Improving Energy Efficiency in Commercial Buildings (IEECB) 2010, April 13th-14th, Frankfurt

Electricity demand in the European service sector: A detailed bottom-up estimate by sector and by end-use

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Abstract
Knowledge about the electricity demand of the tertiary sector by end-use or by sub-sector is crucial to determine the impact of novel technologies as well as to design effective energy efficiency policies. However, statistical information about electricity demand on a European level is only available for the tertiary sector as a whole. The present study aims to calculate and assess the current electricity demand of the tertiary sector in Europe for 29 countries, disaggregated by 8 sub-sectors and 13 (mostly building-related) end-uses such as lighting, electric heating, ventilation and cooling, heat pumps, refrigeration, and data centres with servers.

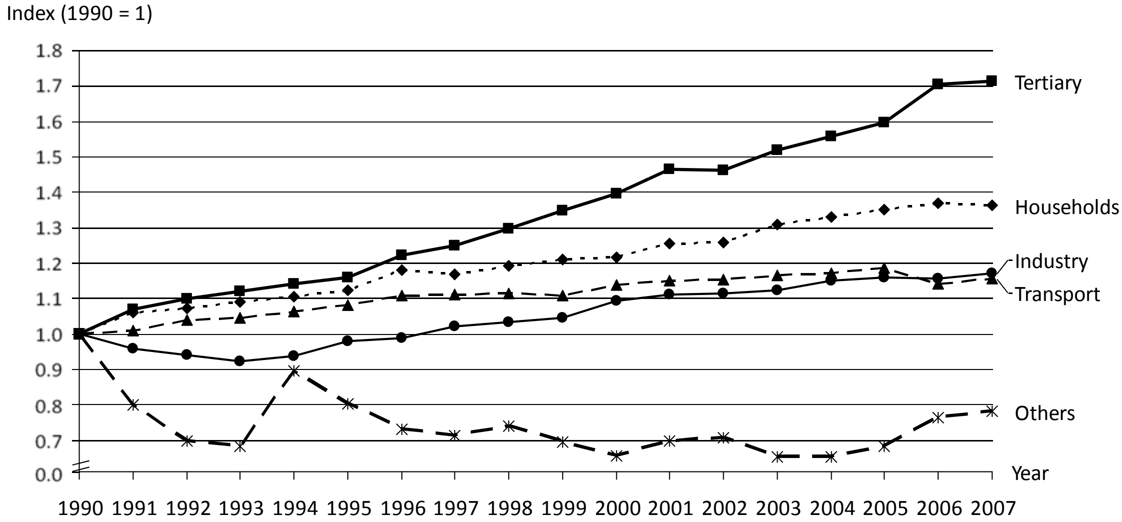
A comparison of the results with Eurostat electricity demand statistics shows that the obtained bottom-up results are a good match with the statistical top-down data - with the exception of some smaller countries. The total demand of the tertiary sector for all countries is slightly underestimated by 2.5 %. The 7 most relevant countries in terms of electricity demand in the tertiary sector, which comprise France, Germany, Italy, the Netherlands, Poland, Spain, and the United Kingdom, are within a range of ±10 %. These results form a good data basis for forecasting the future electricity demand of the tertiary sector using a bottom-up modelling approach, as well as for ex-post estimations of energy efficiency policy impacts.

Introduction
Since 1990 electricity demand in the tertiary sector in the EU27+2 has been increasing significantly with an almost linear trend. Over the fifteen years up to 2005 it increased by almost 60 % and, up to 2007, it reached close to 800 TWh and was thus about 70 % higher than in 1990. The tertiary sector shows the most dynamic development over the past fifteen to twenty years, as can be seen in Figure 1. Furthermore, electricity consumption in the tertiary sector is expected to continue to rise in the future.

Knowledge about the electricity demand of the tertiary sector by end-use or by sub-sector is crucial to determine the impact of novel technologies and other energy-efficiency measures (e.g. organizational measures) as well as to be able to design effective energy efficiency policies. However, statistical information about electricity demand on a European level is only available for the tertiary sector as a whole. Only a few studies have assessed the shares of different end-uses; these show differing results together with a high degree of uncertainty [1, 2, 3, 4]. Studies on a national level are often not comparable due to different definitions and system boundaries [5, 6].

The present study aims to calculate and assess the current electricity demand of the tertiary sector in Europe for 29 countries (EU27, Norway and Switzerland). The results are disaggregated by 8 sub-sectors and 13 (mostly building-related) end-uses including lighting, electric heating, ventilation and cooling, refrigeration, cooking, data centres with servers and others.

Figure 1: Development of electricity demand by sector in the EU27+2 as an index (1990=1)



Source: Eurostat

Methodology

We adopt a bottom-up methodology which consists of a “sum product” of basic drivers such as the number of employees or floor area, specific equipment or diffusion rates (e.g. share of cooled floor area, number of computers per employee) and specific energy consumption indicators. The latter consist of technical data on the end-uses such as installed power. This approach was chosen to allow a subsequent modelling of future electricity demand. After defining the sector, the calculation approach and the drivers used are discussed in this section.

Sector definition

The tertiary sector, also referred to as the service or commercial sector, covers all the economic sectors not part of the primary economic sector (agriculture, forestry, fishery etc.) or the secondary economic sector (industry). Hence, the tertiary sector comprises the NACE sub-sectors G to S (NACE rev. 2.0, see Table 1). The electricity demand of the tertiary sector includes both, building-related energy use of these sub-sectors and other energy use such as street lighting, ventilation of tunnels, public transport infrastructure and others. An exception is the sub-sector “Traffic and data transmission,” where the transportation energy for trains, subways, trams etc. is – as is usual in energy economic analysis – not accounted for in the tertiary sector, but in the transportation sector.

Table 1: Considered economic sub-sectors of the tertiary sector

Economic sub-sector	Nace (2.0)	Description
Trade	G	Wholesale and retail trade
Hotel and restaurant	I	Hotels and restaurants, camping sites, mountain refuges, bars, canteens, catering
Traffic and data transmission	H, J	Transport (railway, road, water, air), storage and communication, cargo handling, post, telecommunications,
Finance	K	Finance and insurance
Health	Q	Health and social work, hospital activities, social work activities with accommodation
Education	P	Primary and secondary education, higher education, driving school activities
Public administration	O	Public administration and defence, compulsory and social security
Other services	L,M,N,R,S	Other services (waste, sport, social services) + real estate and other services

Calculation approach

The electricity demand is determined as the product of the specific energy demand per unit of driver (e.g. number of computers, floor area cooled/ventilated, etc.) multiplied by the quantity of the given driver. The driver is further broken down into an energy service driver (e.g. computers per employee, share of floor area ventilated/cooled, etc.) and a global driver (e.g. floor area or employees). The specific electricity demand is calculated as the product of installed (full load) power and the annual utilisation rate (annual full load hours). Thus, the modelling approach is formally described by the following equation (all values for 2007):

$$T = \sum_{C=1}^{n} \sum_{S=1}^{l} \sum_{E=1}^{k} G_{C,S} \cdot D_{C,S,E} \cdot P_{C,S,E} \cdot U_{C,S,E}$$

