A key to success: Improved statistics on energy end use in buildings

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Abstract

Detailed statistics on energy end-use patterns in buildings is a prerequisite for structured energy and facility management and successful creation, impact prediction, implementation and monitoring of energy policies and proposed actions for reduced GHG-emissions from the building stock. Moreover, lack of evaluation significance is often used as an argument against energy-efficiency actions. The quality of national building energy statistics has during recent years declined, resulting in an increasingly difficult situation for policy makers and energy-efficiency advocates. To improve this situation the Swedish National Energy Agency has launched a new programme, including one project dealing with improved energy statistics in non-residential buildings.

The project runs in six year cycles, and step-wise covers all categories of tertiary buildings. End use will be mapped out in approximately 1 000 buildings during each six-year period. High priority is given to electricity, and its allocation between different end use categories (heating, cooling, lighting, ventilation, etc), although total energy end use is noted as well. The first audits were carried out in 2005, including 123 offices and administration buildings. The second year audits include school buildings and were performed during 2006.

The first-year results provide highly interesting detailed information. Findings from the 2005 audits are e.g. that energy end-use varies with a factor four between buildings, and, contrary to common assumptions, total average electricity consumption in office buildings has decreased. This paper will describe the findings of the two first years of audits; furthermore it will elaborate on the rational behind improved building energy statistics, including important applications of such data.

Background

The need for improved detailed building sector energy statistics is multiple. Several EC directives addressing energy, e.g. the energy performance of building's directive (EPBD), the Energy service directive (ESD), and the Eco-design directive, requires detailed up to date energy statistics. Another driver for improved energy statistics is the national environmental objectives "Reduced climate impact", "Clean air", and "A good built environment". Detailed statistics on energy end-use patterns in buildings is a prerequisite for structured energy and facility management and successful creation, impact prediction, implementation and monitoring of energy policies and proposed actions for reduced GHG-emissions from the building stock. Moreover, lack of evaluation significance is often used as an argument against energy-efficiency actions.

The quality of national building energy statistics has during recent years declined, resulting in an increasingly difficult situation for policy makers and energy-efficiency advocates. To improve this, the Swedish National Energy Agency has carried out a programme called STIL2 ("Statistik i lokaler 2", "Non-domestic buildings statistics 2") during the last four years, dealing with improved energy statistics in non-residential buildings. The programme will be continued for at least another four years.

Before launching the STIL2 programme the most recent available Swedish energy-statistics for non-domestic buildings were collected in 1990, in a project called STIL ("Statistik i lokaler", "Non-domestic buildings statistics"). Apart from delivering up to date energy statistics, the STIL2 programme also enables comparisons between energy end-use in buildings between 1990 and energy end use of today.

Methodology

The STIL2 project runs in six year cycles, and step-wise covers all categories of tertiary buildings. End use will be mapped out in approximately 1 000 buildings during six-year periods. Priority is given to electricity, and its allocation between different end use categories (heating, cooling, lighting, ventilation, etc), although total energy end use is noted as well. The first audits were carried out in 2005, including 123 offices and administration buildings. The second year audits including school buildings and were performed during 2006. In 2007 audits will be carried out in health care buildings.

AUDIT MODEL

A special audit model has been developed for the STIL2 programme. The model includes detailed information on all kinds of energy end use. The model also includes a spread sheet were all key indicators and important information is summarized, and calculation support for a number of key performance indicators.

The project model is developed continuously with e.g. key performance indicators each year when new building categories are included in the study. In the 2006 study in door air quality and interconnections between energy end use and indoor air quality was introduced [see paper 5.339, Gullberg at al, Energy efficient and healthy buildings].

To ensure equal treatment of issues coming up when performing an audit, all staff involved in the project has been trained in the model and its use. Project feed back is constantly given to all staff categories working in the project to enable a smooth project operation.

STATISTICAL SELECTION

Over a period of six years approximately 1 000 buildings in all non-residential building categories will be audited.

