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Energy Demand of Buildings

Buildings today account for 40% of the world's primary energy consumption and are responsible for about one-third of global CO₂ emissions (24% according to IEA, 2008; 33% according to Price *et al.*, 2006). The energy-saving potential is large, with 20% savings expected until 2020 in the European Union alone. The cost efficiency of building-related energy savings is high, as shown in a recent study for the Intergovernmental Panel on Climate Change (Ürge-Vorsatz and Novikova, 2008). In the industrialized countries, between 12 and 25% of building-related CO₂ emissions can be reduced at net negative costs, mainly through heat-related measures. In the developing countries, electricity savings through more efficient appliances and lighting are more important with 13 to 52% of the measures being economically feasible until 2020. As published in the Green Paper on energy efficiency by the European Commission, end energy-consumption in 2005 reached 12×10^9 MWh per year, 40% of which can be attributed to buildings (see Figure 1.1). In the USA, 36% of the total energy consumption occur in buildings. Especially in urban areas, building energy consumption is typically twice as high than transport energy, for example by a factor of 2.2 in London (Steemers, 2003).

Under the Kyoto Protocol, the European Union has committed itself to reducing the emission of greenhouse gases by 8% in 2012 compared with the 1990 level and buildings have to play a major role in achieving this goal. If building energy efficiency is improved by 22%, 45 million tonnes of CO₂ can be saved, nearly 14% of the agreed total savings of 330 million tonnes.

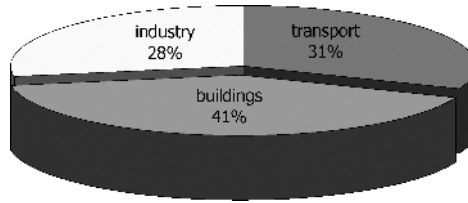


Figure 1.1 Distribution of end energy consumption within the European Union

The European Directive for Energy Performance of Buildings, signed by the European Parliament and Council in 2002, was created to unify the diverse national regulations and calculation methods, to define minimum common standards on building energy performance and to provide certification and inspection rules for a building and its heating and cooling plants. Although the performance directive only defines a common methodology for energy certification, most European countries have now increased their requirements to limit new buildings' energy demand. On average, allowed building transmission losses are now 25% lower. The heat transfer coefficient (U -value) is defined as the reciprocal sum of heat transfer resistances between room and ambient air and is today on average between 0.3 and $0.4 \text{ W m}^{-2} \text{ K}^{-1}$ for a building.

The reduction of energy consumption in buildings is of high socioeconomic relevance, with the construction sector as Europe's largest industrial employer representing an annual investment of 910×10^9 euros (2003), corresponding to 10% of gross domestic product. Almost 2 million companies, 97% of them small and medium enterprises, directly employ 11.8 million people.

The total primary energy consumption in Germany is about 4×10^9 MWh, corresponding to 13 878 PJ (2007 data), and is estimated to decrease by 15% until 2030 (EWI/Prognos, 2005). The main efficiency gains are expected through the reduction of transformation losses, which today are responsible for 3984 PJ and are due to decrease by 37% until 2030. In the building sector, on the contrary, the final energy consumption of 2599 PJ (2000) is only estimated to decline by 4% until 2030, which is due to the slow rate of rehabilitation.

In moderate European climates such as Germany's, about 80% of the total energy consumption is used for space heating, 12% for warm water production and the rest for electrical appliances, communication and lighting. The dominance of heat consumption, almost 80% of the primary energy consumption of households, is caused by low thermal insulation standards in existing buildings. They dominate the residential building stock with 90% of all buildings. Even in 2050, 60% of residential space will be located in existing buildings (Ministry for Transport and Buildings, Germany, 2000). Since the 1970s' oil crises the heating energy demand, particularly of new buildings, has been continuously reduced by gradually intensified energy legislation. With high

heat insulation standards and the ventilation concept of passive houses, a low limit of heat consumption has meanwhile been achieved, which is around 20 times lower than today's average values. A crucial factor for the low consumption of passive buildings was the development of new glazing and window technologies, which enable windows to be passive solar elements 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 in the European Union is estimated to rise by 50% by 2020. Renewable sources of energy can make an important contribution to the supply of electricity and heat. Cooling and refrigeration account for about 15% of total electricity consumption worldwide, and as much as 30% in highly developed countries with a warm climate such as Hong Kong (Government Information Centre, Hong Kong, 2004). Peak electricity loads in many countries now occur in summer rather than in winter. In South Australia, for example, cooling and refrigeration were reported to account for 46% of total electricity consumption on a hot summer's day.

Urban energy management systems should include demand predictions, databases of consumption as well as strategies for operational control and optimization. Consumption data is rarely available on an urban scale, which makes projections of energy requirements difficult. Often there is no strategic energy management plan and demand and supply are not properly matched. Surveys on energy consumption patterns in communities are therefore often based on calculated demand, for example using the appliances used in residential buildings and estimated hours of operation (Zia and Devadas, 2007). A similar demand simulation approach was chosen to analyse the energy efficiency and CO₂ reduction potential in the commercial sector in Japan until 2050 (Yamaguchi *et al.*, 2007). Assuming relatively low increases in insulation thickness (from zero in the year 2000 to 60 mm in 2050), the main efficiency gains were expected through improvements in appliance electrical efficiency. This led to the surprising fact that heat demand even rises, as internal loads due to equipment were supposed to drop. A case study in the UK town of Leicester obtained energy savings of 20% by more efficient lighting in residential buildings, based on measured electricity load curves from the energy supplier (Brownsword *et al.*, 2005).

The chapter aims to contribute information on how much energy is consumed in its different forms in the building sector and which reductions are possible in best case examples. Embedded energy in the building materials and construction process is not included in the analysis, although several studies indicate a rather high importance of material and resource use during building construction and maintenance: for example, Pulselli and colleagues calculated that 49% of all energy is needed for the building manufacturing process, 35% for maintenance and only 15% for use (Pulselli *et al.*, 2007).

1.1 Residential Buildings

1.1.1 Heating Energy

Due to the wide geographical extent of the European Union covering nearly 35° of geographical latitude (from 36° in Greece to 70° in northern Scandinavia), a wide range of climatic boundary conditions are covered. In Helsinki (60.3°N), average exterior air temperatures reach -6°C in January, when southern cities such as Athens at 40°N latitude still have averages of $+10^\circ\text{C}$. Consequently, building construction practice varies widely: whereas average heat transfer coefficients (U -values) for detached houses are about $1\text{ W m}^{-2}\text{ K}^{-1}$ in Italy, they are $0.4\text{ W m}^{-2}\text{ K}^{-1}$ in Finland (see Table 1.1). The heating energy demand calculated from monthly energy balances (according to European Standard EN 832) is comparable in both cases at about $50\text{ kWh m}^{-2}\text{ a}^{-1}$.

