Energy Efficient Buildings with Solar and Geothermal Resources

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WILEY

This edition first published 2014

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

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Library of Congress Cataloging-in-Publication Data applied for

ISBN 9781118352243

Set in 8 on 12 pt Roboto Slab by Silvio Barta

1   2014

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Preface

One of the world's major challenges is the transformation of its energy system, which for a short period in human history has been based on fossil fuels. These resources are approaching their end and create serious environmental damages by emissions and long-term waste issues.

Renewable energy sources have always been available on Earth and can easily cover the planet´s energy demand. New technologies in solar cell and wind turbine manufacturing, innovative materials and efficiency strategies support the transition to environmentally friendly energy systems.

Especially in urban areas, buildings are major energy consumers. All together they account for about 40% of final energy consumption worldwide and are responsible for about one third of overall CO_2 emissions. In urban structures, building energy consumption is typically twice as high as the need for transport energy, and the energy-saving potential is large. Up to 20% can be saved in the short term and within the next decades buildings should become climate neutral. In urban areas, solar technologies are the most suitable energy sources, as solar modules and collectors can be easily integrated into buildings. In denser urban structures, often the individual roof and facade surface areas are not sufficient to make each building zero energy. Here new concepts are required for the design of local supply systems in city quarters with adequate distribution networks and storage capacities.

Planners, engineers and researchers need fundamental knowledge to deal with fluctuating renewable energy sources, to design adequate storage systems and to integrate the energy systems in highly efficient buildings. To achieve efficiency goals, buildings need to use passive and low-energy resources such as solar gains, daylight, natural ventilation or geothermal heat exchange as intelligently as possible.

This new textbook on energy efficient buildings with solar and geothermal resources provides detailed insight into the design and physics of energy efficient buildings. It discusses the theoretical background of solar thermal cooling and heating, of photovoltaics and geothermal energy, and provides information on applications and costs. Many examples help to apply the theory to real praxis applications.

The reader as an engineer, physicist, energy planner, researcher, student or informed layman will profit from the textbook by acquiring in-depth knowledge of today´s new energy systems and building concepts.

This book is based on the knowledge developed within 20 years of research at the Stuttgart University of Applied Sciences on buildings and renewable energy systems. The research centre Sustainable Energy Technologies has been successfully involved in many national and European research and demonstration projects on solar cooling and heating, geothermal energy use, simulation and energy management, zero energy buildings, photovoltaic system technology and many other topics.

Without the support of this research group with about 30 scientists, the broad subject range of the book would not have been possible. I would like to especially thank PhD students and now doctors of philosophy Dilay Kesten and Aysegül Tereci, who produced many results of the first two chapters of building energy efficiency in the urban context; PhD student Tobias Schulze who worked on natural ventilation, and Antoine Dalibard and Felix Thumm who developed the compression chiller and photovoltaic thermal collector models; Dr. Dirk Pietruschka, who did many simulations on solar cooling systems; Ruben Pesch for his contribution to geothermal energy analysis and Mariela Cotrado for her comparison of thermal and electric cooling; Eric Duminil for his very nice irradiance maps; and all the other members of our research team, who discussed the physics and applications of solar and geothermal energy use in buildings.

The layout and design of this book has been completely done by Silvio Barta, an excellent graphic designer, who is even interested in energy technologies and has provided many helpful comments not just on design, but on the contents of the book. Many thanks to his continuous and often tedious work on many details and design issues that are usually lost when concentrating on the contents.

Most heartful thanks are due to Juergen Schumacher, who continuously supports me in my work and life. It is with his simulation environment INSEL that most of the simulation results were obtained.

Ursula Eicker
Stuttgart, August 2013

1 Energy consumption of buildings

Figure 1.1 (previous page): Low-energy residential urban development in Scharnhauser Park, near Stuttgart, Germany (Photo: Ursula Pietzsch).

Figure 1.2 The ebök passive standard office building in Tübingen, Germany after (top), before (bottom left) and during (bottom right) renovation work (Photo: eboek GmbH, Tuebingen).

Buildings account today for about 40% of final energy consumption worldwide, and they are responsible for about one third of overall CO_2 emissions (36% in Europe, 39% in the USA, about 20% in China (IEA Study, 2008)). Especially in urban structures, the building energy consumption is typically twice as high as transport, e.g. approximately by a factor 2.2 in London. The energy-saving potential is large: in the short term (up to 2020), savings of 20% are expected within the European Union, and in the long term (up to 2050), buildings are supposed to be climate neutral. The improvement of building energy efficiency can be economically worthwhile today, as shown by a study of the Intergovernmental Panel on Climate Change: between 12% and 25% CO_2 emissions caused by heating and cooling and between 13% and 52% CO_2 emissions caused by electric lighting and equipment can be reduced economically until 2020.

The European Directive for the Energy Performance of Buildings (EPBD) adopted in 2002 is an attempt to unify the diverse national regulations, to define minimum common standards on buildings' energy performance and to provide certification and inspection rules for heating, cooling and ventilation plants. National energy efficiency action plans have been required since 2006, and European Member States must show how they intend to reach the 9% indicative energy savings target by 2016.

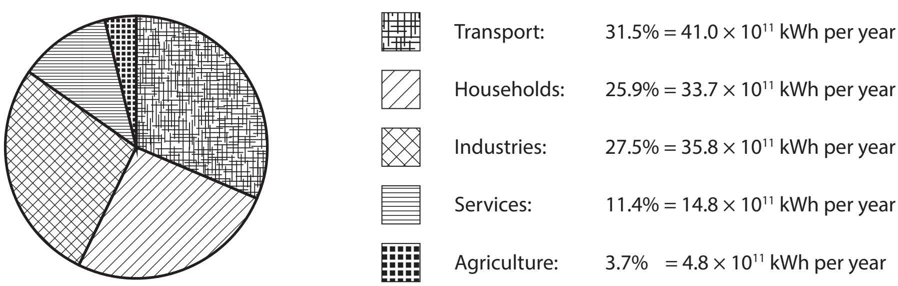


Figure 1.3 Distribution of end energy consumption within the European Union with a total value of 1.3×10^{13} kWh per year (European Environment Agency, 2009).

Average heat transfer coefficients for new buildings are today about 0.3 and 0.4 W m^{-2} K^{-1}. In 2009 the European Union tightened the EPDB directive and now demands nearly zero energy standards for new buildings until 2020. Here the building energy demand is balanced, with the local renewable energy production resulting in a net zero energy demand. For public existing buildings, the zero energy standard will come into effect in 2018.

In moderate European climatic zones like Germany, 80% of residential building energy is consumed by heating, 12% for water heating and the remainder for other electricity consumption, communication and electric lighting. The high percentage of heat consumption is caused by low thermal insulation standards in existing buildings, in which today 90% and even in 2050 60% of residential space will be located. Today, about 1.4% of buildings in Europe are renovated each year energetically. With this rate, there will be a saving of about 40% until 2050 compared to 2005. If the renovation rate were raised to 2% per annum, the energy saving would go up to 74% until 2050.

With high heat insulation standards and the heat recovery ventilation concept of passive houses, a low limit of heat consumption has meanwhile been achieved, which is around 20 times lower than today's values. A crucial factor for low consumption of passive buildings was the development of new glazing and window technologies, which enable the window to be a passive solar element and at the same time cause only low transmission heat losses. In new buildings with low heating requirements, other energy consumption in the form of electricity for lighting, power and air conditioning, as well as warm water in residential buildings, is becoming more and more dominant. Electricity consumption within the European Union is estimated to rise by 50% by 2020. In this area renewable sources of energy can make an important contribution to the supply of electricity and heat.

The majority of the world's new buildings are constructed in Asia. The Asian building sector accounts today for about 25% of the final energy consumption and is expected to rise to 32% in 2030 (World Energy Outlook, 2006). A World Bank study showed that China and India could cut their current energy consumption by 25% with cost-effective retrofitting of lighting, air conditioning, boilers and heat recovery. The Chinese Ministry of Construction states that 95% of all buildings are highly energy consuming and that energy consumption is currently two to three times that of developed countries in achieving the same comfort level (Building Energy Efficiency, an Asia Business Council Book, 2007).

1.1 Residential buildings

To limit transmission heat losses, the average heat loss coefficients of the building envelope are regulated in most countries. In China with severely cold regions (between 5500 and 8000 heating degree days), exterior walls for three-storey buildings are supposed to have *U* values below 0.33 W m^{-2} K^{-1}, high-rise buildings below 0.48 W m^{-2} K^{-1}, whereas in temperate regions, 0.5 W m^{-2} K^{-1} are sufficient. In Japan, today´s wall *U* values are between 0.39 and 1.76 W m^{-2} K^{-1} depending on climatic condition, in Korea between 0.47 and 0.76 W m^{-2} K^{-1}.