The statistical selection for 2005 was based on Statistics Sweden's annual questionnaire for non-residential buildings. On assignment from the Swedish Energy Agency, Statistics Sweden has provided a statistical selection and sent out letters of invitation to these building owners. In total 127 office buildings were audited in 2005, 123 of these building audits had quality assured results. In addition 94 other buildings have been included in the work and been rejected due to non-compliance with one or more of the following criteria:

- The building area should be between 200 and 30 000 m^2.
- At least 80 % of the building should be occupied.
- Buildings included in the study should preferably not sub-deliver energy for heating purposes or electricity to other buildings.
- A full year statistical data on the building's delivered energy should be available (including tenants' end use).
- Buildings should not include too many tenants with individual electrical metering (limit 12-15).
- A prerequisite for the audits is that property owners and/or facility managers provide support when auditing and provide data on delivered energy and water consumption.

The audited buildings comprises in total 834 000 m^2, corresponding to 2.3 % of the total national office building area. The average building area in the study is 6 790 m^2 while the national average office building area is 3 200 m^2. In the audited buildings 90 % of the area was on average used for office purposes. Other occurring businesses were shops and restaurants.

AUDITS

When performing the audits an energy expert is walking through the building together with a building owner representative, with building drawings and a note book at hand. Together with the building owner representative the energy expert is visiting boiler room, ventilation equipment spaces and statistics on delivered energy is checked. Clarifications on the building regarding heating system, electrical installations, and possible connection to adjacent buildings are made. Electrical end use for e.g. fans and pumps can be measured on a momentarily basis with ampere meter. All other building areas are shown by the building owner's representative, and end use for lighting, elevators etc is estimated.

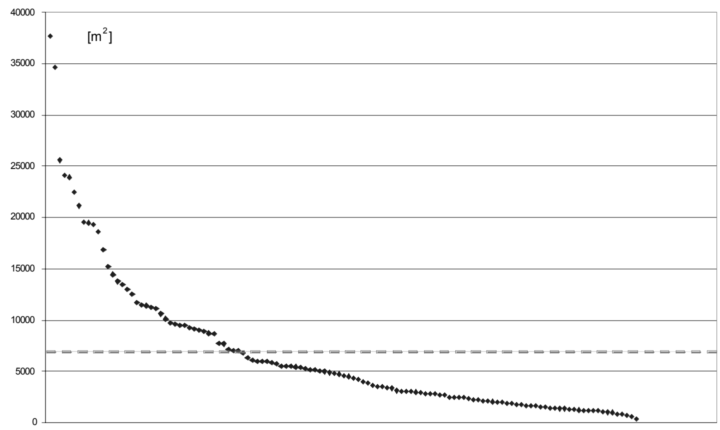

Figure 1. STIL2 variation in building area between the 123 audited office buildings.

The energy expert also visits the building's tenants and estimates end use from their equipment. With help from key indicators and discussions with the individual tenants their yearly energy consumption is then estimated for business related electrical end use.

Audit protocols

When the audit has been carried out, input from the building's total end use is modelled in the STIL2 model. The model has been created to match monitored and estimated data with real operation end use (delivered energy), and all energy auditors are able to revise building input in order to leave the un-identified rest post as small as possible. After the energy audit has been carried out and the energy auditor has modelled the building's energy end use, the results are quality checked by a senior energy expert. Should this senior expert find any questionable results, he can ask the individual energy expert to elaborate more on the audit results or even to re-visit an individual building.

The energy end use results are summarized in individual building reports and anonymously in a project data base comprising all audited buildings. The individual reports are presented to the individual building owners, and the data base is used for improved national energy statistics.

Results

The first year STIL2 audits included 123 office buildings. The audit results have been transformed to national level.

OFFICE BUILDING HEATING SYSTEMS

The Swedish office buildings' area has grown by 34 % from 1990 to 2005, while the total non-residential building stock has increased by 13 % during this period. Today 25 % of all Swedish non-residential buildings are offices (see *Figure 2*).

The carried out audits show that in 2005 district heating was the predominating heat source in office buildings. The share of district heated buildings is higher in offices than in other non-residential buildings. The share of offices in Sweden heated with district heating amounts to 70 % today; this has increased since 1990. The use of oil has decreased from 17 % to merely a few per cent during the same period. Combinations of heat sources are common and increasing. Changes in heating systems between 1990 and 2004 are shown *Figure 3.*

DECREASED RELATIVE ENERGY END USE IN OFFICES

Delivered energy for office building heating, district cooling and electrical end use according to the 1990 and 2005 studies is presented in *Table 1* and *Figure 3.*

Compared to 1990 the use of district heating in 2005 was on average the same in kWh/m², even though district heating in 2005 accounts for a totally larger share of heating than in 1990. This indicates that a development towards a more efficient end use has taken place with regards to heating in offices. The use of oil has decreased and electricity for heating has been reduced to less than half between 1990 and 2005. Increased use of heat pumps is one of the reasons for decreased electrical end use for heating.