With

T = total bottom-up electricity demand of the tertiary sector

$G_{C,S}$ = global driver

$D_{C,S,E}$ = energy service driver

$U_{C,S,E}$ = utilisation rate (annual full load hours) [h/a]

$P_{C,S,E}$ = installed power per unit of driver [W]

Indices:

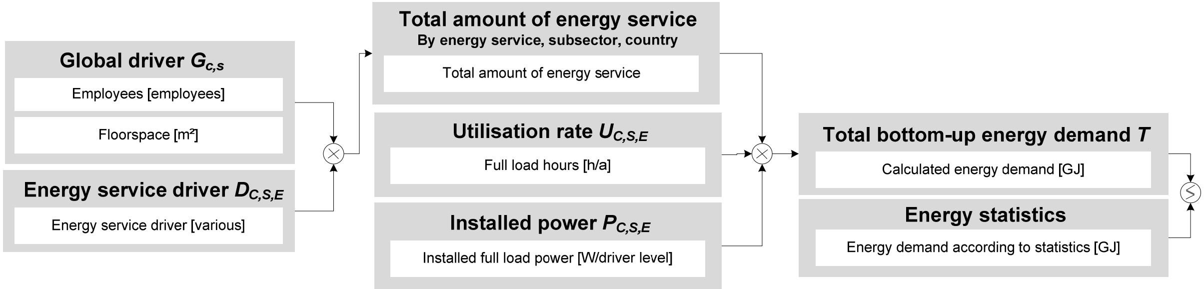
C = country, n = 29

S = sub-sector, l = 8

E = energy service, k = 13

In this way, absolute and relative activity variables (G, D) are coupled with estimates of specific electricity consumption for each energy service relevant to the sub-sector. See Figure 2 for a schematic representation of the calculation approach.

Figure 2: Schematic representation of the calculation structure



Energy service driver & technology data

Several energy services were defined for each of the sub-sectors. These energy services represent distinct appliances as well as building-related and other technologies which are responsible for the main share of the electricity demand in the tertiary sector (see Table 2 for all the energy services considered in the model).

Most energy service drivers are related to the global driver G, either representing floor area or the number of employees in the respective sub-sectors and countries (see Table 2). For energy services that are assumed to be independent of these two global drivers (such as street lighting or cooking), only the energy service driver is used and the respective technological parameters U and P are chosen accordingly. By using energy service drivers, it is assured that the calculated electricity consumption is based on a realistic technological structure on a micro-level.

While heating is found in buildings across all sub-sectors, not all buildings of a given sub-sector are equipped with all the other energy services considered. Each energy service is related to the specific energy service driver D. This energy driver D represents a diffusion, penetration or ownership rate of the respective technology in each of the sub-sectors. The data is explicitly differentiated between sub-sectors and countries. When implementing the described bottom-up(BU)-modelling approach in the forecast model, new and existing buildings are also differentiated (as the incentives and costs for equipping new buildings are quite different from upgrading existing ones).

Typical examples of energy service drivers (D) are:

- Share of ventilated floor area
- Share of floor area with space cooling
- Number and type of information and communication (ICT) devices per employee (e.g. personal computers)

Table 2: The energy services considered and their related energy service driver

Type	Energy service	Description	Energy service driver (D)	Related global driver (G)
El	Lighting	Lighting of different types of rooms (and building-related outdoor lighting)	Share of floor area with lighting	Floor area
El/Th	Ventilation and cooling	Ventilation and cooling of rooms and buildings	Ventilated and cooled floor area of buildings	Floor area
El	Circulation pumps and other heating auxiliaries	Energy-using technologies which transform the energy necessary for distributing fluids, e.g. circulation pumps, ancillary units such as pumps or blower fans in heating systems	Floor area of buildings	Floor area
El	ICT offices	PC, monitors, copy/print, etc.	ICT-infrastructure of one office employee	Number of employees
El	Data centres	Servers in data centres or IT rooms	No. of servers	No. of employees
Th	Hot water	Hot water and process heat (e.g. cleaning)	Floor area of buildings	Floor area
Th	Direct electric space heating	Fuel heating excluded, this energy service covers heat pumps and electric heating	Share of floor area with electric heating	Floor area
Th/El	Laundry	Laundry, particularly in the hotel and health sectors	No. of beds/guests	None
Th/El	Cooking	Cooking in restaurants, health sector, large office buildings	No. of meals, no. of beds/guests	None
El	Refrigeration/freezing	Cooling of products (particularly retail sector)	No. of employees	No. of employees
El	Miscellaneous building technologies	Mainly unspecified electrical appliances	Floor area of buildings	Floor area
El	Street lighting	Lighting of streets and roads	No. of light points	None
El	Elevators	Elevators to provide vertical transportation in buildings	No. of elevators	None
El: specific electricity-based energy service (hardly substitutable) Th: thermal energy service (might be substituted by other energy types)				

Source: ISI, IREES, TEP Energy

Each energy service in each sector is characterized by a specific energy demand. These specific demand values are the product of the installed power P of a technology and its utilisation in full-load hours per year, U. These values are explicitly differentiated between sub-sectors, countries and, whenever possible, implicitly between new and existing buildings and between already installed systems and those that are retrofitted. Based on the calculation scheme, the total bottom-up energy demand for the tertiary sector T can be calculated and differentiated by either sub-sector or energy service.

Technology assumptions and data background

Global drivers: number of employees and floor area

As outlined above, most of the energy services are linked to a physical driver G. In most cases this is either the number of employees or the floor area differentiated by sub-sector.

The floor area is calculated by the number of employees and the indicator floor area per employee. The indicators are based on [7] and on indicators derived from the Odyssee database*: the latter is the case for the countries Denmark, France, Germany, Sweden, UK, and Norway. The indicators are differentiated between countries and between most sub-sectors. For the sub-sectors public administration, traffic and data transmission and other services, they are assumed to be the same. Where data was not available, it was derived from past trends.

The number of employees is taken from the past employment figures by sub-sectors and countries (1990 to 2007) contained in the Eurostat database (see Table 3). The quality and completeness of this data set differs considerably between countries. If necessary, missing data for 2007 were estimated based on the figures for previous years.