If existing building standards are improved to the so-called passive building standard, heating energy consumption can be lowered to less than $20\text{ kWh m}^{-2}\text{ a}^{-1}$. Studies in Switzerland showed that additional investment costs for passive residential buildings are about 14% (Minergie P label). For buildings with a low energy standard (reaching the Swiss Minergie label) investment costs were about 6 to 9% higher (Binz, 2006). Depending on the assumptions made for energy price increases, the additional investment costs can be compensated by lower energy costs during operation. In Germany with its high number of passive building projects, additional investment costs for the high standard are only 3 to 5%.

Since the implementation of the European Building Performance Directive in 2003, nearly all European countries have significantly increased the requirements to reduce transmission heat losses. The European Performance Directive asks for the establishment of a calculation methodology for energy demand and an energy certification process, whereas limits on energy demand are regulated by national laws.

Average U -values for new buildings are about 25% lower than in 2003. The required U -values to achieve passive building standards are listed in Table 1.1 for some cities from different European climates. For these insulation standards, heating energy consumption is between 15 and $20\text{ kWh m}^{-2}\text{ a}^{-1}$. By comparison, today's residential buildings in Germany with low energy standards have annual heating energy

Table 1.1 U -values for residential passive buildings (Truschel, 2002)

U -values $\text{W m}^{-2}\text{ K}^{-1}$	Rome	Helsinki	Stockholm
Wall	0.13	0.08	0.08
Window	1.40	0.70	0.70
Roof	0.13	0.08	0.08
Ground	0.23	0.08	0.1
Mean	0.33	0.16	0.17
U -value			

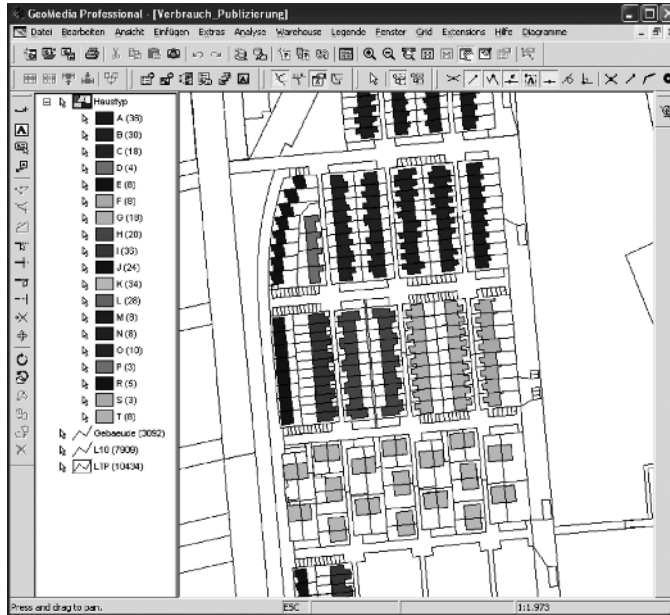


Figure 1.2 Rows of houses analysed in the POLYCITY project, visualized in a geoinformation system

consumption values of around $70 \text{ kWh m}^{-2} \text{ a}^{-1}$. Several hundred houses in rows constructed after the year 2000 in the town of Ostfildern were measured within the European POLYCITY demonstration project (see Figure 1.2). The consumption varies strongly even for the same building type and standard deviations are about 35% of the mean value (Figure 1.3). The distributions for two years of measurement are shown in Figure 1.4.

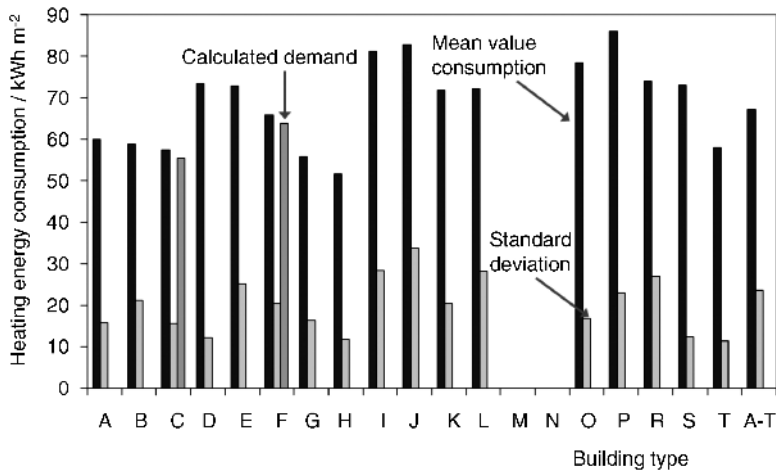


Figure 1.3 Mean measured heating energy consumption and standard deviation of different, newly built rows of houses in Ostfildern, Germany

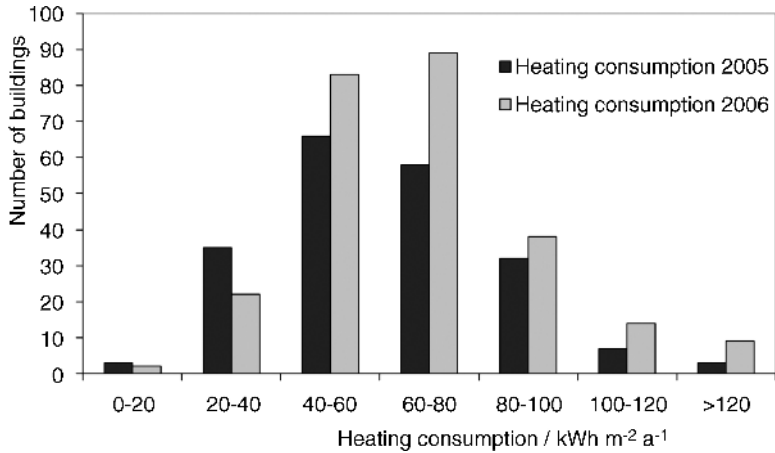


Figure 1.4 Measured heating energy consumption for newly built rows of houses in Ostfildern, Germany

Although 20% of all buildings in Germany were constructed after 1980, they only consume 5% of the total heating energy. Depending on building age and type, older buildings' heating energy consumption varies between 100 and 400 kWh m⁻² a⁻¹. The main challenge of the next decades will therefore be the reduction of heating energy consumption for existing buildings.

Within the POLYCITY project the existing building stock of the town of Cerdanyola near Barcelona in Spain was analysed with over 6000 buildings: 44% of them are single storey buildings, 28% have two floors. More than 90% of the buildings were constructed after 1960 and 65% of the apartments are between 60 and 90 m². The average heating energy consumption is between 90 and 100 kWh m⁻² a⁻¹ and has increased slightly during the last decade due to increased use of central heating systems with integrated warm water production (see Figure 1.7). In comparison, in the urban area of Barcelona with multi-family apartment blocks, heating energy consumption is only 34 kWh m⁻² a⁻¹ on average (Reol, 2005).