However, it should be stressed that these results merely shows delivered energy. Adding delivered energy in terms of

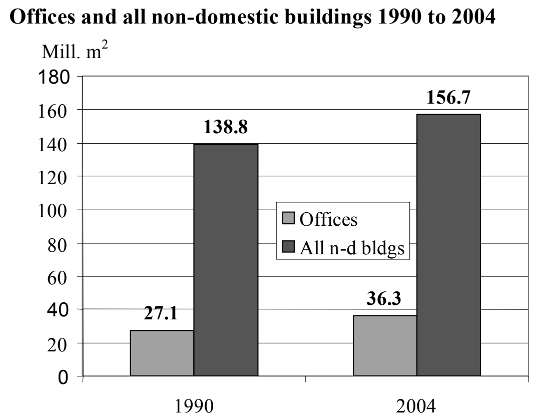

Figure 2. Total heated area in offices and all non-domestic buildings in Sweden. Source: Statistics Sweden.

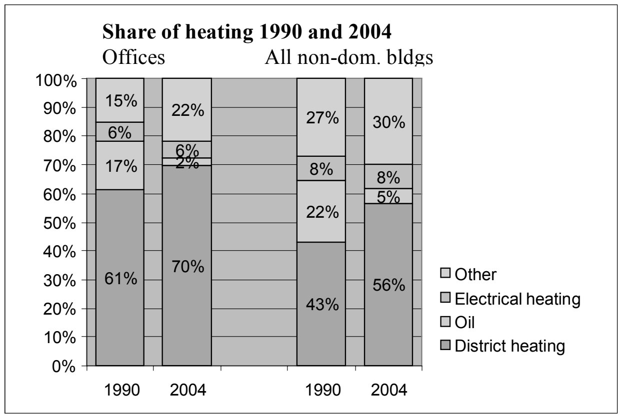

Figure 3. Energy sources for heating in non-domestic buildings in Sweden 1990 and 2005. Source: Statistics Sweden.

Table 1. Delivered energy in Swedish offices 1990 and 2005 respectively.

	1990	2005
District heating	84 kWh/m²	85 kWh/m²
Oil	18 kWh/m²	6 kWh/m²
Electrical heating	21 kWh/m²	9 kWh/m²
District cooling	0 kWh/m²	2 kWh/m²
Electricity	95 kWh/m²	93 kWh/m²
Total	218 kWh/m²	195 kWh/m²

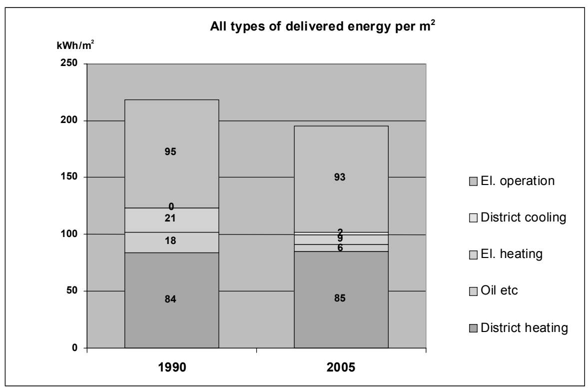

Figure 4. Specific delivered energy end use for heating, cooling and electricity for building operation on Swedish offices 1990 and 2005 respectively.