Table 3: Employees and floor area per sub-sector in the EU27+2

	Education	Finance	Health	Hotels, cafes, restaurants	Other services	Public offices	Traffic and data trans-mission	Wholesale and retail trade	Total
Employees 2000 [1000]	13,495	6,420	18,278	7,651	24,879	12,911	12,836	29,800	126,269
Employees 2007 [1000]	15,591	6,842	21,847	9,429	32,282	15,884	13,729	32,437	148,042
Floor area 2000 [1000 m²]	689,170	120,586	385,541	344,345	740,287	428,428	371,980	1,252,677	4,333,014
Floor area 2007 [1000 m²]	766,940	127,583	468,982	416,101	944,127	461,812	393,978	1,353,945	4,933,468

Source: Eurostat, Odyssee, own calculations

Lighting in buildings

Lighting is a highly relevant end-use energy service for tertiary electricity consumption. In Europe, total lighting accounts for almost one third of total electricity consumption. Of all the economic sectors, the share of energy consumption for lighting is the largest in the tertiary sector [8, 3].

Lighting includes the following types:

- Lighting in indoor work places (e.g. in offices, hospitals, schools, trade)
- Accent lighting (e.g. in retail, hotels and restaurants, leisure and others)
- Ambient lighting (e.g. in nurseries, personnel services)
- Building-related outdoor lighting (with the exception of street lighting which is modelled separately)
- Emergency and security lighting

The electricity demand of lighting depends mainly on four important impact factors: building and room design, lighting technology, user needs and user behaviour. In the tertiary sector, the relevance of these impact factors varies between building types and economic sector. Also there are large differences in the recommended illumination levels across IEA countries [8].

To calculate the electricity demand for lighting, floor area serves as the global driver G as well as the energy service driver D. It is assumed that in all countries and all economic sub-sectors 100 percent of the floor area is equipped with lighting.

Both the installed power P and the annual full load hours U are differentiated by sector and by country. Different economic sectors are assigned different values to take into account different lighting technologies and practices, as well as different requirements (or tasks for the users) and other factors such as daylight availability.

Typical values of installed power P are derived from various sources [9, 10, 11, 12, 13, 14, 15]. Model assumptions for the base year, i.e. for the case without energy-efficiency options (as specified below), vary between 13 and 26 W/m^2 depending on the sub-sector (see Table 4). Full load hours are lowest in the education sector (due to daylight use and relatively low occupancy during evening hours) and highest in the retail sector (often no daylight use at all and long opening hours).

* http://www.odyssee-indicators.org/

Table 4: Typical values of installed power P and of full load hours U for lighting in the base year by sub-sector

	Hotels, Gastro	Health	Educatio n	Wholesale and retail trade	Traffic and data transmission	Other services	Public	Finance
Installed power (W/m^2)	16.0	10.2	15.3	26.1	12.6	14.4	16.6	16.5
Full load hours (h/year)	1906	2004	1607	3187	2500	2169	1769	2080

Source: Assumptions TEP energy referring to [9, 10, 11, 12, 13, 14, 15]

Utilisation rates are also dependent on the latitude and on weather conditions and hence differ from one region to another. More annual full load hours are assigned to Northern countries such as Norway or Estonia (around and above 2500 hours) than to countries in the South (around and below 2000 hours).

Ventilation and cooling

Apart from lighting, ventilation and cooling are also quite important energy services, first due to their particular relevance in some sectors and some European regions and second due to their increasing usage in most sectors and countries of the EU27+2. The electricity for ventilation and cooling can be structured in two main categories, namely the transportation of air or cooling fluids on the one hand and the generation of a chilled medium on the other. Ultimately, the major part of the electricity of ventilation and cooling is consumed by electric motors, which drive fans, compressors, pumps, and other drives in the ventilation and cooling systems. To a certain extent, thermal energy is also used, for instance for air humidification.

Electricity use is particularly high in the following (active) applications [15]:

- Fans for supply and exhaust air
- Drives for heat recovery systems
- Compressors of chillers
- Pumps, air heaters and cooling heat exchangers
- Drives and fans for humidification, water and cooling fluid, and heat rejecter systems

It should be noted, however, that the actual electricity consumed depends largely on demand-side factors of the ventilation and cooling systems [12,11,16].

Electricity demand for ventilation and cooling in Europe is modelled using the share of floor area which is ventilated and/or cooled D, the installed power per square metre P and the utilisation rate U (full load hours). These three factors are all country- and sector-specific.

In contrast to lighting, significantly less than 100 % of the floor area is cooled and/or ventilated. Empirical evidence regarding the quantitative relevance of central air conditioning (CAC) or room air conditioners (RAC) can be found in two studies [17,18]. The amount of cooled floor area was obtained by dividing their results on the installed power by the specific values of the installed capacity per square metre (W/m^2) [18]. If the systems are ideally dimensioned, these values typically range between 70 and 130 W/m^2 (in the case of cooling only air conditioners). However, in practice, cooling systems and devices are often over-dimensioned. For CAC, an over-dimensioning factor of 1.5 is assumed and a factor of 2 for RAC. At first sight, these factors might seem high but note that shares of cooled floor area of more than 100 % would be obtained with lower factors. Countries with missing data were estimated by following the approach used in [20].

The country-specific shares of cooled floor area are obtained by dividing the calculated cooled floor area by the countries' total modelled floor area. For 2007, these shares range between 20 % and 35 % for most countries north of the Alps (a noticeable exception is Germany with only 9 %) and between 50 % and 65 % for the Mediterranean countries. Hence, even with cooling degree days close to 0, a noticeable share of offices and other work places of the tertiary sector is either centrally air conditioned or equipped with RAC. The assumed shares of ventilated and cooled floor area are also differentiated by sector. The sub-sectors of finance (banks and insurances) and trade are assumed to be above average, whereas the sub-sectors health and education are assumed to be below average. These assumptions are based on sectoral differences in the internal and external thermal loads (ICT, lighting, persons and solar energy through large glazing shares) and on the fact that clothing requirements and comfort expectations are higher in some sectors (e.g. the finance sector) and that natural ventilation is more suitable in some building types (e.g. schools) than in others.

Differences in specific energy consumption tend to be due to differences in operation and full load hours U rather than differences in installed power. Indeed, installed power is determined by the maximum requirements of extreme situations, for instance of several consecutive hot summer days. These maximum requirements show more similarity between Nordic and Mediterranean countries than full load hours do.

For this reason, installed power P is assumed to be almost constant across countries (see Table 5). However, full load hours are varied between countries according to an index which represents an increasing (concave) function of cooling degree days. This index equals roughly 1 for most Western and Central European countries. It is above average for Mediterranean countries including Romania and Bulgaria, and below average for the Nordic countries, the Atlantic coast (BENELUX) and the UK and Ireland. France as a whole has an index around the average since it consists of Atlantic, Mediterranean and moderate regions.