1.1.2 Domestic Hot Water

Independent of the level of insulation, water heating is always necessary in residential buildings. The energy consumption is 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 consumption is 440–880 kWh per person or 1760–3520 kWh for an average four-person household. Related to a square metre of heated residential space, a rather low average value of 12.5 kWh m⁻² a⁻¹ is for example used in German legislation. In Switzerland, a fixed value of 14 kWh m⁻² a⁻¹

is used. To increase the share of renewable energy for water heating, some local or regional governments have introduced legislation to cover typically 60% of the warm water demand by solar thermal energy. In Catalunya in Spain, about 75% of the local communities have so-called local ordinances to oblige building constructors to implement solar thermal energy. In Mediterranean climates, the energy need for warm water heating is of the same order of magnitude as heating energy consumption, even for the given building stock. An investigation for urban housing in Barcelona in Spain showed that from a total end energy consumption of 8310 kWh a^{-1} for residential housing of 90 m^2 average size, 29% or $26 \text{ kWh m}^{-2} \text{ a}^{-1}$ was used for warm water production and 38% for heating. Cooling energy need on the other hand is less than $10 \text{ kWh m}^{-2} \text{ a}^{-1}$ (Reol, 2005).

1.1.3 Electricity Consumption

The average electricity consumption of private households is around 3600 kWh per household and year in Germany. Related to a square metre of heated residential space, an average value of $31 \text{ kWh m}^{-2} \text{ a}^{-1}$ is obtained. An electricity-saving household needs only around 2000 kWh a^{-1} . Measured electricity consumption for several hundred newly built houses in Ostfildern showed average annual consumption values between 30 and $50 \text{ kWh m}^{-2} \text{ a}^{-1}$ (see Figure 1.5). The highest number of buildings was in the class between 40 and $50 \text{ kWh m}^{-2} \text{ a}^{-1}$ (see Figure 1.6). 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 $12 \text{ kWh m}^{-2} \text{ a}^{-1}$.

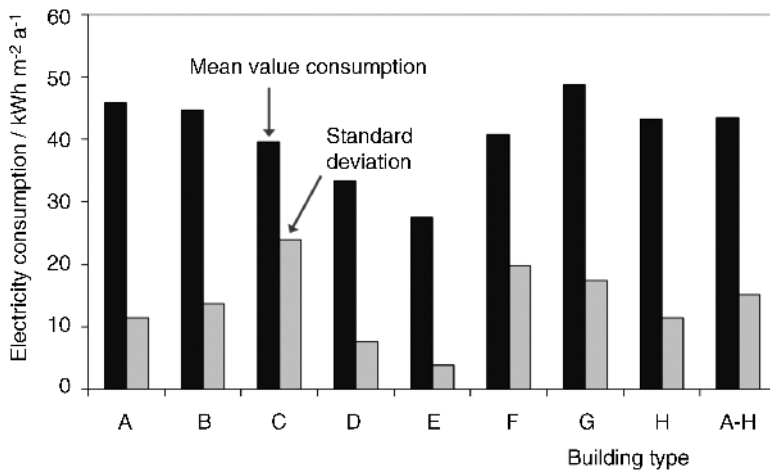


Figure 1.5 Measured electricity consumption of newly built rows of houses in Ostfildern, Germany

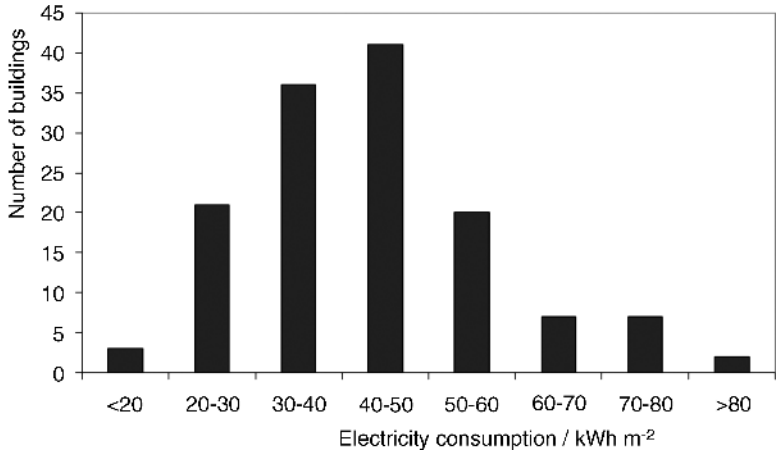


Figure 1.6 Distribution of electricity consumption in newly built rows houses in Ostfildern, Germany

Within the urban housing study in Barcelona, the average electricity consumption was 2160 kWh per household, which corresponds to 24 kWh m⁻² a⁻¹. In the nearby town of Cerdanyola, the measured electricity consumption for mainly single or two-storey buildings was 70 kWh m⁻² a⁻¹, with decreasing consumption during the last decade due to the replacement of electric water heaters (Figure 1.7). The high average consumption can be mainly attributed to a housing stock which is partially heated and cooled with electricity. Apartments without electrical heating systems have electricity

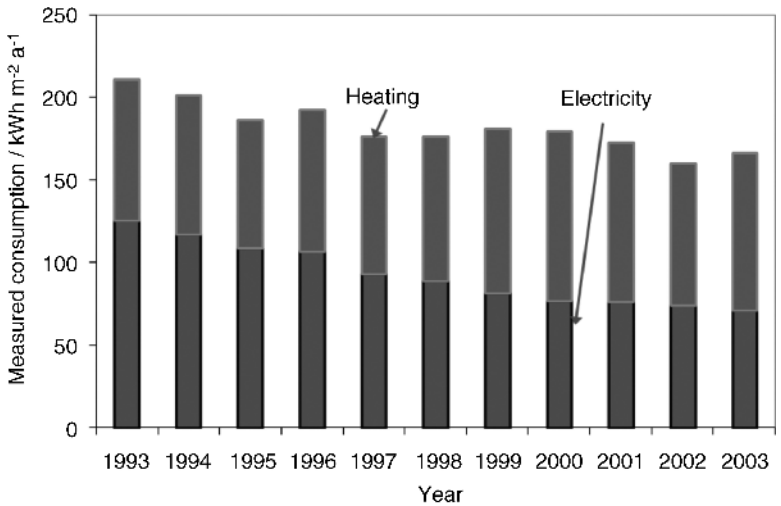


Figure 1.7 Measured heating and electricity consumption (end energy) for 6238 buildings in Cerdanyola, Spain

consumption values between 40 and 50 kWh m⁻² a⁻¹. Measurements of electricity consumption were also taken in a social housing district with 2500 inhabitants in Turin, Italy, within the POLYCITY project: 622 apartments within 30 building blocks were analysed. Here the average electricity consumption per household is low, about 1750 kWh per year, which corresponds to a specific consumption between 14 and 20 kWh m⁻² a⁻¹.