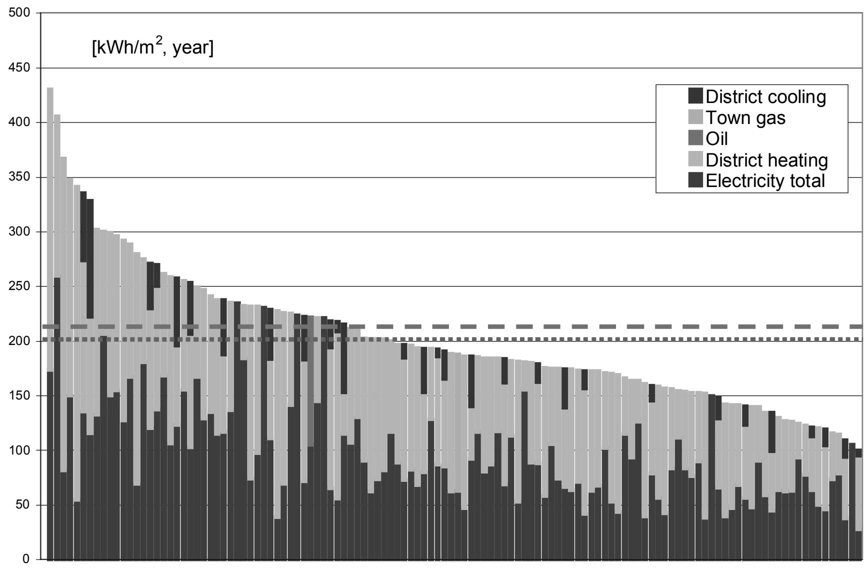

Figure 5. Variation in specific energy end use in 123 audited office buildings. One extreme value (a server hotel with extremely high energy end use, 1 359 kWh/m²) is left out of diagram. The striped line shows average energy end use including the extreme value (211 kWh/m²), the dotted line shows average energy end use excluding the extreme value (202 kWh/m²).

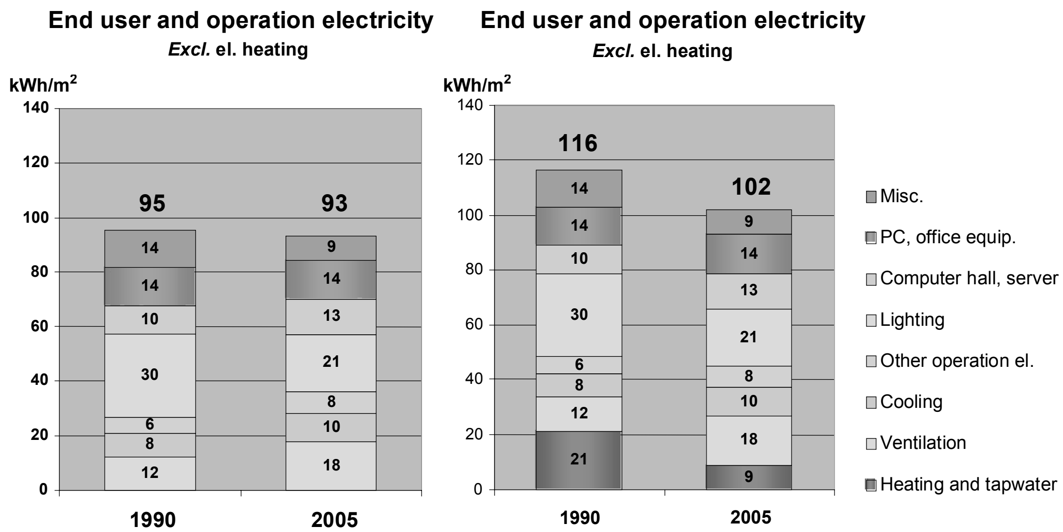

Figure 6. Comparison of electrical end use in office buildings allocated between end-use categories, 1990 and 2005 respectively. Left part of figure excludes electricity for heating and right part of figure includes electricity for heating. Sources: STIL and STIL2.

electricity, oil and district heating does not give the full picture due to differences in system boundaries (primarily transmission and distribution losses).

Electrical end use in offices was approximately at the same level in 2005 as in 1990. This may seem surprising; a common view is that electrical end use in non-residential buildings is rapidly increasing. Such an electricity demand growth was seen in the 1970s and 1980s, but stopped in the 1990s. This development is confirmed by e.g. processing of electrical end-use statistics [The National Board of Housing, Building and Planning].

Major differences in the studied office buildings

The average energy end use in the studied buildings is 211 kWh/m², which transformed to national level with regards to weights of individual buildings in the statistical selection gives a national average of 195 kWh/m². However, the variation between individual buildings is large. Energy end use in the 123 audited varies from 100 to one extreme value of 1 318 kWh/m². The second highest energy end use in the audited office buildings is 430 kWh/m². The average energy end use is significantly affected by the extreme 1 318 kWh/m², average is 211 kWh/m² when including and 202 kWh/m² when excluding this extreme value. Variations in energy end use in the 123 audited office buildings are shown in *Figure 5*.