Table 5: Typical values of specific energy demand for ventilation and cooling by sub-sector

Hotels, Gastro	Health	Education	Wholesale, retail trade	Traffic and data transm.	Other services	Public	Finance
69	23	35	66	28	31	14	52

Source: TEP energy based on [14 19, 20]

Direct electric space heating

Electricity for space heating is linked to the floor area as the global driver G. Heating systems include electrically heated radiators and heating distribution systems, but also the electric pre-heating of air in ventilation systems (energy use of ventilation and cooling does not include this type of energy use). The electricity demand for space heating is approximated by estimating the share of direct electric heating energy systems and behavioural changes of the heating system and building management operators and end-users (e.g. due to energy price changes or information and training), which are reflected in the energy service driver D and in the specific energy demand (P*U), respectively.

Regarding the tertiary sector, very little empirical data is available on the electricity use for space heating. Available data, e.g. from the Odyssee database, is limited to residential buildings. For this reason, assumptions were made regarding the energy service driver D based on analogies (for instance, a share similar to that for multi-family houses was assigned if such data were available, or similar countries were assigned similar shares). These shares vary between 1 % and 5 % for most countries. Exceptions are Belgium/Luxembourg, France, Finland, Greece, Portugal, Slovakia, Switzerland, UK (5 % to 10 %), Bulgaria, Cyprus/Malta, Spain, Slovakia (10 % to 20 %), Sweden and Norway (more than 20 %).

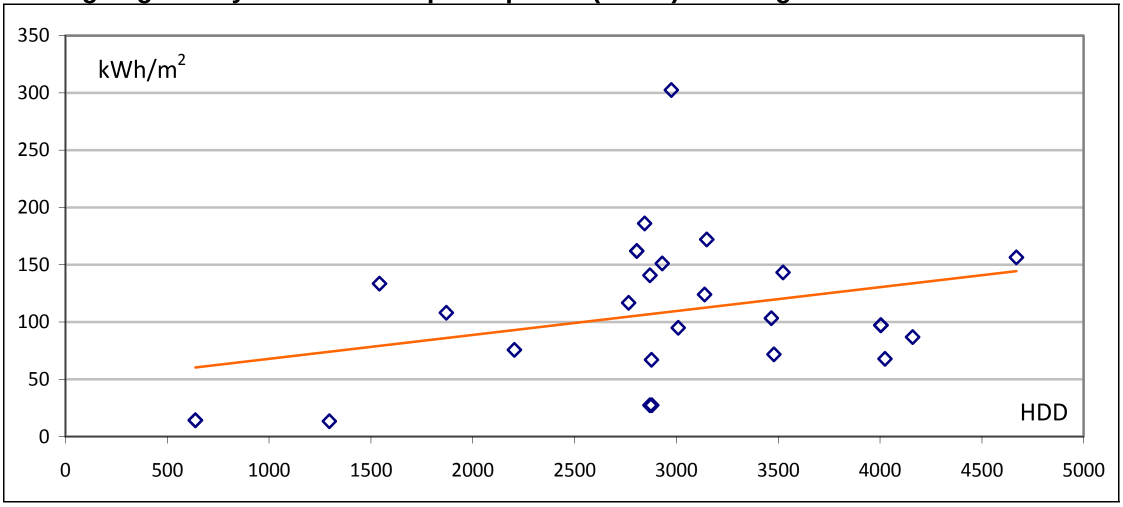
Values of specific heat demand per unit of floor area stem from [7] and partially from the ODYSEE database. Since there is no structural one-to-one correspondence between the different sources ([7], Odyssee, employees from Eurostat and derived floor area), missing values were estimated by the authors taking similarities into account. Due to specific needs, building types and climate conditions, the specific energy demand for heating calculated via full-load hours U and installed power P varies by sub-sector (see Table 6) and by country (see Figure 3, where the different countries are characterized by their average heating degree days, HDD). Sector-specific values of Table 6 are indexed for each sub-sector with country-specific data.

Table 6: Typical values for the specific energy demand for heating (kWh/m²) for countries with moderate climate (e.g. Switzerland, Germany, Austria) by sub-sector

Hotels, Gastro	Health	Educatio n	Wholesale, retail trade	Traffic and data transmission	Other services	Public	Finance
180	99	96	155	114	154	115	132

Source: Assumptions TEP Energy based on [7]

Figure 3: Annual specific energy demand for space heating (kWh/m²) as a function of heating degree days for the example of public (office) buildings



Source: Assumptions TEP energy based on Odyssee and on database used by [7]

Heat pumps for space heating

Regarding the specific energy consumption of the buildings as a whole, the same assumptions are made as for electric heating systems. Assumptions regarding the diffusion of heat pumps for the energy service driver D were partly adopted from [7], but were amended with our own considerations. Currently, that is in 2007 - the year with the most recent data in Eurostat - the relevance of heat pumps in the tertiary sector is very low in most countries, at least in terms of ground-source heat pumps (Eurostat covers ground-coupled heat pumps in its energy statistics, but not air-air heat pumps, or reversible cooling and heating systems).

Hot water and process heat

Hot water is used for various end uses such as domestic water for showering or bathing, or as process heat for cleaning purposes excluding cooking and laundry. It is assumed that all hot water is provided by electricity in the case of low water intensity, i.e. in all sub-sectors but health and hotels/restaurants (see Table 7). In most sectors, decentralised electric boilers are a convenient way to provide hot water and are consequently widespread. For the sub-sectors health and hotels/restaurants, it is assumed that about half of the energy for hot water purposes is provided by electricity.

Table 7: Typical values for the specific energy demand for hot water (kWh/m²) by sub-sector

Hotels, Gastro	Health	Educa tion	Wholesale, retail trade	Traffic and data transmission	Other services	Public	Finance
72	122	37	10	31	22	12	21

Source: Assumptions TEP Energy based on [10, 12, 15]

Auxiliary building technologies (e.g. pumps)

Auxiliary building technologies comprise particularly technologies for pumping water and heating system auxiliaries. Note that other “transportation” facilities such as elevators are treated separately. The energy service is linked to the floor area as the global driver G. Water is used in tertiary sector buildings either as a thermal energy carrier, or as an end-use energy service in showers, laundry facilities, kitchens, and others. Water pumping is often underestimated as an energy consuming category. As a matter of fact, pumping systems are often inefficient and are operated for a long period of the year (mostly at partial loads which results in low full load hours). Fans in forced draught boilers are another auxiliary building technology. Both pumps and fans are necessary to distribute heat and cold in the building when operating heating systems. The installed power P for building technology auxiliaries varies between 6 and 13 W/m^2, with the exceptions of the sub-sectors hotels and restaurants and trade (see Table 8). Specific electricity demand is between about 4 and 9 kWh/m^2. These assumptions are based on [15] while considering that the actual consumption of old buildings is higher than [15], which refers to good practice in new buildings.