In Europe with its wide geographical extent of nearly 35° geographical latitude difference (36° in Greece, 70° in northern Scandinavia), a wide range of climatic boundary conditions are covered. In Helsinki (60.3° northern latitude), average exterior air temperatures reach -6°C in January, when southern cities such as Athens at 40° latitude still have averages of +10°C. Consequently the building standards vary widely: whereas average heat transfer coefficients (*U* values) for detached houses are 1 W m^{-2} K^{-1} in Italy, they are only 0.4 W m^{-2} K^{-1} in Finland. The heating energy demand determined is comparable in both cases at about 50 kWh m^{-2} a^{-1}. The necessary *U* value to achieve the passive house standard with less than 15 kWh m^{-2} a^{-1} heating energy demand for several climate zones are shown in Table 1.1.

***U* values** /W m^{-2} K^{-1}	**Rome** Passive building	**Helsinki** Passive building	**Stockholm** Passive building
Wall	0.13	0.08	0.08
Window	1.4	0.7	0.7
Roof	0.13	0.08	0.08
Ground	0.23	0.08	0.1
Mean	0.33	0.16	0.17

Table 1.1 *U* values required to reach passive standard for different European climates.

In Germany, the heat requirement of residential buildings is between 10 and 250 kWh m^{-2} a^{-1}, depending on the insulation standards. Existing buildings with an average consumption of about

220 kWh m^{-2} a^{-1} have the highest energy-saving potentials by reduction of the transmission heat loss of the building envelope.

With an extremely good insulation of all outer surfaces, avoidance of thermal bridges on critical details like basement walls, attic, etc., as well as an air-proof constructed building shell and a controlled ventilation with heat recovery, the heating energy demand can be reduced to 10 - 15 kWh m^{-2} a^{-1}.

Studies in Switzerland show that the additional investments to achieve the passive house standard are about 14% (Minergie-P Label) and for the low-energy standards about 6 - 9%. In Germany, with a high quantity of passive houses, the additional investment costs are denoted with 3 - 5%.

In comparison current low-energy houses in Germany have around 70 kWh m^{-2} a^{-1} heating demand. Several hundred row houses, all built after 2000, were surveyed as part of the European project POLYCITY. The building heating energy consumption varies strongly even for identical building types as a result of user influence, with standard deviation of 35% on average of the mean consumption.

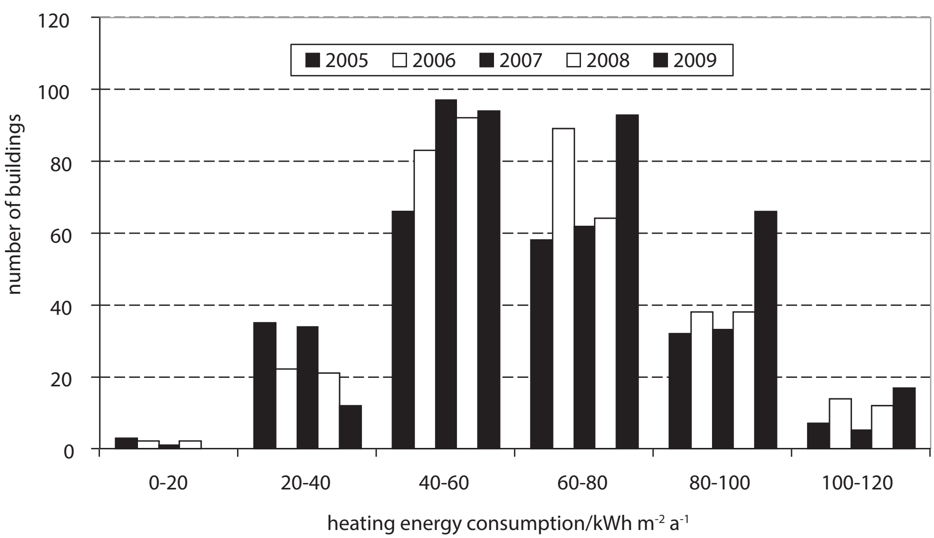


Figure 1.4 Distribution of heating energy consumption of all row houses in the study area supplied by district heating.

Independent of the standard of insulation, water heating is always necessary in residential buildings, and this lies between about 220 (low requirement) and 1750 kWh per person and year (high requirement), depending on the pattern of consumption. For the middle requirement range of 30 - 60 litres per person and day, with a warm-water temperature of 45°C, the result is an annual consumption of 440 - 880 kWh per person, i.e. 1760 - 3520 kWh for an average four-person household. Related to a square metre of heated residential space, in Germany a relatively low value of 12.5 kWh m^{-2} a^{-1} is used in the standards and in Switzerland 14 kWh m^{-2} a^{-1}.

The average electricity consumption of private households, around 3600 kWh per household per year, is of a similar order of magnitude. Related to a square metre of heated residential space, an average value of 31 kWh m^{-2} a^{-1} is the result. An electricity-saving household needs only around 2000 kWh a^{-1}. In a passive building project in Darmstadt (Germany), consumptions of between 1400 and 2200 kWh per household per year were measured, which corresponds to an average value of 11.6 kWh m^{-2} a^{-1} (Passivhausinstitut, 1997).

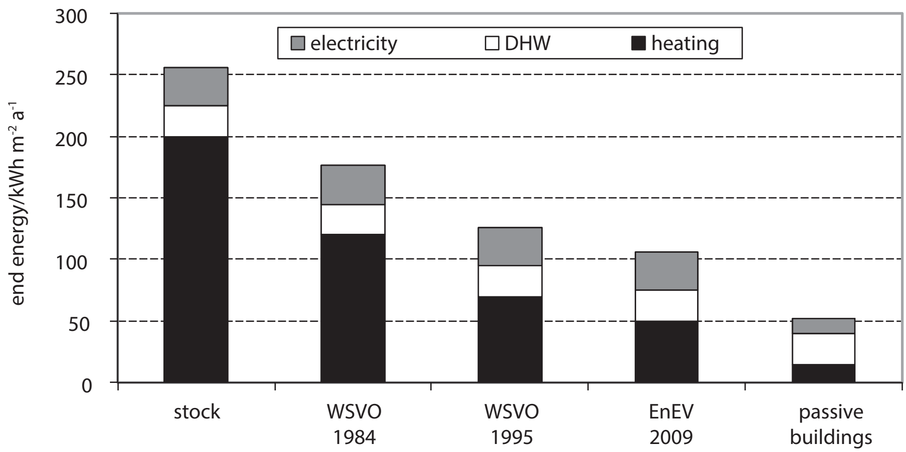


Figure 1.5 End energy consumption for the existing building stock and subsequent legal requirements in residential buildings per square metre of heated floor space in Germany.

According to the 1995 German legislation (WSVO 1995), new buildings were limited in their heating energy demand between 70 and 100 kWh m^{-2} a^{-1} for surface to volume ratios between 0.5 and 1.0 (the lower limit value is marked). Since energy-saving legislation changed in 2002 (EnEV), the building service side is also included in the energy balance and primary energy demand is regulated.

In 2007 energy certificates were introduced in the energy legislation. In 2009 the dependency of maximum demand from A/V ratio was discarded, and the demand was compared with reference buildings with the same geometry. The maximum allowed heating energy demand is currently between 50 and 80 kWh m^{-2} a^{-1}. Further tightening of the energy legislation is expected because of the amendment of the European performance directive, so that in a few years, new buildings with passive house standard can be expected.

1.2 Office and administrative buildings

Existing office and administrative buildings have approximately the same consumption of heat as residential buildings and most have a higher electricity consumption.

Both heat and electricity consumption depend strongly on the building's use. In terms of the specific costs, electricity almost always dominates.

More than half of the running costs are accounted for by energy and technical service. A large part of the energy costs is due to ventilation and air conditioning. The VDI Directive

3807 defines the bases of calculation and the temperature normalisation for measured energy consumption values related to the gross floor area.

The AGES GmbH, Münster, provides an extensive and up-to-date database for buildings of different uses.

Heat consumption in administrative buildings can be reduced without difficulty, by improved thermal insulation, to low-energy standards, and even to a few kWh per square metres and year in a passive building. Related to average consumption in the stock, a reduction to 5 - 10% is possible. Electricity consumption dominates total energy consumption where the building shell is energy-optimised. Measured consumption was between 30 and 130 kWh m^{-2} a^{-1} (see also www.solarbau.de).

Detailed measurements over several years in the first passive office building in Germany (Weilheim/Teck), completed in 2000, illustrate ways of energy optimisation: passive house standard is realisable at low additional costs, the hot water consumption is insignificant in office buildings, and the electrical energy consumption for building services (ventilation, lighting, pumps) can be limited to low target values (< 15 kWh m^{-2} a^{-1}).