Table 2. Electrical end use in office buildings allocated between end-use categories.

	1990	2005
Heating & tap water	21 kWh/m^2	9 kWh/m^2
Fans	12 kWh/m^2	18 kWh/m^2
Cooling	8 kWh/m^2	10 kWh/m^2
Other electricity for building operation	6 kWh/m^2	8 kWh/m^2
Lighting	30 kWh/m^2	21 kWh/m^2
Computer hall, server	10 kWh/m^2	13 kWh/m^2
PC, office equipment etc	14 kWh/m^2	14 kWh/m^2
Miscellaneous	14 kWh/m^2	9 kWh/m^2
Total	**116 kWh/m^2**	**102 kWh/m^2**

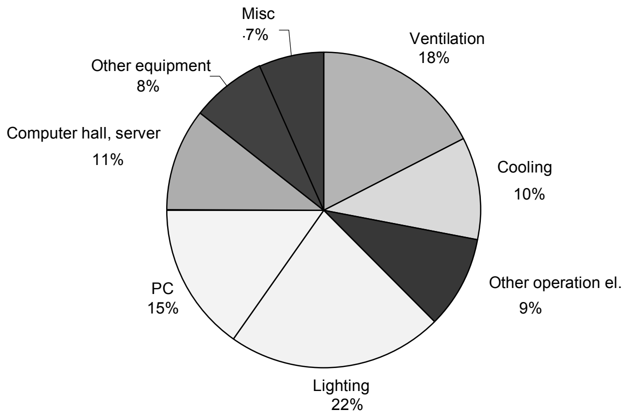

Figure 7. Specific end use in 123 audited office buildings 2005, allocated at end use categories (excluding electrical heating).

ELECTRICAL END USE IN OFFICES

The STIL2 project's most important aim is to give an answer to the question how specific electrical end use is allocated between end use categories. *Figure 6* shows the STIL2 results for electrical end use in office buildings allocated between end-use categories.

An important finding is, contrary to common belief, that total average electrical end use in office buildings not has increased during the last 15 years. Average electrical end use in office buildings has instead slightly decreased. Another important finding is that electricity for lighting has decreased significantly while electricity for ventilation has increased since 1990. As seen in *Figure 6* and *Figure 7*, lighting and ventilation are the largest single electrical end users, together standing for 42 % of total electrical end use in office buildings in 2005. PC and office equipment is the third largest end user in offices.

The specific electricity end use in office buildings has slightly decreased between 1990 and 2005, from 95 to 93 kWh/m^2, when including electricity for business activities and building operation. The decrease is more significant when electricity for heating is included, from 116 to 102 kWh/m^2.

Variations in electrical end use within audited buildings

The total electricity end use in the audited 123 office buildings varies between 30 and 1 318 kWh/m^2. The building with the extreme value 1 318 kWh/m^2 is a computer hotel with numerous PC units and servers. Variations in electrical end use in the audited buildings are shown in *Figure 8* (1 318 kWh/m^2 extreme value of excluded in figure). In *Figure 9* the specific electrical demand allocated at end use categories for the 123 office buildings is illustrated.

Electrical end use varies by up to a factor of four between individual buildings. The most significant reasons for these variations are building size, followed by operation hours for the building and its installations, and whether the ventilation system is equipped with heat recovery. A larger building has lower specific electrical end use than a smaller building. Op-