1.2 Office Buildings

1.2.1 Heating Energy

Existing office and administrative buildings have approximately the same consumption of heat as residential buildings and most have a higher electricity consumption. According to a survey of the energy consumption of public buildings in the state of Baden-Württemberg in Germany, the average consumption of heat is 217 kWh m⁻² a⁻¹. The specific energy consumption of naturally ventilated office buildings in the UK is in a similar range of 200–220 kWh m⁻² a⁻¹ (Zimmermann and Andersson, 1998). From the commercial sector in Japan, values of 59 kWh m⁻² a⁻¹ have been reported (Yamaguchi *et al.*, 2007). Measured heating energy data from a variety of the author's projects (Lamparter office in Weilheim, Germany, Town Hall Ostfildern, Germany, Isbank Tower, Istanbul) and case studies literature has been gathered by the author and is shown in Figure 1.8. Heat consumption in administrative buildings can be reduced without difficulty, by improved thermal insulation, to under

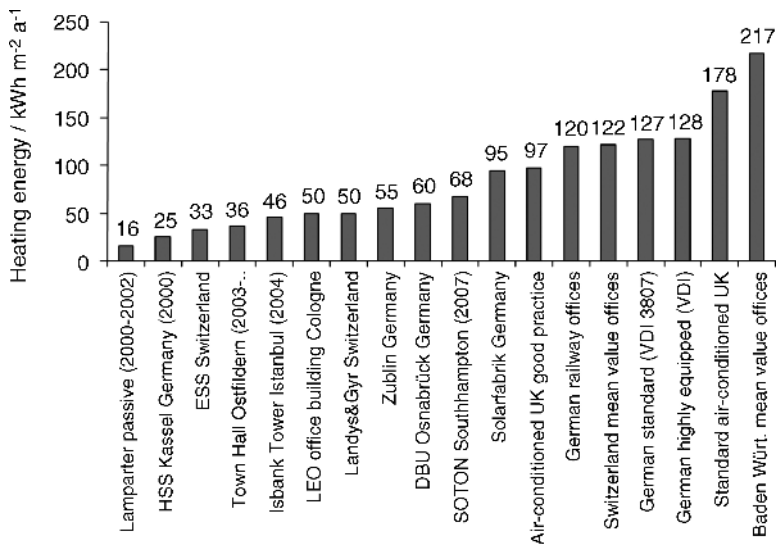


Figure 1.8 Office building projects with measured heating energy consumption in Europe

100 kWh m⁻² a⁻¹, and even to a few kilowatt hour per square metre and year in a passive building.

1.2.2 Electricity Consumption

Total Electricity Consumption

Both heat and electricity consumption depend strongly on the building’s use. In terms of the specific costs, electricity almost always dominates. A survey carried out in public buildings of the German state of Baden-Württemberg found an average electricity consumption of 54 kWh m⁻² a⁻¹, in the UK values between 48 and 85 kWh m⁻² a⁻¹ were measured (see Figure 1.9).

When comparing the energy costs of commercial buildings with the remaining current monthly operating costs, the relevance of a cost-saving energy concept is apparent: more than half of the running costs are accounted for by energy and technical services. A large part of the energy costs is due to ventilation and air-conditioning.

Electricity consumption dominates total energy consumption where the building shell is energy optimized and can be reduced by 50% at most. Even in an optimized passive energy office building in southern Germany, electricity consumption remained at about 35 kWh m⁻² a⁻¹, mainly due to the consumption by office equipment such as computers (see Figure 1.10).

While the measured values for heat consumption correspond well with the planned values, the measured total electricity consumption exceeds the planned value of 23.5 kWh m⁻² a⁻¹ by 42%. A survey of good practice office buildings in the UK showed that electricity consumption in naturally ventilated offices is 36 kWh m⁻² a⁻¹ for a cellular office type, rising to 61 kWh m⁻² a⁻¹ for an open-plan office and up to

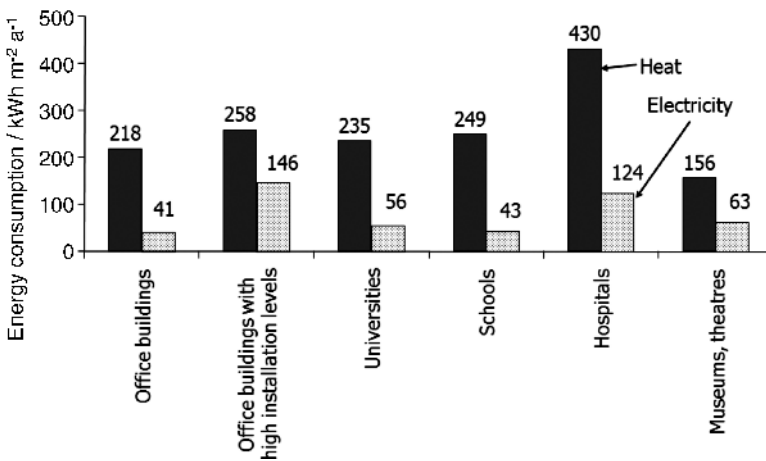


Figure 1.9 Final energy consumption by building type in Baden-Württemberg

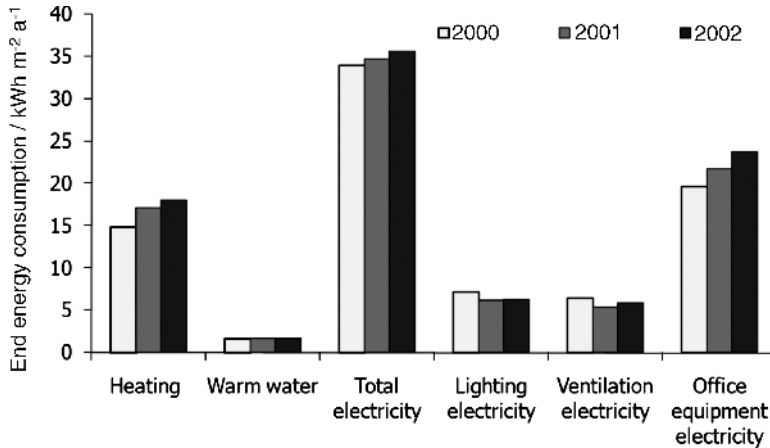


Figure 1.10 Measured consumption of electricity, heat and water heating in an office building with passive house standard in Weilheim-Teck, Germany