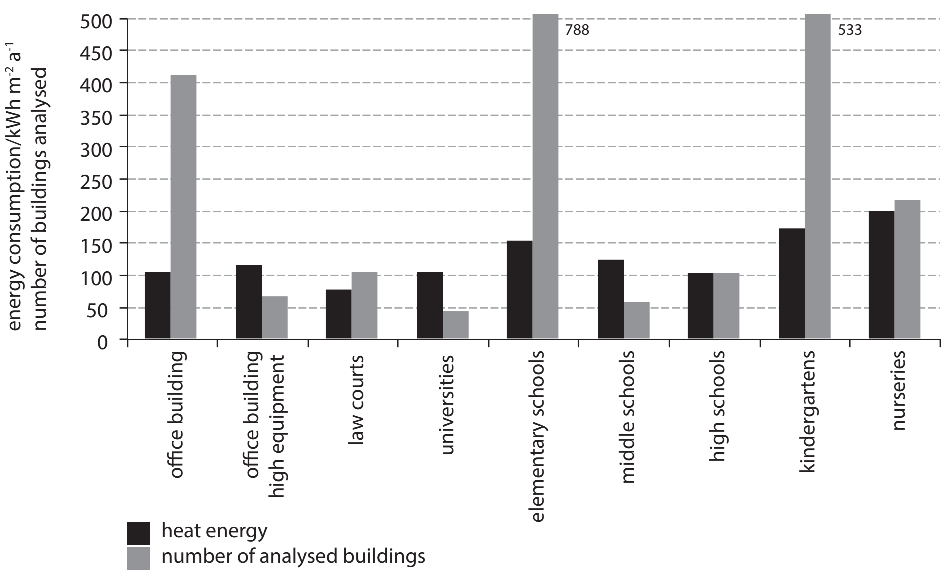


Figure 1.6 Statistical heating energy consumption values per m^2 of gross floor area from the AGES GmbH.

The main consumer of electric energy is office equipment, which is responsible for more than 40% of the total energy consumption, with a rising trend during the three measurement years even though energy-saving equipment was used.

While the passive house standard was confirmed by measurements, the measured values for total electricity consumption exceeded the planning value of 23.5 kWh m^{-2} a^{-1} by 45%.

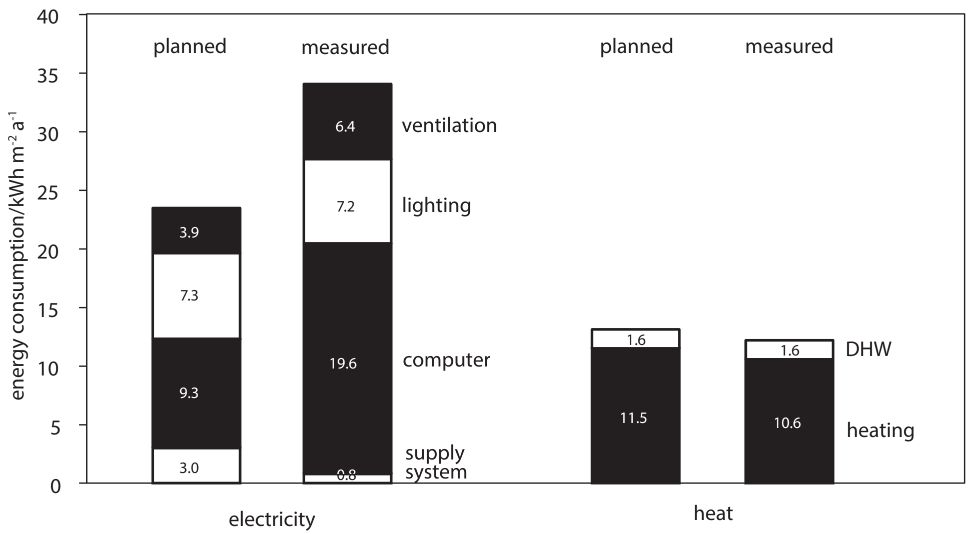


Figure 1.7 Measured consumption of electricity, heat and water heating in an office building with a passive house standard in Weilheim/Teck, Germany.

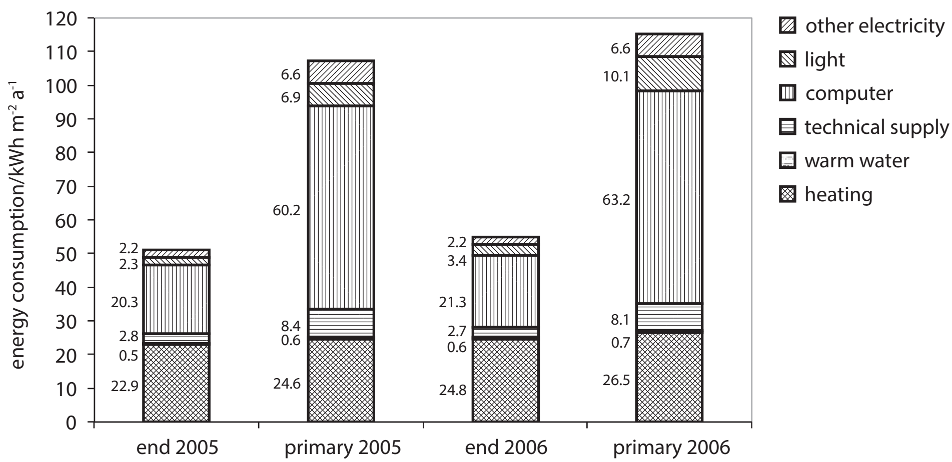


Figure 1.8 Measured end energy and primary energy consumption in the renovated offices of the engineering firm ebök in Tübingen, Germany.

It is also possible to achieve the passive house standard through building rehabilitation. Detailed measurements at an office building in Tübingen, Germany show that a very low thermal heat consumption of less than 25 kWh m^{-2} a^{-1} can be achieved, although not all building elements such as the ground floor can be well insulated due to the low ceiling heights.

Within the total consumption, particularly when considering primary energy, the electrical energy consumption dominates and is mainly caused by office equipment.

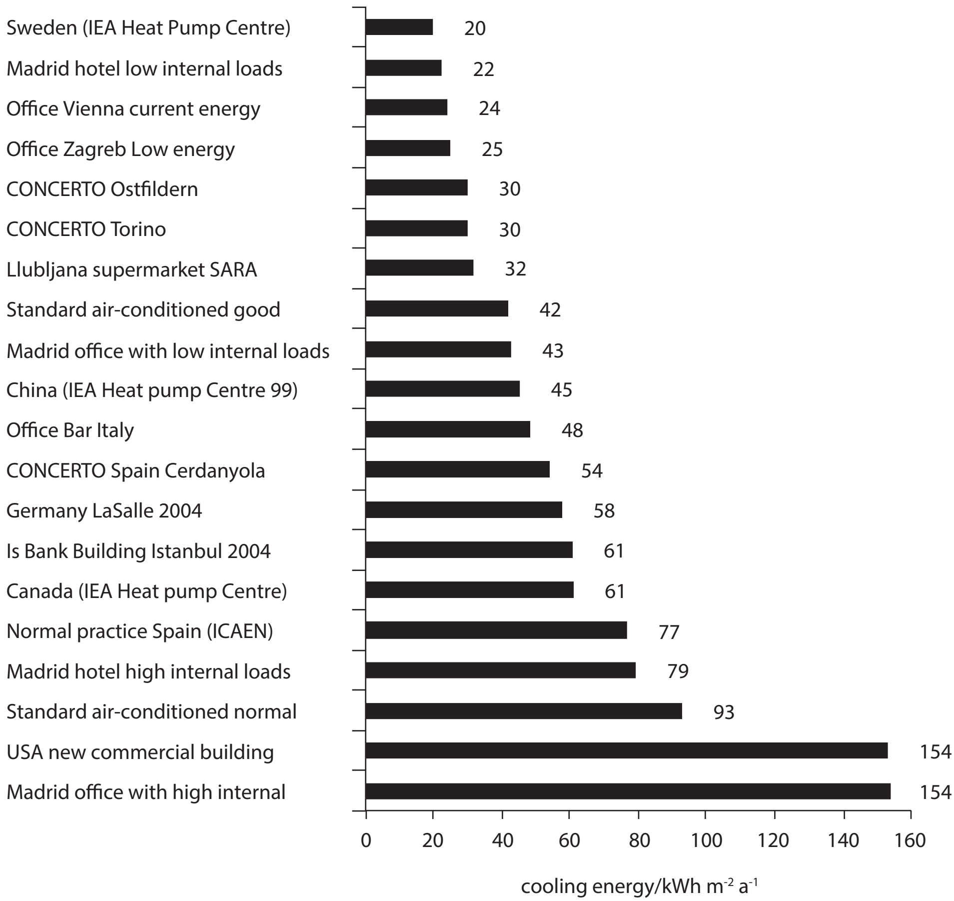


Figure 1.9 Survey of cooling energy requirements of buildings.