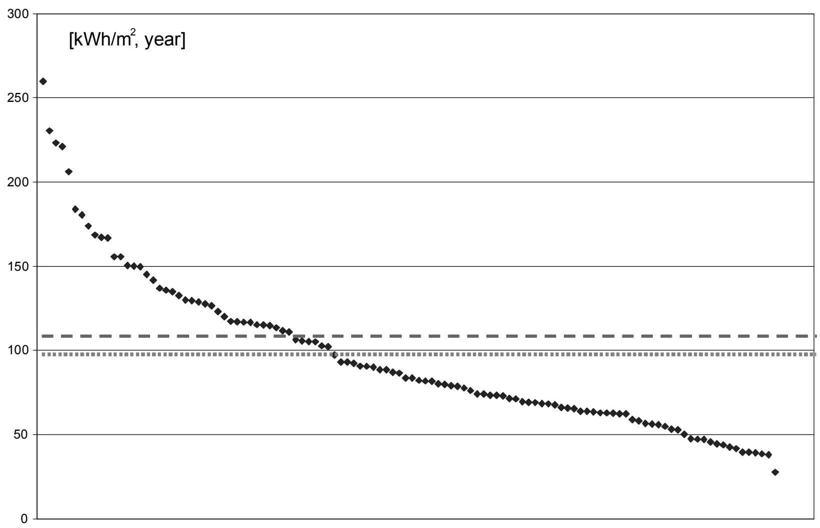

Figure 8. Variations in electrical end use in the audited buildings. (1 318 kWh/m^2 extreme value is excluded in figure. This extreme value is a server hotel.). Average value of audited buildings indicated in figure. The striped line shows average energy end use including the extreme value, the dotted line shows average energy end use excluding the extreme value.

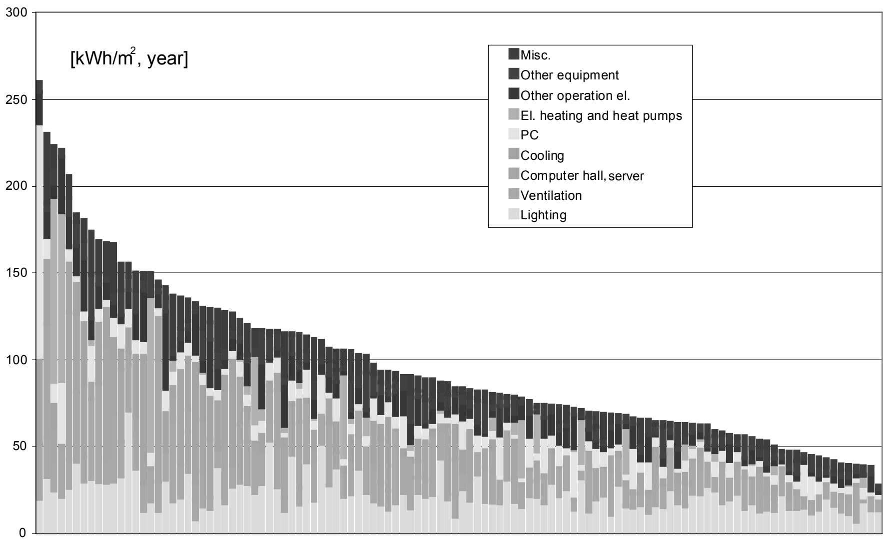

Figure 9: Specific electrical demand allocated at end use categories is illustrated (1 318 kWh/m² extreme value excluded) for audited buildings in the STIL2 study.

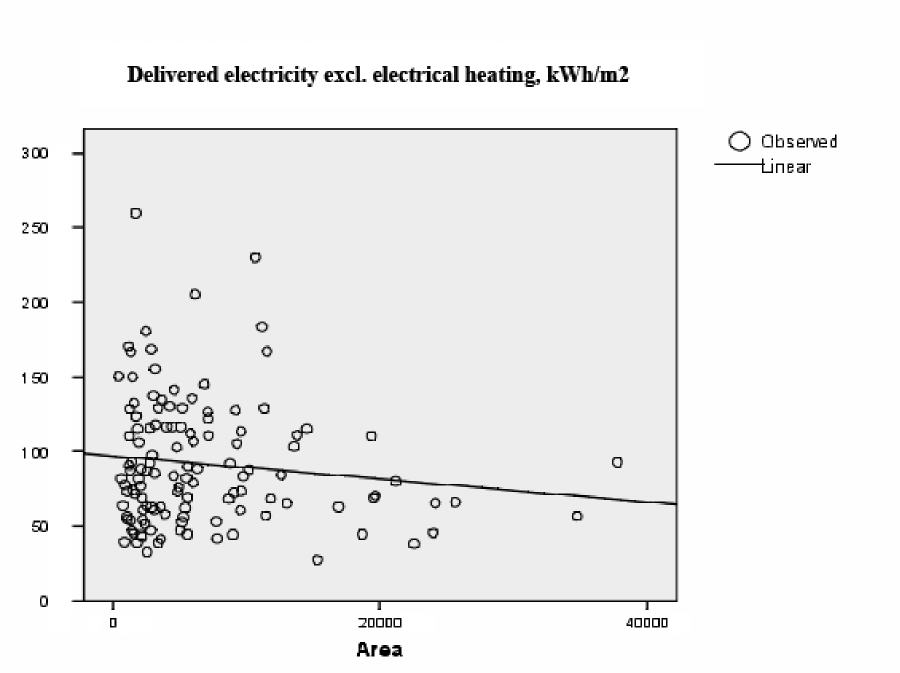

Figure 10. Distribution of electrical end use in the STIL2 project office buildings.

erational hours have a major impact on business electrical end use, particularly operation hours for ventilation systems. Finally, installing ventilation heat recovery equipment has a major impact on the office building's total energy end use. The age of the building does not have any significant impact on the office building's specific electrical end use.