132 kWh m⁻² a⁻¹ for an air-conditioned office (Zimmermann and Andersson, 1998). Recent measurements in a university building in Southampton (Figure 1.11) within the European-funded Ecobuilding project SARA gave electricity consumption for equipment alone of 64 kWh m⁻² a⁻¹. A study on commercial buildings in Osaka, Japan, indicated an average electricity consumption of 75 kWh m⁻² a⁻¹, but was not split into different uses (Yamaguchi *et al.*, 2007). A survey on 6000 commercial buildings in the USA showed a range of total electricity consumption for offices and commercial buildings between 165 and 220 kWh m⁻² a⁻¹ (Energy Information Administration,

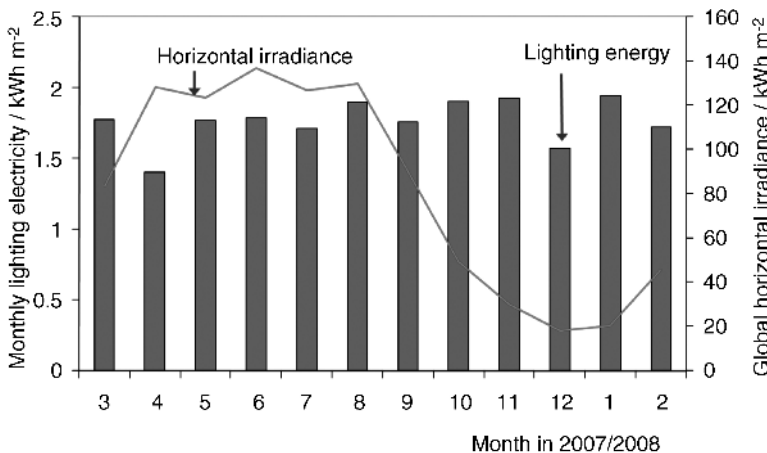


Figure 1.11 Monthly lighting energy and global horizontal irradiance for a newly constructed university office building in Southampton

2006). If about $60 \text{ kWh m}^{-2} \text{ a}^{-1}$ is subtracted for lighting (survey, US Department of Energy, 2002) and $50 \text{ kWh m}^{-2} \text{ a}^{-1}$ for cooling, this corresponds to an average electricity consumption for equipment between 55 and $110 \text{ kWh m}^{-2} \text{ a}^{-1}$.

Lighting Energy Consumption

Lighting energy contributes typically less than 10% of the total end energy consumption in residential buildings: for example, about 500–770 kWh per household in Spain and about 3% of electricity consumption in the UK (Ashford, 1998). In office buildings lighting often dominates the total electricity consumption (36% of the electricity consumption for offices in Germany and about 20% of electricity consumption in the UK commercial/public sector). The lowest values measured are around $5 \text{ kWh m}^{-2} \text{ a}^{-1}$ and can rise as high as $50\text{--}70 \text{ kWh m}^{-2} \text{ a}^{-1}$ for banks or commercial buildings in the UK and the USA (BINE, 2000). For the ZUB office building in Kassel, Germany, with façade high windows, a low room depth of 4.6 m and daylight-dependent artificial lighting control, average lighting electricity consumption of $3.5 \text{ kWh m}^{-2} \text{ a}^{-1}$ was measured during an intensive monitoring exercise (Hauser *et al.*, 2004). A survey of lighting electricity demand or consumption has been carried out by the author and is shown in Figure 1.12. It includes measured data from office building projects like the Lamparter building, the ZUB Kassel and several case studies from the UK, the USA, Germany, etc.

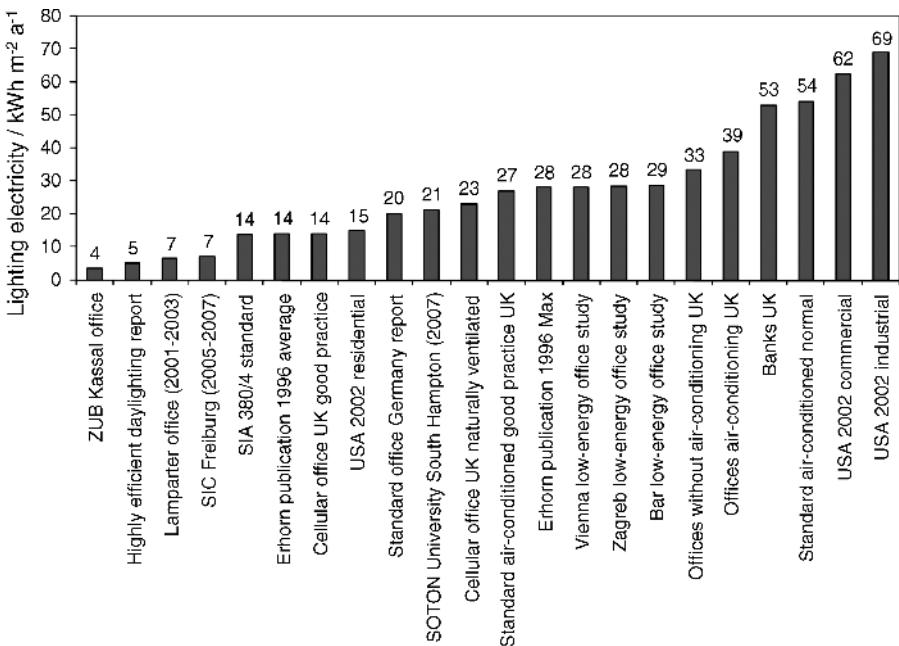


Figure 1.12 Lighting energy consumption in office buildings

Table 1.2 Approximate values for nominal flux of light, and specific connected power of energy-saving lighting concepts

Room type	Required illuminance level/ lux	Specific electric power/ W m^{-2}
Side rooms	100	3–5
Restaurants	200	5–8
Offices	300	6–8
Large offices	500	10–20

Even in newly constructed eco-buildings, electrical energy consumption for lighting can be high, especially if the users do not effectively reduce artificial lighting. A recently built office building at the University of Southampton was intensively monitored within the European SARA demonstration project (construction completed in 2005 with a 2600 m^2 surface area). A total annual lighting electricity value of $21 \text{ kWh m}^{-2} \text{ a}^{-1}$ was measured. The daily and monthly values showed that there was no seasonal influence on lighting energy consumption (see Figure 1.11). Only on weekends was there a reduction of lighting consumption, by a factor of 10.

Worldwide, 20% of the electricity produced is used for lighting. Studies show that the introduction of market-available and highly efficient light-emitting diode technology could reduce this consumption by 30% until 2015 and by 50% until the year 2025 (European Commission, 2006).

If energy-saving lighting concepts are applied, the connection power in office rooms can be as low as $6\text{--}8 \text{ W m}^{-2}$, while standard values are still between 10 and 20 W m^{-2} (see Table 1.2).