1.3 Air conditioning

Air conditioning in buildings and refrigeration is responsibly for about 15% of the total energy consumption worldwide, in hot and humid climates for 30% (Government Information Centre Hong Kong, 2004). Cooling energy is often required in commercial buildings, with the highest consumption worldwide in the USA with up to 150 kWh m^{-2} a^{-1}. Breembroek and Lazáro (1999) quote values between 20 kWh m^{-2} a^{-1} for Sweden, 40 and 50 kWh m^{-2} a^{-1} for China and 61 kWh m^{-2} a^{-1} for Canada.

Our own overview of the cooling energy requirement of different building projects shows a typical cooling energy consumption for administrative buildings between 20 and 60 kWh m^{-2} a^{-1} in Europe.

In the food industry, the energy consumption for cooling is considerably higher with an energy consumption between 82 and 345 kWh per square metre of sales floor. The main part of the required energy is not used for space conditioning, but rather for cooling food (O.Ö Energiesparverband, 1996).

In Southern Europe, the installed cooling capacity is often dominated by the residential market. Although in Spain less than 10% of homes have air-conditioning systems, 71% of the installed cooling capacity is in the residential sector.

About 50% of internal loads are caused by office equipment such as computers, printers, photocopiers, etc., which leads to an area-related load of about 10 - 15 W m^{-2}. Modern office lighting has a typical connected load of 10 - 20 W m^{-2} at a luminance level of 300 - 500 lx. The heat given off by people, around 5 W m^{-2} in an enclosed office or 7 W m^{-2} in open-plan offices, is also not negligible. Typical mid-range internal loads are around 30 W m^{-2}, resulting in a daily cooling energy of 200 Wh m^{-2} day^{-1}, in the high range between 40 and 50 W m^{-2} and 300 Wh m^{-2} day^{-1}.

Detailed own measurements in a passive standard office building in Weilheim, Germany, described above, show 30 - 35 W m^{-2} internal loads, in a south office with two people and a computer workstation. In a north office with two computer workstations, the loads were about 50 W m^{-2}. The resulting daily intern loads in the south office were between 200 and 300 Wh m^{-2} compared with 400 and 500 Wh m^{-2} in the north office.

Further measurements in the context of the German funding programme SolarBau Monitor showed that for rather low total internal loads from about 92 to 188 Wh m^{-2} day^{-1}, office equipment also clearly dominates.

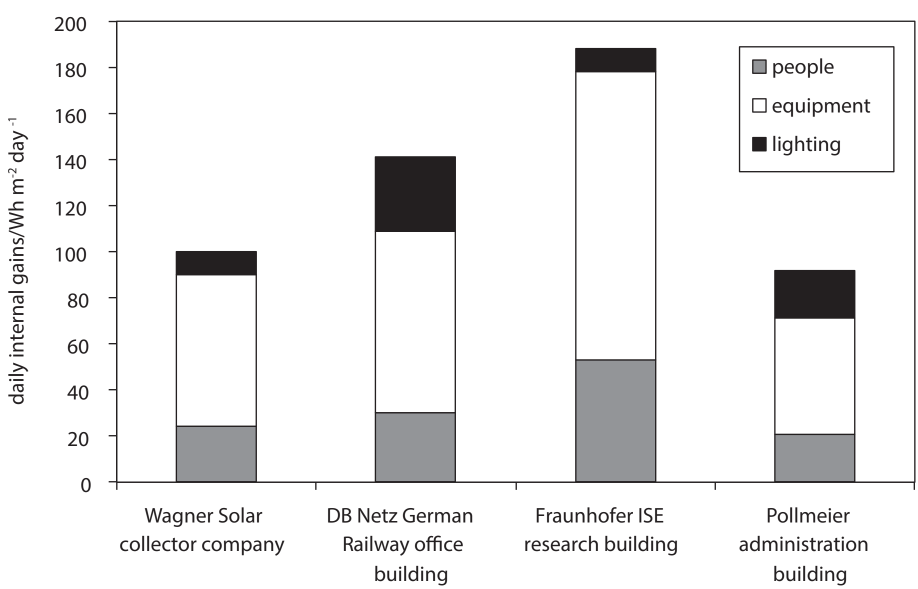


Figure 1.10 Measured distribution of internal gains in buildings of the SolarBau monitor project.

External loads depend greatly on the surface area of the glazing as well as the sun-protection concept. On a south-facing facade, a maximum irradiation of about 600 W m^{-2} occurs on a sunny summer day. The best external sun protection reduces this irradiation by 80%. Together with the total energy transmission factor (g value) of low-e coated double glazing of typically 0.65, the transmitted external loads are about 78 W per square metre of glazing surface. In the case of a 3 m^2 glazing surface of an office room, the result is a load of 234 W, which creates an external load of 20 W m^{-2} for a room surface area of 12 m^2. This situation is illustrated in Figure 1.11 for south-east- and west-facing facades in the summer.

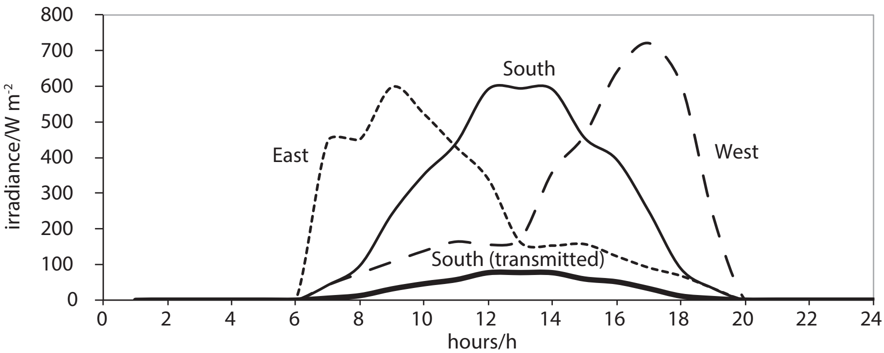


Figure 1.11 Diurnal variation of irradiance on different facade orientations and transmitted irradiance by a sun-protected south facade on a day in August (Stuttgart).

The shading coefficients of sun-protection devices depend particularly on the arrangement of the sun protection: external sun protection can reduce the energy transmission of solar radiation by 80%, whereas with internal sun protection a reduction of at most 60% is possible.

Sun shading system	Colour	Energy reduction coefficient/-
External sun shades	Bright	0.13 - 0.2
External sun shades	Dark	0.2 - 0.3
Internal sun shades	Bright	0.45 - 0.55
Reflection glazings	-	0.2 - 0.55

Table 1.2 Energy reduction coefficients of internal and external sun protection.

External loads depend on the relation of window surface to floor space as well as the chosen shading system. For area ratio between 0.1 and 0.7 the typical external loads are between 8 and 60 W m^{-2} (Arsenal Research, 2007). Together with the internal loads there are 25 - 90 W m^{-2} total cooling loads.

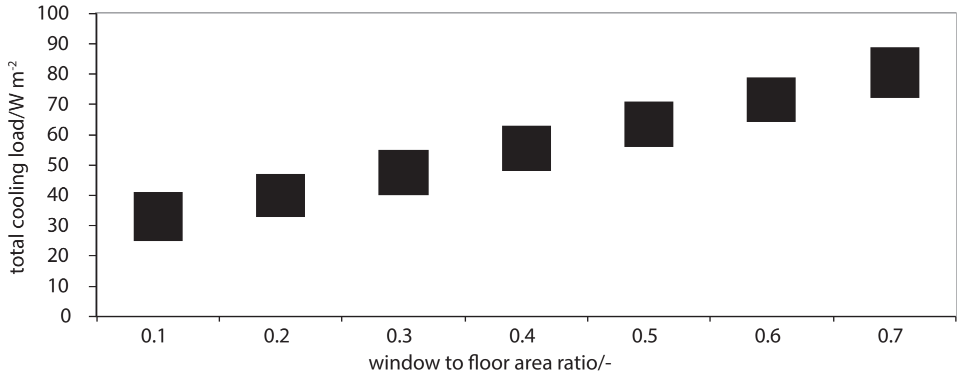


Figure 1.12 Cooling load as a function of the window to floor area ratio to net area.

In case of a very high energy-intensive use like computer centres or server rooms, the cooling loads could increase up to 1000 W m^{-2}.