Not all buildings include all categories of end use. Average values therefore have to be used with care. Merely a handful of end use categories are present in all buildings. Most end use categories are missing in at least some of the audited buildings. Thus the sensitivity of the results is varying between different end use categories. Lighting, ventilation and PC are end use categories present in all audited buildings, and no major differences can be seen in the audit results for these end use categories.

Lighting is much more energy efficient now

The carried out analysis of electricity consumption for lighting shows a clear reduction in energy demand in office buildings between 1990 and 2005. Electricity for lighting has decreased with 30 % during these 15 years, from 30 to 21 kWh/m². This reduction is due to several reasons. Two of these reasons are development of lighting technology and effective energy policies in the lighting area. The installed *effect* for lighting has decreased significantly over the past 15 years. In *Table 3* the distribution in installed effect (W/m²) between different light sources is presented.

The use of incandescent light sources in office buildings has decreased and the dominating light source fluorescent tubes have been cut by half in terms of installed effect. This is explained by the introduction of more efficient technology and probably also better lighting planning. Offices are retrofitted relatively often and it is reasonable to assume that a significant part of the office buildings audited in STIL2 has been retrofitted including an upgrading of the lighting system as one part.

A comparison between public and private owned office buildings indicate that fluorescent T8 tubes with HF ballasts are more common in publicly owned office buildings than in private owned offices, while it is the opposite situation with fluorescent T5 tubes. The difference in installed effect is minor. The difference in technology may be explained by a more frequent change of tenants, and thereby more frequent retrofitting, in the private sector.

Ventilation has increased

The specific end use for fans in office buildings has increased from 12 to 18 kWh/m^2 between 1990 and 2005. During this period an increased use of mechanical ventilation and increased

Table 3. Installed effect for lighting [W/m^2].

Light source	1990	2005
For whole building:		
Incandescent	2.1	1.2
Fluorescent light	15.3	7.7
of which		
- conventional ballast	15.3	4.9
- HF ballast + T8	0.0	1.1
- HF ballast + T5	0.0	1.7
CFL	0.3	0.7
Other light source	0.2	0.8
Unknown	0.6	0.0
Total all building	18.5	10.5
Office room	**23.0**	**13.0**

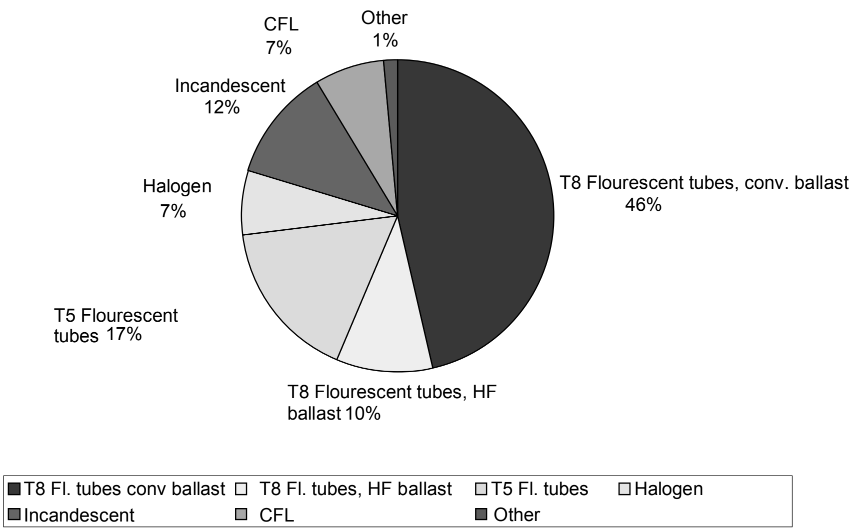

Figure 11. Installed effect for different kinds of light sources in the STIL2 study's 123 audited office buildings.