1.2.3 Air Conditioning

Annual sales of electrical room air-conditioning units are about 43 million units with the main markets in China (12 million) and the USA (11.8 million). The market penetration in Europe is smaller (about 2.8 million units in 2002), but has a high growth rate. Per thousand inhabitants, there are 0.6 installed units in Germany, 14 in Spain and 12 in Italy. The growth of climatized building area in Europe is estimated to rise from 3 m^2 per inhabitant (year 2000) to 6 m^2 per inhabitant (year 2020). The rising air-conditioning sales are due to increased internal loads through electrical office appliances, but also to increased demand for comfort in summer. Summer overheating in highly glazed buildings is often an issue in modern office buildings, even in north European climates. This unwanted and often unforeseen summer overheating leads to the curious fact that air-conditioned buildings in Northern Europe sometimes consume more cooling energy than in Southern Europe where there is a more obvious architectural emphasis on summer comfort. According to an analysis of a range of office buildings, an average of $40 \text{ kWh m}^{-2} \text{ a}^{-1}$ was obtained for southern climates, whereas $65 \text{ kWh m}^{-2} \text{ a}^{-1}$ was measured in north European building projects (Santamouris, 2005). Today in German office buildings the energy demand for air-conditioning

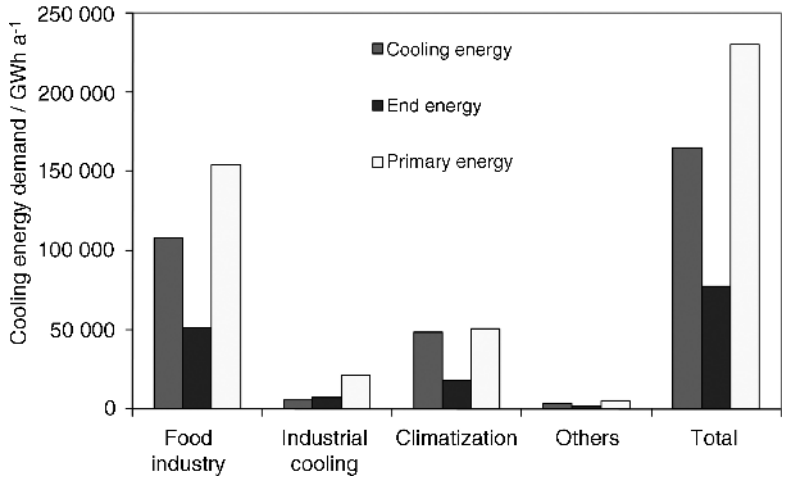


Figure 1.13 Cooling energy demand for different branches in Germany (DKV, 2002)

is estimated to be between 40 000 (Nick-Leptin, 2005) and 50 000 GWh per year (DKV, 2002). The total electricity consumption for cooling in Germany has reached 14% of the total electricity consumption, which corresponds to 5.8% of the total primary energy demand. The main cooling energy demand is in the food industry, followed by climatization applications and industrial cooling (see Figure 1.13).

The largest European air-conditioning manufacturer and consumer is Italy, accounting for nearly half of all European production (Adnot, 1999): 69% of all room air-conditioner sales are split units, with total annual sales of about 2 million units. In 1996 the total number of air-conditioning units installed in Europe was about 7 500 000. In Southern Europe, the installed cooling capacity is dominated by the residential market. Although less than 10% of homes in Spain have air-conditioning systems, 71% of the installed cooling capacity is in the residential sector (Granados, 1997).

Between 1990 and 1996, electricity consumption for air-conditioning in the European Union rose from about 24 000 GWh per year to 44 000 GWh per year and further increases up to 123 000 GWh per year in 2010 and nearly 160 000 GWh in 2020 are predicted (Adnot, 1998). Spain and Italy together are responsible for about two-thirds of the total cooling energy demand (Adnot *et al.*, 2003, see Figure 1.14). About 25% of the total electricity consumption is caused by room air-conditioners, the rest by central air-conditioners. The average coefficient of performance (COP) for all cooling technologies is currently about 2.7 (cooling power to electricity input) with a target of about 3.0 for 2015. Energy labelling is now obligatory in the EU for cooling devices of less than 12 kW power. The best label (A class) is obtained for units with COP's above 3.2.

Cooling energy is often required in commercial buildings, with the highest consumption worldwide being in the USA. In Europe the cooling energy demand for such buildings varies between 3 and 30 MWh per year. Not much data is available

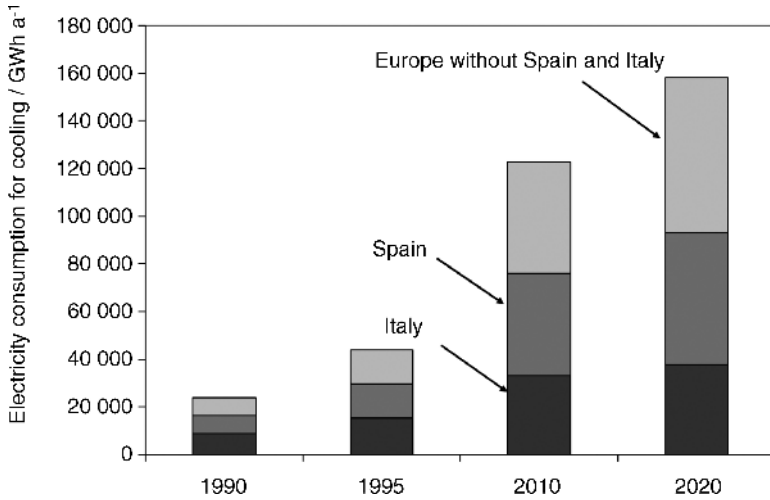


Figure 1.14 Projected electricity consumption for cooling in Europe with the two main consumer countries, Italy and Spain

for area-related cooling energy demand. Breembroek and Lazáro (1999) quote values of 20 kWh m⁻² a⁻¹ for Sweden, 40–50 kWh m⁻² a⁻¹ for China and 61 kWh m⁻² a⁻¹ for Canada. The author’s own survey of area-related cooling demand is shown in Figure 1.15. For residential buildings, the Catalan building research centre, Institut Cerdá estimated a typical cooling energy demand in Catalunya of 13 kWh m⁻² a⁻¹.

In the food trade the energy consumption for cooling is significantly higher, with a total electricity demand between 82 and 345 kWh per square metre of sales area, about 50–60% of total electricity consumption (O.Ö. Energiesparverband, 1996). The demand is dominated by food cooling equipment.