Table 8: Typical specific energy demand for auxiliary building technologies by sub-sector

	Hotels, Gastro	Health	Education	Wholesale, retail trade	Traffic and data transmission	Other services	Public	Finance
Specific energy demand (kWh/m^2)	8.9	6.0	3.7	8.4	4.7	3.9	7.2	7.1

Source: Assumptions TEP energy based on [10, 15]

Refrigeration

Refrigeration in the tertiary sector covers a wide variety of different systems, including appliances such as beverage coolers and ice-cream freezers. Five major refrigerator types were defined for the analysis (see Table 9) and aggregated to an overall energy service. The overall energy service driver D is based on stock figures published in the Ecodesign study on commercial refrigeration [21]. Data on technological characteristics such as installed power P and utilisation U are derived from the same source. Depending on the refrigerator type, the assumed installed total power P is very heterogeneous, ranging from 500 Watt for small freezers up to approximately 7 kW for large chillers. For the allocation of refrigerators per sector, it was assumed that a 70 % share of refrigerators is found in the retail/wholesale sector, followed by hotels and restaurants with a 15 % share; the remaining share is allocated proportionally to the remaining sectors.

Table 9: Appliance types, stock number, utilization hours, consumption and installed power for refrigeration for the EU25

Appliance	Number of appliances	Annual utilisation Hours - h	Av. Installed power total - kW	Electricity consumption in 2006 (TWh)
Remote open vertical chilled multi deck cabinets	1,312,630	4,015	7.03	37.0
Remote open horizontal frozen island	172,117	4,015	7.39	5.1
Plug in one door beverage cooler	6,323,941	3,285	0.78	16.2
Plug in horizontal ice-cream freezer	2,709,285	3,285	0.50	4.4
Spiral cold vending machine	1,092,956	3,285	0.83	3.8
Total	**11,610,930**	**3,712**	**1.51**	**66.6**

Source: [21]

Cooking

Cooking is only considered for hotels and restaurants and the health sub-sectors. The process heat in restaurants and cafes is defined as comprising 58°% cooking and 42°% hot water. The energy service driver D for cooking in restaurants and hotels is the number of guests per employee. The process heat in health is defined as 48°% cooking and 52°% laundry and hot water. The energy service driver for cooking, hot water and laundry in the restaurants and hotels sub-sector is guests/employee.

Laundry

The process heat in hotels is assumed to be composed of 50 % cooking and 50 % laundry and hot water. For this energy service, the number of guests per employee in the sub-sector hotels was chosen as the energy service driver D. The data for guests (overnight stays) are based on Eurostat statistics. Laundry is only considered for the hotels and restaurants and the health sub-sectors.

ICT – office equipment

ICT - office equipment comprises all kinds of information and communication technologies like computers, monitors, printers, copiers, telephones, scanners and even coffee machines. Within ICT, desktop computers and laptops still show the highest share of the electricity consumption in a typical office, while printers and copiers are the second most important group. In recent years, a steady replacement of CRT (cathode ray tubes) by LCD (liquid crystal display) monitors could be observed as well as an increasing market diffusion of laptops, which are replacing desktop PCs. These structural changes have had substantial impacts on electricity demand.

The printers and copiers used in offices are mostly photoelectrical. They account for more than 90 % of the electricity consumption of all printers in offices. Thus, inkjet printers play a minor role in terms of energy consumption. Overall, the electricity consumption of copiers and printers is quite low when compared to the electricity demand of the tertiary sector as a whole, and only accounts for about 1 %.

As all the ICT appliances together have a share of about 4 % in total tertiary sector electricity consumption, they are calculated as one combined energy service "ICT office equipment". Thus, the energy service D is defined as the average infrastructure of one employee working in an office, made up of one computer (55 % laptop and 45 % desktop), one telephone, and a 5 % share each of a printer, a scanner, a coffee machine, a photocopier and a fax [15][15]. Sub-sector differences are considered by applying "typical office employees" distributions. For instance, for the finance sector, these are 100 % of employees, for other sectors, the figures are considerably lower. The average annual power consumption per employee working in an office is calculated based on the running hours U (differentiated by standby and on-mode) and the installed power P of the different devices [15].

ICT – data centres

The total electricity demand for ICT data centres is composed of the electricity demand of the ICT data centre infrastructure and the electricity demand of the servers themselves. The ICT data centre infrastructure can be subdivided into the infrastructure (cooling equipment, lighting, etc.), which needs about 50 % of the total electricity demand of ICT data centres, and the storage and network equipment, which amounts to about 10 % of the electricity required. This means the complete infrastructure of ICT data centres requires 60 % of the total electricity demand. In contrast, the servers themselves need only 40 % of the total electricity demand of ICT data centres.

The electricity demand of the ICT data centres is estimated based on classifying the studied countries into three sub-categories (i.e. low density, medium density, high density of electronic equipment), which depend on the technological development of each country. For each of these three subcategories and sub-sectors, assumptions were made about the number of employees per server. These ranged from the lowest value of 18 in the sub-sector of finance in high density countries up to 94.5 in the health sub-sector in the low-density group. The average over all the sub-sectors varies from 24.3 in high-density countries to 65.5 in low-density countries.

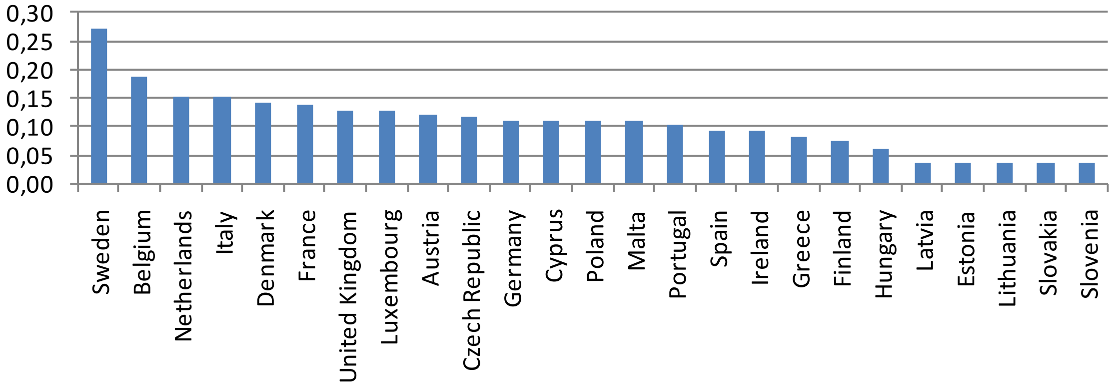
The total number of servers per country and sub-sector is calculated using the total number of employees per sub-sector from Eurostat as the global driver G and the number of servers per employee as the energy service driver D. 239 W was assumed as the average installed power P of a server and 8760 h for the annual full load hours U, which is equivalent to constantly running servers. These resulted in an average electricity consumption of 2.1 MWh per server.

Elevators

The total energy demand for elevators is calculated using the total number of elevators as the energy service driver D. Relevant publications [22, 23] show that single elevator installations are most common in the health sector due to a high frequency of usage. In addition, elevators have quite different characteristics in terms of running time and usage, between different sub-sectors as well. Therefore, several elevator types were defined for several sub-sectors with typical utilisations (running time) U and installed power P. To calculate the installed power P, a suitable combination of stand-by power and running consumption was used combined with typical running and stand-by times.