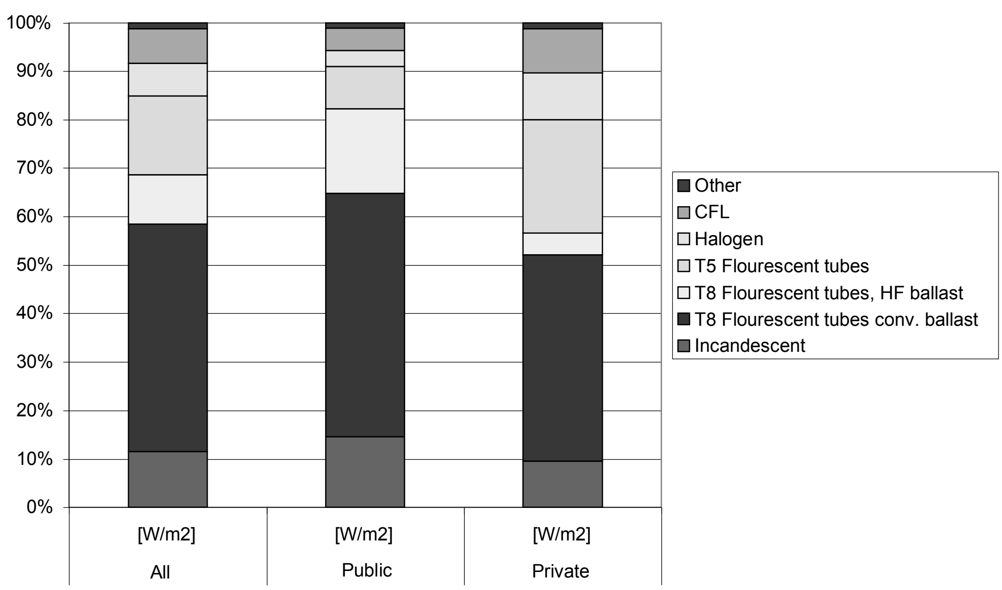

Figure 12. Variation in installed effect per m^2 for different kind of lighting in private and publicly owned office buildings respectively.

operation hours have been noticed. However, it was noted in the STIL2 project that energy efficiency of fans has increased in terms of specific fan power (SFP).

Cooling has increased

Specific end use for cooling has increased in office buildings from 8 to 10 kWh/m^2 between 1990 and 2005. This increase should have been much larger if we had not have a significant rise in use of district cooling and "free cooling" during the same period of time.

Computers and office equipment has increased surprisingly little

The number of personal computers and electrical office equipment has considerably increased between 1990 and 2005. At the same time the installed number of larger computers has drastically decreased. In terms of energy demand the growing number of office devices has almost been balanced by the change of IT technology solutions. In offices the specific electricity end use for computers, server rooms and office equipment has increased by surprisingly low 12 per cent, from 24 to 27 kWh/m^2, since 1990.

Electrical heating significantly reduced

The specific electrical end use for heating and tap water heating has significantly decreased in office buildings between 1990 and 2005, from 12 to 9 kWh/m^2. This is mainly explained by increased use of district heating and heat pumps.

Conclusions

The STIL2 project has made valuable energy statistics available to be used in implementation of EC Directives, national environmental goals, and creation and evaluation of new policy measures. The first year's study showed that energy end use has not increased in office buildings from 1990 to 2005. It also showed that the two single largest electrical end use categories in Swedish office buildings in 2005 are lighting and ventilation, together standing for 42 % of total electrical end use. PC and office equipment is the third largest end user in offices.

The project also shows good examples of effective energy-efficiency policy measures, e.g. policy measures in the lighting area. Another interesting finding of the project is the observed variation in specific energy end use of up to a factor of four between buildings. The most significant explanation for such variations is building size, followed by operation hours for the building and its installations. A third explanatory factor is whether the ventilation system is equipped with heat recovery, while building age does not appear to be of significance for the individual building's specific electrical end use.

The project has provided rich material full of details for all energy end use categories in office buildings. Further analyses of different kinds are possible, and the results from the STIL2 study and material from audits are publicly available on the Swedish Energy Agency's web site. It would be highly interesting to see a similar study being carried out in other countries, and to compare energy end use per category between countries.

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