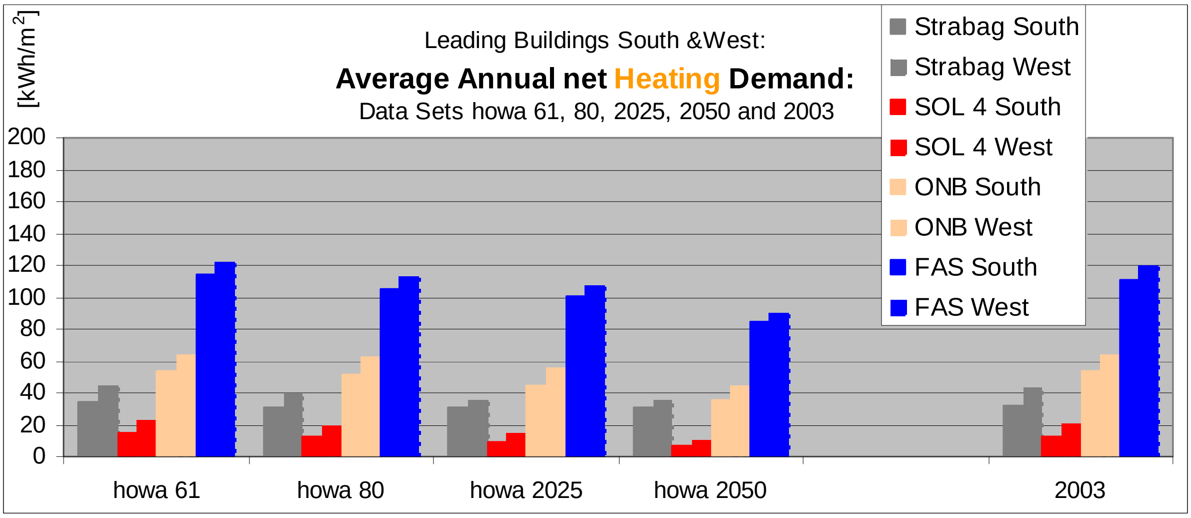
Graph 41: Heating energy demand of all buildings (South)

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



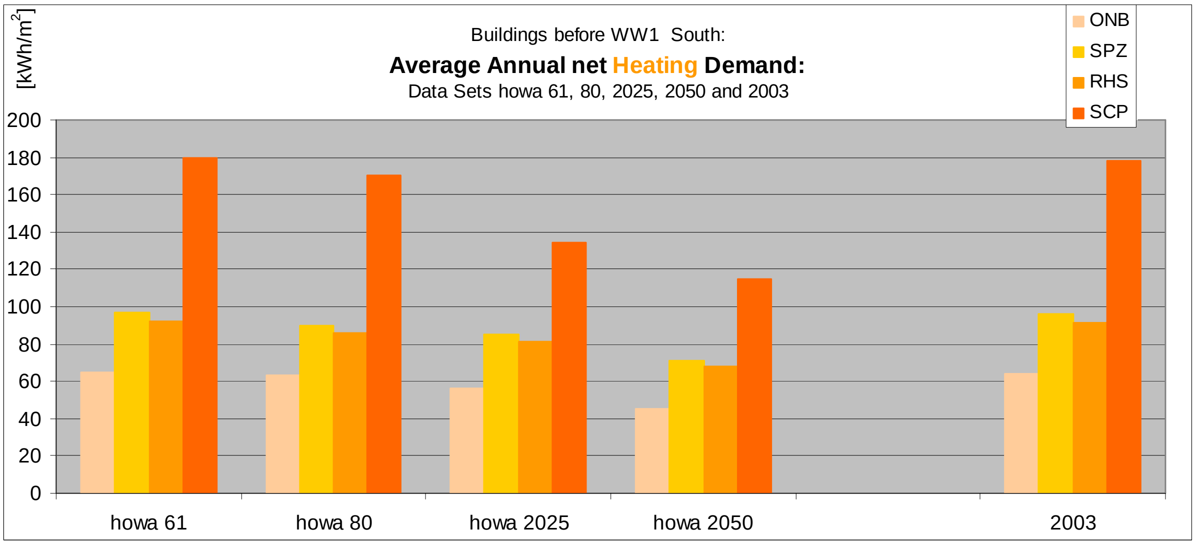
Graph 42: Heating energy demand of leading buildings (South)

With FAS as leading building for the cohort of buildings from after WW2 this group clearly ranges last in regards to heating energy efficiency, with buildings from before WW1 demanding approximately half of this groups requirements. This is still more than modern buildings, highly glazed or passive, need for heating purpose.

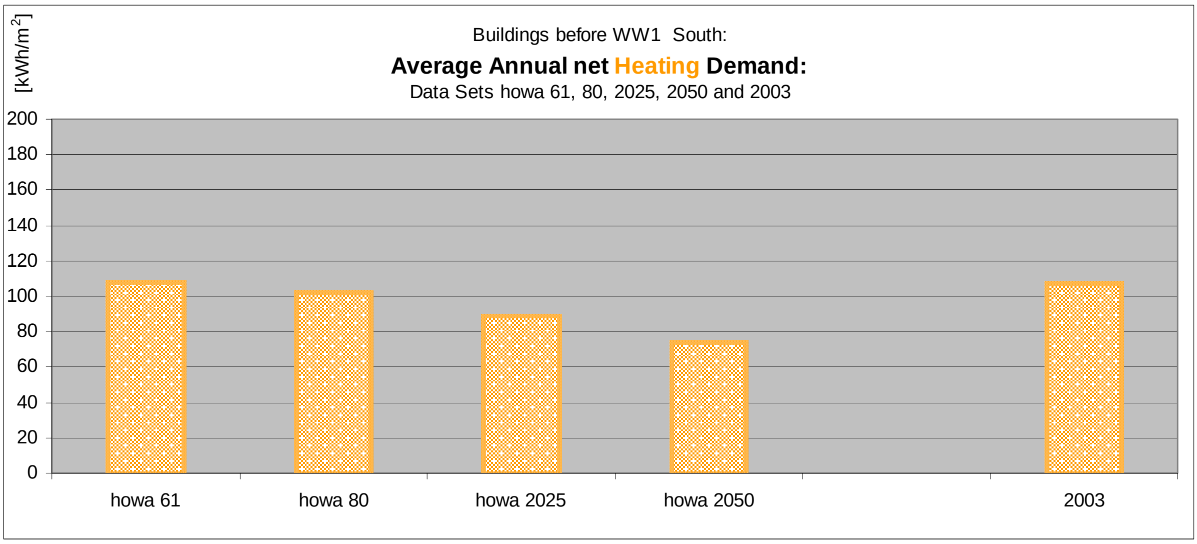


Graph 43: Heating energy demand of leading buildings (South & West)

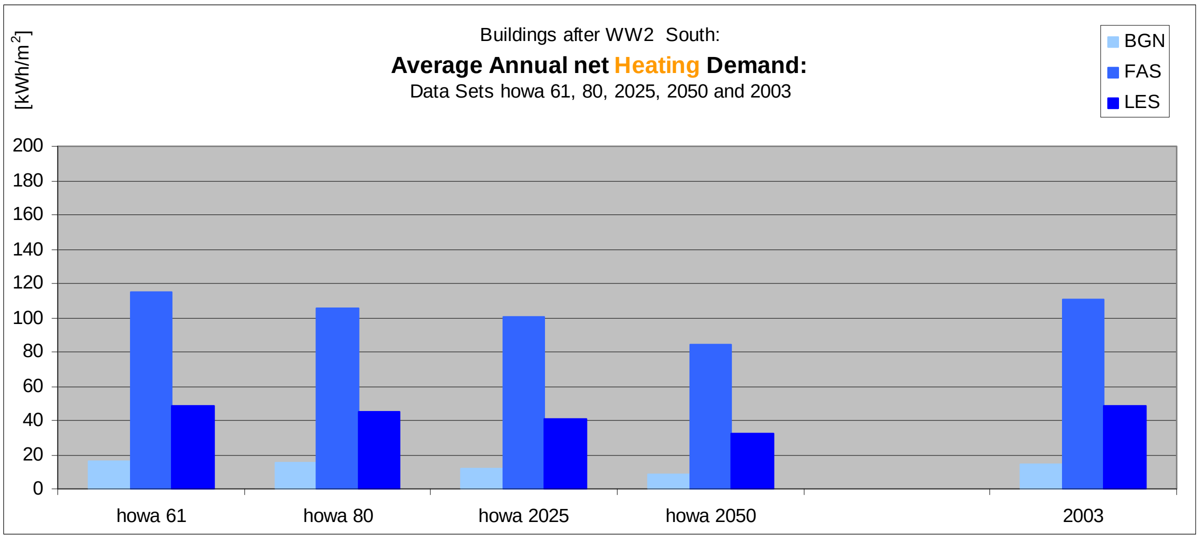
2003 clearly does not display any decrease in heating demand as this year featured a rather cold winter. It is therefore only included in simulation here to evidence that even in very hot future years heating requirements can still remain high.



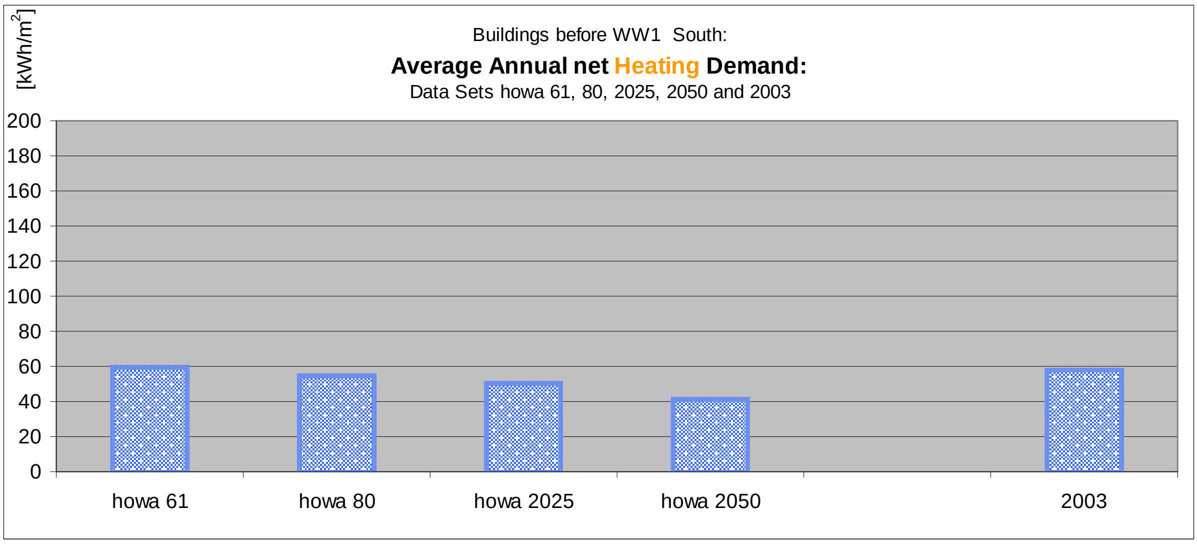
Graph 44: Heating energy demand of buildings dating from before World War 1 (South)



Graph 45: Average Heating energy demand of buildings dating from before World War 1 (South)

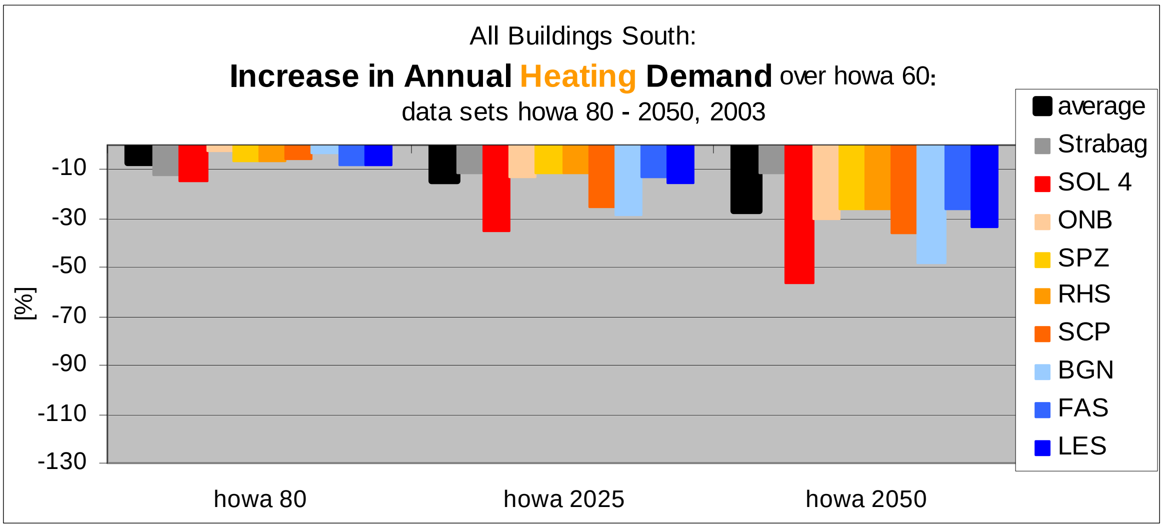


Graph 46: Heating energy demand of buildings dating from after World War 2 (South)



Graph 47: Average Heating energy demand of buildings dating from after World War 2 (South) **Fehler! Textmarke nicht definiert.**

In relative terms the decrease of net heating demand against the baseline of climate data set "howa61" in average ranges at about 10 to 15% for all sample buildings for both climate data set "howa 80" and "howa 2025". The increase for "howa 2050" over the baseline is more than double and nearly touches 30%. In other words: net heating demand for "howa 2050" is reduced by a third as compared to demand under "howa 61".

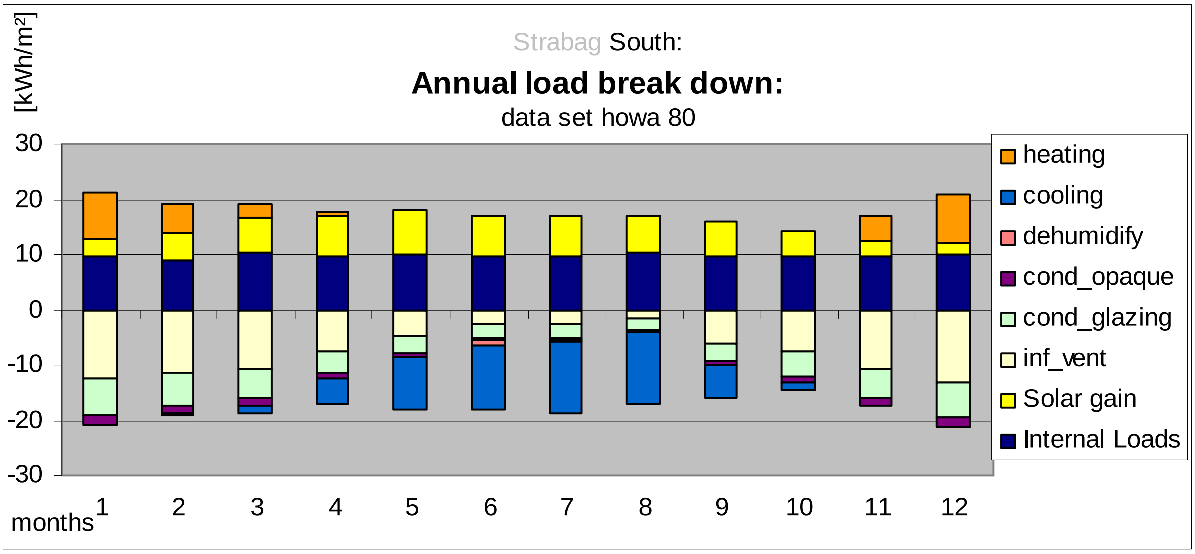


Graph 48: Decrease in Heating demand

6.1.3 Annual load break down

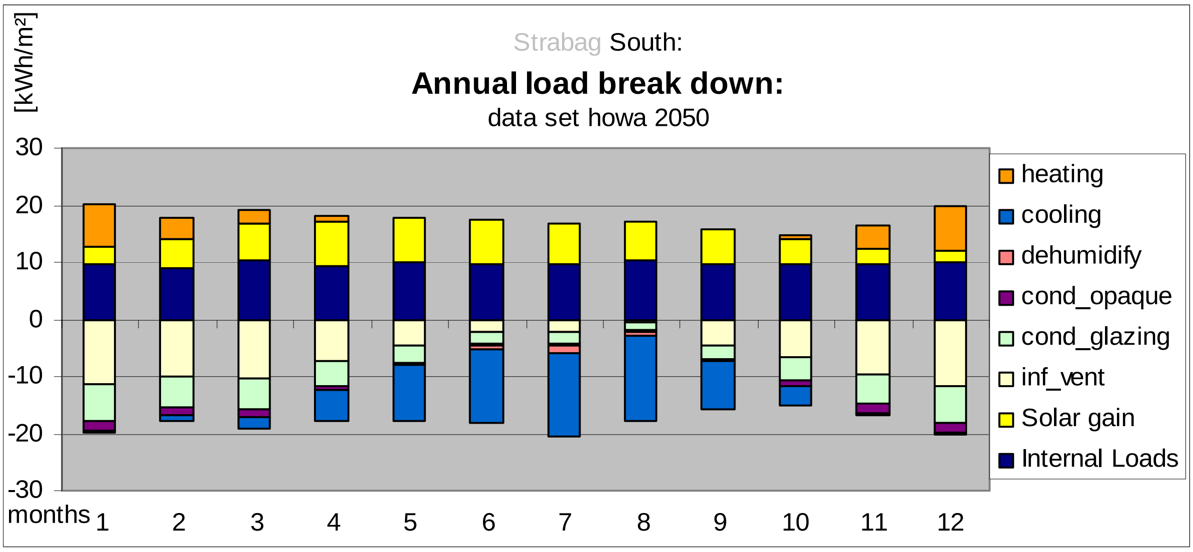
Annual net cooling and heating demand still don't give indications as to how energy demand is spread over the months of the year. This can only be determined by means of annual load break downs. These show clearly which heat gains and losses occur in each month and how these gains and losses have to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

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



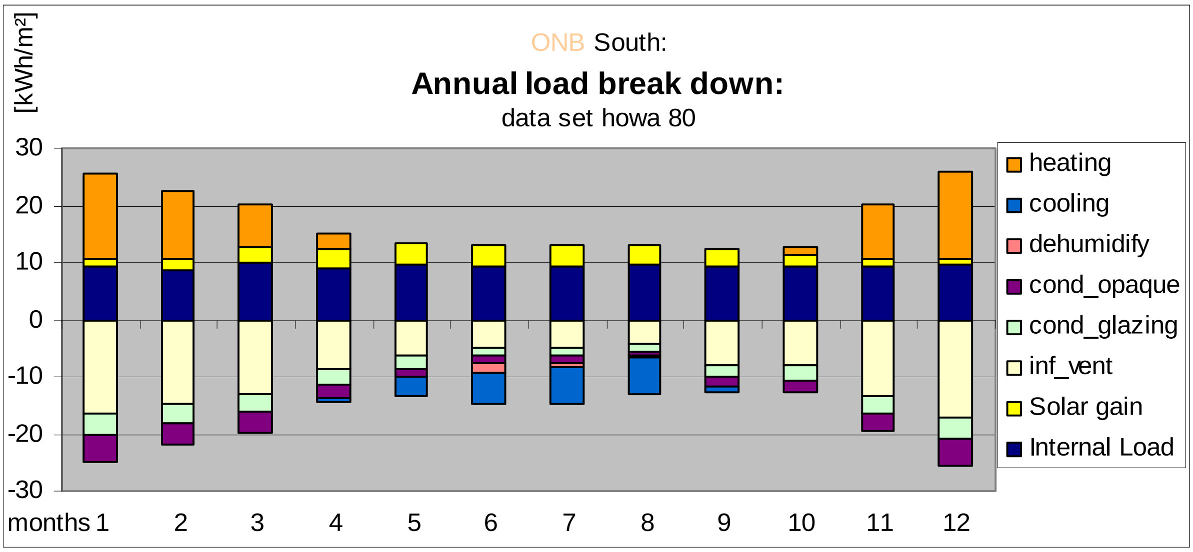
Graph 49: Annual load break down for “howa 80” in Strabag

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



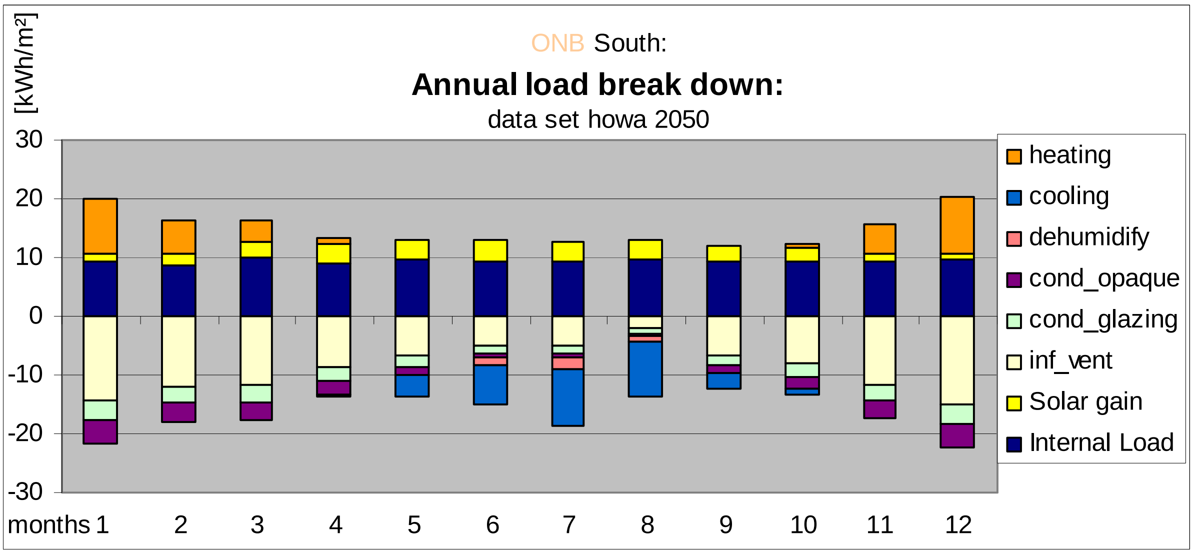
Graph 50: Annual load break down for “howa 2050” in Strabag

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



Graph 51: Annual load break down for “howa 80” in ONB

Cut backs in heating demand in the future (climate data set “howa 2050”) are evident and so is the increase in cooling demand. Both are mainly caused by reduced losses by ventilation and conduction in winter as in summer.



Graph 52: Annual load break down for “howa 2050” in ONB

6.1.4 Final and Primary energy demand

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

The calculation of both final and primary energy demand however strongly depends upon the conversion factors chosen for COPs (especially for cooling) and – for primary demand only: - PEI (primary energy index) of electricity for mechanical cooling. For the present investigation several sources of literature on this subject have been consulted and exemplary calculations run. The following tables indicate the chosen factors as well as their source while the following graphs outline the margin of values these factors can result in for final and primary energy consumption in the leading sample buildings. [24]

COP cooling	
Value	**source**
3,0	Project “PH Office. Standard für energieeffiziente Bürobauten” [25]
2,48	Recknagel[26]

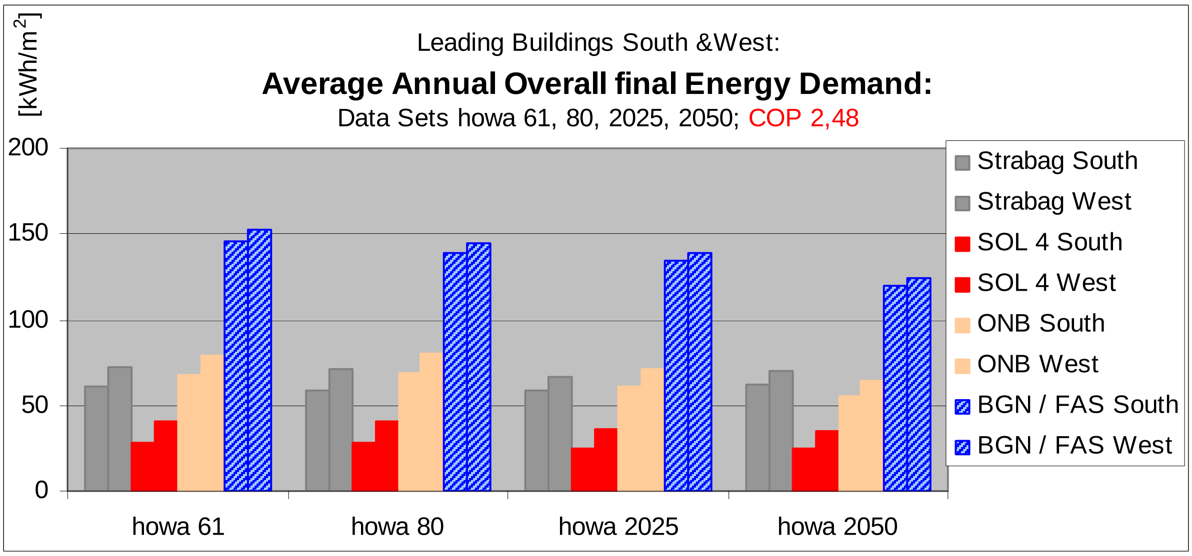
Table 5: Provenience of COP factors

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

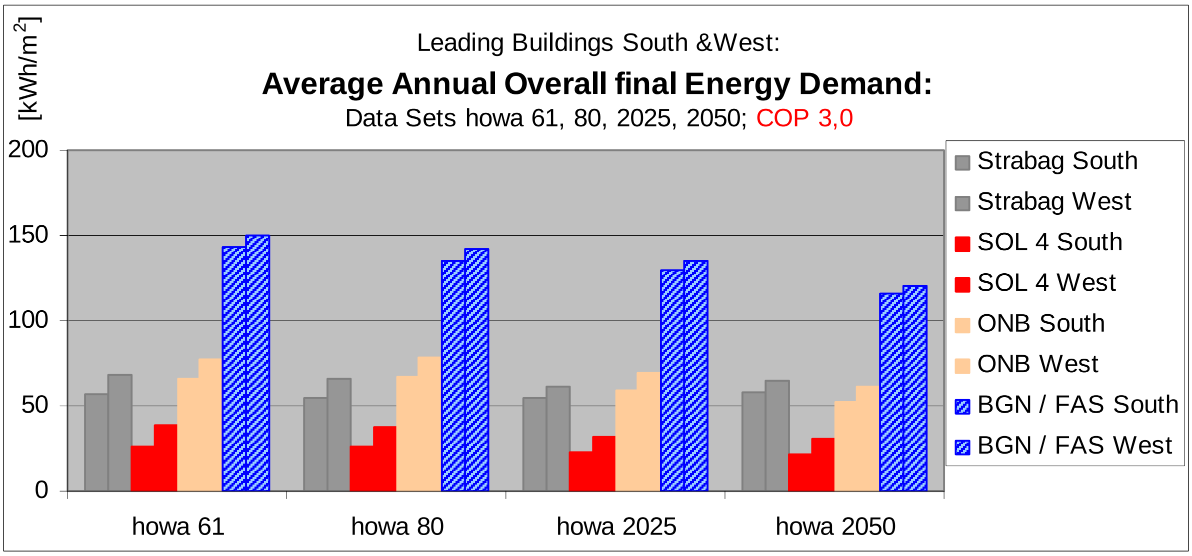
[24] For the heating system (both combustion and distribution) a degree of efficiency of 95% was assumed, including 5% of auxiliary electricity (as in project “PH Office. Standard für energieeffiziente Bürobauten”).