Public street lighting
Public street lighting explicitly excludes domestic or commercial outdoor lighting, lighting of sport fields, tunnel lighting and traffic signs. It only covers the relatively homogenous category of public street lights. This definition is in line with the relevant Ecodesign preparatory study [24]. Street lighting accounts for about 6 % of the electricity consumption of the tertiary sector in Europe. This value varies between 3 and 12 % from country to country, depending on the density of light points and the lamp technologies used. An average installed power P of 116 watts per light point and annual full load hours U of 4,150 h are assumed [25]. The development of light points is related to the length of the road network, which is itself in relation to the country's population. Thus, the energy service driver D is light points per inhabitant with population as the global driver.

Figure 4: Light points (luminaires) for outdoor street lighting per capita by country



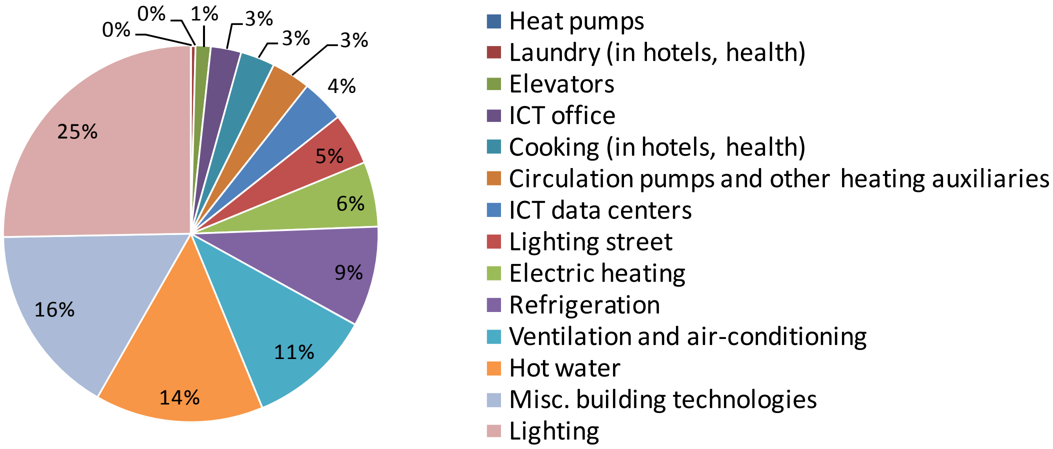
Source: [25]

Besides the light points, the second parameter required to calculate the electricity consumption is the type of lamps used. The two prevailing lamp types are high pressure mercury (HPM) and high pressure sodium (HPS) lamps. HPS lamps consume substantially less electricity than HPM lamps. As the lamp shares vary considerably between countries, they are also differentiated in the model. While, for example, Italy, Greece, Poland, Cyprus and Germany show the highest shares of HPM lamps with about 50 %, Belgium, Netherlands, Sweden, Ireland and the UK have shares below 5 % [25]. Thus, street lighting electricity consumption is calculated by the number of light points in a country and the country's lamp mixture.

Results
The calculation results allow a breakdown of the tertiary sector's electricity consumption by country, energy service and sub-sector, which is shown in the following figures.

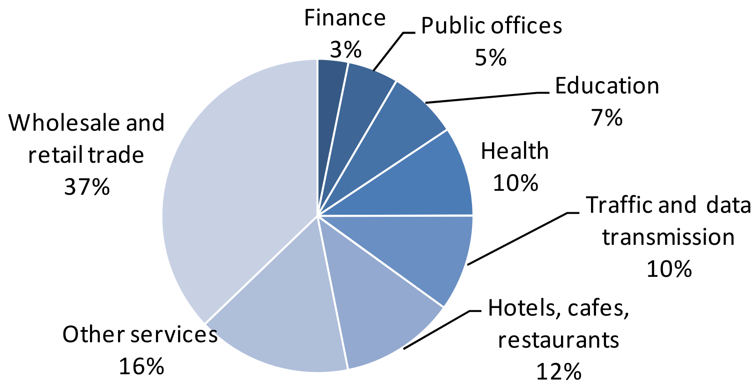
The breakdown by energy service for the EU27+2 reveals the importance of certain energy services. Lighting (25 %), hot water (14 %), ventilation and cooling (11 %), other building technologies (16 %) and refrigeration (9 %) account for about three quarters of the total electricity demand of the tertiary sector, whereas the other nine energy services together make up the remaining 25 % of total consumption.

Figure 5: Breakdown of the electricity demand by energy service in the EU27+2 tertiary sector in 2007



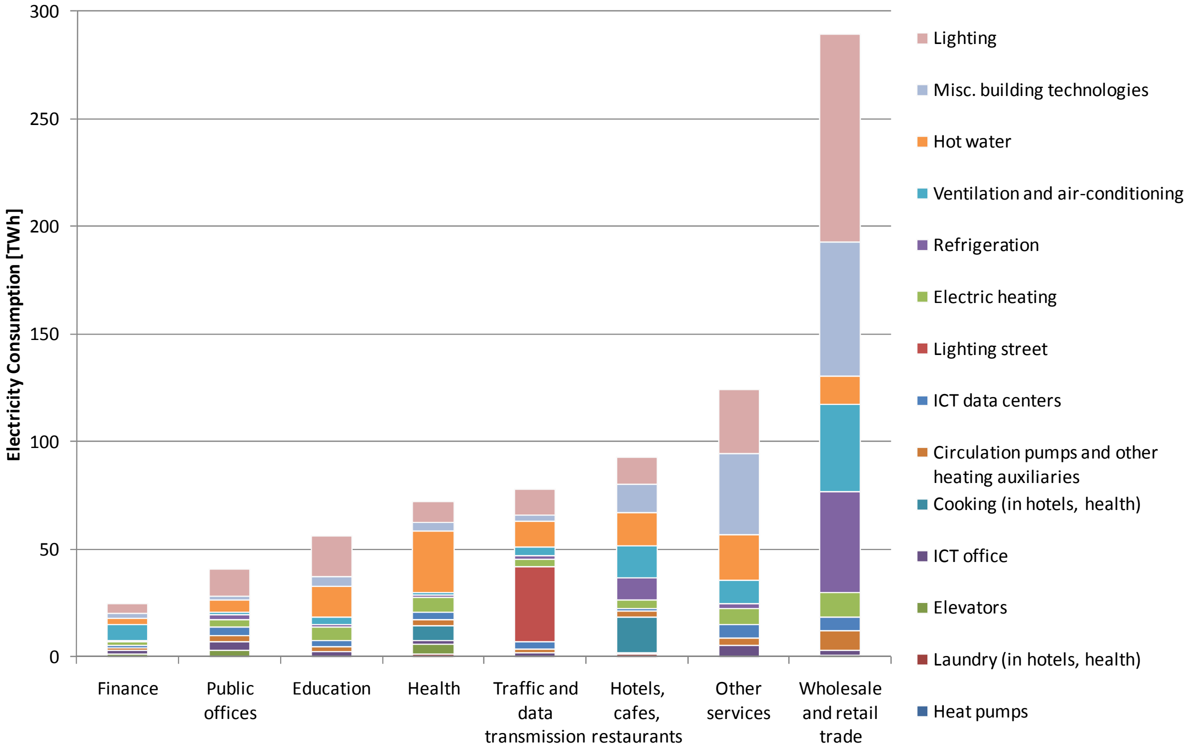
The breakdown by sub-sector clearly reveals the high electricity consumption of the wholesale and retail trade sector with 37 % (see Figure 6). The shares of the remaining sectors range from 3 to 16 %.