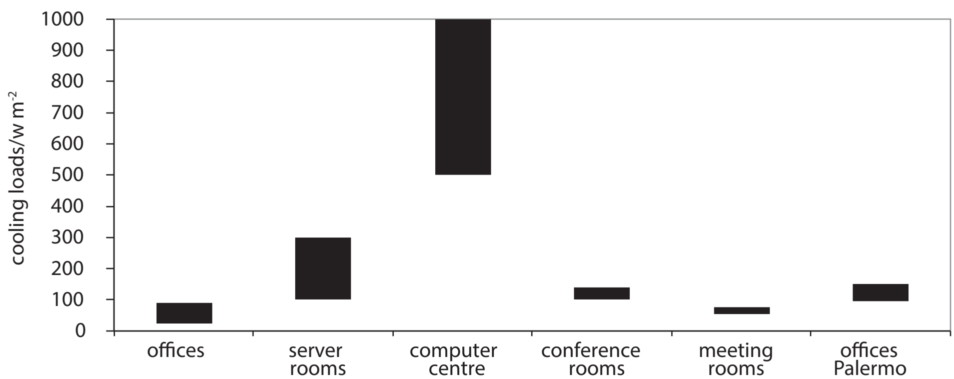


Figure 1.13 Typical cooling loads for buildings in Germany and offices in Palermo, Italy.

The sum of external and internal loads leads to an average cooling load in administrative buildings of about 50 W m^{-2}. The cooling load is dominated in many cases by the external loads.

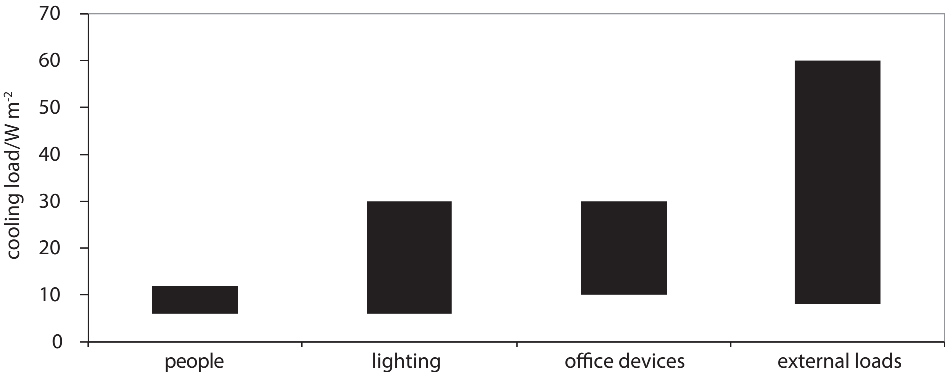


Figure 1.14 Cooling load distribution in office buildings.

1.4 Lighting electricity consumption

The average share of lighting in electricity consumption is 36% in administrative buildings, compared to only about 5% in the industrial sector. Due to the high luminous efficiency of daylight, the internal thermal loads due to lighting are in addition reduced, and thus also the problem of summer overheating in offices.

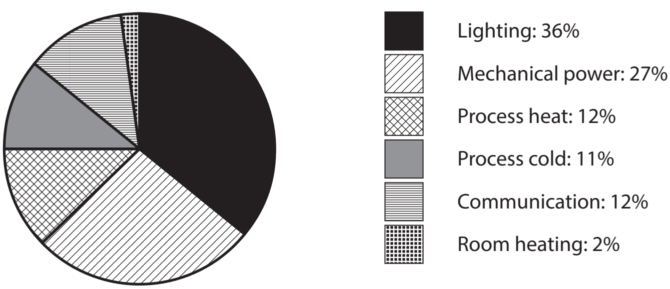


Figure 1.15 Average electricity consumption and lighting contribution for small consumers (trades, service sector and public sector) in Germany, 1998.

The lowest measured electricity consumption values for lighting are below 5 kWh m^{-2} a^{-1} in office buildings, e.g. the ZUB office building in Kassel, Germany, with facade high windows, a shallow room depth of 4.6 m and natural light-dependent dimming. During an intensive period of measurement evaluation, yearly values of 3.5 kWh m^{-2} a^{-1} were determined. For unregulated illumination in supermarkets or banks, the electrical consumption for lighting can reach values of 50 - 70 kWh m^{-2} a^{-1}.

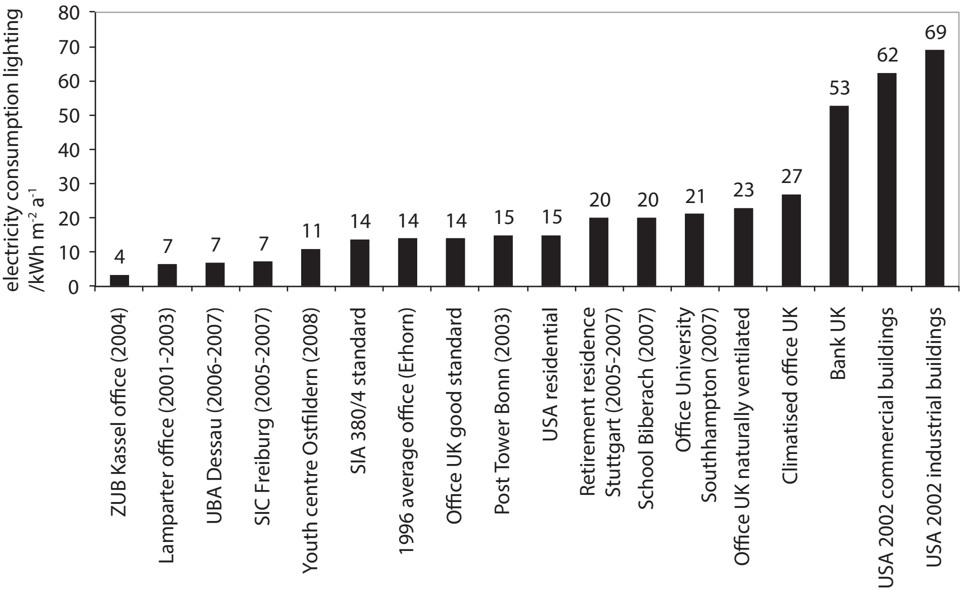


Figure 1.16 Electrical consumption for lighting in non-residential building types (measured values with years).

As part of one of the author's European research projects, an administration building of the University of Southhampton completed in 2005 with 2600 m^2 was measured in detail. The electricity consumption for illumination was 21 kWh m^{-2} a^{-1}. An analysis of the daily and monthly consumption data demonstrated that there was no seasonal dependency in the lighting. The illumination consumption decreased only at the weekend by a factor of 10. The potential for electricity consumption savings through dimming dependent on natural light is clear.

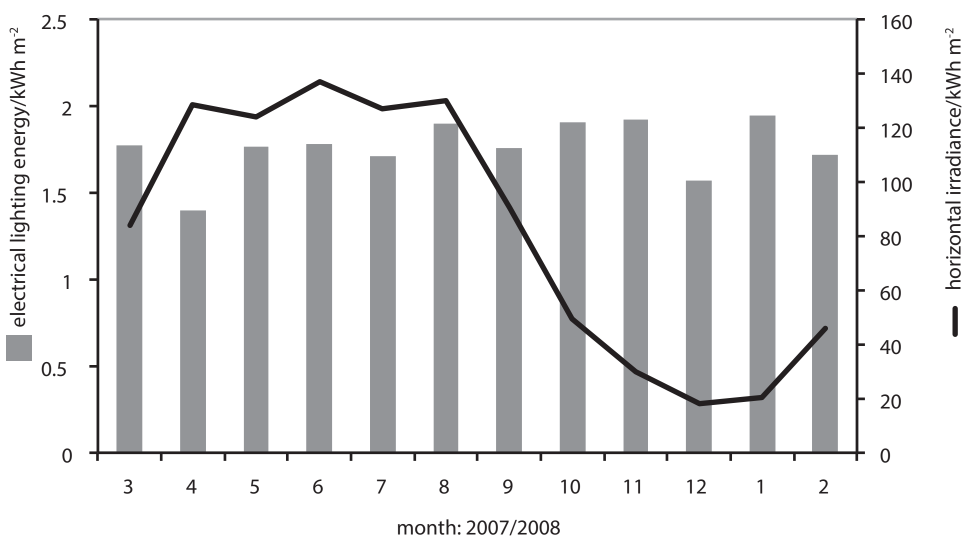


Figure 1.17 Monthly irradiance and measured illumination consumption for a new building in Great Britain.

In residential buildings, illumination contributes normally less than 10% to total electricity consumption. In Great Britain, 3% of electricity consumption was attributed to lighting.