[25] Programmlinie Haus der Zukunft (Hg.) (2010)

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

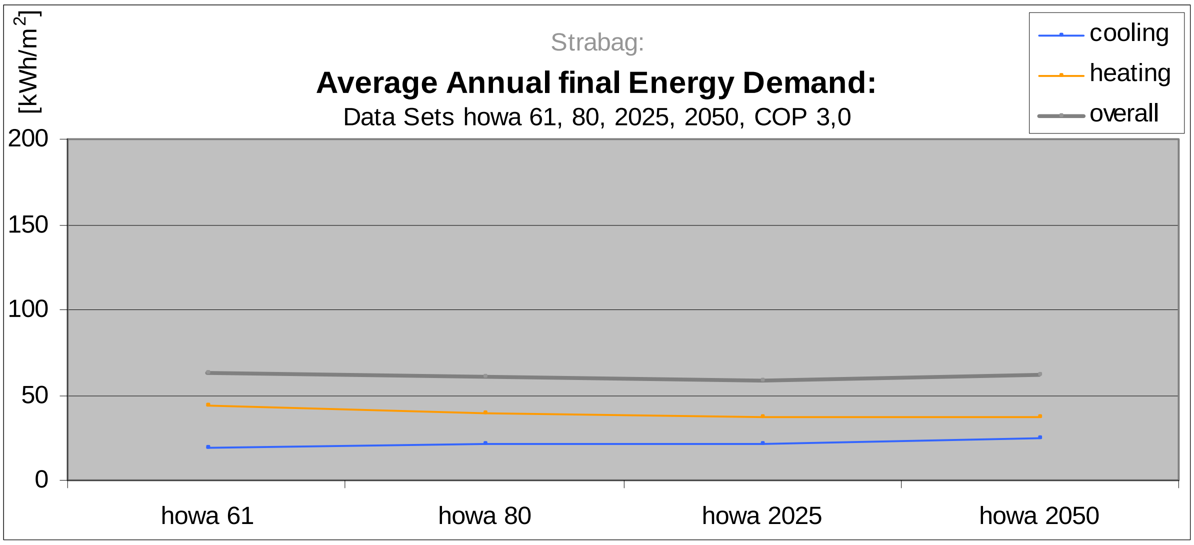


Graph 53: Final energy demand for COP 2,48

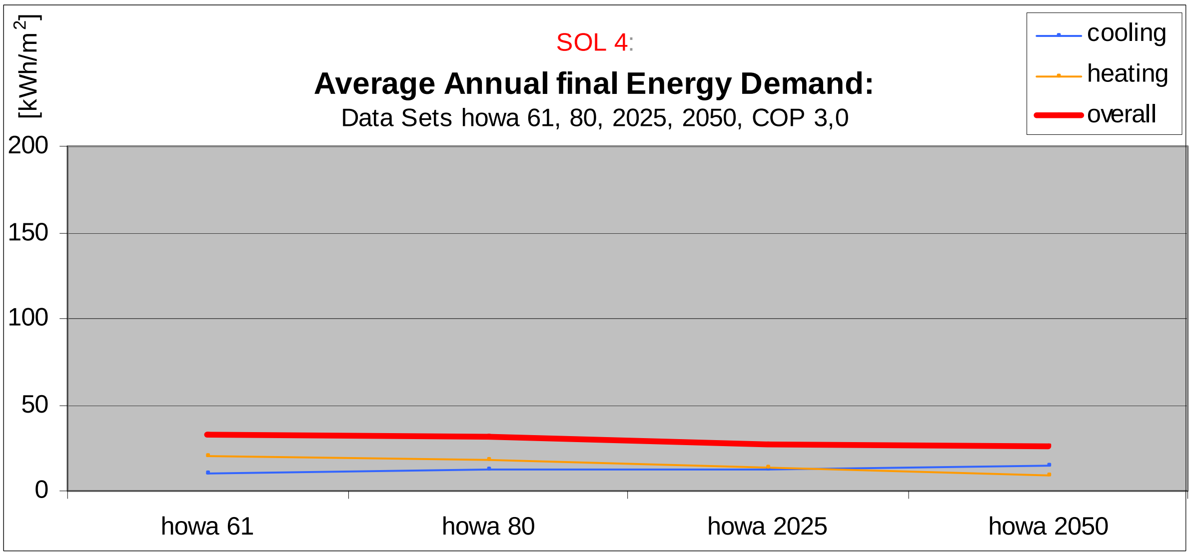


Graph 54: Final energy demand for COP 3,0

When analyzing these results building wise it becomes evident that, due to its more favourable COP, cooling less impacts upon final energy demand than heating. Thus, modern buildings with net cooling surpassing net heating demand already today display final energy demands for cooling which are only slightly lower than those for heating. These values gradually approximate towards the end of the temporal resolution. Overall final energy demand in consequence stagnates or decreases slightly.

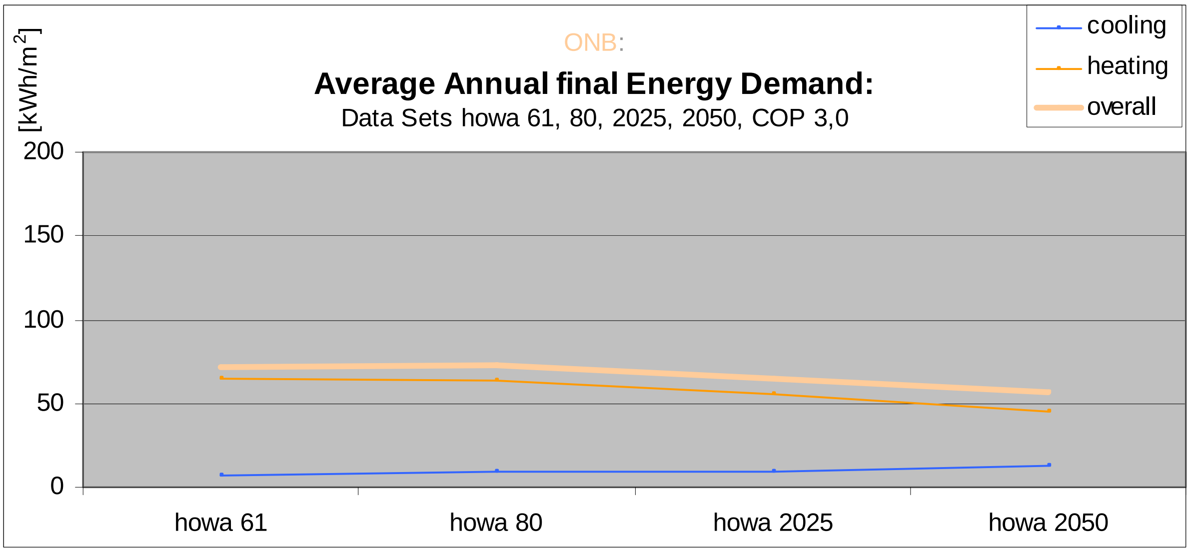


Graph 55: Final energy demand for COP 3,0 in Strabag

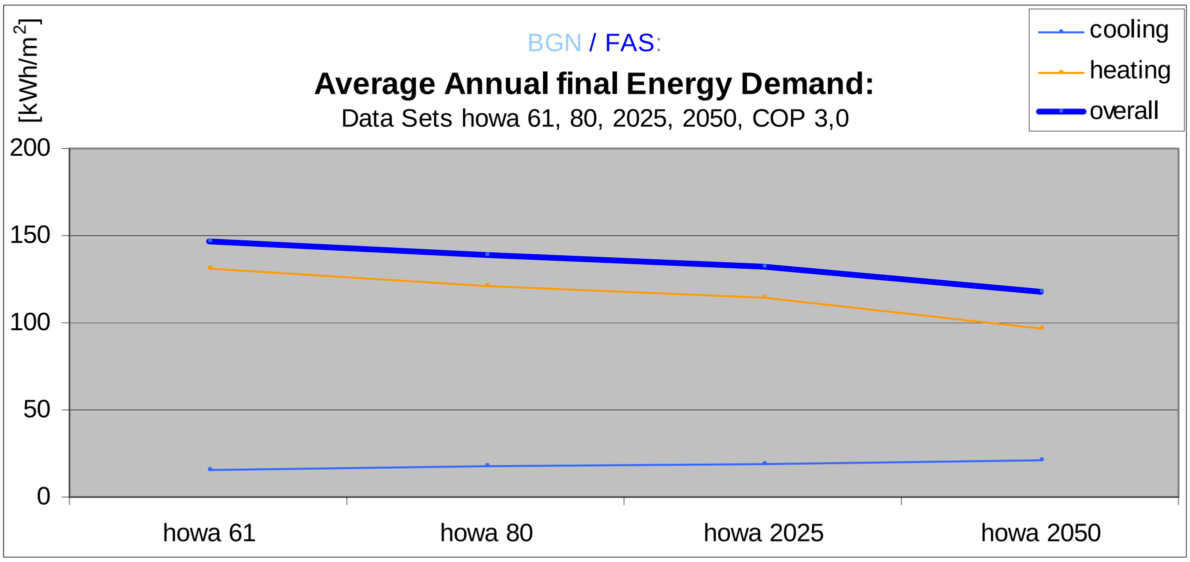


Graph 56: Final energy demand for COP 3,0 in SOL 4

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



Graph 57: Final energy demand for COP 3,0 in ONB



Graph 58: Final energy demand for COP 3,0 in BGN

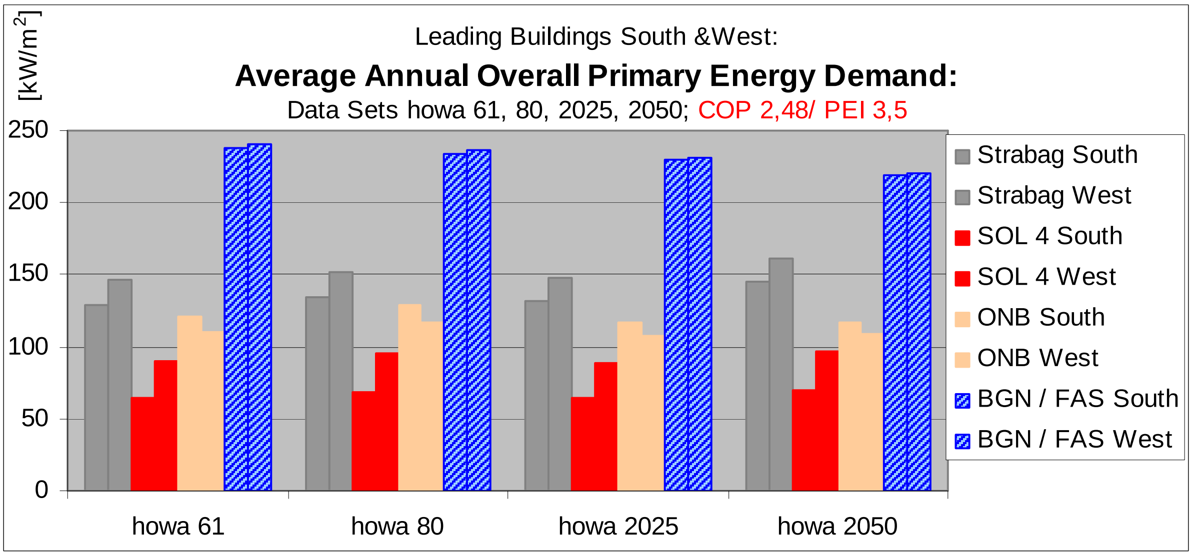
Results of calculation on primary energy demand as shown hereafter have to be considered with high caution; Not only are these results strongly influence by the choice of conversion factors as demonstrated but it also has to be kept in mind that PEI might well change over the course of the decades to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

PEI electricity	
Value	**source**
3,51	OIB guideline, draft October 27, 2010 [27]
2,6	Project "PH Office. Standard für energieeffiziente Bürobauten [28]"

Table 6: Provenience of PEI factors

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

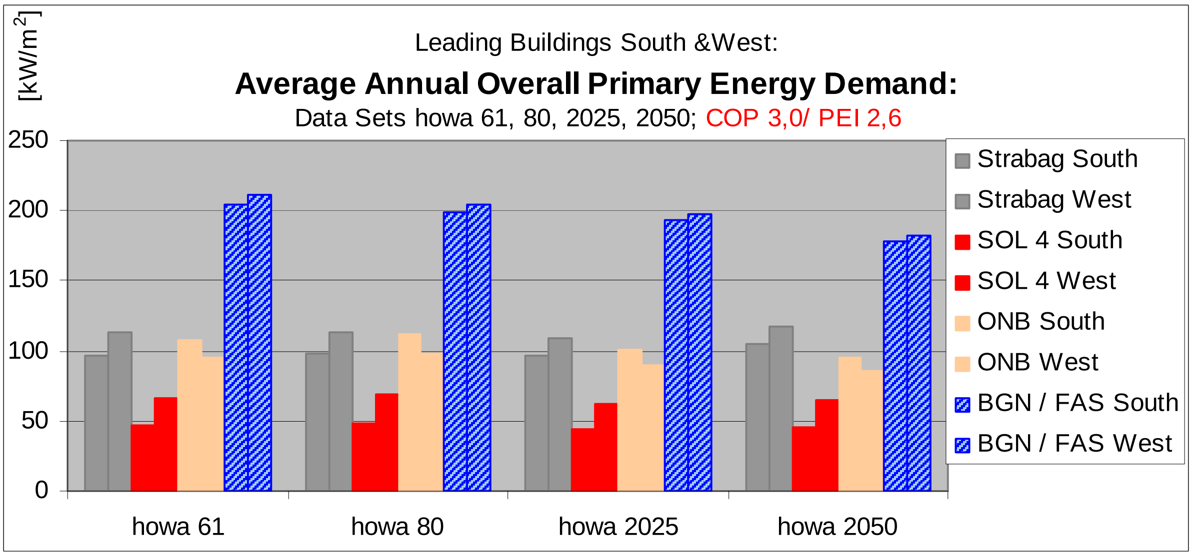
The differences between results from different climate data sets are clearly outnumbered for all buildings by differences effectuated by various conversion factors which range up to 50 kWh/m^2. Herein, COP and PEI are likewise influencing.



Graph 59: Primary energy demand for COP 2,48 & PEI 3,51

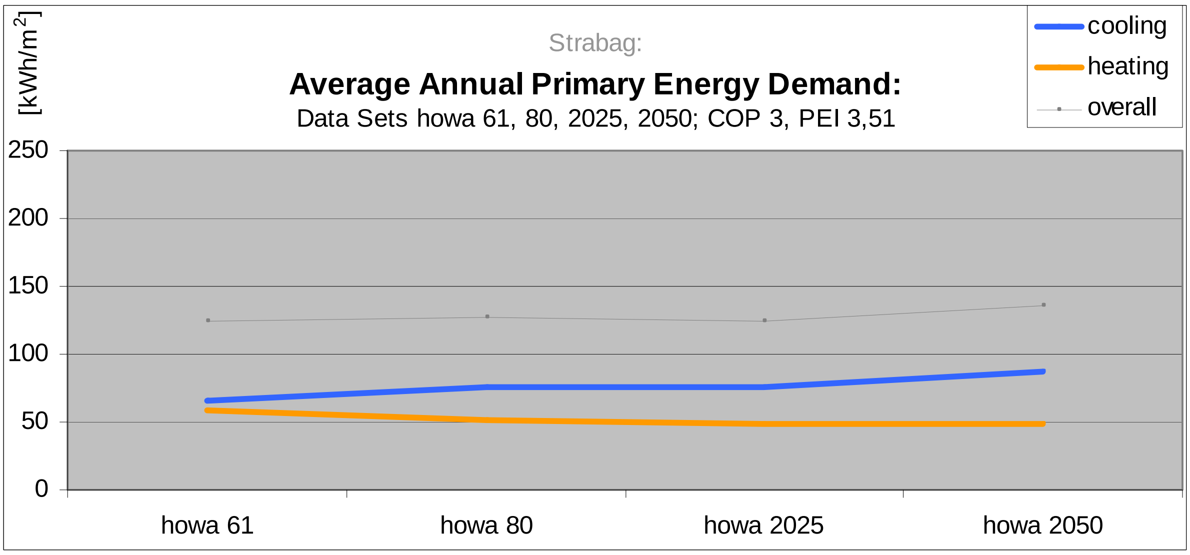
[27] Richtlinie 6, Energieeinsparung und Wärmeschutz (Österreichisches Institut für Bautechnik, Wien, 2010), Österreichisches Institut für Bautechnik, 27.10.2010.

[28] see Table 5: Provenience of COP factors, page 68

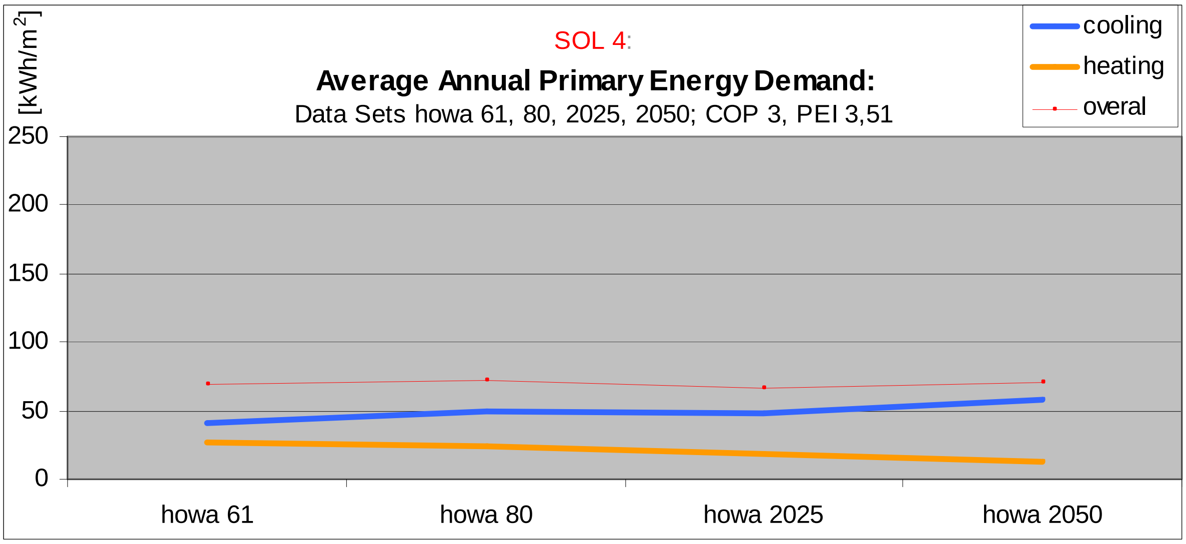


Graph 60: Primary energy demand for COP 3,0 & PEI 2,6

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

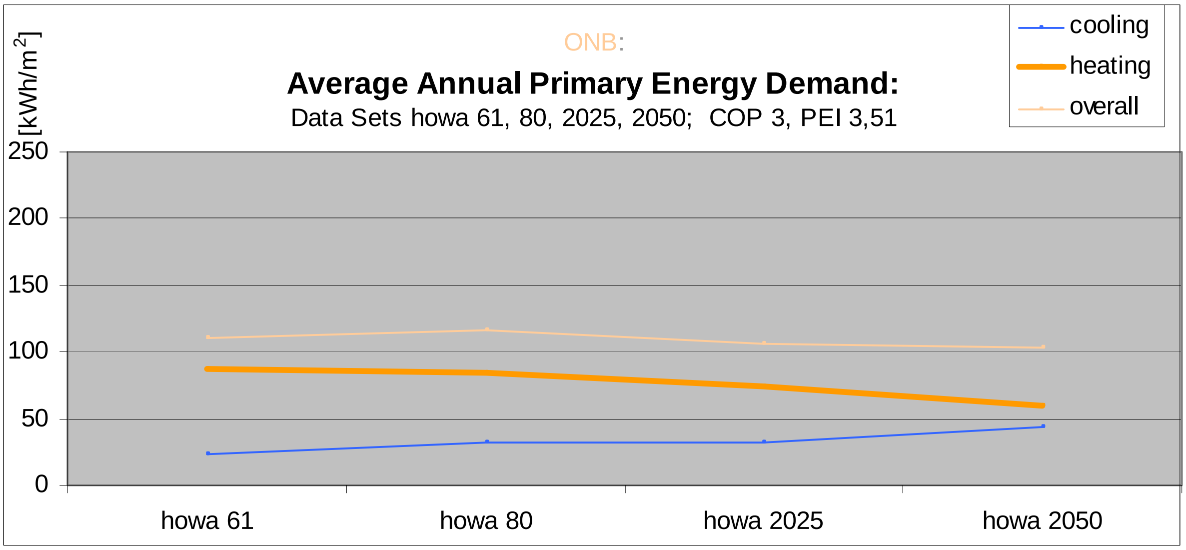


Graph 61: Trend Primary energy demand for Strabag COP 3,0 & PEI 3,51

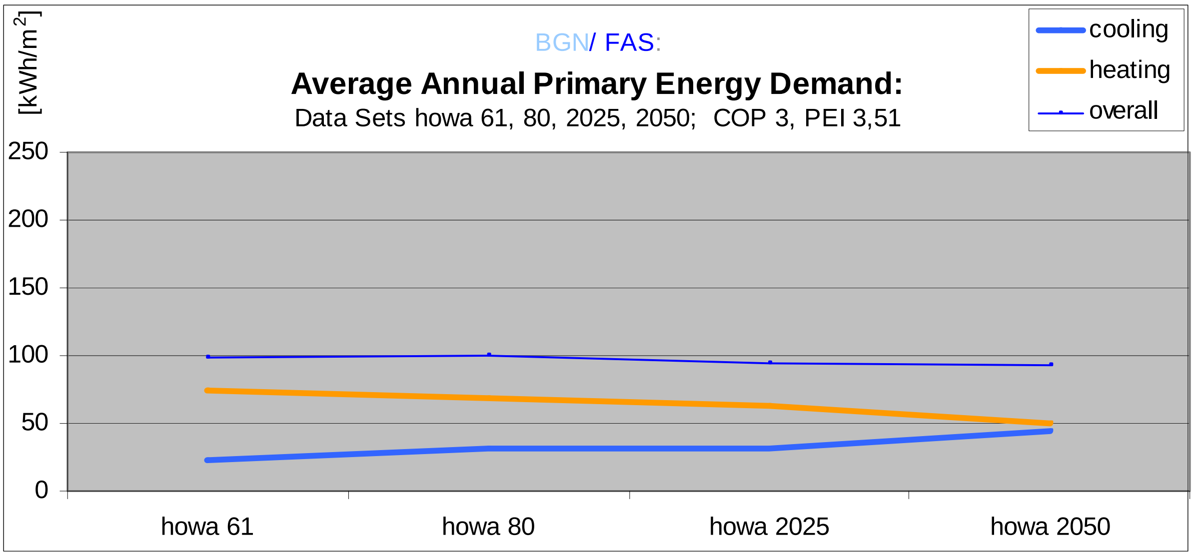


Graph 62: Trend Primary energy demand for SOL 4 COP 3,0 & PEI 3,51

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



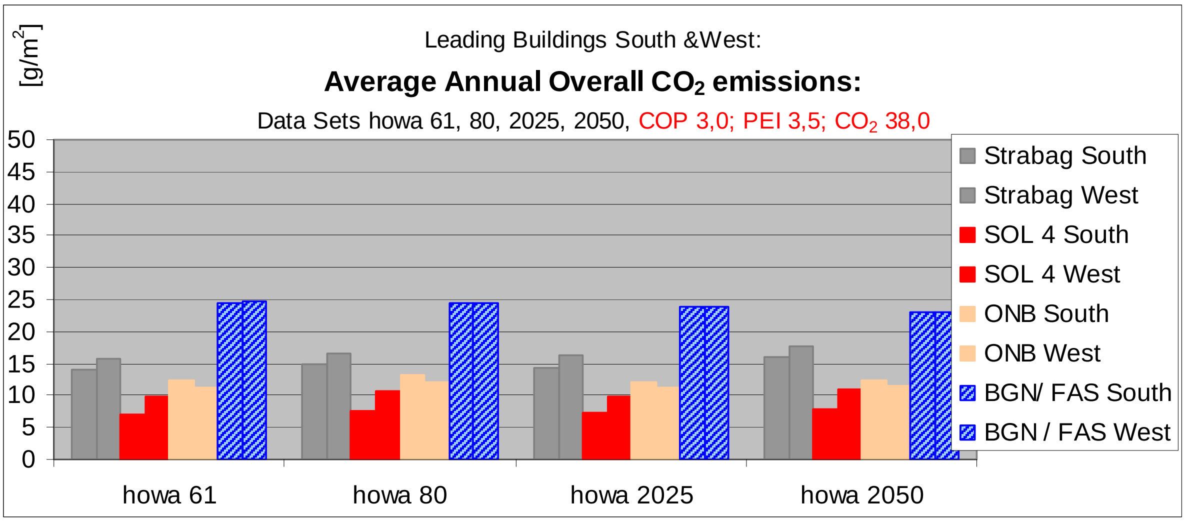
Graph 63: Trend Primary energy demand for ONB, COP 3,0 & PEI 3,51