Figure 6: Electricity demand of the tertiary sector of the EU27+2 by sub-sector in 2007



A breakdown of the electricity demand by energy service and sub-sector shows substantial differences between sub-sectors (see Figure 7). The share of refrigeration, for example, is the highest by a large margin in the wholesale and retail trade, while the share of hot water is highest in the sub-sector of health. Elevators, ICT equipment and data centres have the highest shares in the finance and public offices sub-sectors.

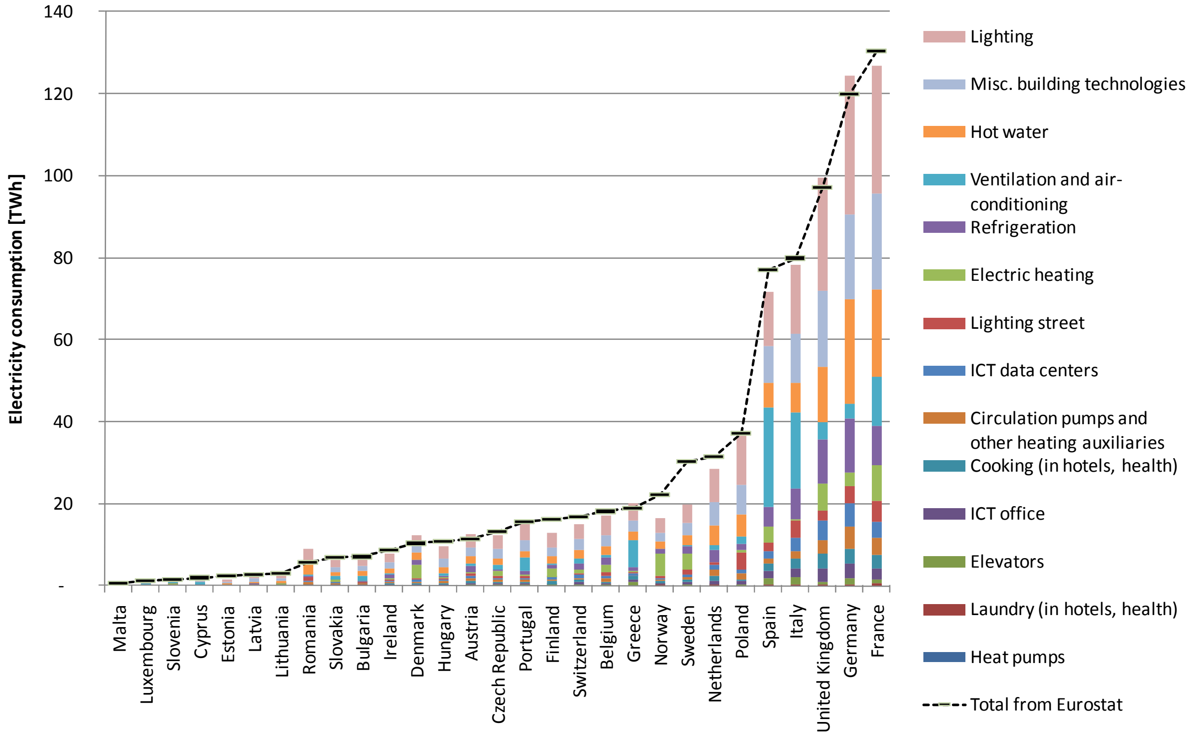
Figure 7: Electricity consumption by sub-sector and energy service for the EU27+2



The total calculated electricity demand T for 2007 amounts to about 779 TWh for the EU27+2. Compared with the statistical electricity demand of the tertiary sector of 798 TWh, the bottom-up model is able to explain 97.5 % of the tertiary sector's electricity demand.

Despite the very good match between the calculated data and the Eurostat statistics for the EU27+2, a closer look at the country level reveals some deviations between the bottom-up values and the energy statistics (see Figure 8). Countries like Norway, Sweden and the Netherlands are underestimated, while the bottom-up estimates for Romania and Denmark were too high. For Romania in particular, the relative differences are huge and might indicate either erroneous statistics or differing definitions of the tertiary sector. However, since the calculated data show general agreement with the Eurostat statistics for the larger countries, with differences in the range of ±10 %, they provide a good basis for further analysis like bottom-up electricity demand projections. Moreover, the deviations in absolute terms (TWh) are low for almost all the countries.

Figure 8: Share of energy service in total electricity demand by country (1 = 100 %)



Conclusions

A comparison of the results with Eurostat electricity demand statistics shows that the obtained bottom-up results are a good match with the statistical top-down data - with the exception of some smaller countries. The total electricity demand of the tertiary sector of the EU27 plus Norway and Switzerland is slightly underestimated by 2.5 %. The 7 most relevant countries in terms of electricity demand in the tertiary sector - France, Germany, Italy, the Netherlands, Poland, Spain, UK - are within a range of +-10 %. These results therefore provide a good data basis for bottom-up modelling of the future electricity demand of the tertiary sector. Furthermore, these detailed bottom-up estimations can be used as a basis for designing energy efficiency policies and provide a sound starting point for ex-ante and ex-post estimations of their impacts. As such they also form the foundation for a bottom-up model which is being developed by the authors to forecast the electricity demand of the tertiary sector up to 2035.