1.5 Influence of the urban form on energy consumption of buildings

Today around 50% of the world's population are living in cities, which already account for 75% of all energy use. Urban areas with their industries and power stations are estimated to be responsible for about 60 - 70% of global CO_2 emissions (Satterthwaite, 2008). Residential buildings alone represent 63% of the total energy consumption in the European building sector and account for 10% of total greenhouse gas emissions (Balares et al., 2007).

The policies and urban master plan decisions on zoning influence the urban energy demand. The urban density refers to the number of people inhabiting a given urbanised area. Urban density can be influenced by increasing building depth, by increasing building height or reducing spacing or by increasing compactness.

The urban density can affect the total energy demand of a city in different ways, and these effects are complex and conflicting. Density supports district energy systems and infrastructure facilities are closer so it reduces also the energy requirement for distributing heat or cold. Steadman (1979) assumed that high-density linear development along transport routes would be more energy efficient than compact central development, as linear patterns allow better natural lighting, ventilation and passive solar gain. Building energy costs were estimated higher than travel energy demand. High density can increase energy demand due to limitation on natural ventilation, lighting and solar gains (Hui, 2001). In cooling-dominated climates, higher building densities reduce energy demand. On the other hand, in dense urban settlements the concentration of services reduces the need to travel large distances, and generally efficient transport is difficult to provide in the low-density cities. When comparing 10 major cities in the USA with 12 European cities, European cities were five times as dense, and the US cities consume 3.6 times as much transport energy per capita. A compact city is the most fuel efficient of all urban forms, with 43% less fuel consumption than 'business-as-usual' development (Newton, 1997).

The effects caused by urban design on heating, cooling and lighting energy demand of the spaces are different, and their influences are varying according to climatic conditions (see Table 1.3).

The main factors that affect daylight use and solar gains in buildings are the distance between buildings, the height of the facing building, the orientation of and the reflectance from the facing buildings, the size of openings and the size of the shading device. The daylight performance is especially significant for office buildings characterised by high lighting energy consumption and where the productivity of the employees is highly affected by lighting conditions. In residential buildings, electricity consumption for lighting is much less influenced by daylight performance due to a higher evening use profile.

Simulation models are often used to assess the annual energy consumption for electric lighting or the impact of daylight on the thermal behaviour of the building. The building energy performance in an urban context is evaluated by changing the height of the buildings while keeping the urban design density constant. To quantify the urban canopy layer assessments, the height to width ratio (aspect ratio) of the street canyon can be used.

	Heating	**Cooling**	**Lighting**
Height and width of buildings	Multi-storey buildings and compact forms reduce the heat losses from the building envelope.	Multi-storey buildings and compact forms reduce the heat gains from the building envelope.	Shading impact increases with increasing height to width ratio, causing higher artificial lighting requirement.
Street configuration	Density of the area increases the mutual shading and reduces the solar gains with increased heating and reduced cooling demand. District heating and cooling systems can be used efficiently in dense areas. Efficiency of solar heating and cooling systems decreases because of the shading effect of other buildings on the solar collecting area.		High density causes more daylight-controlled artificial lighting energy consumption at lower floor levels.
Thermal and optical properties of buildings	Low *U* value reduces the heat losses from building envelope.	Low *U* value reduces the heat gains from building envelope.	High reflection provides high illuminance levels and results in less electric lighting consumption.
	Low albedo and high absorption of the building envelope increase the urban heat island effect.		High visual transmission of glass provides high illuminance levels and results in less electric consumption.

Table 1.3 Urban effects on heating, cooling and lighting demand.

To analyse urban geometry configuration changes and building energy performance, the analysis should start from room scale that is a basic space of a building in an urban quarter. This is mainly important for electrical lighting requirements, which strongly depend on the location of a room within a building. In residential buildings, where energy efficient daylight is less important, it is not necessary to simulate individual rooms within a building.

When the electric lighting demand has been calculated, heating and cooling demand calculations can be done considering the thermal effects generated by artificial lighting. In this way, the total (heating, cooling and electric lighting) energy demand of the room is calculated. The building energy demand is obtained by adding up all rooms' energy demand in the building. Using the same approach, a complete urban site energy performance can be determined. The results presented have been obtained by two dissertations within the European PhD school CITYNET (Kesten, 2012 and Tereci, 2012).

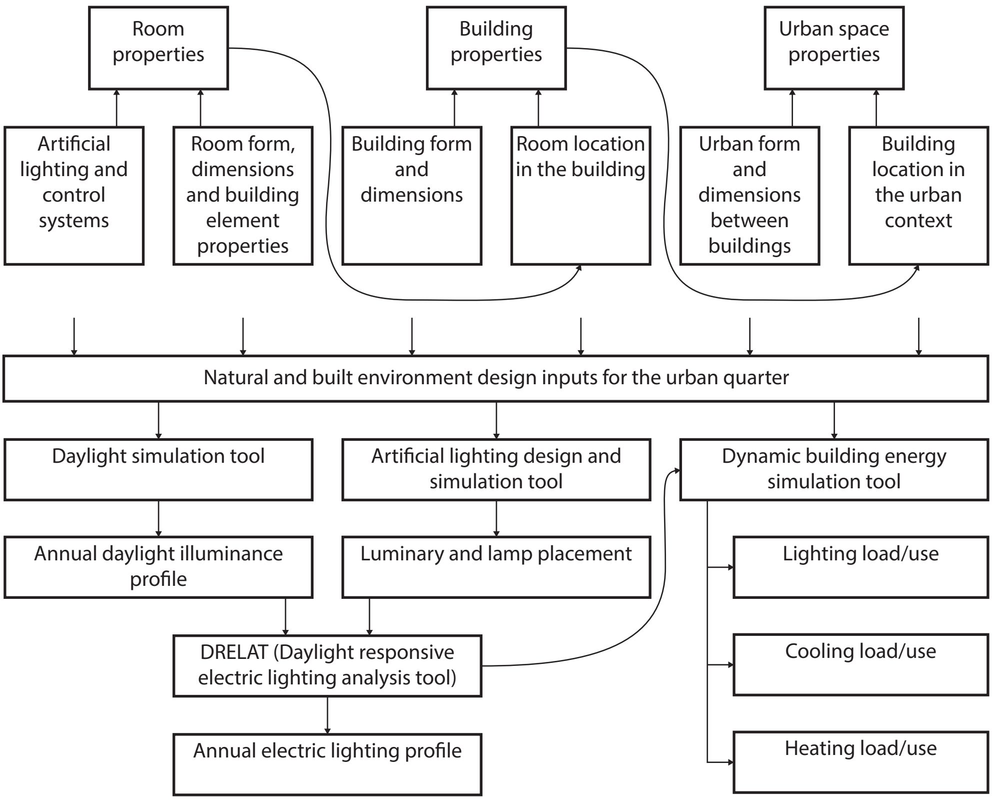
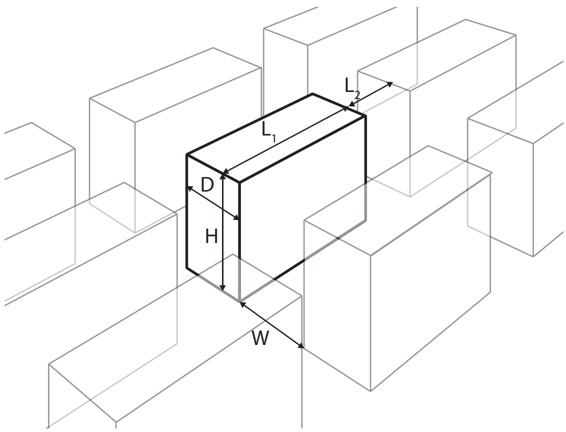


Figure 1.18 Analysis model for energy performance of buildings in an urban context (Kesten, 2012).

1.6 Office buildings in an urban context

The real urban texture is highly complex to compute. In order to limit these complexities, some archetypes were defined, and these simplified types are used especially for energy use studies. Two generic urban types are considered here: separated and continuous units. Separated unit, defined by geometrical ratios, are shown in Figure 1.19. Sixty different building configurations were analysed, corresponding to five levels of spacing distance (L_1/L_2), four levels of building depth (D/L_2), four levels of aspect ratios (H/W) and the cases without surrounding blocks. All simulations were conducted for all four cardinal directions: north, east, south and west.



Frontal length (L_1)
Depth (D)
Height (H)
Distance between units (L_2)
Street width (W)

Spacing distance (L_1/L_2)
Aspect ratio (H/W)
Building depth to frontal length (D/L_2)

Figure 1.19 The form structure labels H, D and L_2 refer to the height, depth and frontal length of each unit, L_1 refers to the spacing between the units and W to the width of the street.