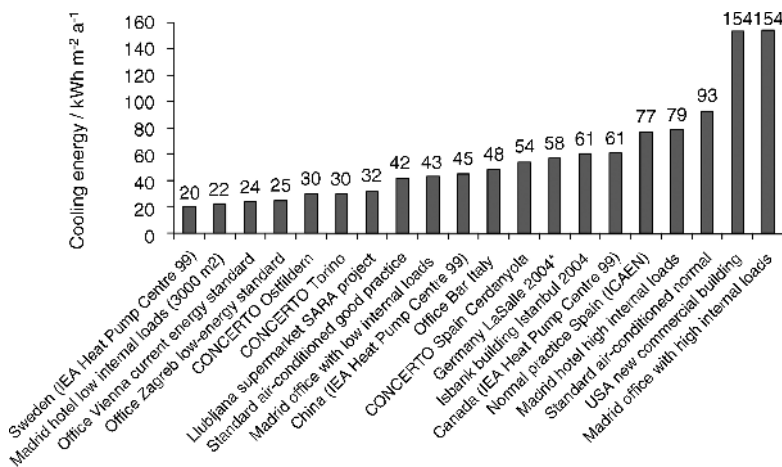


Figure 1.15 Cooling energy demand for new commercial buildings

Internal Loads

Under moderate climatic conditions, demand for air-conditioning exists only in administrative buildings with high internal loads, provided of course that external loads transmitted via windows are reduced effectively by sun protection devices. About 50% of internal loads are caused by office equipment such as PCs (typically 150 W including the monitor), printers (190 W for laser printers, 20 W for inkjets), photocopiers (1100 W), 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 an illuminance 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 an open-plan one, is also not negligible. Typical mid-range internal loads are around 30 W m⁻² or a daily cooling energy of 200 Wh m⁻² d⁻¹, and in the high range between 40–50 and 300 Wh m⁻² d⁻¹ (Zimmermann, 2003).

Detailed three-year measurements in an energy-efficient office building varied between 30–35 W m⁻² for a southern office with two persons and one computer workstation and around 50 W m⁻² for a northern office occupied by two persons with two computer workstations. This resulted in daily internal loads in the south-facing office of around 200–300 Wh m⁻² d⁻¹ and 400–500 Wh m⁻² d⁻¹ for the heavier equipped northern office. Detailed monitoring results from four other office buildings in Germany showed that appliances always dominate the internal loads, which were between 92 and 188 Wh m⁻² d⁻¹ (Voss *et al.*, 2007, see Figure 1.16).

External Loads

External loads depend greatly on the surface proportion of the glazing as well as the sun-protection concept. On a south-facing façade, a maximum irradiance of 600 W m⁻² can occur on a sunny summer’s day. The best external sun-protection can reduce this

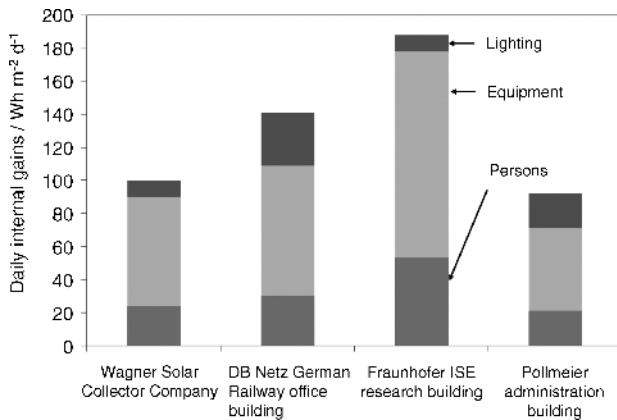


Figure 1.16 Measured internal gains in new office buildings in Germany

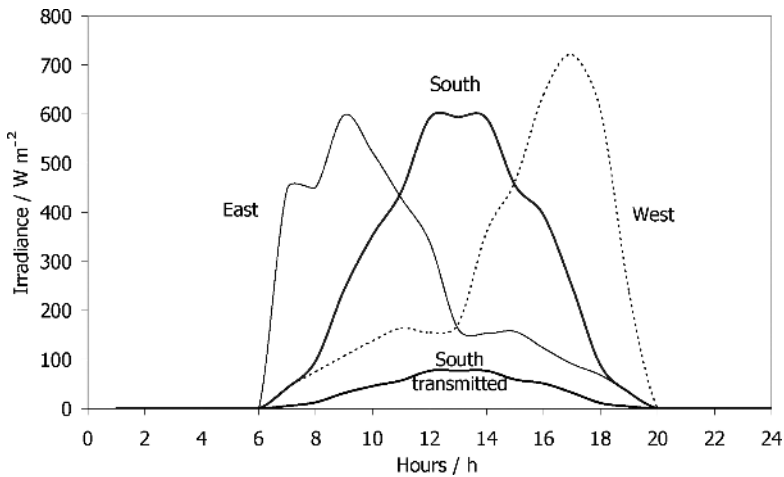


Figure 1.17 Diurnal variation of irradiance on different façade orientations and transmitted irradiance by a sun-protected south façade on a day in August (Stuttgart)

irradiation by about 80%. Together with the total energy transmission (g -value) of a 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 m² glazing surface of an enclosed office, the result is a load of 234 W, which creates an external load of about 20 W m⁻² based on an average surface of 12 m². This situation is illustrated for south-east-and west-facing façades in the summer in Figure 1.17. The total external and internal loads lead to an average cooling load in administrative buildings of around 50 W m⁻² (see Figure 1.18). The loads are typically dominated by office equipment and external loads (see Figure 1.19). External loads depend on the ratio

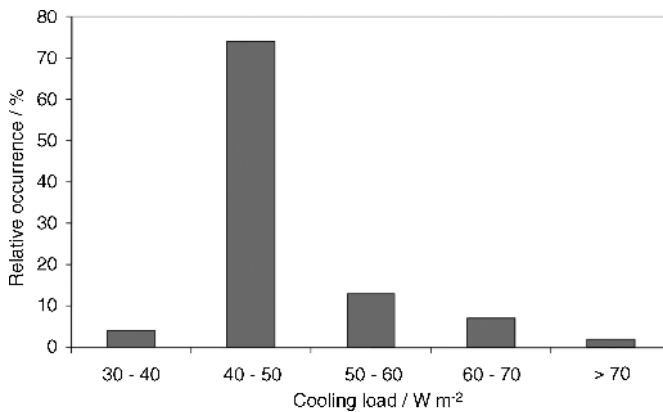


Figure 1.18 Occurrence of typical loads of office buildings in Germany

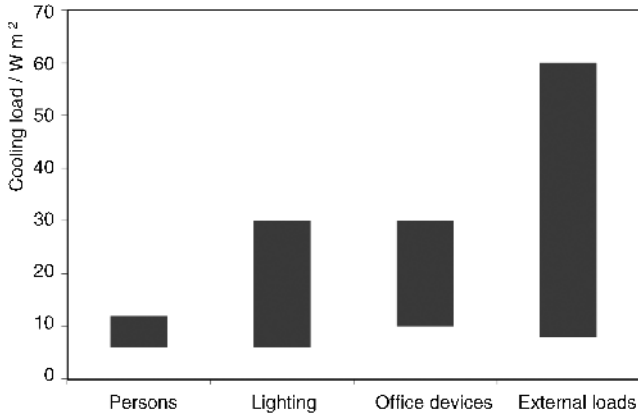


Figure 1.19 Bandwidth of cooling load distributions in office buildings (minimum and maximum)

between window and floor surface area and the shading system chosen. For surface ratios between 0.1 and 0.7, typical external loads are between 8 and 60 $W m^{-2}$ (Arsenal Research, 2007). With internal loads varying between 17 and 29 $W m^{-2}$ this results in typical total cooling loads between 40 and 90 $W m^{-2}$ (see Figure 1.20). If buildings have very energy-intensive functions (such as computer centres, server rooms, etc.) the cooling load can be as high as 1000 $W m^{-2}$ (see Figure 1.21).