References

[1] Gruber, Edelgard; Plesser, Stefan; Dusee, Rinto; Sofronis, Ilias; Lima, Pedro; Riviere, Philippe; Rialhe, Anne (2008). El-Tertiary: Monitoring Electricity Consumption in the Tertiary Sector, D26 - report on the project results (http://www.eu.fhg.de/el-tertiary/, access: 31.01.2010)

[2] Bertoldi, Paolo; Atanasiu, Bogdan (2009). Electricity Consumption and Efficiency Trends in the European Union – Status Report 2009. European Commission Joint Research Centre (JRC), Institute for Environment and Sustainability

[3] Bertoldi, Paolo; Atanasiu, Bogdan (2006). Efficiency Trends in the Enlarged European Union – Status Report 2006. European Commission Joint Research Centre (JRC), Institute for Environment and Sustainability

[4] De Almeida, Anibal T.; Caetano, Antonio; Fong, Joao (2006). Residential and Tertiary Sectors Technologies – Role of Electricity Demand. University of Coimbra, Eurolectric

[5] Schlomann, Barbara; Gruber, Edelgard; Geiger, Bernd; Kleeberger, Heinrich; Herzog, Till; Konopka, Daria-Maria (2008). Energieverbrauch des Sektors Gewerbe, Handel, Dienstleistungen (GHD) für die Jahre 2004 bis 2006. Fraunhofer Institute for Systems and Innovation, Lehrstuhl für Energiewirtschaft und Anwendungstechnik (IfE) Technische Universität München, GfK Marketing Services GmbH & Co. KG, Karlsruhe, München, Nürnberg

[6] Abreu, Carlos; Adnot, Jeroen; Riviere, Philippe (2007). Tertiary electricity consumption in France, report for El-Tertiary: Monitoring Electricity Consumption in the Tertiary Sector

[7] Jochem E. (Work Package Leader), Barker T., Scrieciu S., Schade W., Helfrich N., Edenhofer O., Bauer N., Marchand S., Neuhaus J., Mima S., Criqui P., Morel J., Chateau B., Kitous A., Nabuurs G. J., Schelhaas M.J., Groen T., Riffeser L., Reitze F., Jochem E., Catenazzi G., Jakob M., Aebischer B., Kartsoni K., Eich-hammer W., Held A., Ragwitz M., Reiter U., Kypreos S., Turton H. (2007): EU-Project ADAM: Adaptation and Mitigation Strategies: Supporting European Cli-mate Policy - Deliverable M1.1: Report of the Base Case Scenario for Europe and full description of the model system. Fraunhofer ISI. Karlsruhe. November.

[8] IEA (2006): Light's labour's lost - policies for energy efficient lighting, International Energy Agency (ed.), Energy efficiency policy profiles, Paris: IEA.

[9] Weber L. (2002): Energie in Bürogebäuden: Verbrauch und energierelevante Entscheidungen, vdf Hochschulverlag AG an der ETH Zürich(Hrsg.).Zürich.

[10] Aebischer, B., Catenazzi, G. (2007): Der Energieverbrauch der Dienstleistungen und der Landwirtschaft, 1990 – 2035. Ergebnisse der Szenarien I bis IV und der zu-gehörigen Sensitivitäten BIP hoch, Preise hoch und Klima wärmer. Bundesamt für Energie, Bern, März.

[11] Jakob M., Jochem E., Honegger A., Baumgartner A., Menti U., Plüss I. (2006): Grenzkosten bei forcierten Energie-Effizienz-Massnahmen und optimierter Gebäudetechnik bei Wirtschaftsbauten. Bundesamt für Energie (Hrsg.). Bern. November.

[12] Aiulfi D., Primas, A., Jakob M. et al. (2009): Energieverbrauch von Bürogebäuden und Grossverteilern - Erhebung des Strom- und Wärmeverbrauchs, der Verbrauchsanteile, der Entwicklung in den letzen 10 Jahre und Identifizierung der Optimierungspotentiale. Basler & Hofmann, Sorane, CEPE, ETH Zürich und i.A. Bundesamt für Energie (BFE)(Hrsg.). Bern.

[13] SIA (1995): SIA Empfehlung 380/4:1995, Elektrische Energie im Hochbau, Ausgabe 1995. Zürich. November.

[14] SIA (2006a): SIA Empfehlung 380/4:2005, Elektrische Energie im Hochbau, Ausgabe 2006. Zürich. November.

[15] SIA (2006b): SIA Merkblatt 2024: Standard-Nutzungsbedingungen für die Energie- und Gebäudetechnik. Zürich, August

[16] Wellig, B., Kegel, B. et al. (2006): Verdopplung der Jahresarbeitszahl von Klima-kälteanlagen durch Ausnützung eines kleinen Temperaturhubs, Ernst Basler + Partner, Zürich, i.A. Forschungsprogramm UAW, Bundesamt für Energie, Bern

[17] Adnot, J., Riviere, P., Marchio, D., Holmstrom, M., Naeslund, J., Saba, J., Becirspahic, S., Lopes, C., Blanco, I., Perez-Lombard, L., Ortiz, J., Papakonstantinou, N., Doukas, P., Joppolo, C. M., Casale, C., Benke, G., Giraud, D., Houdant, N., Co-lomines, F., Gavriliuc, R., Popescu, R., Burchiu, S., Georges, B., Hitchin, R. (2003): Energy Efficiency and Certification of Central

Air Conditioners (EECCAC). Study for the D.G. Transportation-Energy (DGTREN) of the Commission of the E.U., Paris.

[18] Rivière, A. et al. (2008): Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Tasks 1 to 5. Draft reports as of July 2008

[19] Aebischer, B., Jakob, M., Catenazzi, The late G. Henderson (2007b): Impact of climate change on thermal comfort, heating and cooling energy demand in Europe. Proceedings eceee Summer Study 2007, Colle sur Loup, France, June (ISBN 978-91-633-0899-4).

[20] Jakob, M., Catenazzi, G., Jochem, E., Shukla, A. (2008): Adaptation to and mitigation of climate change in the tertiary sector of Europe. Proceedings of the IEECB'08 - Fifth International Conference on Improving Energy Efficiency in Commercial Buildings, Frankfurt, April.

[21] Monier, V.; Mudgal, S.; Iyama, S.; Tinetti, B. (2007): Preparatory studies for ecodesign requirements for EuPs - Lot 12: Commercial refrigerators and freezers: Bio Intelligence Service.

[22] Lindegger, U. (2009): Energy efficient elevators and escalators. Assessment Report EU. Project report E4 project. (http://www.e4project.eu/Documenti/WP2/E4-WP2-D2.3-AssessmentReportEU.pdf, access: 31.01.2010)

[23] Nipkow, J. (2005): Elektrizitätsverbrauch und Einspar-Potenziale bei Aufzügen. Bundesamt für Energie Schweiz. (http://www.bfe.admin.ch/php/modules/enet/streamfile.php?file=000000008982.pdf&name=000000250057.pdf, access: 31.01.2010)

[24] Van Tichelen, P.; Geerken, T.; Jansen, B.; Vandem Bosch, M.; Van Hoof, V.; Vanhooydonck, L.; Vercalsteren, A. (2007): Preparatory studies for eco-design requirements for EuPs - Lot 9: Public street lighting: VITO.

[25] Van Tichelen, P.; Geerken, T.; Jansen, B.; Vandem Bosch, M.; Van Hoof, V.; Vanhooydonck, L.; Vercalsteren, A. (2007): Preparatory studies for eco-design requirements for EuPs - Lot 9: Public street lighting: VITO.