To calculate the daylight illuminance, the raytracing programme Radiance was used. The annual electricity consumption with a daylight-responsive control system was simulated in Radiance based on the lighting programme Daysim. The heating and cooling analysis including the annual electricity consumption with daylight-responsive control was carried out using the EnergyPlus simulation programme. EnergyPlus uses the hourly electric lighting schedules to integrate daylight-responsive electric lighting into thermal calculations.

The office building type is a cellular plan office, and the working schedule is weekdays from 08:30 am till 6:30 pm. The envelope was designed according to the German Energy Saving Ordinance 2009 (EnEV 2009). A pavilion type of urban generic form is used, which means a detached block of building. The three-storey reference building has a 10 m depth and a 20 m length. The reference office is located in the first floor – middle axis of the building and facing south. The dimensions of the office room are 2.5 m width, 4.5 m depth, 2.5 m height, and it has a 50% window to wall ratio.

Figure 1.20 shows total annual energy demand of the south-orientated sample office space under four different aspect ratio (*H/W*) scenarios in Southern German climatic conditions. The energy demand is strongly influenced by the *H/W* ratio when it changes from 0.5 to 1 and increases by 20%. The total energy demand slightly decreases with aspect ratios above 1. The increase of the heating and electric lighting energy demand is more than compensated by the decrease of the cooling energy demand. Therefore, the total energy demand decreases by 6%. On the other hand, the daylight-responsive electric lighting demand rises from 7 to 10 kWh m^{-2} a^{-1}.

When decreasing the ratio of the lateral distance between buildings L_1 to the frontal length of the building L_2 from $L_1/L_2=1.5$ to $L_1/L_2=0.25$, which corresponds to an increase in urban site density from 17% to 29%, the heating and lighting demand slightly increases by 5% and the cooling demand decreases by 7%. For a given building height to width ratio (here $H/W=0.5$), the change of the L_1/L_2 ratio is not very relevant for blocking or increasing solar gains entering the space.

The annual energy demand is also not much affected by the building depth to the frontal length (D/L_2). The annual heat demand increases by less than 2% with increasing D/L_2 ratios, as the solar gains reduce. A similar tendency can be observed in the daylight-responsive electricity demand.

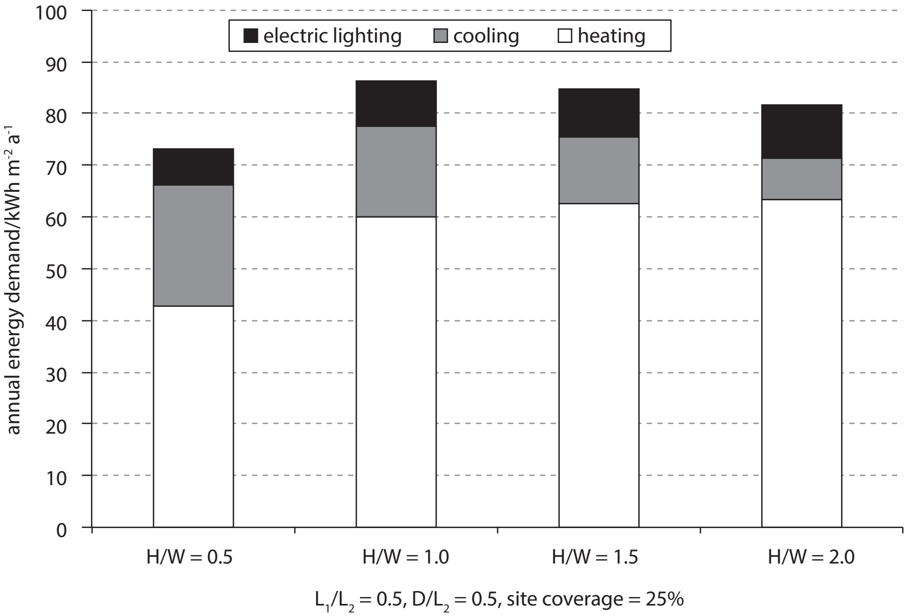


Figure 1.20 Annual energy demand of an office building room as a function of aspect ratios (H/W).

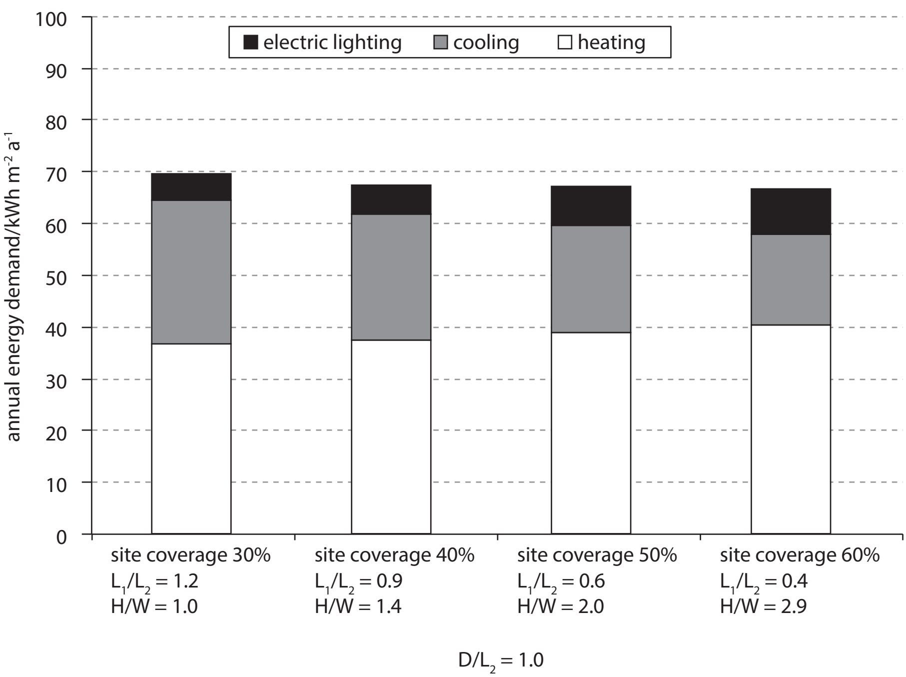


Figure 1.21 Heating, cooling and lighting demand of high-rise office blocks for different densities in Stuttgart.

High-rise office blocks with different site densities were also analysed for Southern German climatic conditions. The 10-storey reference building has 24.4 m depth, 24.4 m length and 30 m height. The energy consumption of the office room's daylight-controlled artificial lighting was evaluated for different site coverage. The required illumination level of the office room is 500 lux (lx), and the artificial lighting system was designed to supply this level.

When the shading effect due to the surrounding buildings is taken into account, the electric lighting demand increases. The cooling energy demand is also affected by daylight-responsive controlled artificial lighting, as there is less heat gain generated by artificial lighting. In Figure 1.21, the effects caused by external obstructions can be observed. The shading effect results in less cooling requirement due to a decrease in solar gains. The simulated annual heating demand increases from 36 to 40 kWh m^{-2} a^{-1}. At 60% site coverage, the annual cooling loads decrease to 17 kWh m^{-2} a^{-1}, which is about 36% less than at 30% site coverage.

For the sample office room, the annual electric lighting demand was also evaluated for each site density as a function of floor height. On the first and fifth floor, the influence of site coverage is very important, whereas the top floor is no longer shaded by neighbouring buildings. This height sensitivity of lighting energy demand makes urban simulations complex.

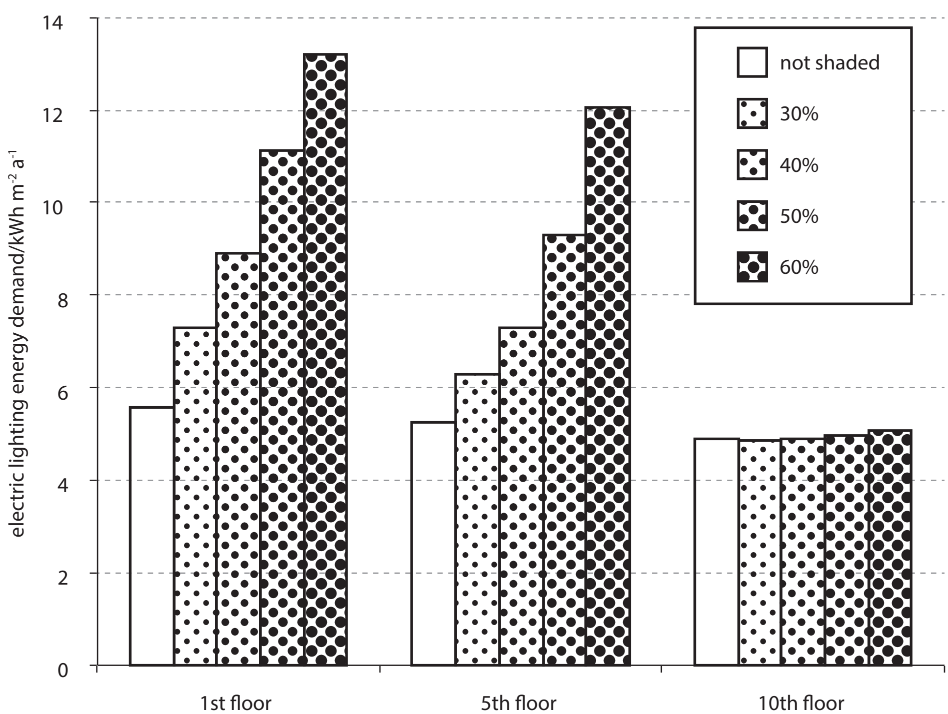


Figure 1.22 Daylight-responsive artificial electric lighting demand of office blocks for different site densities and different floor levels.