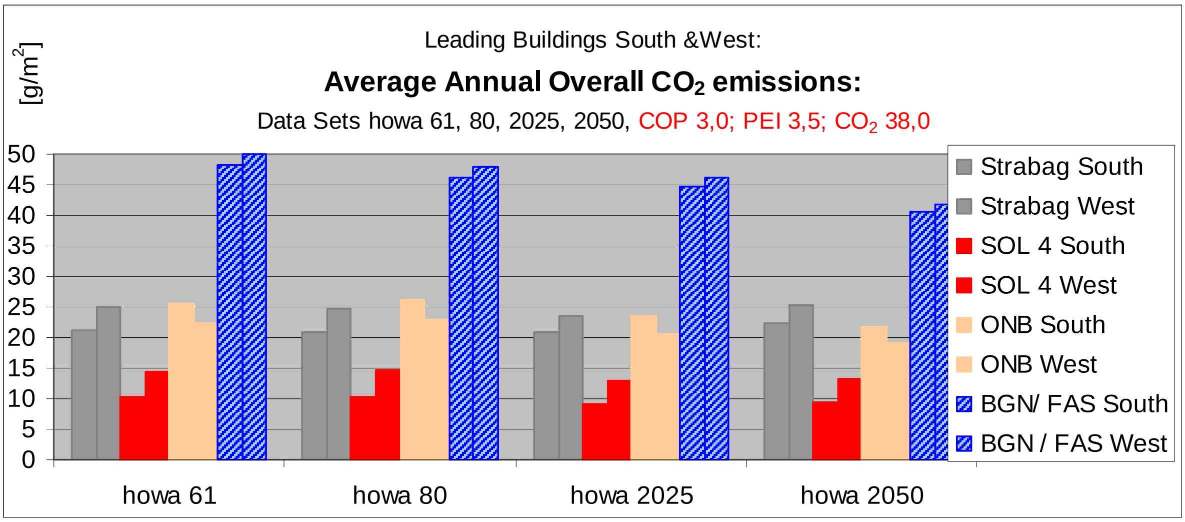
Graph 64: Trend Primary energy demand for LES, COP 3,0 & PEI 3,51

6.1.5 CO_2 - Emissions

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



Graph 65: CO_2 Emissions for Leading Buildings, COP 3,0; PEI 3,51, CO_2 38,0;



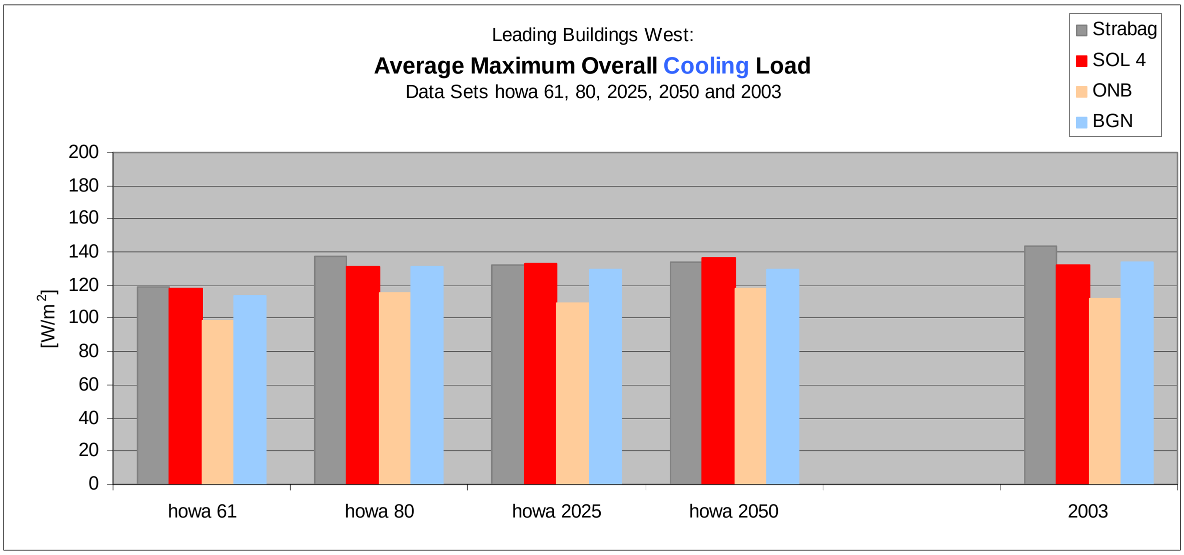
Graph 66: CO_2 Emissions for Leading Buildings, COP 3,0; PEI 3,51, CO_2 200,0;

6.1.6 Maximum cooling load

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

Maximum cooling loads of all leading building range clearly above the threshold of approximately 40 W/m^2, which can be provided by hybrid cooling measures only[29]. Again, results for passive house SOL4 have to be regarded with caution as they do not reflect the actual situation in a full scale passive house but only reflect the constructive properties of the building shell.

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

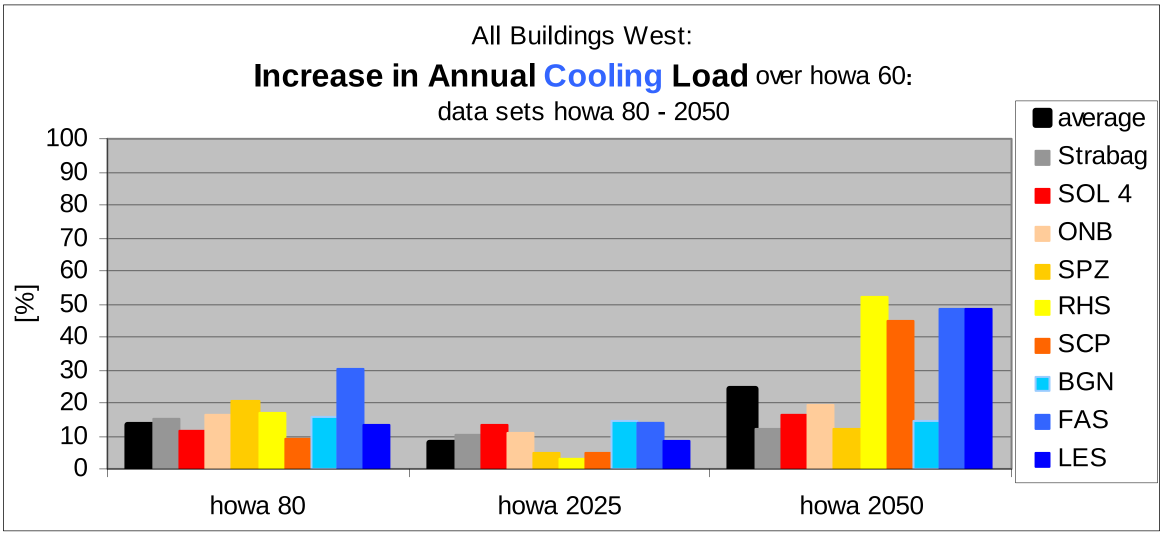


Graph 67: Maximum Cooling Load

The increases in maximum cooling over the temporal resolution from climate data set “howa 61” to “howa 2050” is not as clear and consistent as is the increase in cooling demand[30]. In some buildings such as Strabag and BGN higher loads are found under climate data set “howa 80” than under “howa 2025” and even “howa 2050”.

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

[30] see Graph 40: Increase in net cooling demand , page 65



Graph 68: Increas in Maximum cooling load **Fehler! Textmarke nicht definiert.**

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

6.1.7 Cooling load under Design Day Conditions

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

The corresponding Austrian technical norm ÖNROM B 8110-3 (1999)[31] includes two descriptions for the compilation of Design Day climate data sets.

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

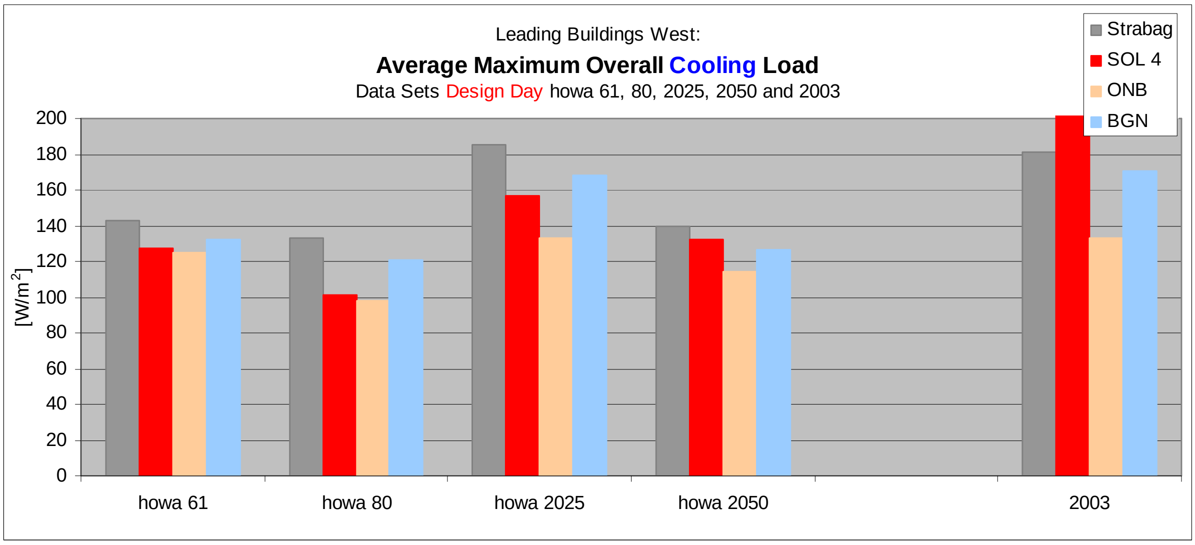
Not only does this compilation mode disconnect the complex relationship of corresponding data for both temperature and irradiation, it furthermore is also useless for the depiction of several different climate data sets referring to different stages in the temporal evolvement of climate change.

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

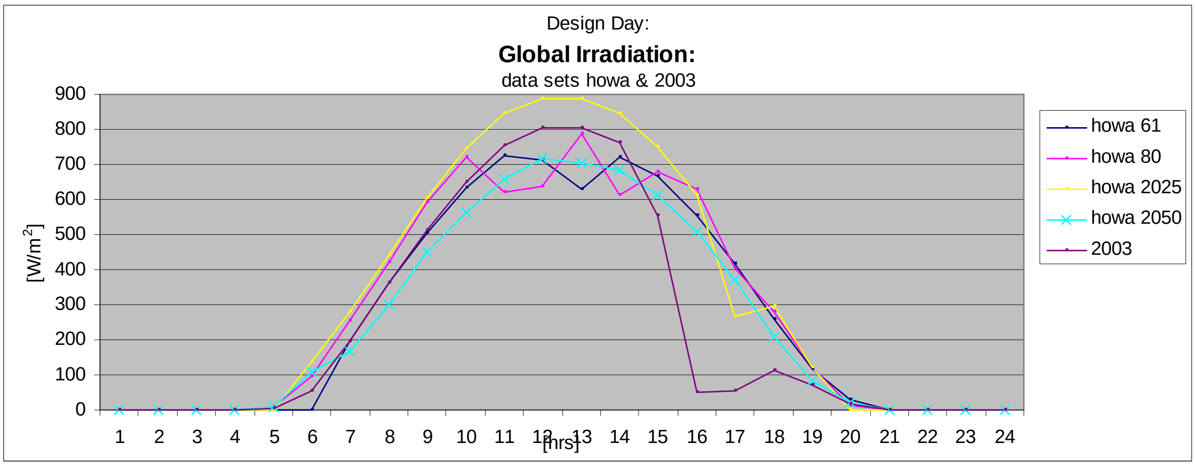
Option 2 takes local conditions into account and asks for a 24 hours' set of outdoor air temperatures which is not surpassed on more than 13 days in long-term mean. Irradiation data for these 24 hours is to be withdrawn from June 15 of this long term mean.

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

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



Graph 69: Maximum cooling load under Design Day conditions



Graph 70: Global Irradiation of Design Days

6.1.8 Conclusions and Discussion

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

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

Cooling demand
Increases:

- Net cooling demands generally increase over the course of time by an average of 80%.
- Two distinct steps are discernable in this increase: one (between “howa 61” and “howa 80”) has actually already taken place while the second one is detectable between “howa 2025” and “howa 2050”.

- The average increase in absolute figures range around 20 kWh/m^2.

Orientation

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

Building types

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

Heating demand

Decreases:

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

Orientation

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

Building types

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

Final energy demand

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

Maximum cooling load

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

Simultaneous decrease of heating and increase of cooling demand will require a shift in paradigm of conditioning. Many old buildings as of today are not at all equipped with cooling devices. This will bring them to the verge of unuseability under future conditions in summer[32]. Their significant heating demands will be somewhat diminished by milder winters, although remaining high in absolute values.

[32] for conditions to be expected in ONB and BGN without cooling refer to page 87

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

Solar and internal heat loads from electronic equipment make up for the most significant drivers of cooling demand. Thus high glazing fractions of the exterior wall and high occupancy strongly influence a building's performance under hot summer conditions[33]. Options to reduce both offer first approaches to reduce cooling demands.

6.2 Module 2: Discussion of comfort models

Mechanical cooling in offices is always applied with the aim of providing thermal comfort for office workers and thus enabling them to fruitfully pursue their daily work. This is to say that thermal comfort and energy demand for cooling are reciprocally linked.

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

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

- ÖNORM EN 7730

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

- ÖNORM B 8110-3

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

[33] The energy efficiency of electronic equipment which constitutes the single most relevant internal heat source was kept constant for all buildings here. For effects of different levels of energy efficiency of electronic equipment refer to: Berger, T., Pundy, P. (2010)

Adaptive Comfort Model

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

- ÖNORM EN 15251

categorises buildings according to their users’ expectations regarding thermal comfort. Therein **Category II** refers to new and refurbished buildings with normal expectations; this applies for Strabag. If mechanical cooling is applied – which is the case in Strabag – the PPD/ PMV comfort model acc. ÖNORM 7730 should be followed and a temperature limit of **26°C** should not be surpassed in single office rooms.
Category III refers to existing buildings with moderate expectations; this applies for ONB and BGN. In these mainly naturally ventilated buildings which allow for a certain user’s influence on indoor climate an adaptive comfort model may be applied. Therein comfort temperature limits depend upon a gliding average outdoor temperature which takes into account shifting weather conditions and users’ expectations depending thereon. However, for cooling load calculation a comfort temperature limit of **27°C** is applied.
Surpassing comfort temperature limits is acceptable for 3 resp. 5 % of working hours weekly, monthly and yearly.

However, chapter A.2., page 28, of ÖNORM EN 15251 contains two remarkable, limiting statements concerning the foreseen comfort limits:

- Temperature limits are based on comfort studies which did not take workers’ productivity into account.
- In the range above 25°C these temperature limits are based on a restricted amount of data. In the following graph, this applies for all values of “EN 15251 K3_up_lim” above the black line: significantly more than half the years time is concerned[34].

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

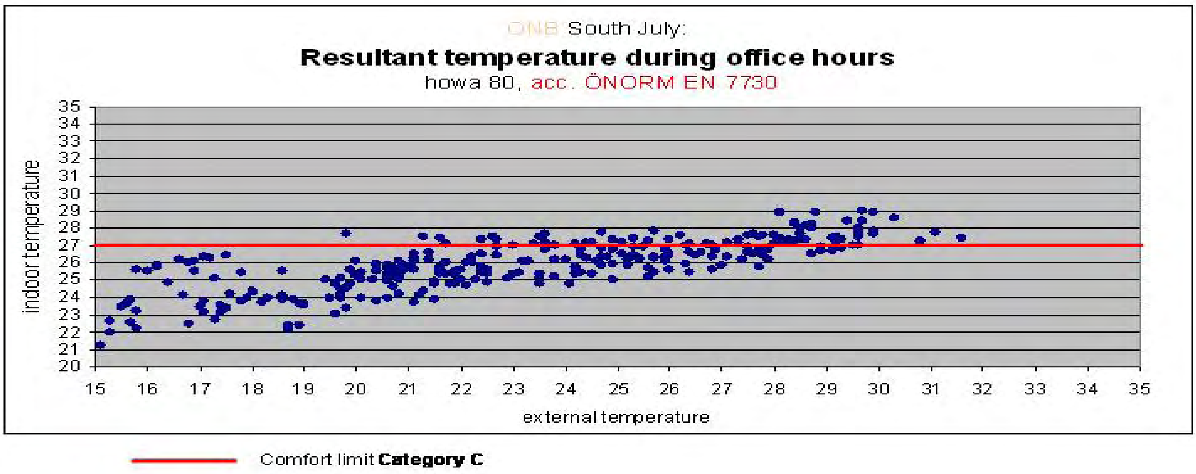
This present situation was taken as a starting point for the following investigation: both buildings hereafter are simulated under non cooled conditions (Simulation mode “real”) and the resulting indoor temperatures are scrutinized. For the assessment of the comfort situation thus evolving in the buildings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

[34] see Graph 13: Annual swing of upper and lower comfort limit for climate data set “howa 2050” acc. EN 15251 , page 28

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

Table 7: Investigated sample buildings, simulation modes and employed climate data set in Module 2a

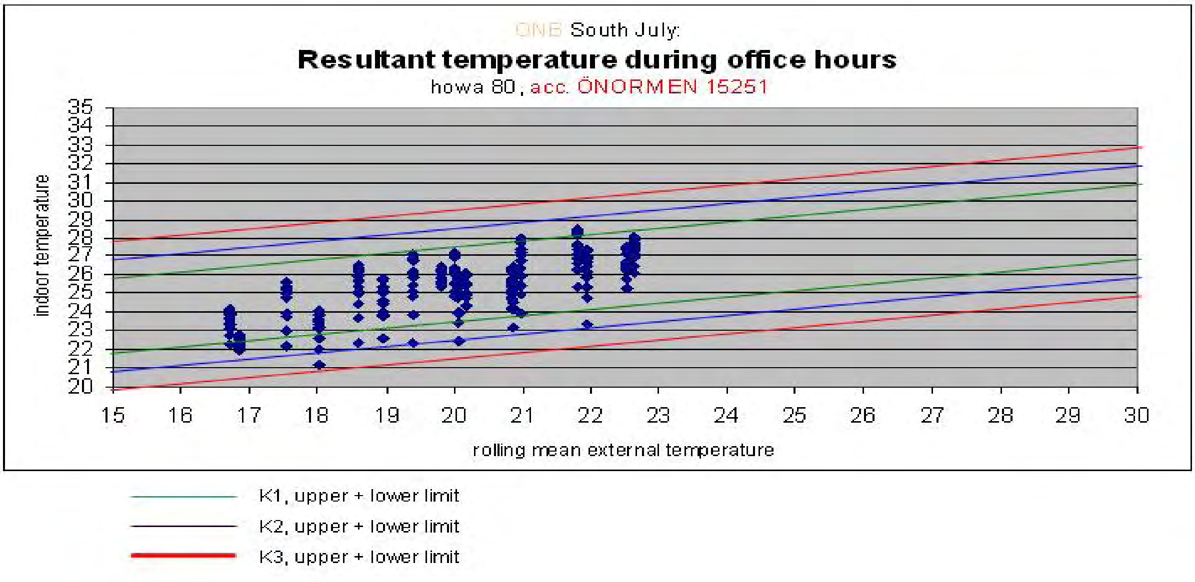
6.2.1 Comfort in Buildings from before WW1: ONB



Graph 71: Resultant temperature in ONB under data set „howa 80" according to EN 7730 **Fehler! Textmarke nicht definiert.**

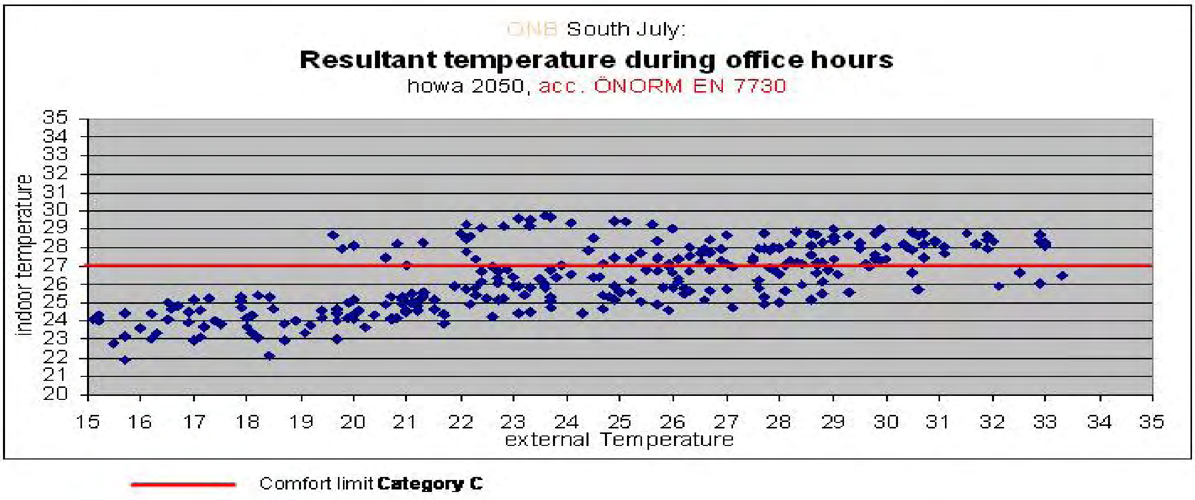
The applicable comfort temperature limit of category C is discernable surpassed in 23 office hours during the investigated month of July of "howa 80" in ONB. Furthermore, it can be seen from Graph **71** that indoor temperatures tend to run about 2 to 3 K in excess of outdoor temperatures as long as these outdoor temperatures range up to 24°C. Beyond this threshold, internal and external temperatures gradually approximate, therein manifesting the damping effect of the building's thermal mass.