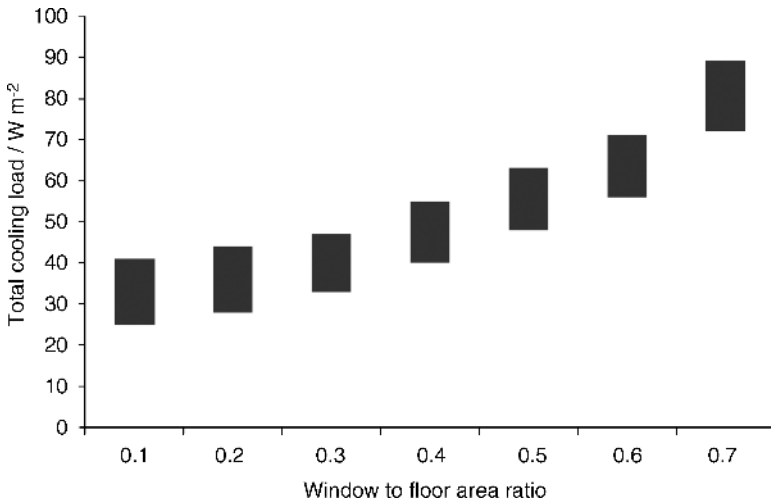


Figure 1.20 Total cooling loads as a function of window to floor surface area. Internal loads are between 17 and 29 $W m^{-2}$

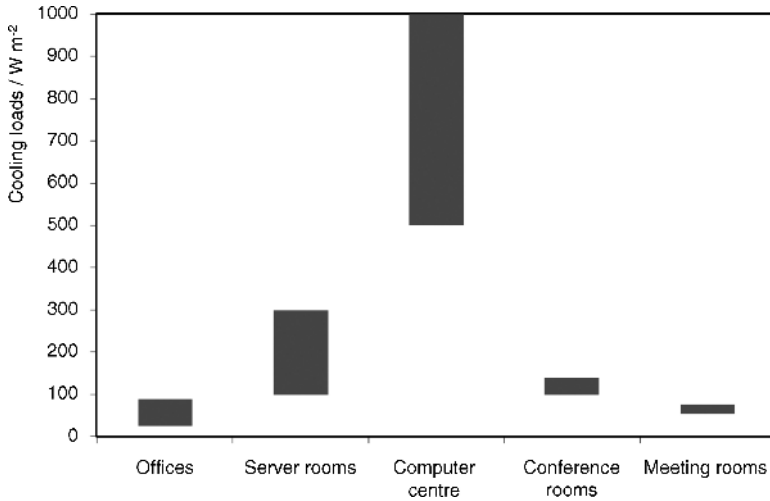


Figure 1.21 Range of cooling loads for different building and room types

1.3 Conclusions

The energy demand of existing buildings in moderate climates is dominated today by heating energy due to low levels of insulation standards. In warm climates cooling dominates the total consumption. However, as building standards continuously improve, there is a clear shift from the dominance of thermal energy to electrical

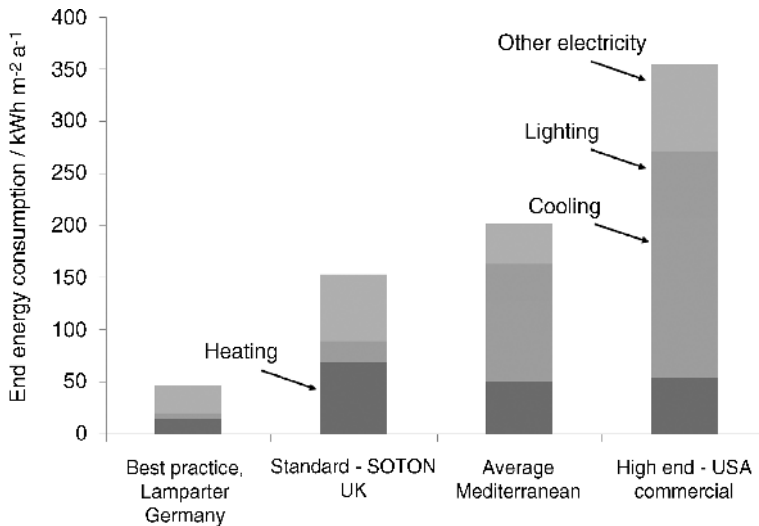


Figure 1.22 End energy consumption including thermal energy for heating and cooling and electrical energy for lighting and appliances from two case study projects and studies from Spain and the USA

energy consumption. Heating energy can be drastically reduced down to $15 \text{ kWh m}^{-2} \text{ a}^{-1}$ even in cold climates, while cooling energy demand is on the increase due to higher levels of comfort, but also to ever-increasing internal loads. These are caused by more electrical equipment in both the residential and non-residential sector. Measured electrical energy consumption is often at $50 \text{ kWh m}^{-2} \text{ a}^{-1}$ or more, although best practice examples show that consumption levels in residential buildings can be at only $12 \text{ kWh m}^{-2} \text{ a}^{-1}$ and $35 \text{ kWh m}^{-2} \text{ a}^{-1}$ in office buildings. Lighting electricity consumption in well-designed buildings can be as low as $5 \text{ kWh m}^{-2} \text{ a}^{-1}$, but can also reach values of nearly $70 \text{ kWh m}^{-2} \text{ a}^{-1}$ and thus adds to the cooling energy demand. As a result, cooling energy consumption levels in a moderate European climate are typically between 30 and $60 \text{ kWh m}^{-2} \text{ a}^{-1}$, but can reach values as high as $150 \text{ kWh m}^{-2} \text{ a}^{-1}$. The results of the author's measurements in a best practice passive office building and a 'standard' building from the EU eco-building program, combined with the average Mediterranean values provided by the Catalan Energy Institute and statistics from the US government, summarize the status of building energy consumption today (see Figure 1.22).