1.7 Residential buildings in an urban context

Settlement types for residential buildings were chosen using urban generic forms based on the work of Martin and March (1972). The generic urban forms have simple and repeatable characteristics, thus eliminating the complexities found in real urban sites and allowing for a more systematic comparative analysis of geometry and built form. These forms are represented in Figure 1.23.

For the analysis of residential buildings, the electricity consumption from lighting and appliances are included using given load profiles. Here no separate daylighting simulations are carried out, but the effects of shading on heating and cooling demand is considered. The residential settlement types are chosen as pavilion settlement types for one-family houses, apartment and high-rise blocks, as terrace settlement type for row houses and as pavilion courtyard settlement types for old houses.

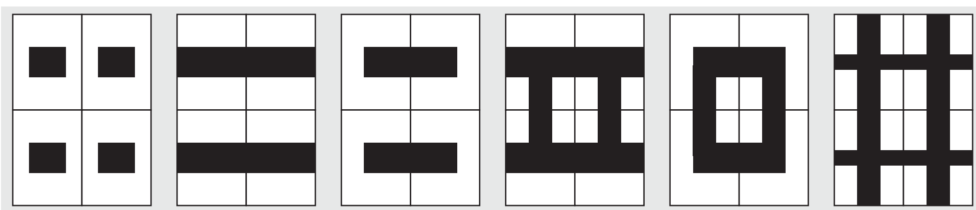


Figure 1.23 Generic urban zones based on the classification system of Martin and March (1972) with pavilions, slabs, terraces, terrace-courts, pavilion-courts and courts.

The urban shading effect is simulated with all obstructing buildings around the simulated one. The model includes the reflectance from the obstruction surfaces, and an albedo factor is defined for obstruction buildings and the ground. Site densities are defined as the ratio of built-up area to total area and were varied between 30% and 60%, as below 30% obstructions are nearly negligible and above 60% the buildings become unrealistically close (Tereci, 2012).

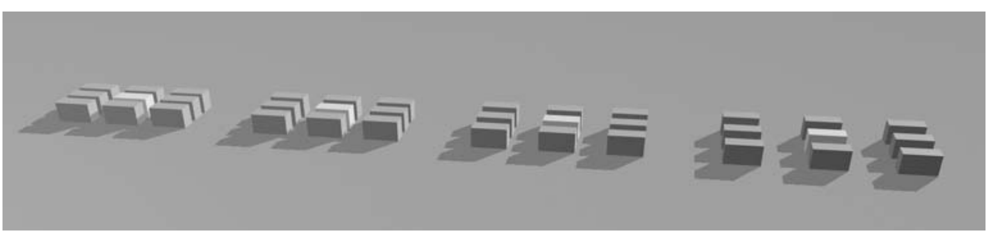


Figure 1.24 EnergyPlus models of multifamily buildings for shading simulations with site densities varying between 60% and 30%.

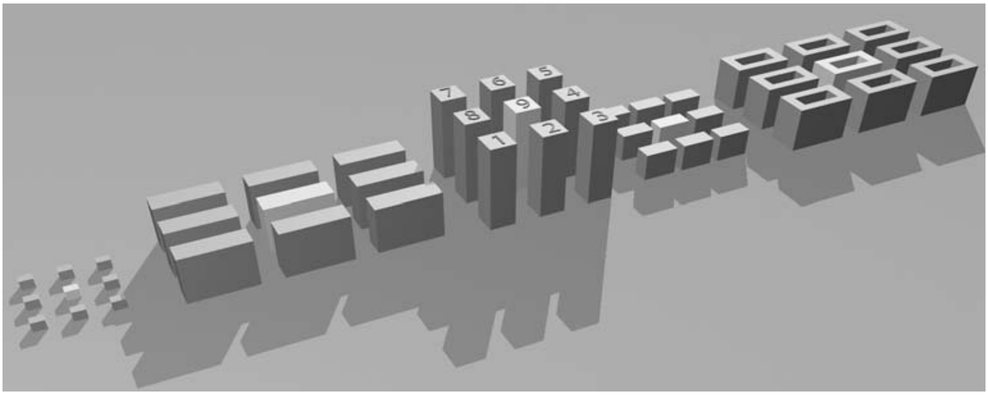


Figure 1.25 EnergyPlus models of building types and the urban quarter constituted of 9 generic building blocks from each building type. The distance between the buildings varies according to site densities. The building position numbers (1 - 9) are analogous for each cluster.

Geometry	**Single-family house**	**Multifamily house**	**Old high-rise block**	**Row houses**	**Old apartment (courtyard)**
Length	**10.5 m**	**20 m**	**24.4 m**	**7 m**	**10 m**
Width	**10.5 m**	**14 m**	**24.4 m**	**10 m**	**10 m**
Height	**3.5 m**	**10.8 m**	**30 m**	**7 m**	**13 m**
			U values/W m^{-2} K^{-1}		
Wall	0.5	0.3	0.88	0.5	1.45
Roof	0.3	0.3	0.97	0.3	1.3
Floor	0.22	0.22	0.85	0.22	2.6
Window	1.6	1.6	2.57	1.6	2.9

Table 1.4 Geometric properties and *U* values of building types.

The classification of the urban settlements traditionally relies on their population and activity type. German statistic data and measurements from a case study project near Stuttgart were applied for estimating the occupancy scenario (Strzalka et al., 2011). All residential buildings were simulated using the same occupation scenario.

The scenario is based on a family with four people with no daytime use of the flat except weekends. Every house has television, computer, washing machine, dishwasher, oven, fridge and microwave. It was assumed that appliances were used early in the morning and evening time for weekdays and weekend. EN ISO 13791 was taken as an input for internal gains from occupants. The lighting was defined with 13 W m^{-2} and 40% of those are convective gains. The heating set point is 19°C and cooling set point is 26°C.

The heating, cooling, electricity and hot water demand for buildings without obstructions are simulated and serve as a baseline for comparison.

Reference buildings	Heating demand	Cooling demand	Electricity demand	Hot water demand
		per kWh m^{-2}		
Single-family house	72	10	23	28
Multifamily house	44	11	33	28
Old high-rise block	83	16	21	28
Old apartment with courtyard	168	4	25	28
Row houses	74	4	19	28

Table 1.5 Dynamic simulation results of reference buildings without shading effect using typical *U* values from the German building stock. The electricity demand shown includes appliances and a lighting energy demand of 5 kWh m^{-2} a^{-1}.

The highest heating demand value of the old courtyard apartment is 168 kWh m^{-2} a^{-1} with a cooling demand of 4 kWh m^{-2} a^{-1}. The minimum heating demand value of the multifamily house is 43.7 kWh m^{-2} a^{-1} with 11.4 kWh m^{-2} a^{-1} cooling demand. The thermal performance of the multifamily house is better than the other forms due to the most compact building form with the smallest outside wall area.

1.8 Site density effect

First the heating and cooling demand of a building type in the centre of an urban structure was analysed as a function of site density (building position 9 described above). In a second step the influence of the position of each building within the urban setting is shown.

For single-family houses with a building standard corresponding to the construction years between 1995 and 2001, the heating demand increases by 17% (to 84 kWh m^{-2} a^{-1}) for a 60% site density compared with the unshaded situation (with 72 kWh m^{-2} a^{-1}). Using an increased albedo of 0.7 for the surroundings instead of 0.2, the heating demand slightly reduces to 79 kWh m^{-2} a^{-1} for the 60% site coverage.

Similar results are obtained for the multifamily houses. Without any shading effect the heating consumption of multifamily house is 43.7 kWh m^{-2} a^{-1} and increases by 20% for 60% site coverage. The rather low cooling demand of 11.4 kWh m^{-2} a^{-1} reduces with site density to 6.4 kWh m^{-2} a^{-1}, i.e. by 44%.