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



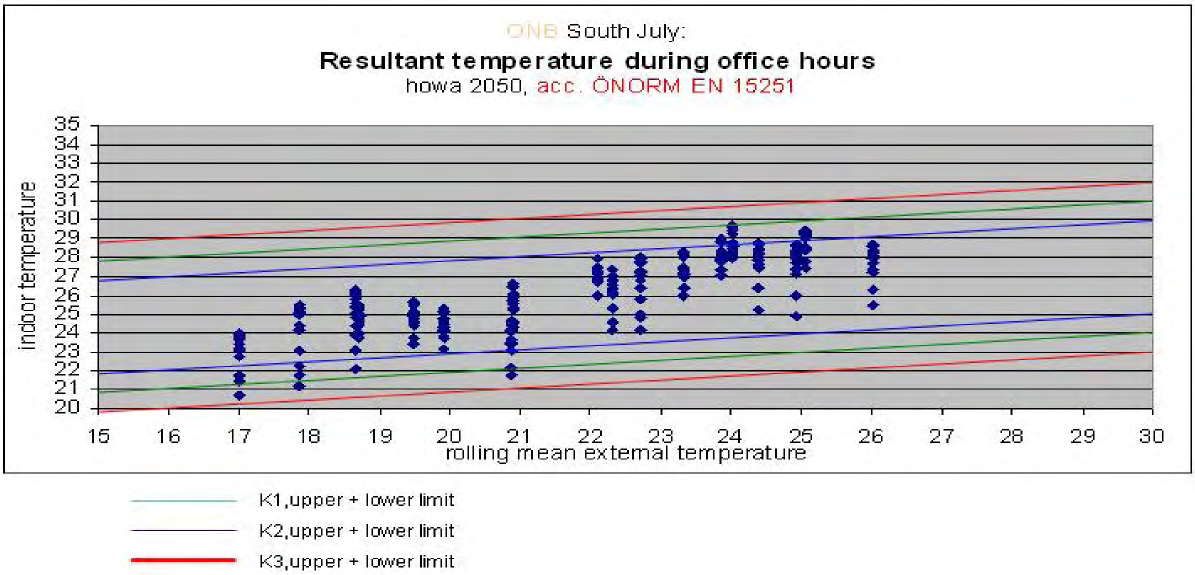
Graph 72: Resultant temperature in ONB under data set „howa 80" acc. to EN 15251 **Fehler! Textmarke nicht definiert.**

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



Graph 73: Resultant temperature in ONB under data set „howa 2050“ acc. to EN 7730 **Fehler! Textmarke nicht definiert.**

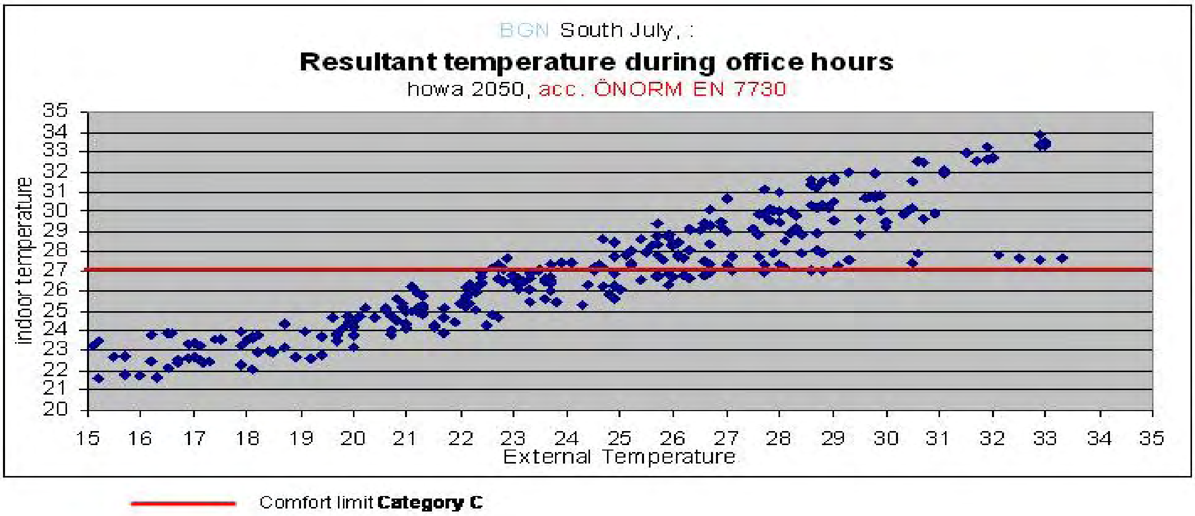
When comparing results under ÖNORM EN 15251 for “howa 80” and “howa 2050” the shift of rolling mean temperatures to higher values around 26°C is obvious. Still, no surpassing of comfort limits takes place as temperatures up to 31°C would be acceptable under these conditions for buildings of category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



Graph 74: Resultant temperature in ONB under data set „howa 2050“ acc. to EN 15251 **Fehler! Textmarke nicht definiert.**

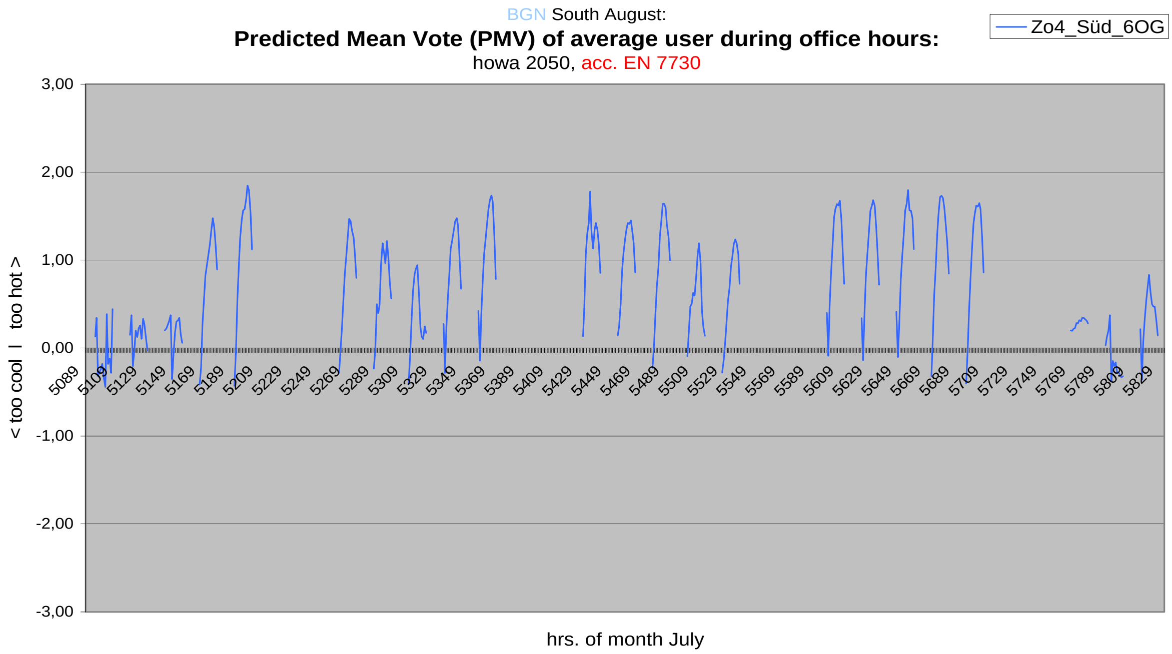
6.2.2 Comfort in Buildings form after WW2: BGN

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



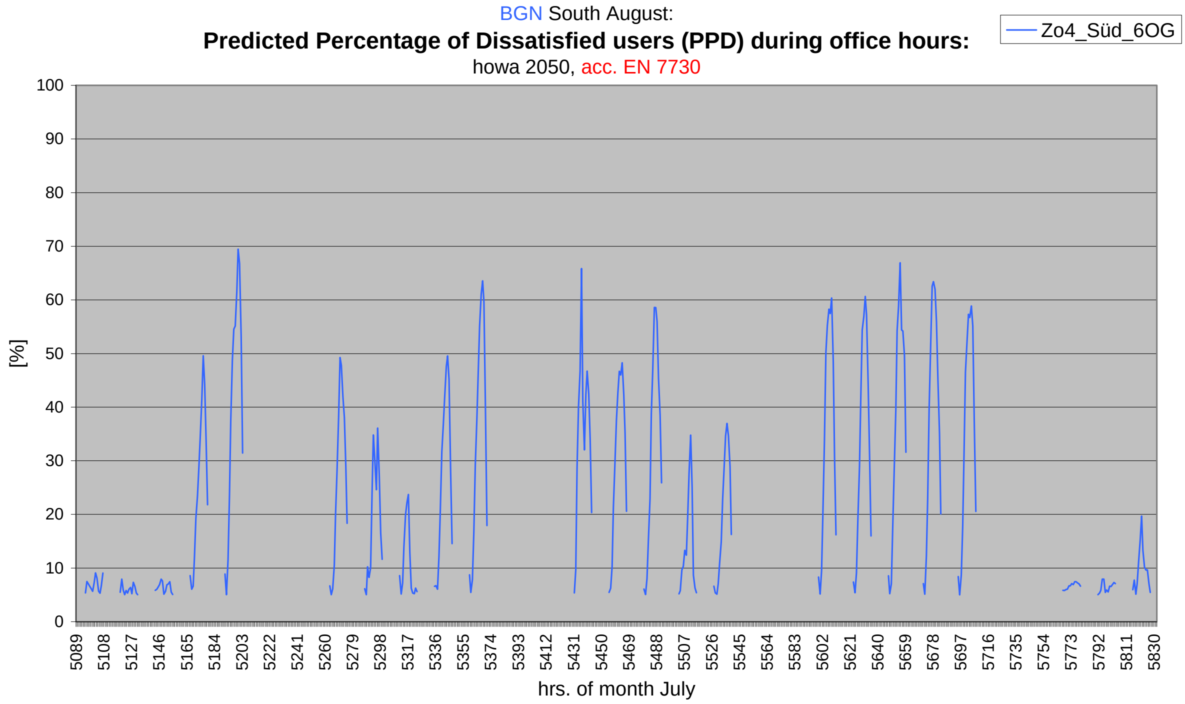
Graph 75: Resultant temperature in BGN under data set „howa 2050“ acc. to EN 7730 **Fehler! Textmarke nicht definiert.**

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



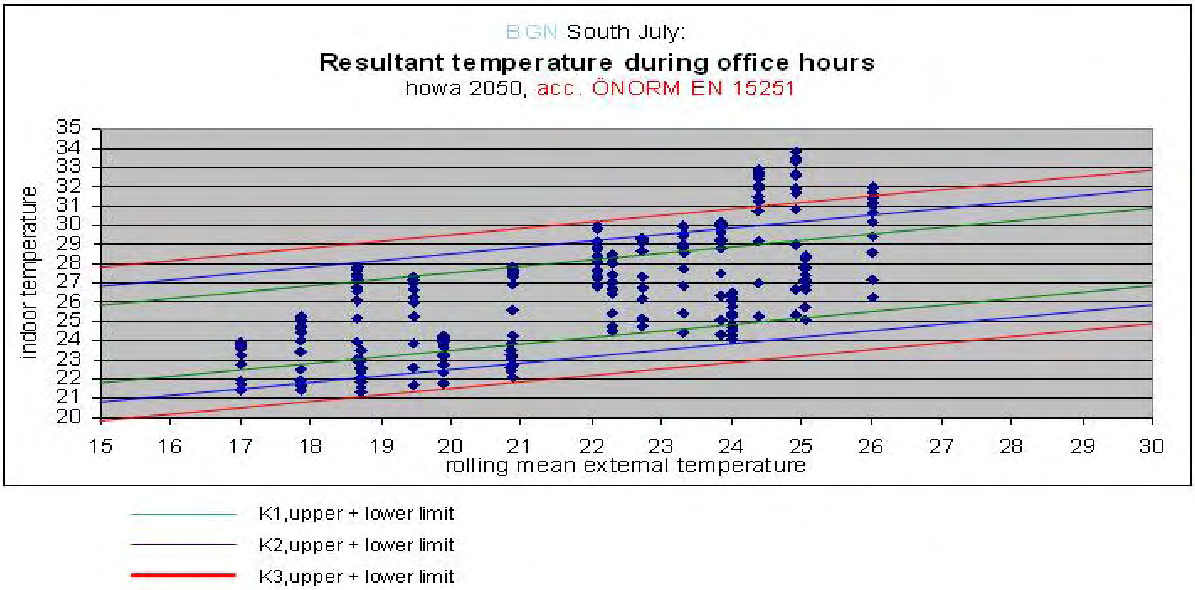
Graph 76 : Predicted mean vote during office hours in BGN under data set howa 2050 **Fehler! Textmarke nicht definiert.**

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



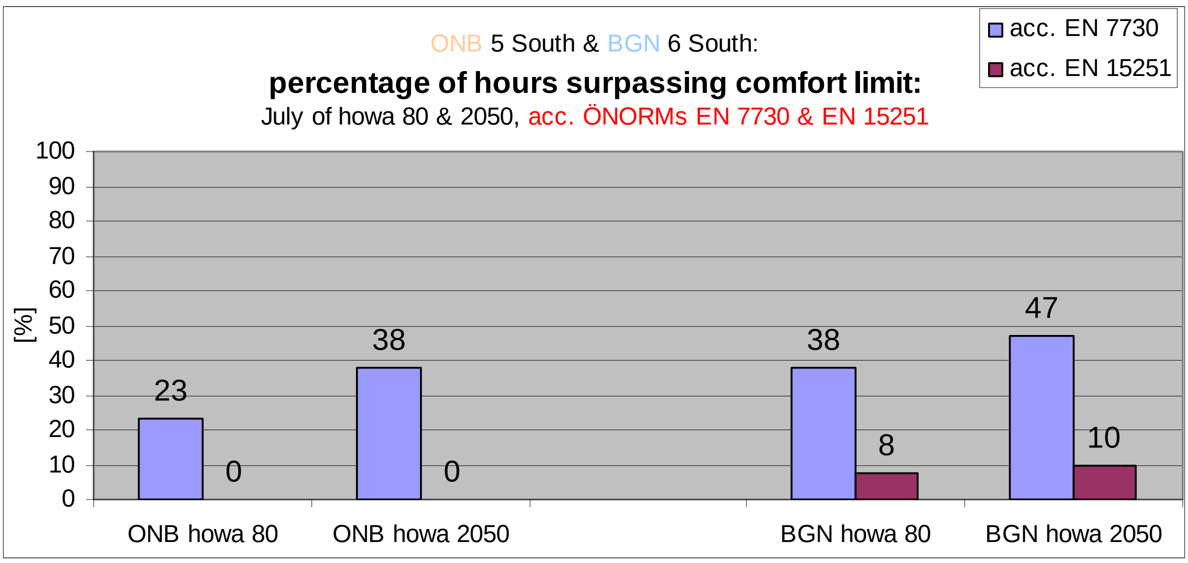
Graph 77: Predicted percentage of dissatisfied users during office hours in BGN under data set howa 2050

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



Graph 78: Resultant temperature in BGN under data set „howa 2050“ acc. to EN 15251 **Fehler! Textmarke nicht definiert.**

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



Graph 79: Percentage of office hours surpassing comfort limits

6.2.3 Conclusions and Discussion

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

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

This makes up for the decisive difference to the Fanger model which clearly aims at conditioned buildings although, in day to day engineering, it is generally applied to all sorts of office blocks. Extensive studies by Michael Humphreys and Fergus Nicol[35] et al have evidenced, however, that people in free running buildings react differently, especially if in control of their personal microclimate by means of shading, window opening etc[36].

6.3 Module 3: Impacts of urban heat island

Urban heat island effects have been abundantly described in respective literature[37] and are well known to result in increased urban outdoor temperatures as compared to the surrounding countryside. The present module's simulation aimed at exemplary calculation of differences in cooling and heating energy demand on different urban location within the city of Vienna.

Three such locations[38] were examined for the complete temporal resolution form “61” to “2050” in all leading buildings. Internal conditioning of these buildings was kept uniform (simulation mode “Standard”).

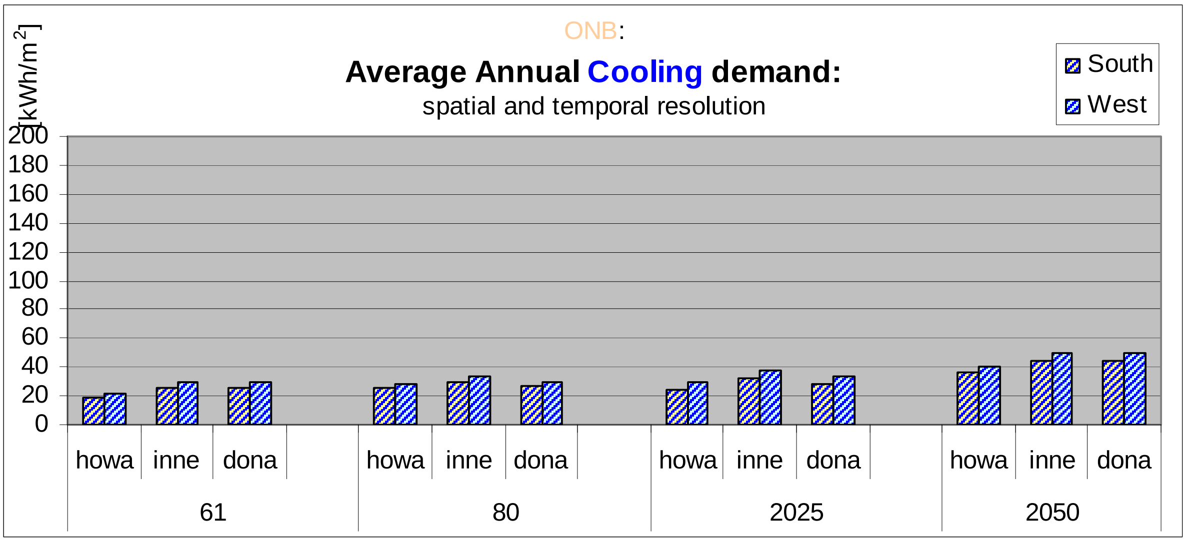
[35] Nicol, J. F. & Humphreys, M. A. (2002).
[36] see page 129
[37] see chapter 9.2.4 Urban heat island, page 136
[38] as described in chapter 1.3 Description of climate data sets, page 20

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

Table 8: Investigated sample buildings, simulation modes and employed climate data set in Module 4

6.3.1 Net Cooling energy demand

Climate data sets “inne” represent the inner most location of the three different spatial resolutions simulated within this study. As was to be expected from abundant literature on the phenomenon of urban heat island, this location is the hottest one[39] and yields the highest net cooling demand in consequence, with “dona” ranking second and “howa” showing lowest figures. Differences between hottest and coldest location are within a margin of about 5 kWh/m^2. This is roughly a quarter of the difference found for each location for the temporal resolution from “61” to “2050”. Again, West facing office rooms are found to have slightly higher cooling demands than those orientated to the South

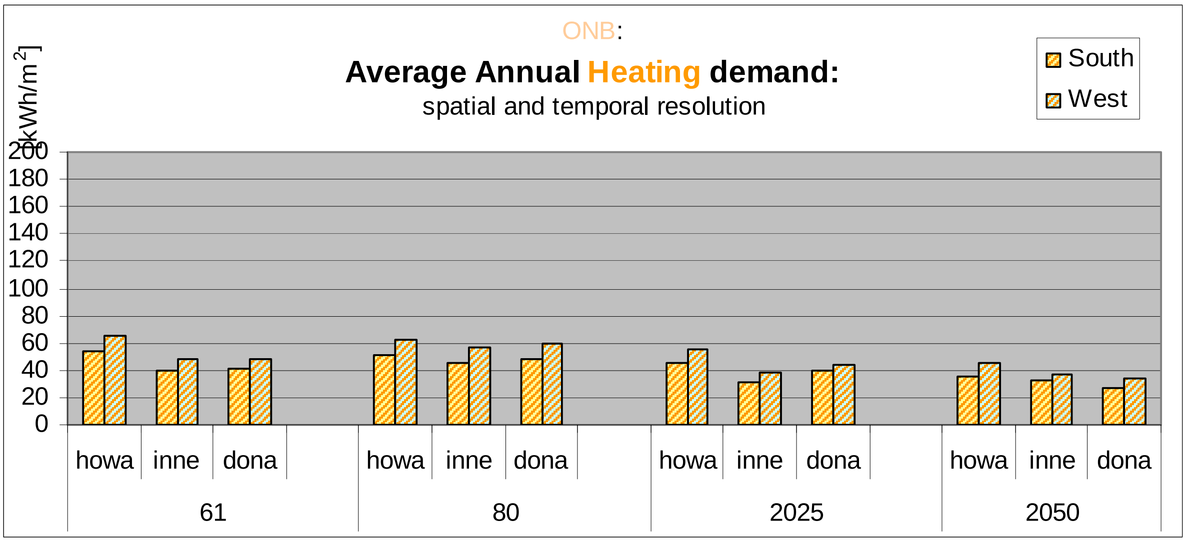


Graph 80: Impact of urban heat island on net cooling energy demand for ONB **Fehler! Textmarke nicht definiert.**

[39] see Graph 10, page 26

6.3.2 Net Heating energy demand

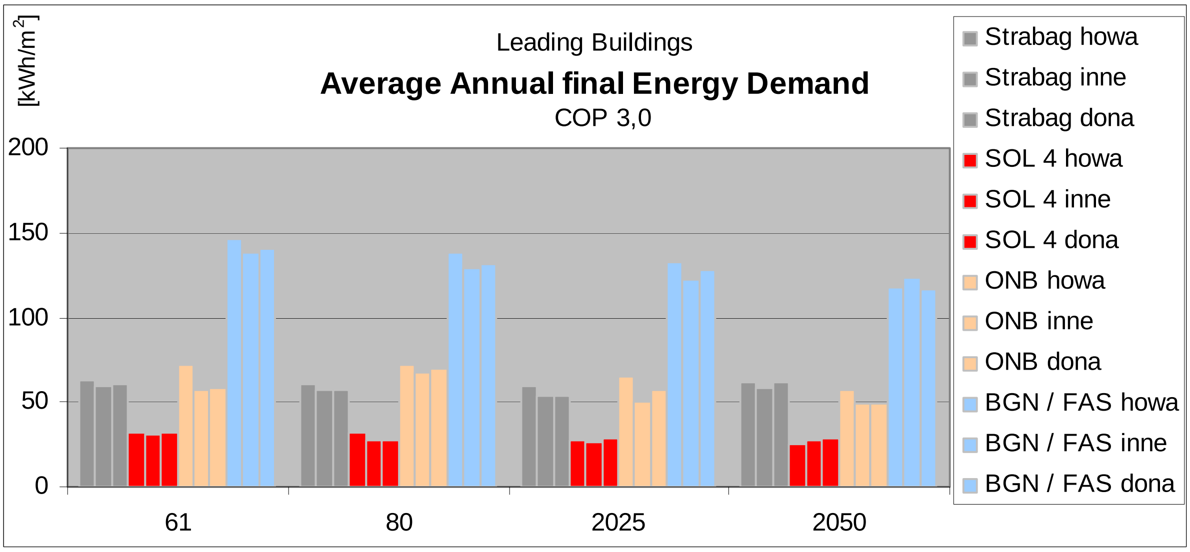
Mirror inverted to the situation for cooling, the hottest location out of the three urban sites investigated displays the lowest heating demands, the coldest requires most heating. The difference between these two tends to be slightly higher than in the case of cooling, reaching up to 10 kWh/m^2. The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



Graph 81: Impact of urban heat island on heating demand of ONB **Fehler! Textmarke nicht definiert.**

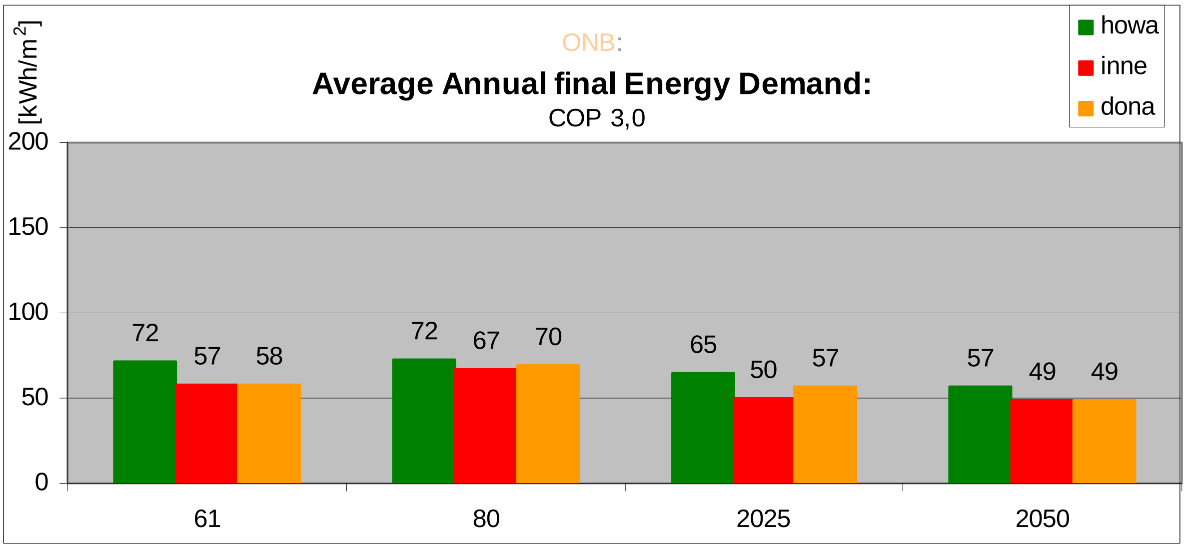
6.3.3 Final and Primary Energy demand

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



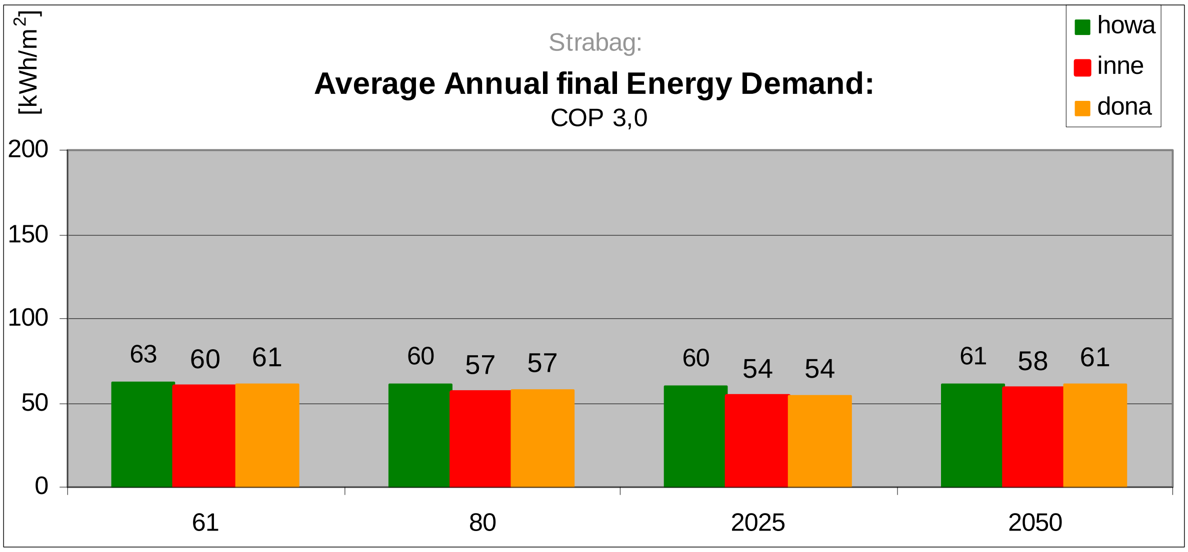
Graph 82: Temporal and spatial resolution of final energy demand in leading buildings **Fehler! Textmarke nicht definiert.**

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



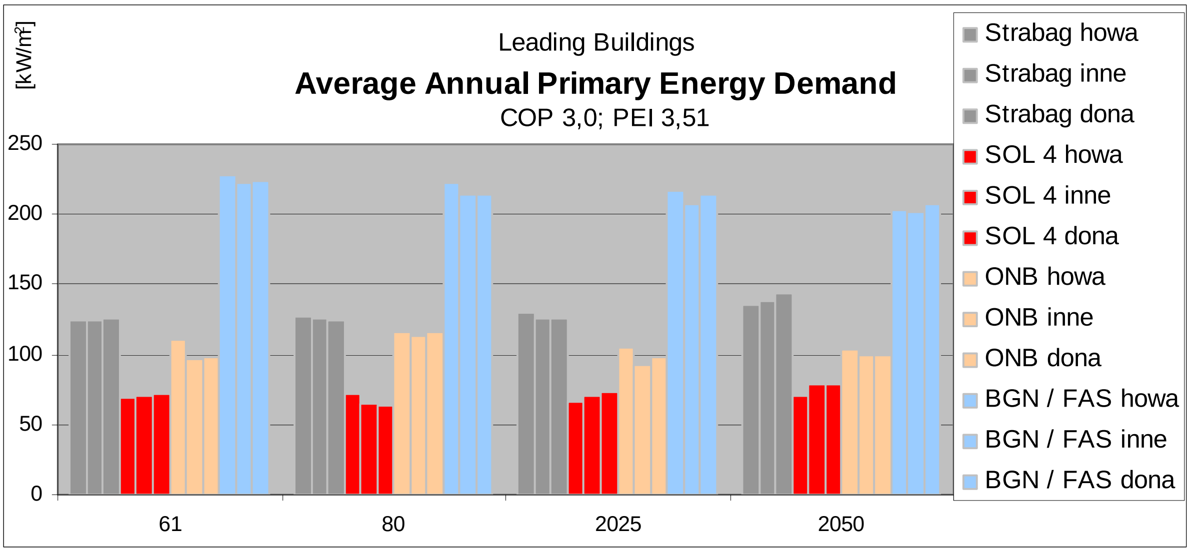
Graph 83: Temporal and spatial resolution of final energy demand in ONB

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



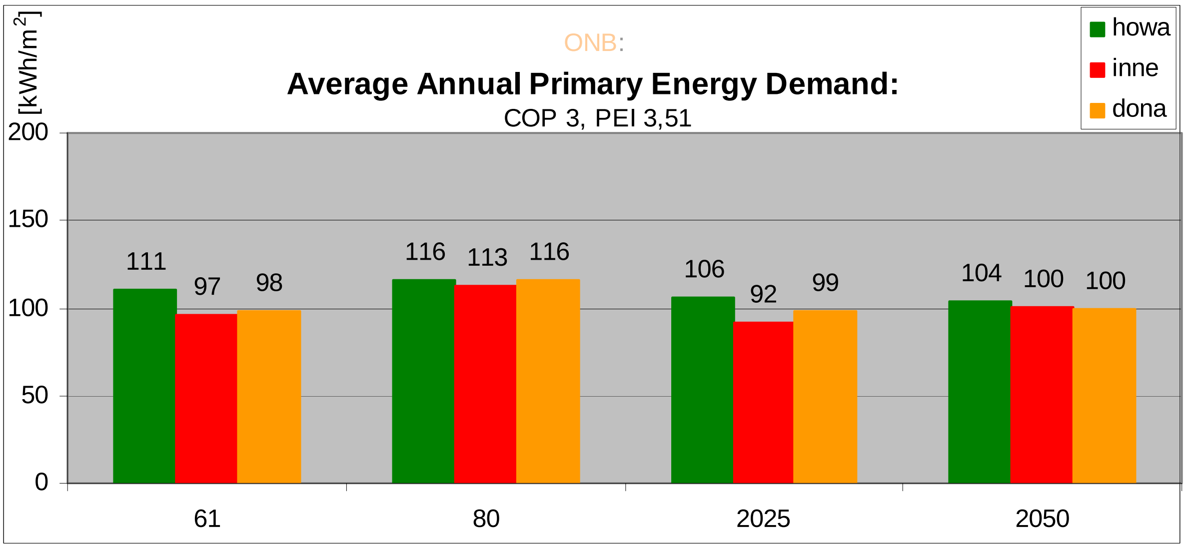
Graph 84: Temporal and spatial resolution of final energy demand in Strabag

The situation is slightly less uniform when looking at overall primary energy demand: as can be seen in Graph **61** to Graph **64**, page 64, the trend of temporal resolution, apart from partly being influenced by the chosen conversion factors, differs for building types, again depending on whether cooling or heating is predominant in a particular building.



Graph 85: Temporal and spatial resolution of primary energy demand in leading buildings

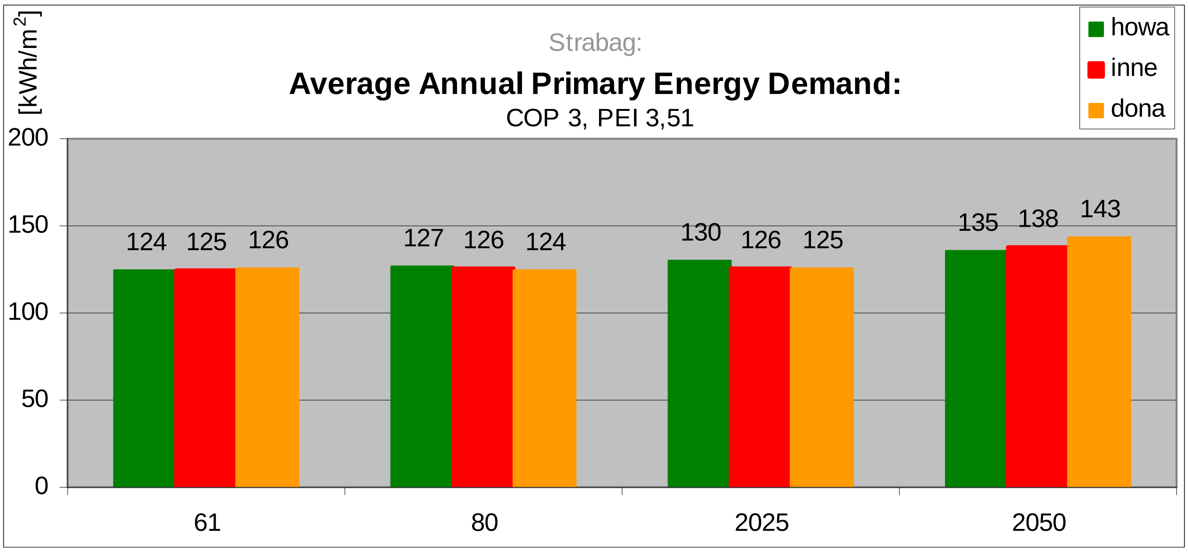
In buildings from before WW1 such as ONB heating demand by far exceeds cooling demand. Hence, due to the overall decrease in heating demand in temporal resolution overall demand also decreases slightly and does so for all spatial resolutions. The hottest location “inne” therefore yields the lowest overall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



Graph 86: Temporal and spatial resolution of primary energy demand in ONB

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

In highly glazed buildings such as Strabag, cooling demand surpasses heating requirements. This effectuates overall primary energy demand to slightly increase over time as hotter climate data sets cause more cooling (see Graph **61**, page 64). However, as these differences are small, the trend for spatial resolution is unambiguous: the hottest location "inne" mostly ranges medium.



Graph 87: Temporal and spatial resolution of primary energy demand in Strabag

6.3.4 Conclusions and Discussion

- The used climate change scenario (REMO-UBA) shows a warming trend of ~0,4 °C per decade in Vienna. The range of thermal variability within the urban area of Vienna has the magnitude of ~ 1 °C. It takes around 25 years, that the cooler regions of Vienna reaches the nowaday temperature regime of the city

- The use of reference year guarantees the inclusion of the diurnal cycle and the day to day variability, but still this data represent the average situation. Thus it is essential to look on the results of the summer 2003, when interpreting the demant for cooling.

- The summer 2003 is not suitable to define maximum cooling demant, as the summer 2003 had only record maximum monthly temperatures, but no records on daily base. Climate change will also increase the occurrence of maximum daily temperatures higher than 40 °C, which has not been the case jet in Vienna.

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

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

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

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

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

6.4 Module 4: Impacts of optimizations in the buildings’ envelop

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

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

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

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

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

Table 9: Investigated sample buildings, simulation modes and employed climate data set in Module 3

6.4.1 u - value

Additional layers of insulation (preferably to be applied externally[40]) result to be the single most effective optimisation of the outer building shell in terms of both net and final energy demand. While this measure insignificantly increases cooling demand in summer due to slightly hindered heat removal during night time hours it remarkably reduces the buildings' heating demand and thereby further enhances the effects of shrinking demands due to global warming.

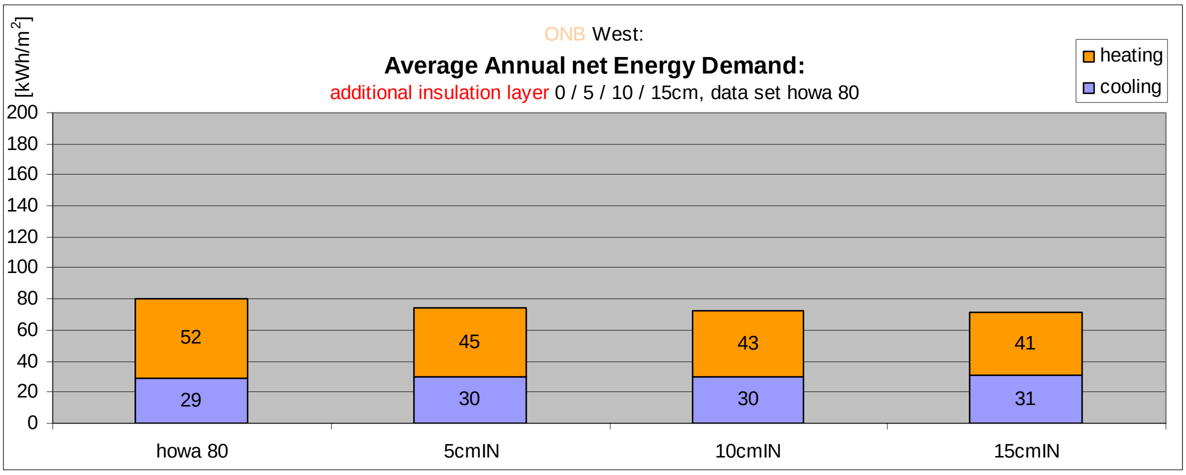
ONB

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

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

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

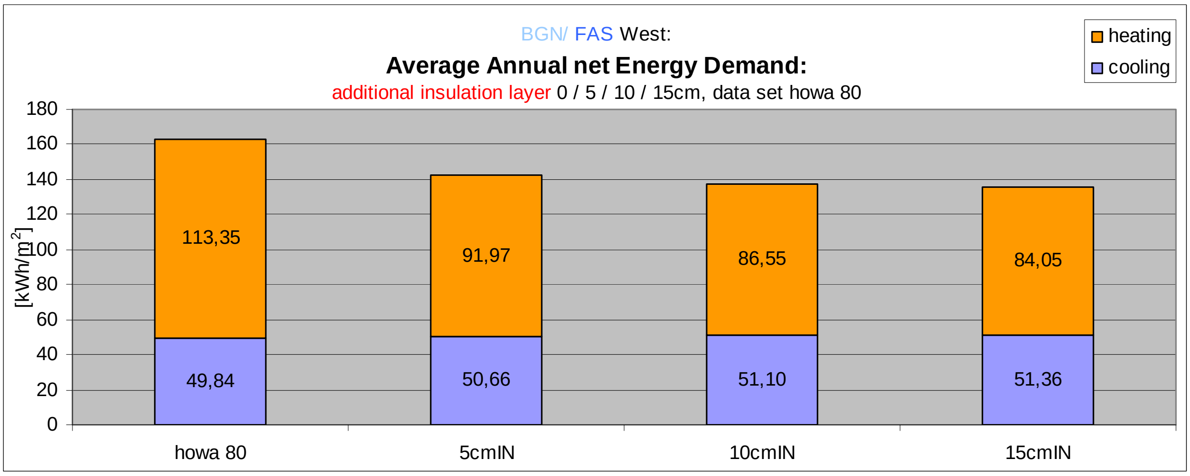
[40] Exceptions have to be considered in historical buildings such as ONB where internal insulation was assumed in order to leave the external appearance untouched. Related concerns about condensation and thermal bridges have to be taken into account.



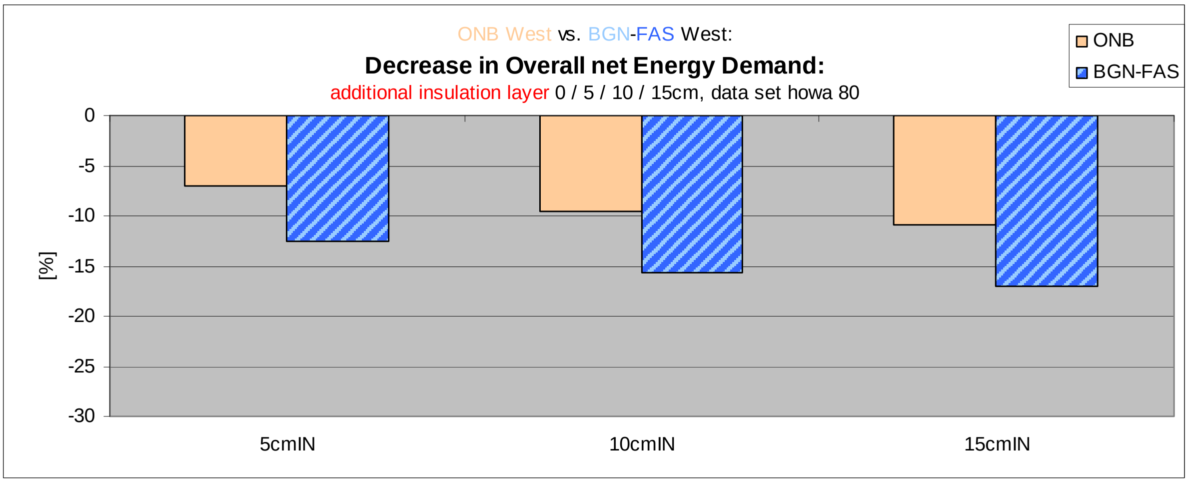
Graph 88: Influence of additional internal insulation layers on Overall net energy demand in ONB

BGN / FAS

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

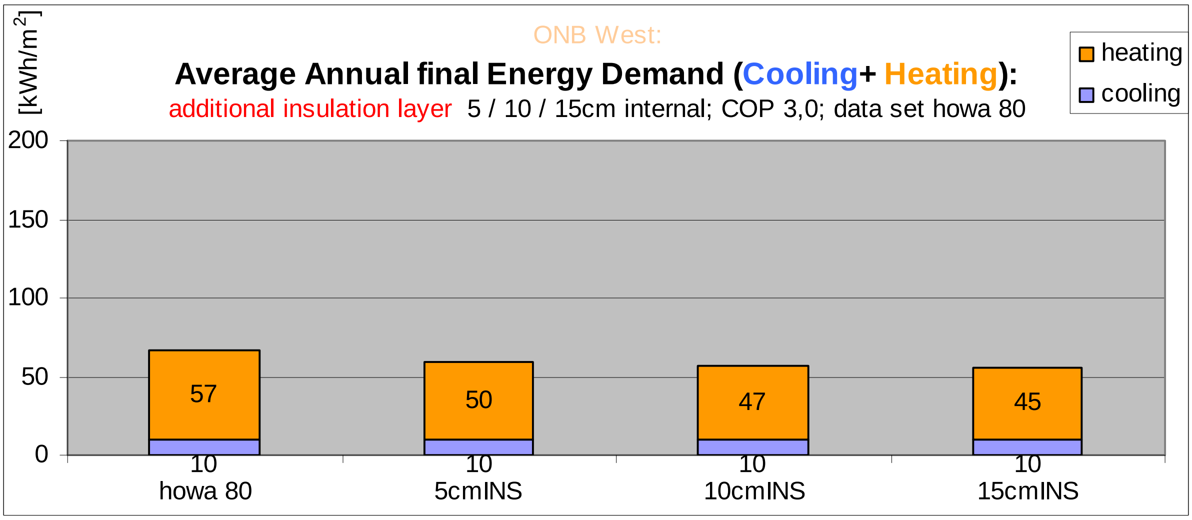


Graph 89: Influence of additional internal insulation layers on Overall net energy demand in BGN/ FAS



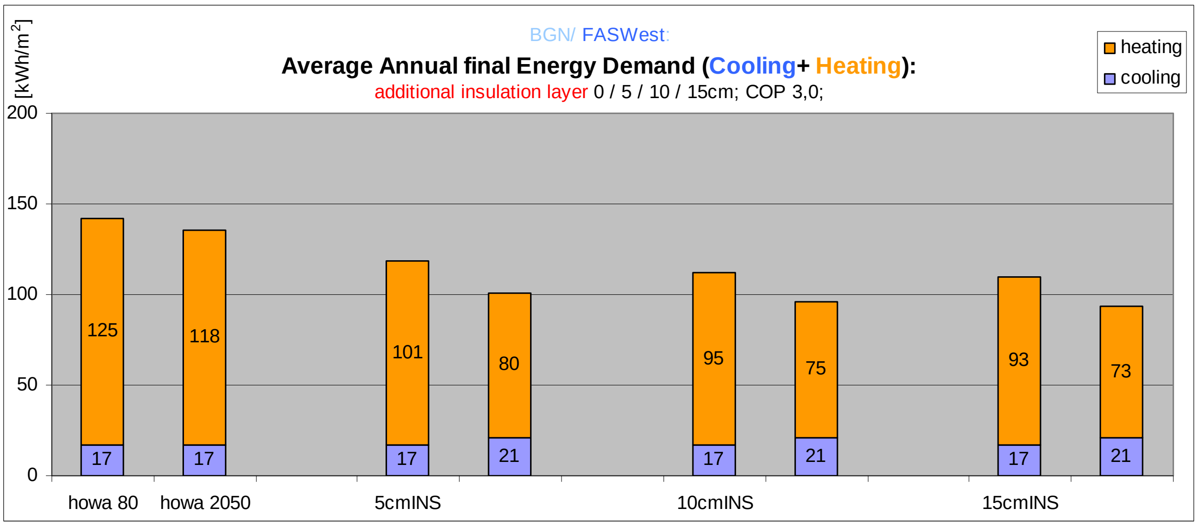
Graph 90: Comparison of decrease in overall net Energy demand

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



Graph 91: Final Energy Demand due to additional layers of internal insulation in ONB

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



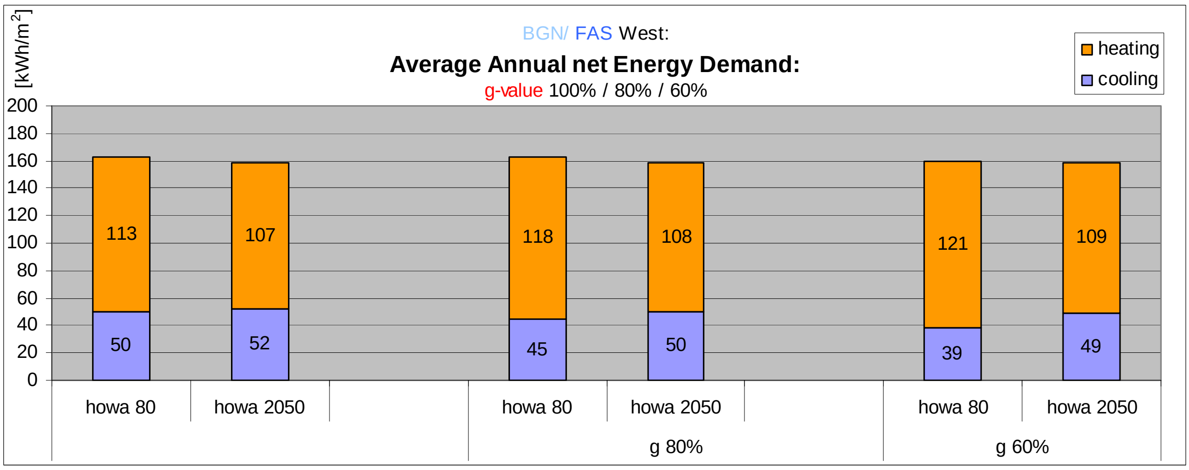
Graph 92: Final Energy Demand due to additional layers of internal insulation in BGN/ FAS

6.4.2 g - value

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

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

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



Graph 93: Influence of g – values on Overall net energy demand in BGN/ FAS

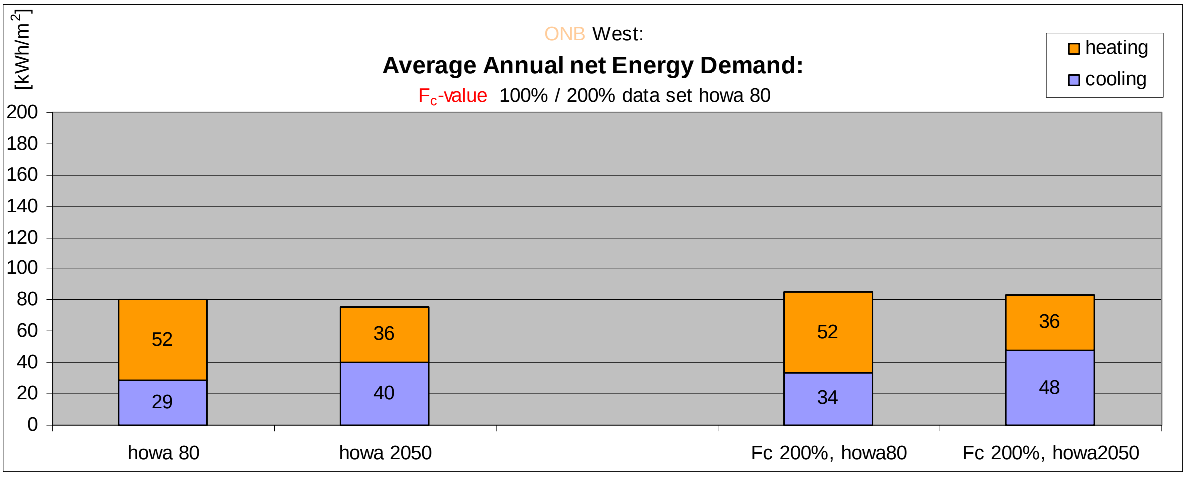
6.4.3 F_c -value

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

<u>From external to inter space shading</u>

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

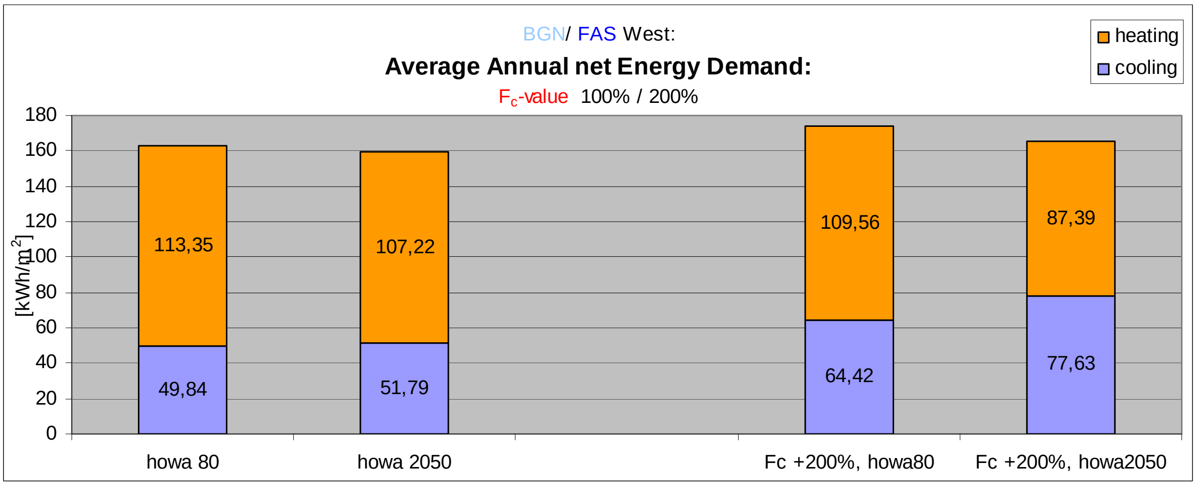
If shading is instead placed in between two window panes, this is equivalent to an increase of F_c-value by approximately 100%. The resulting overall net energy demands are depicted hereafter: while heating demand is assumed to stay unchanged, cooling demand is increased by approximately 5%.



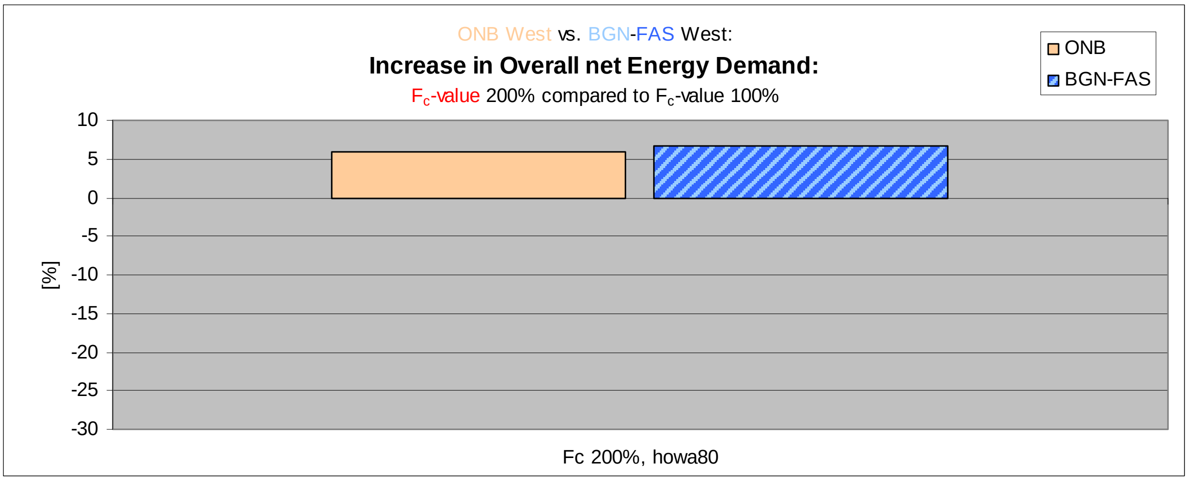
Graph 94: Influence of F_c – values on Overall net energy demand in ONB

From inter space to internal shading

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



Graph 95: Influence of F_c – values on Overall net energy demand in BGN/ FAS



Graph 96: Increase of overall net energy demand due to increases of F_c – Value

6.4.4 Conclusions and Discussion

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

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

6.5 Concluding Portraits of the Leading Buildings

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

6.5.1 Strabag: highly glazed

Constructive properties

This building type is characterized by its extremely high glazing fraction of the outer wall which may well reach up to nearly 100%. This glazing displays a low g-value with solar protective properties. Still, given the high share of transparent building elements in the external wall, these properties are insufficient to completely counteract the impacts of high solar loads.
Even this building’s u-value ranges low though, of course, higher than opaque building elements would do. In other words: good glass (in terms of heat insulation) is still worse than average opaque walls.
F_c-value is rather high as shading can’t be positioned on the outside due to considerations of possibly occurring wind pressures. Instead, shades are placed in the panes’ interspaces.
Office space is optimized to house workplaces on least necessary floor area resulting in comparatively high occupancy ratios and in consequence: high internal loads due to occupancy.
Thermal mass of walls is near to inexistent, mass of ceilings remaining as single source for thermal storage.

Net energy

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

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

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

Final and primary energy

Final energy demand trend (COP 3,0)
Combined final energy demand is slightly dominated by heating demand today. While this heating demand decreases over the temporal resolution, cooling demand increases at the same time resulting in the values of heating and cooling demand to be nearly equal by the time of data set “howa 2050”. Hence, the overall final energy demand of this building type stagnates over the temporal resolution.

Primary energy demand trend (PEI 3,51)
In terms of primary energy demand cooling dominates already today, regardless of conversion factor chosen for PEI. This domination further

increases over the run of time. By howa 2050, primary energy heating demand for Strabag makes up for roughly half its cooling demand. The overall primary energy demand slightly increases, depending on the conversion factor chosen for PEI.

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

Possible Optimizations
This building type allows for very limited optimization only; due to the highly glazed external wall, additional insulation is practically impossible. Likewise, g-values of the glazing can hardly be improved as solar protective glazing is already in place. More effective, external shading would be desirable, demanding however for further technological development for robust such shading which is insensitive to high wind pressures. Furthermore, such external glazing strongly impacts upon the building's appearance and may well be contradictatory to the original design perception. This stated, the reduction of internal heat loads[41] remains as single most effective measure to decrease the dominant cooling loads of this building type.

6.5.2 SOL 4: passive house

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

Net energy

Cooling demand absolute
Results of simulation indicate rather high cooling loads; however, these results have to be viewed in the light of considerations described in chapter 6.1.1 Net Cooling Energy Demand, page 48, and do not necessarily depict the real situation in the building which employs nocturnal ventilation not accounted for here.

Heating demand absolute
Keeping heating requirements low is a major goal of the passive house standard. Therefore, this building type displays very low demand, even so,

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

again, results do not take into account some integral features of the passive house standard on the building's conditioning's side, such as heat recovery in the mechanical ventilation system which would decrease demands roughly by a further annual 15kWh/m^2.

Cooling load absolute
Absolute cooling load is comparatively high.

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

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

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

Possible Optimizations
SOL 4 is optimized regarding cold winter conditions. Additional insulation layers therefore appear economically senseless. For summer conditions, the simulation indicates few points of possible intervention in terms of optimization of the building's constructive properties. However, internally heat loads should be restricted (– which, again, is already the case in the real building).

6.5.3 ONB: built before WW1

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

Net energy
Cooling demand absolute

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

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

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

Final and primary energy

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

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

Influence of the urban heat island
As differences of locations are generally bigger in heating than in cooling demands and ONB is dominated by its heating demand, colder sites such as “howa” yield remarkably higher overall net energy demands than locations in the city centre. Overall demands decrease over temporal resolution. The same is true for final and primary energy demand.

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

6.5.4 BGN/ FAS: built after WW2

Constructive properties
Adverse to the other three sample building, for the building epoch of after WW2 no single building was investigated. BGN/ FAS rather represent the combination of two buildings of this period, each being some sort of worst case for either winter or summer requirements. Hence, the broad margin of possibilities covered by construction dating from this time is shown.
u-value of BGN is surprisingly low and underlying data therefore has to be doubted. u-values of FAS appear more plausible for this epoch.
g-values are rather high, permitting high solar gains. As rooms are small and heights limited, their windows – although medium size in absolute terms – result in high glazing fractions allowing, again, for high solar loads. Small rooms furthermore make up for high occupancy ratios. Mass in BGN appears surprisingly high, especially for ceilings.

Net energy

Cooling demand absolute
Cooling demand is high, continuously increasing over temporal resolution.

Heating demand absolute
Heating demand is likewise high, continuously increasing over temporal resolution.

Cooling load absolute
Maximum cooling load is high.

Final and primary energy

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

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

Influence of the urban heat island
As differences of locations are generally bigger in heating than in cooling demands and BGN/ FAS is dominated by it’s heating demand, colder sites such as howa yield remarkably higher overall net energy demands than locations in the city centre. Overall demands decrease over temporal resolution. The same is true for final and primary energy demand.

Possible Optimizations

Additional layers of exterior insulation hold high potentials of improvements, especially as concerns with cultural heritage might not to be expected as frequently as with buildings dating from before WW1. F_c- values are optimize able as the appliance of exterior shading seems generally feasible in this building type. Reductions of glazing fraction by the application of smaller windows can be considered, however, the availability of sufficient lighting for office use has to be kept in mind. Internal heat loads should be reduced by lower occupancy ratios. This might inflict removal of light interior walls and new room layouts.

7 Excursus: User behaviour

User behaviour and acceptance are key parameters for building performance, where performance is meant not only in relation to energy consumption, but also to user satisfaction and productivity. Energy consumption in buildings is closely linked to operational and space utilization characteristics as well as the behaviour of the occupants. The occupant tries to optimize thermal comfort, air quality, lighting and noise. The amount of user intervention on the indoor environmental conditions has a high impact on user acceptance and user satisfaction [Hoes et al., 2009; Zimmermann, 2007].

The objective was to learn from existing buildings in warmer climate zones regarding energy demand, comfort and productivity of workers. The influence of climate change on thermal comfort and the models to assess thermal comfort are discussed. This section provides an overview on

- Best-practice demonstration buildings in warmer climate zones: HVAC-concepts, user behaviour and user satisfaction.
- Future usage profiles with consideration of telework
- Influence of indoor environmental conditions on user satisfaction and user productivity.
- Methodologies to assess user satisfaction and productivity. Discussion of comfort models.
- Concepts to improve user satisfaction regarding rising outdoor temperatures.

7.1 Best practise data of selected demonstration buildings

Authors: Christoph Neururer, Roman Smutny of BOKU Vienna

Due to the overall objectives of this research project a literature research on office buildings in warmer climate zones was done. The analysis focuses on measures to improve thermal comfort and user satisfaction. The goal was to gather data about user acceptance and user behaviour in office buildings and their satisfaction with the building's performance.

The selection criteria for the demonstration buildings were:

- Built / operated in warm climate zones
- Energy efficient building
- Availability of a description for technical equipment (HVAC)
- Availability of energy performance evaluation
- Availability of social analysis (POE post occupancy evaluation)

Because of the multidimensional requirements it was difficult to detect a sufficient amount of buildings. Therefore some innovative school buildings as well as innovative office buildings in temperate climate zones have been added.

7.1.1 Summary of best practise building concepts and conclusions

Information on relevant building properties and qualitative indicators for user comfort have been gathered. The findings for user satisfaction and relevant measures are very diverse and not directly comparable for all buildings. Scarcely anywhere the methodology is explained or the basics for data ascertainment are specified. Therefore the possibilities of comparison of energy consumption or demand as well as of user acceptance are limited.

The **AVAX headquarter in Athens**, Greece, achieved one of the best ratings in overall user acceptance. The building provides an automatically rotated shading device in response to temperature and solar radiation with optional manual override via infrared remote controls. This results in a high daylight factor of close to 10% on top of the workstations and an excellent rating for lighting conditions. The external shading fins are used to control the solar gains, while the internal gains are minimized by energy efficient artificial lighting. This results in reduced cooling load. A raised false floor permits the installation of local air-conditioning units covering the local peak load demand as well as fans for incoming fresh air and air exhaust. Furthermore, hybrid cooling techniques are applied:

- Night ventilation as “pre-cooling” strategy by operating a mechanical ventilation system when the outdoor temperature is lower than the indoor temperature
- Manually controlled ceiling fans during the summer season, which brings the comfort zone from 25°C to 29°C
- A central cooling system (air/water heat pump) combined with a cold storage system reduces cooling peak load and saves costs.

Less than 3% of the occupants complain about discomfort and the majority is able to properly operate the terminal devices [EULEB, 2007].

The **Malta Stock Exchange in La Valetta**, Malta, achieved a relatively neutral rating in overall user acceptance. This building is located in a historic building, which was refurbished in 2001. The cooling and ventilation strategy is a mixture of passive and active systems. The cellular offices and meeting rooms are air-conditioned. The central atrium is conditioned by three complementary strategies:

- Night time convective cooling if the external temperature drops below 23°C
- Direct cooling by passive downdraught evaporative cooling (PDEC) relying on hydraulic nozzles, which humidify the air
- Indirect cooling by cooling coils with chilled water

The rating of thermal comfort in summer and winter is neither positive nor negative. Unfortunately, no information is available on possibilities for occupants to influence the indoor climate. The perceived air quality in winter and summer achieved poor results, which are indicating inadequate ventilation and cooling by the PDEC system [EULEB, 2007].

The **GUZZINI Headquarters in Recanati**, Italy is a good example on improving user acceptance. The building was designed to be effectively ventilated by natural means for the mayor part of the year. The initial cooling and ventilation strategy foresaw the automatic opening of the air vents when inside temperature rises above 22 °C remaining open until 25 °C. Above this temperature the building is operated under a mechanical mode with the air conditioning system. After the initial period, user dissatisfaction recommended to change the opening pattern of the air vents and the temperature at which the windows open. Furthermore, the control system was altered to manually adjust the panels and to allow the occupants to modify their own local environmental conditions. The lighting concept received a very positive judgement as well [EULEB, 2007]:

- The northern and southern transparent facades provide the use of natural light within the offices.
- The shading system ensures good day lighting levels.
- Light is also brought into the building by the central glazed atrium.

The **Sanitas-BUPA Headquarter in Madrid**, Spain uses an interesting ventilation and cooling strategy. It is designed to work with the high thermal mass of the construction and with indoor patios featuring vegetation and water elements. Ceilings with cool radiant panels ensure efficient cooling in the offices. In winter the thermal comfort and air quality is well rated. However the building scores poorly on temperature and air quality in summer, as the natural ventilation and cooling are sometimes insufficient.
To reduce the cooling load and optimize lighting conditions, selective artificial lighting is coordinated with natural lighting. The lighting control system automatically readjusts the lighting level to always achieve the minimum amount of Lux desired - the user opinion is very positive [EULEB, 2007].

The **National Centre of Renewable Energies in Navarra**, Spain achieved good results in thermal comfort. The occupants can be separated in two groups: researchers and office workers. Most of the occupants are researchers working on subjects linked with the technologies implemented in the building itself. So their answers are more positive than those from the office workers. For this reason the results are quite divergent but haven’t been displayed separately.
The rating for thermal comfort is quite high in winter as well as in summer. The building is heated and cooled by under floor system, which control the air and radiation temperature. An absorption-type refrigeration system is used for cooling. The heat source feeding the generator uses pre-heated water from the evacuated solar tube collector panels on the roof of the building, supported by natural gas boilers. To optimize the cooling load the south facade has both internal and external shading systems. The motorised blinds on the outside of the windows are controlled by sensors but can also be operated manually [EULEB, 2007].

The **primary school of Empoli**, Italy applies innovative elements and scored a really good user rating. An "Intelligent Window" was realized that, consisting of several elements, each with a specific or variable function, depending on the outdoor conditions in order to optimize:

- Passive solar gains
- Active solar gains
- Window ventilation
- Shading
- Cooling by night ventilation

The elements of the “Intelligent Window” are situated in two main sections. The upper section contains glazing panels with a variable transparency film on a roller system.

The lower section is a ventilation system with filter cartridge, externally cladded with glass.
The south-eastern facade has a large window area. This provides high passive solar gains as well as good daylight conditions. The solar heat gains are stored in the extensive building mass. The remaining energy demand for space heating and hot water is covered by a condensation heat generator and emitted by radiators.
Indoor curtains control glare. External blinds provide an efficient protection from solar overheating. Shading is provided by movable aluminium overhangs.
Natural cooling and natural ventilation is guaranteed by many openings, south and north facing. On the north side there are movable openings that allow air movement under the external roof. The roof is ventilated and also provides ventilation to the classrooms additionally to the “Intelligent Window”. During the daytime winter season the "Intelligent Windows" provides fresh air by means of a ventilation system with a cross-flow heat recovery unit, where each classroom having an independent unit [EULEB, 2007].

The office and laboratory building of the **Fraunhofer Institute for Solar Energy Systems ISE in Freiburg**, Germany scored well in thermal comfort and lighting. Passive cooling is used in the offices, while the thermal mass elements of the building are cooled by night ventilation. In the laboratories an air-conditioning unit is necessary because of the requirement of a constant room temperature. The ventilation strategy is twofold:

- The offices can be naturally ventilated by opening windows and the window frames have slots to allow ventilation when the windows are closed.
- Additionally the offices can be ventilated mechanically to ensure a good air quality in spite of a high user density.
- The central atrium is integrated into the ventilation concept of the main structure. During daytime, the preconditioned supply air is blown into the atrium via a ground heat exchanger.

To enable passive cooling, the cooling load was reduced and daylight usage was improved with special shading devices. The shading elements are realized as a split external shutter, whose upper part can be used for light control. The elements are operated by a building control system, but manual operation by the users is possible at any time. All rooms have an additional internal anti-glare shield.
The shading elements are part of the daylight-oriented lighting concept. The lighting concept consists of:

- Convenient room proportions
- Skylights (top windows) in the facade aligned with the ceilings
- Skylights (top windows) in the intermediate walls between offices and hall.
- Artificial light design is a two-component lighting system
    - The basic lighting is ensured by indirectly shining standing lamps, which are switched and automatically adjusted according to the available daylight.
    - The individual table lamps are used for the direct workplace lighting. These are controlled locally in offices with small daylight supply and regulated on constant illumination.
    - A simple automatic timer switches off the ceiling lights over the corridors after a certain time.

[EULEB, 2007; SolarBau:Monitor, 2002].

Conclusions

- Unfortunately, in all analysed buildings, no information was available on building manual, special instructions or dress codes.
- The best ratings in thermal comfort were achieved, where occupants may control the indoor environment to suit it to their own personal comfort. This could be provided by local adjustments of central controlled systems or by using additional devices in peak times.
- In nearly all analysed buildings a lighting concept was an essential design criterion. Wherever applicable the buildings were orientated regarding solar radiation. Large windows with fixed and variable shading devices were relevant for good ratings in lighting. Sometimes anti-glare shields were installed additionally.
- External shading devices were applied in all analysed buildings and internal shading devices are used additionally in some buildings. Centrally controlled shading systems with manual override were well accepted. The shading devices were always integrated in and dimensioned for the cooling concept. They reduce the cooling energy demand during working hours and also on weekends or during unoccupied hours.
- Passive cooling systems combined with active cooling systems achieved the best results for thermal comfort in summer. Locally controlled air conditioning is essential for good user ratings. Only the primary school of Empoli achieved good results without an active cooling system – unfortunately no information on summer break was available. Therefore it seems that active cooling systems are necessary to achieve high comfort. Additional passive cooling systems help to reduce the energy demand and increase comfort as well.
- Night ventilation was a key measure to reduce energy demand and support user satisfaction in most of the analysed buildings.
- The energy demand for ventilation is significantly higher, if only mechanical ventilation systems are used. Additional natural ventilation helps to reduce the energy demand and provides good comfort if the air distribution is well planned.
- During summer the natural ventilation was often inadequate because of insufficient air movement. Ceiling fans or table fans are very effective to improve thermal comfort in summer.

7.2 Future usage profiles in the context of telework

Authors: Christoph Neururer, Roman Smutny of BOKU Vienna

Reliable usage profiles are necessary to calculate the energy demand and thermal comfort of buildings. The use and spread of information and communication technology continues to grow in recent times. As a result, more employees are able to work from remote locations by the use of computer networks and telecommunication devices. These changes also have an impact on usage profiles, actual busy time and occupation of buildings and consequently the internal load. For dynamical thermal simulation the relevant parameters are:

- Employment level (full time or part-time)
- Standard weekly hours
- Overtime hours
- Weekend working
- Percentage of telework and work outside company premises

Telework is quite a new phenomenon and reliable time series for the European Union or Austria are currently not available. Moreover in Austria’s legal practise there is no agreed definition of telework. To have a consistent terminology the definition of Article 2 of the European Framework Agreement on Telework of 2002 should be used: “*Telework is a form of organising and/or performing work, using information technology, in the context of an employment contract/ relationship, where work, which could also be performed at the employer’s premises, is carried out away from those premises on a regular basis.” [FAOT, 2002]*

Credible usage profiles can’t be obtained from the analysed best practise buildings. In most cases there is only general data regarding typical office hours or typical hours of use available. Anyhow, to get suitable input data for thermal simulation, the findings of the Fourth European Working Conditions Survey (EWCS) carried out in 2005 should be used [EWCS, 2007]. The fifth European Working Conditions Survey is already in the final stage of the fieldwork but currently (April 2011) the results are not available [Eurofound, 2010]. Table 8-1 shows the development of telework in the EU and Austria based on the EWCS in 2000 and 2005. In 2000 the average share of part time teleworkers was about 5 % in the EU15 and about 4.2 % including the former candidate countries [Welz and Wolf, 2010]. In 2005 this figure increased to 7 % for the entire EU27. The use of telework is clearly growing in almost all countries of the EU. This development is concurrent with technological advances in internet, home computing systems and other telecommunication devices.

Year	Country	% involved in telework at least ‘a quarter of the time or more’	% involved in telework ‘almost all of the time’
2000 [EWCS, 2001]	EU15	5	1
	Austria	6	3
2005 [EWCS, 2007]	EU27	7.0	1.7
	Austria	8.6	3.2

Table 10: Share of teleworkers in the EU and in Austria 2000 and 2005 (all employees)

Quite similar results could be derived from the annual Labour Force Surveys of the Statistics Austria, but the questionnaires used a slightly different terminology of telework compared to the EWCS. In general, the share of part time teleworkers in Austria rose till 2005 and remains static around 21 %.

Year	Terms of employment	% involved in telework at least 'sometimes or more'	% involved in telework at least 'half of the time or more'
1999 [Doppel et al. 2003]	Total	3.9	1.6
2005 [Hammer & Klapfer]	Total	13.4	6.5
2005 [LFS-AT, 2006]	Total	23.5	6.8
	Full-time job	24.4	6.4
	Part-time job	20.2	8.1
2007 [LFS-AT, 2008]	Total	21.2	10.8
	Full-time job	21.4	10.6
	Part-time job	20.3	11.4
2009 [LFS-AT, 20010]	Total	21.0	10.3
	Full-time job	21.5	10.2
	Part-time job	19.8	10.6

Table 11: Share of teleworkers in Austria 1999 till 2009 (all employees)When

comparing different types of telework, the findings of the fourth EWCS shows that telework performed on a part time basis is more common than full-time telework [Welz and Wolf, 2010]. Also the Labour Force Survey of 2005 in Austria shows similar results in the group 'half of the time or more'. From 2007 on the share of teleworkers is constant for full-time jobs and part-time jobs

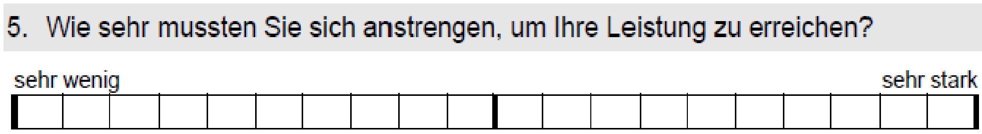
7.3 Productivity and comfort models: a discussion

Author: Alexander Keul of University of Salzburg

7.3.1 Productivity measurement methods

Office work is a compact bundle of mostly mental/social activities compared to the wide array of physical labour. Nevertheless, office activities range from monotonous, repetitive types (e.g. highly-formalized work of accountants) to more creative forms (e.g. media production, university research). Therefore, it makes no sense to apply extrinsic productivity measurement, asking how productive the very activity was and actually is per se. People as experts for their own workplaces are quite efficient to apply an intrinsic productivity measurement when they are asked to assess the mental workload of an activity they are often doing. We all know that under psychic/physical/environmental stress, routine activities cause more effort, produce more errors and result in early exhaustion. Under climatic stress which follows from climate change in a non-adaptive office environment, office workers should experience more mental workload and be less productive in terms of work time, quality of work, physical comfort and mental/emotional well-being.

To measure the mental workload of an office activity, the NASA Task Load Index (TLX) is an internationally used psychometric method (compare [Xiao et al., 2005]). It consists of several statements (like: How hard did you have to strain to achieve your performance?) with a 20-point Likert scale between „very little“ and „very hard“ – see the German version:


5. Wie sehr mussten Sie sich anstrengen, um Ihre Leistung zu erreichen?

sehr wenig sehr stark

Graph 97: Example of the NASA Task Load Index (TLX) [Xiao et al., 2005]). Question: “How hard did you have to strain to achieve your performance?”). Answer: 20-point Likert scale from „very little“ to „very hard“

For the measurement of environmental (here: thermal) stress, office workers have to rate their mental workload for routine daily activities they are accustomed to, not of new types of activities causing stress in itself (e.g. trouble-shooting an electronic instrument). NASA-TLX is a very quick instrument that people can easily fill in in-between work and which does not distract and/or block activities. It can be used in a paper-and-pencil or an electronic version, e.g. popping up from time to time on the personal computer.

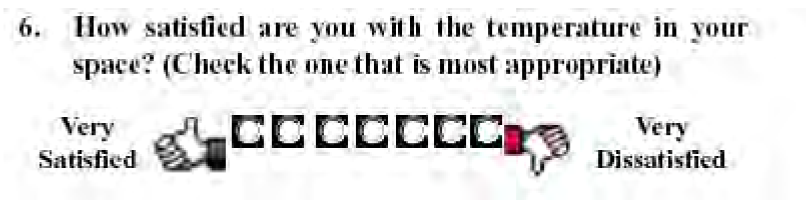
Experimental projects trying to measure productivity as a function of thermal stress often combine NASA-TLX with other (non-)standardized instruments. An example: Akimoto et al. used NASA-TLX, a clinical asthenopia (eye strain) test, an (ad-hoc) „vitality level“ checklist, an evaluation list on subjective fatigue symptoms and worker behaviour via number of steps (pedometer), metabolic rate (accelerometer) and state of seating (seat thermometer), [Akimoto et al., 2010].

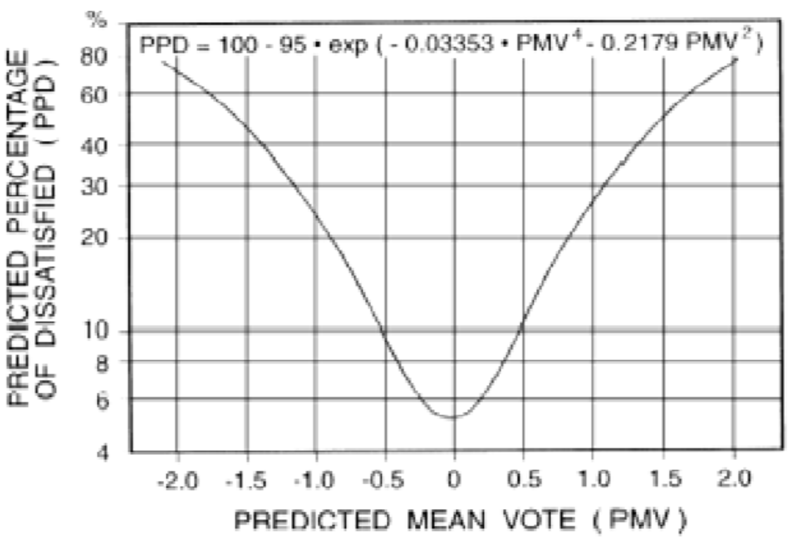
Other common measurements are self-rated percentage of work productivity [Leaman & Bordass, 2000; Batenburg, 2008]. This can be combined with physical and psychological symptoms [Wyon, 2004], and/or absence from work, visits to doctors [Fisk, 2000].
Haynes makes a distinction between productivity of individual process work, group process work, concentrated study work, and transactional knowledge work [Haynes, 2008]. Productivity has to take into account what type of social milieu and interaction is involved in „normal office work“ of the respective subject under study. In a theoretical paper he splits into physical environment (office layout, comfort) and behavioural environment (interaction, distraction), [Haynes, 2007].

When measuring office productivity in a climate change study, the different components delineated here should be carefully monitored in the field before asking workers to administer a test-kit on individual productivity.

7.3.2 Future role and limits of the Fanger model

To assess thermal comfort, the scientific model of Danish research by Povl Ole Fanger (1934-2006) is used worldwide. Human thermal comfort is defined by ASHRAE (the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.) as „the state of mind that expresses satisfaction with the surrounding environment“ [ASHRAE-55, 2004] maintaining thermal comfort for occupants of buildings or other enclosures is one of the important goals of Heating, Ventilation & Air Conditioning design engineers. Thermal comfort is affected by heat conduction, convection, radiation and evaporative heat loss. It is maintained when the heat generated by human metabolism is allowed to dissipate, stabilizing thermal equilibrium with the surroundings. Any heat gain or loss beyond this generates a sensation of discomfort. This sensation of feeling hot or cold is not just dependent on air temperature alone. Factors determining thermal comfort include air temperature, mean radiant temperature, air movement / velocity (wind chill factor), relative humidity (via perspiration), insulative clothing and activity levels [Wikipedia, 2011].
The factors were assessed experimentally in the 1970s, leading to the development and refinement of ASHRAE Standard 55. Perceived comfort was found to be a complex interaction of these variables. However, the majority of individuals is satisfied by an ideal set of values. As the range of values deviate progressively from the ideal, fewer and fewer people are satisfied. This observation was expressed statistically as the percentage of individuals who expressed satisfaction by comfort conditions and the predicted mean vote (PMV) (see [ASHRAE, 2004]):





Graph 98: Predicted percentage dissatisfied (PPD) as a function of predicted mean vote (PMV). [ASHRAE, 2004]

After 40 years of practical use, engineers and social scientists see the strengths and weaknesses of the rather static, generalistic Fanger model quite clearly. Two instructive examples are quoted here. Their importance for climate change studies is obvious:

- **[Becker et al., 2009]** A field study, conducted in 189 dwellings in winter and 205 dwellings in summer, included measurement of hygro-thermal conditions and documentation of occupant responses and behavior patterns. Both samples included both passive and actively space-conditioned dwellings. Predicted mean votes (PMV) computed using Fanger's model yielded significantly lower-than-reported thermal sensation (TS) values, especially for the winter heated and summer air-conditioned groups. The basic model assumption of a proportional relationship between thermal response and thermal load proved to be inadequate, with actual thermal comfort achieved at substantially lower loads than predicted. Survey results also refuted the model's second assumption that symmetrical responses in the negative and positive directions of the scale represent similar comfort levels. Results showed that the model's curve of predicted percentage of dissatisfied (PPD) substantially overestimated the actual percentage of dissatisfied within the partial group of respondents who voted TS > 0 in winter as well as within the partial group of respondents who voted TS < 0 in summer. Analyses of sensitivity to possible survey-related inaccuracy factors (metabolic rate, clothing thermal resistance) did not explain the systematic discrepancies. These discrepancies highlight the role of contextual variables (local climate, expectations, available control) in thermal adaptation in actual settings.
- **[Van Hoof, 2008]** The predicted mean vote (PMV) model of thermal comfort, created by Fanger in the late 1960s, is used worldwide to assess thermal comfort. Fanger based his model on college-aged students for use in invariant environmental conditions in air-conditioned buildings in moderate thermal climate zones. Environmental engineering practice calls for a predictive method that is applicable to all types of people in any kind of building in every climate zone. In this publication, existing support and criticism, as well as modifications to the PMV model are discussed in light of the requirements by environmental engineering practice in the 21st century in order to move from a predicted mean vote to comfort for all. Improved prediction of thermal comfort can be achieved through improving the validity of the PMV model, better specification of the model's input parameters, and accounting for outdoor thermal conditions and special groups. The application range of the PMV model can be enlarged, for instance, by using the model to assess the effects of the thermal environment on productivity and behaviour, and interactions with other indoor environmental parameters, and the use of information and communication technologies. Even with such modifications to thermal comfort evaluation, thermal comfort for all can only be achieved when occupants have effective control over their own thermal environment.

Thermal neutrality is not necessarily the ideal thermal condition as preferences for non-neutral thermal sensations are common. At the same time, very low and very high PMV values do not necessarily reflect discomfort for a substantial number of persons. The PMV model is applied throughout every type of building all across the globe and its use is prescribed in thermal comfort standards. However, it was found that for naturally ventilated buildings the indoor temperature regarded as most comfortable increases significantly in warmer climatic contexts, and decreases in colder climate zones. This important milestone in thermal comfort research led to the development of an adaptive comfort model [Nicol & Humphreys, 2002a, 2002b and 2010]. The support for the PMV model is still larger than that for this adaptive model, which was expressed by the latest round of standard revisions that only included the adaptive model as an optional method in very restricted conditions.

Parameter	ISO 7730 (ISO, 2005a)	Humphreys and Nicol PMV free from bias if	Comment
Clothing insulation	0–2 clo (0–0.310 m^2K/W)	$0.3 < I_{cl} < 1.2$ clo (chair included)	Overestimation of warmth of people in lighter and heavier clothing, serious bias when clothing is heavy. Little information exists for conditions when $I_{cl} < 0.2$ clo
Activity level	0.8–4 met (46–232 W/m^2)	$M < 1.4$ met	Bias larger with increased activity. At 1.8 met overestimation sensation of warmth by 1 scale unit
'Hypothetical heat load'		$M{\cdot}I_{cl} < 1.2$ units of met·clo	Serious bias at 2 units
Air temperature	10–30°C		Overestimation warmth sensation $t_o > 27$°C. At higher temperatures bias becomes severe. Upper limit t_o approx. 35°C in ISO 7730
Mean radiant temperature	10–40°C		
Vapor pressure or relative humidity	0–2.7 kPa or 30–70%	RH < 60%	Suggested bias becomes important if $p_a > 2.2$ kPa
Air velocity	0–1 m/s	$v_a < 0.2$ m/s	Overestimation warmth sensation $v_a > 0.2$ m/s. Underestimation cooling effect increased v_a

Table 12: Validity intervals for PMV input parameters, taken and adapted from ISO 7730 and [Nicol & Humphreys 2002]. Table taken from [van Hoof, 2008, p.192]

According to ISO 7730, for a valid model output, the Fanger input parameters need to be within certain numerical limits. For air temperature, optimum office results are reported for 24° C, with a tendency (see Table 8-3 [van Hoof 2008]) to overestimate warmth sensations from 27° C upwards. This means, for typical indoor summer temperatures in non-airconditioned offices, the classical PMV model has to be treated with caution. Instead of merely criticising errors of the classical model (e.g. [Becker & Paciuk, 2009], model adaptation runs should be made directly by ASHRAE to encompass hotter environments with lighter occupant clothing and ventilation rates over 1 m/sec.

7.3.3 Classical and more sustainable thermal coping

[Brager & de Dear, 1998 and 2003] have expressed clearly that Fangers laboratory approach has to be enriched by social, cultural and historic aspects. Comfort standards always mirror concepts, values and wishes of people who produce them. Besides environmental conditions also expectations and recall of past conditions play their role. When the author visited a university institute in communist Czechoslovakia in wintertime around 1980, the standard office conditions there was 15 °C room temperature with people wearing their winter coat.

Thinking about sustainable offices under changing climatic conditions requires testing for classical and non-classical thermal coping methods. Innovation is not only offered by high-tech (e.g. thermally activated ceilings, individual air condition practices etc.), but also by low-tech (e.g. natural ventilation systems and simple technology such as a ceiling fan [Ho et al., 2009]). The results can be surprising, but effective: [Ho et al., 2009] found for an increase of normal air speed from the fan that thermal comfort significantly shifted to allow higher supply air temperature or higher heat load in the room while maintaining the same comfort level. To develop and adapt sustainable energy concepts for office buildings in changing climate, observations and reports from warmer to tropical countries should be systematically analysed and used instead of a conservative extension of Euro- or Americocentric building practices and models. Climatic adaptation is a technical, but also a cultural achievement.

7.4 Recommendations and Outlook

Authors: Christoph Neururer, Roman Smutny of BOKU Vienna; Alexander Keul of University Salzburg

Recommendations for thermal simulation and analysis of user comfort:

- Natural lighting was an issue in all analysed buildings. Selective artificial lighting was often coordinated with natural lighting to achieve the desired amount of Lux at minimal electrical energy consumption. Therefore it could be interesting to investigate different lighting concepts for thermal simulation.
- The desire to open windows in summer is obviously stronger than the reasonable consideration that it would remain cooler with closed windows [Plesser et al., 2008]. Therefore it is suggested to take into account the share of occupants, who use the shading devices and windows properly.
- The findings of the best practise database and future usage profiles in the context of telework were not inconsistent with the simulation scenarios in Table 4 and Table 5 in Berger & Pundy [Berger & Pundy, 2009 p.17 and p.27].
- The percentage of permanently absent occupants in the simulation scenarios “Tele” and “Tele Siesta” of Berger & Pundy is significantly higher than the values from literature (see chapter “future usage profiles in the context of telework“).
- A suggestion regarding ventilation schedules for Table 5 in Berger & Pundy is to add a scenario based on the difference between external and internal temperature. Most ventilation concepts in the best practise buildings weren’t based on time schedules but rather on temperature differences.
- The simulation of thermal comfort should take a scenario with ceiling fans into account.
- Surveys to evaluate productivity have to take into account what type of social milieu, interaction and distraction is involved in „normal office work” and how much mental workload (e.g. concentration) is actually needed to fulfil the specific work task.
- For non-air-conditioned office buildings in summer the PMV- and PPD-figures of the classical Fanger-model (ISO 7730) have to be treated with caution. The demonstrations buildings showed good comfort values despite higher indoor air temperatures. The adaptive comfort model of Nicol & Humphreys (EN

15251) or an adaption of the Fanger-model or a combination of both seem to be appropriate. The positive impact of user intervention the indoor environment as well as of air velocity by ceiling fans should be taken into account.

Conclusions for retrofit measures:

Changing climatic conditions affect the urban microclimate as well as the duration of heat-waves and lead to an increased demand for retrofit measures of the building and HVAC system. The lessons of existing demonstration buildings in hotter climates and the lessons of comfort analysis deliver starting points for more sustainable retrofit concepts. The most important insights are:

- The best ratings in thermal comfort were achieved, where occupants may control the indoor environment to suit it to their own personal comfort.
- The best ratings in thermal comfort were achieved, where an active cooling system is supported by passive cooling solutions. However, retrofit measures of office buildings in Austria should avoid active cooling systems in order to minimise energy demand. Retrofit measures just with passive cooling concepts should be carefully planned to reach the comfort targets. This means that the simulation for energy efficiency and comfort has to take microclimate (e.g. urban heat island effect) and climate change into account as well as variations of optimal user behaviour (utilization of shadings, lighting and window ventilation).
- Important passive cooling retrofit measures are:
    - External shading: effective shading and suitable wind resistance
    - Lighting concept: efficient lamps, daylight concepts, reduction of operation to actual demand
    - Energy efficient equipment (computers, screens, printers, copiers, etc.) and reduction of operation to actual demand
    - Ceiling fans and/or table fans: Extension of the comfort interval
    - Night ventilation
    - Ground heat exchange

Federal subsidies for thermal retrofit measures should take these passive cooling measures into account. A dynamical thermal simulation should be requested as quality assurance. The simulation should be done by standardized input parameters for microclimate (heat island effect), climate change (duration of heat waves) and non-optimal user behaviour (shadings, lighting, window ventilation).

Prospects and outlook

Climate change affects the urban microclimate (heat island effect) as well as the duration of heat-waves. Existing buildings and new buildings with no capacity to buffer the increasing cooling load will have problems with thermal comfort. This reduces the productivity of office workers (and pupils) and might reduce as well rental incomes. Many existing buildings already have these problems and the number of buildings as well as the negative impacts will increase due to climate change.

Especially concerned are office buildings, administration buildings, schools, universities etc. in urban areas.

Low tech passive cooling solutions seem to be an appropriate thermal retrofit measure. The effectiveness for comfort and energy efficiency should be systematically analysed for different combinations of passive cooling solutions.

Concepts for sustainable office buildings in changing climate can be derived by observations and reports from buildings in warmer to tropical countries. A systematic analysis should be performed instead of a conservative extension of Euro- or Americocentric building practices and concepts. Climatic adaptation is a technical, but also a cultural achievement.

8 Conclusions and Further Research

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.

Impacts of climate change

Impact of different climate data sets:
Future climate data sets yield increasing cooling energy demands, while heating demands shrink. Trends for overall final and primary energy demand evolve differently, depending on buildings' properties: recently constructed buildings tend to yield higher net cooling than heating demands already today; their overall final energy demand will stagnate or slightly increase over the years. Historic buildings constructed before WW1 and after WW2 even by the year 2050 are clearly dominated by high net heating demands. Hence, overall final energy demand of these buildings decreases over the decades to come due the decrease in heating requirements. Notwithstanding, these overall demands remain high in absolute terms.

The picture is slightly less uniform for the development of maximum cooling loads; Even though they, too, will increase, this increase is less pronounced and its trend over the course of time is less consistent.

It has to be kept in mind, that both simulated demands and maximum loads are based on averaged climate data sets which do not necessarily include possible extremes.

Impact of different comfort models:
The definition of what is regarded as "uncomfortable" according to the two existing normative comfort models ("Fanger" and "Addaptive") remarkable impacts upon cooling requirements and consequent energy demand. Care has to be take to distinguish between conditioned buildings (which call for the application of the

"Fanger" model) and free running buildings (to be assessed according to the "Adaptive" model). Users' ability to adjust to outdoor climatic conditions should be harnessed in free running buildings by giving them control over their direct indoor environment. When doing so, potential for reductions in cooling demand can be harnessed.

Impact of urban heat island:
Locations in CBDs generally display higher cooling and lower heating demands than sites to the city outsides already today. Annual differences range in the order of magnitude of up to 5 kWh//m^2 for cooling and about 10kWh/m^2 for heating in Vienna. In consequences, both net and final energy demand is lower in inner city locations than on the outskirts. This relation appears consistent over the course of time, leaving inner city locations as those with least overall final energy demand.

Possible measures for reduction of energy demand

Impact of optimization of buildings' envelops:
Even in view of climate change, external thermal insulation of opaque buildings' surfaces yields bests results in terms of overall final energy requirements due to significant reductions in heating energy demand. This is especially true for old buildings which are dominated by their heating demand. Changes in quality of windows rather aim at decreasing cooling demand and therefore run second in the consideration of overall final energy demand.

Further Research
This present study assessed the impacts of climate change to be expected for office buildings in urban areas such as Vienna. Several fields for further investigations evolve logically from the conclusions drawn here:

- Impacts upon energy supply and market (including estimations for conversion factors to be applied under changing conditions) as well as for mitigation and adaptation policy
- Additional economic assessments in the area of comfort models and the influence of users' satisfaction with indoor comfort on buildings' return on investment
- Smart technology for conditioning for indoor comfort with least energy consumption, robust and easy access to climate control for single building users
- Appliance of hybrid and passive cooling systems under conditions of climate change
- Implications of climate change for several zero emission- and plus energy – concepts which are currently intensively discussed in endeavours to further reduce building stocks' green house gas emissions and energy demands.
- Influence of climate change on live in residential buildings, especially in densely populated urban areas, including investigations on impacts of increased night time temperatures for human sleep and regeneration
- Options for the appliance of traditional passive cooling strategies in hot climate regions in modern context.

9 Appendix

9.1 Graphs &Tables

Graphs

Tables

9.2 References

9.2.1 Climate change research

Birol, Faith: >> Die Sirenen schrillen <<. Die Internationale Energieagentur (IEA) schlägt Alarm: Schneller als erwartet könnte der Welt das Öl ausgehen - die Gefahr einer Versorgungskrise wächst. In: IP, Jg. April 2008.

Bosch, Peter (April 2010): Climate Proof Cities. Veranstaltung vom April 2010. Kassel, Germany.

Brunner, Conrad U.; Steinemann, Urs; Jürg, Nipkow (Jänner 2008): Bauen, wenn das Klima wärmer wird. Herausgegeben von Bundesamt für Bauten und Logistik.

Christenson, M.; Manz, H.; Gyalistras, D. (2006): Climate warning impact on degree-days and building energy demand in Switzerland. In: Energy Conversion and Management, H. 47, S. 671–686.

Eigenbauer, Andreas; Heumesser, Ursula (2009): Das "Städtische Energieeffizienzprogramm" (SEP). In: Perspektiven, H. 1_2, S. 84–85.

Fohler-Norek, Christine (2009): Das Wiener Klimaschutzprogramm und seine Erwartungen an den Energieausweis. In: Perspektiven, H. 1_2, S. 82–83.

Frank, Andreas; Formayer, Herbert; Seibert, Petra; Krüger, Bernd C.; Kromp-Kolb, Helga (November 2003 - Juni 2004): reclip:more - Projektjahr 1 Projektteil BOKU-Met Validierung – Sensitivitätstests. Arbeitsbericht für den Zeitraum 1.11.2003 – 30.6.2004.

Frank, Th (2005): Climate change impacts on building heating and cooling energy demand in Switzerland. In: Energy and Buildings, H. 37, S. 1175–1185.

Friedbacher, Robert (2009): Darstellung der Energieversorgung im Amtsgebäudebereich. In: Perspektiven, H. 1_2, S. 90–91.

Gruehn, Dietwald: Raumentwicklungsstrategien zum Klimawandel – Vorstudie für Modellvorhaben. Zusammenfassung des Zwischenberichts zu den räumlichen Wirkfolgen von Klimaänderungen und ihrer raumordnerischen Relevanz. Unter Mitarbeit von Technische Universität Dortmund. Herausgegeben von Bau und Stadtentwocklung Bundesministerium für Verkehr.

Haas, Willi; Weisz, Ulli; Balas, Maria; McCallum, Sabine; Lexer, Wolfgang; Pazdernik, Katja et al. (November 2008): Identifikation von Handlungsempfehlungen zur Anpassung an den Klimawandel in Österreich. 1.Phase 2008. Klimaforschungsinitiative AustroClim.

Holzer, Peter; Hammer, Renate (Jänner 2008): Sommertauglichkeit im Klimawandel. Department für Bauen und Umwelt, Donau-Universität Krems.

Huber, Karl Heinz (2009): Amtsgebäude - Energieausweis - Ausweispflicht als Vorbildwirkung der Stadt Wien. In: Perspektiven, H. 1_2, S. 88–89.

Jaros, Marion: Klimawandel - Anpassungsbedarf und Anassungsstrategien für Großstädte am Beispiel Wien. Auswirkungen des Klimawandels auf thermischen Komfort und Energiebedarf ausgewählter Wiener Gebäude und Integration von Anpassungsstrategien in die Praxis - unter gleichzeitiger Berücksichtigung von Aspekten des Klimaschutzes. Unter Mitarbeit von Helga Kromp-Kolb, Martin Treberspurg und Andreas Muhar et al.

Katzschner, Lutz (April 2010): Ideas - Thermal comfort and Urban Design. Veranstaltung vom April 2010, aus der Reihe "Workshop Kassel, Thermal comfort and Urban Design". Kassel, Germany.

King, David A. (Janary 2004): Climate Change Science: Adapt,Mitigate, or Ignore? In: Science, H. 303, S. 176–177.

Krause, Ernst (2009): Richtlinie über die Gesamtenergieeffizienz von Gebäuden. Umsetzung durch nationale Normung und CEN. In: Perspektiven, H. 1_2, S. 16–17.

Krec, Klaus (2009): Das Labeling für passive Sommertauglichkeit. In: Perspektiven, H. 1_2, S. 73–74.

Krec, Klaus (2009): Klimadatengenerator. In: Perspektiven, H. 1_2, S. 65–66.

Kromp-Kolb, Helga; Jaros, Marion (2009): Klimawandelszenarien für Österreich und potenzielle Auswirkungen des Klimawandels auf den Energieverbrauch von Gebäuden. In: Perspektiven, H. 1_2, S. 70–72.

Loibl, Wolfgang; Beck, Alexander; Dorninger, Manfred; Formayer, Herbert; Gobiet, Andreas; Schöner, Wolgang (June 2007): reclip:more. Research for Climate Protection: Model Run Evaluation.

Lowry, William P.; Lowry, Porter Prescott (2001): Fundamentals of biometeorology. Interactions of organisms and the atmosphere. St. Louis Mo.: Peavine Publications/Missouri Botanical Garden Press.

Mittringer, D. I.: Stadtentwicklungsplan für Wien 2005. MA 18, Referat Stadt- und Regionalentwicklung.

Moarefi, Mehdi (2009): Die Normenserie ÖNORM H 5055. "Wirtschaftlicher Energieeinsatz in Gebäuden". In: Perspektiven, H. 1_2, S. 40–41.

Mohnl, Hans (2009): Klimadatenmodell. In: Perspektiven, H. 1_2, S. 62–64.

Müller, Andreas (Septmeber 2009): Hat Heizen Zukunft? Entwicklung des Wärmebedarfes im österreichischen Gebäudebestand bis 2050. Veranstaltung vom Septmeber 2009. TU Wien.

Penney, Jennifer; Wieditz, Ireen (May 2007): Cities Preparing for Climate Change. A Study of Six Urban Regions.

Pfafferott, Jens Ü.; Herkel, Sebastian; Kalz, Doreen E.; Zeuschner, Andreas (2007): Comparison of low-energy office buildings in summer using different thermal comfort criteria. In: Energy and Buildings, H. 39, S. 750–757.

Pöhn, Christian (2009): Betrachtung der Energiekosten für Gebäude aus dem 20.Jahrhundert. In: Perspektiven, H. 1_2, S. 45–48.

Popp, Katharina (2009): Das Energieausweis-Vorlage-Gesetz. Die Umsetzung der zivilrechtlichen Teile der Richtlinie 2002/91/EG. In: Perspektiven, H. 1_2, S. 18–19.

Prettenthaler, Franz: Heizen und Kühlen im Klimawandel. Joanneum Research und Wegener Zentrum; Graz.

Rosenfeld, Arthur H.; McAuliffe, Patrick (2007): Opportunities in the Building Sector: Managing Climate Change. California Energy Commission. International Seminar on Planetary Emergencies.

Rück, Christan (2009): Der Energieausweis und Wiener Wohnen. In: Perspektiven, H. 1_2, S. 86–87.

Santamouris, M. (2001): Energy and climate in the urban built environment. London: James & James.

Schneider, Andrea (April 2010): Klimawandel zukunftsfähig gestalten. Impact of climate change on thermal comfort in buildings. Veranstaltung vom April 2010, aus der Reihe "Workshop Kassel, Thermal comfort and Urban Design". Kassel, Germany.

Shimoda, Yoshiyuki (2003): Adaption measures for climate change and the urban heat island in Japan's built environment. In: Building Research & Information, H. 31, S. 222–230.

Streicher, Wolfgang; Michlmair, Markus (2009): Systematik der Berechnung des Kühl(technik)energiebedarfs. In: Perspektiven, H. 1_2, S. 67–69.

Wagmeister, Stefan (2009): Die Normenserie ÖNORM B 8110. "Wärmeschutz von Gebäuden und Bauteilen". In: Perspektiven, H. 1_2, S. 35–39.

Walsh, C. L.; Hall, J. W.; Street, R. B.; Blanksby, J.; Cassar, M.; Ekins, P.; Glendinning, S. (2007): Building knowledge for a changing climate. Collaborative research to understand and adapt to the impacts of climate change on infrastructure, the built environment and utilities. Newcastle: Newcastle University.

Werner, Peter; Chmella-Emrich, Elke; Vilz, Andrea (2008): Folgen des Klimawandels: Gebäude und Baupraxis in Deutschland. Unter Mitarbeit von Institut Wohnen und Umwelt. Herausgegeben von Bau und Stadtentwicklung Bundesministerium für Verkehr.

9.2.2 Standard office rooms

Bauer, Wilhelm (2004): Flash of inspiration in a Think-berth. about the office of the future. Fraunhofer Institute for Industrial Engineering IAO. Koelnmesse GmbH / ORGATEC.

CB Richard Ellis (Hg.): Wien Büromarktbericht - erstes Quartal 2008.

CB Richard Ellis (Hg.): Wien Büromarktbericht - Viertes Quartal 2005.

CPB Immobilientreuhand (Hg.): Wien Büromarktbericht - Frühjahr 2008.

CPB Immobilientreuhand (Hg.): Wien Büromarktbericht - Frühjahr 2009.

Crescini, Gabriella (2007): Die Planung des Bürokonzeptes beginnt mit der Wertschöpfungsanalyse. In: KMU-Magazin, H. 2, S. 50–54.

FORUM - Zeitschrft des Bundes der Öffentlich bestellten Vermessungingenieure (Hg.) (2002): Bürobewertung - Kenngrößen schaffen Werttransparenz. BDVI-Modell zur Bewertung von ÖbVI-Büros.

Frauenhofer Institut für Arbeitswirtschaft und Organisation (IAO) (Hg.). (2003): Mehr Leistung in innovativen Arbeitswelten. Innovationsoffensive OFFICE 21®. Stuttgart.

Fuchs, Wolfram (2004): Welcome to the Business Club. about modern office buildings. Koelnmesse GmbH / ORGATEC.

Gosztonyi, Susanne (2007): Best-Practise Glasbauten in Europa. Zusammenstellung, qualitative Bewertung und Empfehlungen.

Greml, Andreas; Kapferer, Roland; Leitzinger, Wolfgang; Höfler, Karl (2010): Qualitätskriterien für Komfortlüftungen im EFH. Herausgegeben von FH Kufstein, Energie Tirol, AIT, AEE INTEC und TB Greml.

Greml, Andreas; Kapferer, Roland; Leitzinger, Wolfgang; Höfler, Karl (2010): Wesentliche Bestell- bzw. Ausschreibungskriterien für Komfortlüftungen im EFH. Unter Mitarbeit von Arbeitsgruppe „Pro Komfortlüftung NÖ".

Horx, Matthias (2004): Smart Work! about the work world of the future. Koelnmesse GmbH / ORGATEC.

Kapferer, Roland; Leitzinger, Wolfgang; Höfler, Karl; Greml, Andreas (April 2010): Qualitätskriterien für Komfortlüftungen im MFH. Herausgegeben von Energie Tirol, AIT, AEE INTEC und TB Greml.

Kelter, Jörg (März 2001): Office Index 2000. Ergebnisse einer empirischen Studie zur Untersuchung von Büro-Arbeitswelten und zukünftigen Entwicklugen. Institut Arbeitswissenschaft und Organisation. Stuttgart.

Lasalle, Jones Lang: Büromarktüberblick Q1 2008.

Minister der öffentlichen Arbeiten (Preußen) (1907): Bestimmungen für die Ausführung von Konstruktionen aus Eisenbeton bei Hochbauten.

neuberger research (Hg.) (2002): Real Estate Investment Monitor. Ergebnisse der Umfrage unter internationalen Entscheidungsträgern und Investoren der Immobilienwirtschaft. Wien.

neuberger research (Hg.) (2003): Großflächenbroschüre - Neubau Erstbezug ab 5.000 m² - Vergleich zentraler Marktangebote für 2003. Großbüroflächen - Neubau Erstbezug ab 5.000 m² - Vergleich zentraler Marktangebote für 2003. Wien.

neuberger research (Hg.) (2005): Betriebskosteninhalte von Wiener Büroimmobilien. Wien.

Noller, Tillmann; Lautenbacher, Siegfried (2004): Potential spaces. Koelnmesse GmbH / ORGATEC.

Preisler, A.; Krenn, C. (2005): Sunny Research! Nachhaltiges Gebäude- und Energiekonzept für ein modernes Büro- und Gewerbegebäude. Herausgegeben von Innovation und Technologie Bundesministerium für Verkehr. Wien.

Probst, Jörg; Beck, Klaus; Dell, Gerhard; Jung, Patrick; Egger, Christiane; Öhlinger, Christine (2008): Bürogebäude mit Zukunft. Leitfaden zur Optimierung der Energiebilanz und des Nutzungswertes von Bürogebäuden in Oberösterreich. Herausgegeben von Oberösterreichischer Energiesparverband.

Programmlinie Haus der Zukunft (Hg.) (2010): PH Office. Standard für energieeffiziente Bürobauten. Endbericht. Unter Mitarbeit von Robert Lechner, Thomas Zelger und Felix Heisinger et al. Bundesministerium für Verkehr, Innovation und Technologie. Wien. (Impulsprogramm Nachhaltig Wirtschaften).

Schlomann, Barbara; Gruber, Edelgard (2009): Energieverbrauch des Sektors Gewerbe, Handel, Dienstleistungen (GHD) für die Jahre 2004 bis 2006 - Abschlussbericht. Abschlussbericht an das Bundesministerium für Wirtschaft und Technologie (BMWi) und an das Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Fraunhofer-Institut für System- und Innovationsforschung.

Karlsruhe, München, Nürnberg.

Schlomann, Barbara; Gruber, Edelgard (2009): Energieverbrauch des Sektors Gewerbe, Handel, Dienstleistungen (GHD) für die Jahre 2004 bis 2006 Kurzfassung. Abschlussbericht an das Bundesministerium für Wirtschaft und Technologie (BMWi) und an das Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU). Fraunhofer-Institut für System- und Innovationsforschung. Karlsruhe, München, Nürnberg.

Schriefl, Ernst (2007): Modellierung der Entwicklung von Treibhausgasemissionen und Energieverbrauch für Raumwärme und Warmwasser im österreichischen Wohngebäudebestand unter der Annahme verschiedener Optimierungsziele. Betreut von Reinhard Haas. Wien. Technischen Universität Wien, Fakultät für Elektrotechnik und Informationstechnik.

Statistik Austria (Hg.) (2001/ Bearbeitungsstand: 14.11.2007): Gebäude- und Wohnungszählung 2001. Standard-Dokumentation + Metainformationen.

Verwaltungs-Berufsgenossenschaft - VBG (Hg.) (2006): Büroraumplanung - Hilfen für das systematische Planen und Gestalten von Büros. Hamburg.

Voss, K.; Herkel, S.; Löhnert, G.; Wagner, A. (2005): Bürogebäude mit Zukunft. Erfahrungen mit innovativen Bürogebäuden. Wambsganß, M. (Hg.). Köln: TÜV - Verlag.

Wimmer, Robert; Hohensinner, Hannes; Tengler, Tobias; Bintinger, Rudolf; Becic, Alma (2006): Informationsknoten für nachwachsende Rohstoffe und ökologische Materialien (II) Onlineinformationen plus Serviceangebot. Unter Mitarbeit von Andrea Mittermair. Herausgegeben von Innovation und Technologie Bundesministerium für Verkehr.

9.2.3 Thermal comfort

Baker, Nick; Standeven, Mark (1996): Thermal comfort for free-running buildings. In: Energy and Buildings, H. 23, S. 175–182.

Bauer, Barbara; Österreichisches Institut für Baubiologie und -ökologie (2009): Nachhaltig Bauen und Bewerten. Vom Energie- zum Nachhaltigkeitsausweis ; Tagungsband ; Kongress ; Messezentrum Wien, 19.-20. Februar 2009. Wien: IBO Verl.

Bundesministerin für Arbeit, Gesundheit und Soziales (Oktober 1998): Arbeitstättenverordnung.

Darmawan, A. (1999): Adaptive Thermal Comfort: A Multicultural Issue. Sydney, Australia.

Dear, Richard J. de; Brager, Gail S. (2002): Thermal comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55. In: Energy and Buildings, H. 34, S. 549–561.

Dostal, Paul; Kupski, Sebastian; Katzschner, Antje (April 2010): Thermal Comfort and Urban Design. Veranstaltung vom April 2010. Kassel, Germany.

Gossauer, Elke (2008): Nutzerzufriedenheit in Bürogebäuden - Eine Feldstudie. Analyse von Zusammenhängen zwischen verschiedenen Komfortparametern am Arbeitsplatz. Dissertation. Betreut von Andreas Wagner und Wolfgang Bischof. Karlsruhe. Universität Karlsruhe, Fraunhofer ISE.

Holmes, Michael J.; Hacker, Jacob N. (2007): Climate change, thermal comfort and energy: Meeting the design challenges of the 21st century. In: Energy and Buildings, H. 39, S. 802–814.

Humphreys, Michael (1978): Outdoor temperatures and comfort indoors. In: Building Research and Practice.

Krec, Klaus (2006): Bewertung der Sommertauglichkeit von Gebäuden. Schönberg am Kamp.

Krec, Klaus (2007): Ausgewählte Verfahren der Sommertauglichkeitsanalyse. Schönberg am Kamp.

Krec, Klaus (2010): Halbsynthetische Klimadaten für Wien. Erläuterungen zum Klimadatensatz. Schönberg am Kamp.

McCartney, KJ; Humphreys, MA (2002): Thermal comfort and productivity. Oxford Centre for Sustainable Development, Oxford Brookes University, Oxford, UK. Proceedings: Indoor Air 2002.

Moos, Waike (2006): Skript - Deskriptive Statistik. Hochschule Niederrhein.

Nicol, J. F.; Humphreys, Michael A. (2002): Adaptive thermal comfort and sustainable thermal standards for buildings. In: Energy and Buildings, H. 34, S. 563–572.

Nilsson, A. Lena (1986): Blood Flow, Temperature, and Heat Loss of Skin Exposed to Local Radiative and Convective Cooling. In: The Journal of investigative dermatology.

OIB-330.6-076/10, 27.10.2010: Richtlinie 6, Energieeinsparung und Wärmeschutz.

Pültz, Gunter; Hoffmann, Sabine (2007): Zur Aussagekraft von Simulationsergebnissen auf Basis der Testreferenzjahre (TRY) über die Häufigkeit sommerlicher Überhitzung. In: Bauphysik, H. 29, S. 99–109.

Robinson, Darren; Haldi, Frédéric (2008): Model to predict overheating risk based on an electrical capacitor analogy. In: Energy and Buildings, H. 40, S. 1240–1245.

Runa Tabea Hellwig (Oktober 2005): Thermische Behaglichkeit. Unterschiede zwischen frei und mechanisch belüfteten Bürogebäuden aus Nutzersicht. Dissertation. Betreut von Gerd Hauser Wolfgang Bischof Gerhard Hausladen. München. Technische Universität München, Institut für Entwerfen und Bautechnik.

Schettler-Köhler, Horst-Peter (2007): Energieeinsparung contra Behaglichkeit? Berlin: BMVBS (Forschungen / Bundesministerium für Verkehr, Bau und Stadtentwicklung, Bundesamt für Bauwesen und Raumordnung ;121).

Seppänen, Olli; Fisk, William; Faulkner, David (2003): COST BENEFIT ANALYSIS OF THE NIGHT-TIME VENTILATIVE COOLING IN OFFICE BUILDING. Herausgegeben von Environmental Energy Technologies Division. Lawrence Berkeley National Laboratory, University of California. Berkeley.

van der Linden, A. C.; Boerstra, Atze C.; Raue, Arjen K.; Kurvers, Stanley R.; Dear, Richard J. de (2006): Adaptive temperature limits: A new guideline in The Netherlands. A new approach for the assessment of building performance with respect to thermal indoor climate. In: Energy and Buildings, H. 38, S. 8–17.

van der Linden, Kees; Boerstra, Atze C.; Raue, Arjen K.; Kurvers, Stanley R. (2002): Thermal indoor climate building performance characterized by human responses. In: Energy and Buildings, H. 34, S. 737–744.

Waltjen, Tobias (2003): Wärmeansprüche des Menschen. Physikalische, physiologische, psychologische und soziale Bedingungen für thermische Behaglichkeit. IBO – Österreichisches Institut für Baubiologie und -

ökologie. Wien.

Wong, Nyuk Hien; Khoo, Shan Shan (2003): Thermal comfort in classrooms in the tropics. In: Energy and Buildings, H. 35, S. 337–351.

Zimmermann, M. et al. Handbuch der passiven Kühlung. Rationelle Energienutzung in Gebäuden (Frauenhofer IRB Verlag, Stuttgart, 2003).

9.2.4 Urban heat island

Acero, J. A. (2010): Urban Modelling: Considering climate and air quality in urban planning. Veranstaltung vom April 2010, aus der Reihe "Workshop Kassel, Thermal comfort and Urban Design". Kassel, Germany.

Ashie, Yasunobu; Ca, Vu Thanh; Asaeda, Takashi (1999): Building canopy model for the analysis of urban climate. In: Journal of Wind Engineering and Industrial Aerodynamics, H. 81, S. 237–248.

Barton, Mark; Oke, T. R. (2000): Tests of the performance of an algorithmic scheme of the hourly urban heat island. Veranstaltung vom August 2000. Third Symposium on the Urban Environment.

Blocken, Bert; Carmeliet, Jan (2004): Pedestrian Wind Environment around Buildings. Literature Review and Practical Examples. In: Journal of Thermal Env. & Bldg. Sci., H. 28.

Bornstein, Robert D. (1968): Observations of the Urban Heat Island Effect in New York City. Unveröffentlichtes Manuskript, August 1968.

Bozonnet, Emmanuel (2005): Impact des microclimats urbains sur la demande énergétique des bâtiments Cas de la rue canyon. Doctorat. La Rochelle. Université de La Rochelle.

Bretz, Sarah; Akbari, Hashem; Rosenfeld, Arthur (1998): Practical issues for using solar-reflective materials to mitigate urban heat islands. In: Atmosphere, H. 32, S. 95–101.

Brown, Michael J.; Grimmond, Sue; Ratti, Carlo (2001): Comparison of Methodologies for Computing Sky View Factor in Urban Environments. International Society of Environmental Hydraulics Conf., Tempe, AZ.

Bruse, Michael (2010): Urban models and planning. Veranstaltung vom April 2010. Kassel, Germany.

Davenport, Alan G.; Grimmond, C. Sue B.; Oke, Tim R.; Wieringa, Jon (2000): Estimating the roughness of cities and sheltered country. Herausgegeben von American Meteorological Society.

de La Flor, Francisco Sánchez; Domínguez, Servando Alvarez (2004): Modelling microclimate in urban environments and assessing its influence on the performance of surrounding buildings. In: Energy and Buildings, H. 36, S. 403–413.

dos Santos, Iara Goncalves; Lima, Henrique Gazzola de; Assis, Eleonoar Sad de: A comprehensive approach of the sky view factor and building mass in an urban area of the city of Belo Horizonte, Brazil. The Federal University of Minas Gerais, Belo Horizonte, MG, Brazil.

Eliasson, Ingegärd (2000): The use of climate knowledge in urban planning. In: Landscape and Urban Planning, H. 48, S. 31–44.

Gál, T.; Rzepa, M.; Gromek, B.; Unger, J. (2007): Comparison between sky view factor values computed by two different methods in an urban environment. In: Acta Climatolgica et Chorologica, H. 40-41, S. 17–26.

Gandemer, Jacques (1975): Wind environment around buildings: aerodynamic concepts. 4th International Conference: Wind effects on buildings and structures.

Gandemer, Jacques; Guyot, Alain (1981): La protection contre le vent. Aérodynamique des brise-vent et conseils pratiques. Unter Mitarbeit von Centre scientifique et technique du batiment.

Giridharan, R.; Lau, S. S. Y.; Ganesan, S.; Givoni, B. (2007): Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong. In: Building and Environment, H. 42, S. 3669–3684.

Grimmond, C. S. B.; Oke, T. R. (2009): Aerodynamic Properties of Urban Areas Derived from Analysis of Surface Form. Herausgegeben von American Meteorological Society.

Leitl, Bernd M.; Kastner-Klein, P.; Rau, M.; Meroney, R. N. (1997): Concentration and flow distributions in the vicinity of U-shaped buildings. Wind-tunnel and computational data. In: Journal of Wind Engineering and Industrial Aerodynamics, H. 67&68, S. 745–755.

Matzarakis, Andreas (2001): Die thermischen Komponente des Stadtklimas. Habilitation. Betreut von Helmut Mayer. Freiburg. Universität Freiburg, Meteorologisches Institut der Universität Freiburg.

Moin, Uddin Mohammad; Tsutsumi, Jun-ichiro (2004): Rapid Estimation of Sky View Factor and Its Application to Human Environment. In: Journal of the Human-Environmental System, H. 7, S. 83–87.

Mursch-Radlgruber, Erich; Trimmel, Heideline (2009): Räumlich und zeitlich hochaufgelöste Temperaturszenarien für Wien und ausgewählte Analysen bezüglich Adaptionsstrategien. Räumliche Differenzierung der mikroklimatischen Eigenschaften von Wiener Stadtstrukturen und Anpassungsmaßnahmen. Institut für Meteorologie, Deparment Wasser-Atmospäre-Umwelt, Universität für Bodenkultur Wien.

Oke, T. R.: An algorithmic scheme to estimate hourly heat island magnitude. University of British Columbia, Vancouver, Canada. 2nd Urban Environment Symposium.

Oke, T. R. (1999): Boundary layer climates. 2. ed., reprinted. London: Routledge.

Oke, Tim R. (2006): Initial Guidance to obtain representative meteorological observations at urban sites. World Meteorological Organization.

Reuter, Ulrich (April 2010): Thermal comfort and urban development - Needs for further research? -. Veranstaltung vom April 2010, aus der Reihe "Workshop Kassel, Thermal comfort and Urban Design". Kassel, Germany.

Robinson, Darren; Stone, Andrew (2004): Solar radiation modelling in the urban context. In: Solar Energy, H. 77, S. 295–309.

Rosenfeld, Arthur H.; Akbari, Hashem; Bretz, Sarah; Fishman, Beth L.; Kurn, Dan M.; Sailor, David; Taha, Haider (1995): Mitigation of urban heat islands: materials, utility programs, updates. In: Energy and Buildings, H. 22, S. 255–265.

Sasaki, Ryoji; Uematsu, Yasushi; Yamada, Motohiko; Saeki, Hiromu (1997): Application of infrared thermography and a knowledge-based system to the evaluation of the pedestrian-level wind environment around buildings. In: Journal of Wind Engineering and Industrial Aerodynamics, H. 67&68, S. 873–883.

Schatzmann, Michael; Leitl, Bernd (2002): Validation and application of obstacle-resolving urban dispersion models. In: Atmospheric Environment, H. 36, S. 4811–4821.

Svensson, Marie K.; Eliasson, Ingegärd (2002): Diurnal air temperatures in built-up areas in relation to urban planning. In: Landscape and Urban Planning, H. 61, S. 37–54.

Tan, Siew-Ann; Fwa, Tien-Fang (1992): Influence of Pavement Materials on the Thermal Environment of Outdoor Spaces. In: Building and Environment, H. 27, S. 289–295.

Verkaik, J. W. (2001): A method for the geographical interpolation of wind speed over heterogeneous terrain.

Westbury, Philippa; Miles, Stewart (2002): Practical tools to assess wind effects on buildings for environmental and hvac design. Veranstaltung vom 2002. Veranstalter: CIBSE Conference.

Wieringa, Jon (1993): Representative Roughness parameters for homogeneous terrain. In: Boundary Layer Meteorology, H. 63, S. 323–363.

9.2.5 Users' behaviour

Akimoto, T., Tanabe, S., Yanai, T. & Sasaki, M. (2010): *Thermal comfort and productivity – Evaluation of workplace environment in a task conditioned office.* Building and Environment, 45, 45-50.
ANSI/ASHRAE Standard 55-2004: *Thermal Environmental Conditions for Human Occupancy.* Atlanta, GA: ASHRAE, Inc.
Becker, P. & Paciuk, M. (2009): *Thermal comfort in residential buildings – Failure to predict by Standard model.* Building and Environment, 44, 948–960.
Tania Berger and Peter Pundy (2009): *Adapting office buildings to climate change: optimization of thermal comfort and energy demand*, Vienna, 2009
Brager, G.S. and de Dear, R.J. (1998): *Thermal adaptation in the built environment: a literature review.* Energy and Buildings, 27, 1, 83-96.
Brager, G.S. and de Dear, R.J. (2003): *Historical and cultural influences on comfort expectations.* In R.Cole & R.Lorch (Eds.), Buildings, culture and environment: Informing local and global practices (pp.177-201). Oxford: Blackwell.
Doppel, L., Judith Brocza, Romana Haiszan, Manuela Feutl, Ulrike Kofler, Martin Rapf, Karin Steiner and Andrea Egger (2003): *Status Bericht - Auf dem Weg von Telearbeit zu eWork*, Federal Ministry of Economy, Family and Youth Austria, Vienna
EULEB, Helmut F.O. Müller, Dipl.-Ing. Jörg Schlenge (2007): *European high quality Low Energy Buildings*. University of Dortmund, partially funded by the "Intelligent Energy Europe" program of the European Commission, Project-No.: EIE-2003-172 EULEB; www.euleb.info
Eurofound, (2010): *Fifth European Working Conditions survey;* European Foundation for the Improvement of Living and Working Conditions: Online: 15.11.2010, http://www.eurofound.europa.eu/ewco/surveys/ewcs2010/index.htm
EWCS, Pascal Paoli and Damien Merllié (2001): *Third European Survey on Working Conditions 2000*, European Foundation for the Improvement of Living and Working Conditions (Eurofound), Dublin, 2001, ISBN 92-897-0130-7
EWCS, Agnès Parent-Thirion, Enrique Fernández Macías, John Hurley, Greet Vermeylen (2007): *Fourth European Working Conditions Survey*, European Foundation for the Improvement of Living and Working Conditions (Eurofound), Dublin, 2007, ISBN 92-897-0974-X
Fanger, P.O. (1970): *Thermal Comfort.* New York: McGraw-Hill. 1970
FAOT (2002): *Framework Agreement on Telework*, European Trade Union Confederation (ETUC), BusinessEurope (formerly UNICE), European Association of Craft, Small and Medium-sized Enterprises (UEAPME) and European Centre of Enterprises with Public Participation and of Enterprises of General Economic Interest (CEEP). Brussels, 16. July 2002.
Hammer, Gerald and Klapfer, Karin (2006): *Vereinbarkeit von Beruf und Familie*, Statistics Austria, Vienna, 2006, ISBN 3-902479-74-4
Haynes, B.P. (2007): *Office productivity: a theoretical framework*. Journal of Corporate Real Estate, 9 (2), 97-110.
Haynes, B.P. (2008): *An evaluation of the impact of the office environment on productivity.* Facilities, 26 (5/6), 178-195.
Ho, S.H., Rosario, L. and Rahman, M.M. (2009): *Thermal comfort enhancement by using a ceiling fan.* Applied Thermal Engineering, 29, 1648–1656.
Hoes, P., J.L.M. Hensen, M.G.L.C. Loomans, B. de Vries, D. Bourgeois (2009): *User behavior in whole building simulation*, Energy and Buildings 41, 2009, DOI: 10.1016/j.enbuild.2008.09.008
Leaman, A. & Bordass, W.(2000): Productivity in buildings: the 'killer' variables. In D. Clements-Croome (Ed.), Creating The Productive Workplace. London: E. & F.N. Spon.
LFS-AT, Cornelia Moser, Melitta Fasching, Barbara Bauer (2010): *Arbeitskräfteerhebung 2009 - Ergebnisse des Mikrozensus*, Statistics Austria, Vienna. ISBN 978-3-902703-55-2
LFS-AT, Reinhard Eichwalder, Brigitte Mitterndorfer, Melitta Fasching (2008): *Arbeitskräfteerhebung 2007 - Ergebnisse des Mikrozensus*, Statistics Austria, Vienna. ISBN 978-3-902587-65-7
LFS-AT, Reinhard Eichwalder, Brigitte Mitterndorfer, Melitta Fasching (2006): *Arbeitskräfteerhebung 2005 - Ergebnisse des Mikrozensus*, Statistics Austria, Vienna. ISBN 3-902479-84-1
Nicol, J. F. & Humphreys, M. A. (2002a): *Adaptive thermal comfort and sustainable thermal standards for buildings.* Energy and Buildings, 34, 563-572.
Nicol, J. F. & Humphreys, M. A. (2002b): *The validity of ISO-PMV for predicting comfort votes in every-day thermal environments.* Energy and Buildings, 34, 6, 667-684.
Nicol, J. F. & Humphreys, M. A. (2010): *Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN 15251.* Building and Environment, 45, 1, 11-17.
Plesser, Stefan; Kuchen, Ernesto; Fisch, M. Norbert (2008): *Ergebnisse einer Evaluierung von Energiekonzepten für Bürogebäude und Schlussfolgerungen für die Energieeffizienz und das Raumklima*, Bauphysik 30, Heft 6, 2008, DOI: 10.1002/bapi.200810050
SolarBau:Monitor, (2002): *SolarBau:Monitor*. Fraunhofer Institute for Solar Energy Systems ISE, Federal Ministry of Economics and Technology, http://www.archiv.solarbau.de/monitor/index.htm
Tuohy, P.G., Humphreys, M.A., Nicol, F., Rijal, H.B. & Clarke, J.A. (2009): *Occupant behaviour in naturally ventilated and hybrid buildings*. ASHRAE Transactions, 115, 1, 6099.

Van Hoof, J (2008): *Forty years of Fanger's model of thermal comfort: comfort for all?* Indoor Air, 18, 182–201.
Wikipedia, (2011): *Wikipedia: Thermal comfort.* http://en.wikipedia.org/wiki/Thermal_comfort Feb 24, 2011.
Wyon, D.P. (2004): *The effects of indoor air quality on performance and productivity.* Indoor Air, 14 (Suppl 7), 92–101.
Xiao, Y. M., Wang, Z. M., Wang, M. Z. & Lan Y. J. (2005): The appraisal of reliability and validity of subjective workload assessment technique and NASA-task load index. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi, 23 (3), 178 – 181.
Welz, Christian & Wolf, Felix (2010): *Telework in the European Union*, European Foundation for the Improvement of Living and Working Conditions (Eurofound), Dublin.
Zimmermann, Gerhard(2007): *Modeling and Simulation of Individual User Behavior for Building Performance Predictions*, SCSC Proceedings of the 2007 summer computer simulation conference, San Diego, CA, USA 2007, ISBN: 1-56555-316-0