Comparing Commercial Building Energy Use Around the World

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ABSTRACT

In the US, Western Europe, and the rest of the world, existing commercial buildings consume a great amount of energy, generating a rising level of carbon emissions. There is growing interest in better understanding the relative energy use of commercial buildings around the globe, as understanding the energy intensity of buildings, and energy usage patterns, are key to comparing and choosing best practices among different countries. The US EPA's ENERGY STAR® Commercial Buildings program, with its National Energy Performance Rating System, the European Commission's Directive on Energy Performance of Buildings, and the European GreenBuilding Programme all aim to cut commercial building energy use and costs, and minimize the resulting greenhouse gas emissions.

Available databases on commercial building energy use vary by country. The US has a comprehensive database, the periodically updated Commercial Buildings Energy Consumption Survey (CBECS), that provides a good overview of the sector's energy use. Other countries, including Japan, France, Canada, Germany and the United Kingdom, have also developed databases.

Comparing commercial building energy use among different countries is a significant challenge, with wide climatic and construction type variations, and varying quality of the data on energy consumed, fuel conversion factors used, building/space types, and floor area for calculating energy intensity. This paper presents a summary of data available around the globe, makes some initial comparisons of these data, and raises issues and questions for future research to allow better comparisons.

Introduction

As buildings account for a large proportion of total energy use, and commercial buildings are a growing share of this use, there is a great need to gather better data on building energy performance and to be able to compare performance across locations so that best practices can be more rapidly diffused. Commercial buildings[1] use a tremendous amount of energy, about 11% of the world total, and are a primary driver contributing to the growth in greenhouse gas emissions. In the United States (US), for example, commercial sector energy use increased from 10% to more than 17% of national energy use between the years 1960 and 2000, while energy use for residential buildings remained at about 20% of the national total during this time period. This development reflects the evolution of the country's economy toward a more service-sector based structure and away from heavy manufacturing. It is also leading to a rising awareness of the

[1] For the purposes of this paper, "commercial buildings" are considered to include all buildings other than residences and manufacturing facilities. These buildings are sometimes considered to be called "tertiary sector", or "service" sector buildings.

importance and potential for commercial building energy and emissions savings, which is simultaneously generating a need for more information to enable decision makers to minimize energy waste in these buildings.

As the interest in energy savings and emissions reductions grows, there is also an increased need to understand the relative energy performance of different types of buildings, in different regions, to better understand best practices in construction and operation for replication elsewhere. Unfortunately, energy use in commercial buildings is complicated to understand, due to the wide range of building uses and ownership, variations in the size and complexity of energy systems, differences in energy system operation, and other factors.

Overall, there is evidence of an alarming disconnect between predicted building energy performance according to the methods established in building thermal codes and actual measured building energy performance. From a building thermal engineering and energy efficiency policy setting perspective it is vital that the causes of this gap be identified and subsequently addressed; otherwise we are wasting our time while missing a major opportunity.

International Energy Consumption Trends in the Commercial Sector

Growth in the commercial sector has been rapid in the recent past, leading to increased interest in understanding sectoral energy use and opportunities for efficiency improvement. There has been a tendency, as national economies grow toward more specialized services and enterprise management, for the share of national energy use held by the commercial sector to grow relative to other sectors (MacDonald 2004). This is witnessed by the significant increase in the commercial sector energy consumption seen in all economies. Over the period from 1980 to 2000, China's consumption in this sector increased by 4.5 times, Malaysia's 5.1 times, Indonesia's by 6.6 times, Korea's by 6.6 times and Thailand's by 6.9 times (APERC 2001).

Dramatic as these figures are they reveal nothing about the relative efficiency of the commercial sector in different countries nor provide any insight regarding the potential for this growth to be abated. An insight into this requires data on the spread in building energy performance per unit service provided, or in other words some kind of efficiency metric.

Efficiency Metrics and Data Issues

Traditional intensity performance indicators such as energy consumption per unit of economic activity are too crude to be useful as an indicator of real building energy performance. It is perfectly possible for a group of buildings to have a low energy intensity (energy consumption per unit economic output) because their economic output is very high even while their energy efficiency is rather low, or vice versa. Additionally, community subsidized public swimming baths might have an inherently low economic output per unit energy use while an office dealing with currency trading might have a very high economic output per unit of energy use; however, in economic and engineering terms the unexploited cost-effective energy savings potentials might be similar in both cases.

Building energy performance could be compared on a strict energy-use--unit-area basis; however, this is only partially informative because it doesn't take account of variations in the key circumstantial factors that drive building energy use including: building function, occupancy patterns, climate, comfort levels and indoor air quality levels. It would, therefore, be more appropriate to develop and compare normalized performance indicators, e.g. by expressing heating and cooling loads as a normalized function of heating and cooling degree days. Even this is fraught with difficulty because these functions could be non-linear (following on the previous example, at low levels of heating or cooling demand, some heating/cooling associated load might be relatively insensitive to climate and possibly dominated by the energy required to distribute the heating or cooling medium) and could be sensitive to the precision and nature of comfort levels required.

While these other factors are important and need a great deal of further study, energy use per unit area, even with its shortcomings, can be a very useful first measure of energy efficiency. It can be a valuable tool in determining the relative performance of different buildings by comparing annual per-square-meter energy consumption, or energy usage intensity (EUI). Benchmarking provides a good overall picture of relative energy usage for a given facility and can be an important first step to understand energy usage and savings potential, particularly when comparing similar types of buildings in similar climates.

For this paper, all EUI information is presented in the international units of $kWh/m^2/year$ (while US building energy data are generally presented in $kBTU/feet^2/year$, most countries in the world use the metric system for measurement and reporting, and that convention/system of units is used in this paper; the energy use for all fuels is converted to kWh and summed, not just the electrical usage as is traditionally reported in those units in the US). For all data included in this paper, we have attempted to present delivered, or site, energy use, when available, as that provides the most transparent method for comparison of building energy performance, without potential for confusion regarding what conversion factors have been used to account for the losses from primary (source) to delivered energy. However, primary energy values are sometimes more useful in allowing overall impacts of delivered energy consumption patterns to be assessed.

The strength of the EUI comparisons is their ease of use and widespread familiarity. Despite this, knowledge is lacking regarding causes of variation that have been observed and the relative impacts of factors such as schedules, functional uses, and density of use on the energy performance.

More sophisticated comparison methods have been developed and are in use in some countries including the US (Energy Star rating systems are an example, see www.energystar.gov). However, such systems require more data than just floor area, and sectoral segmentation issues arise regarding what types of buildings can be examined.

National EUI Data Sources

The quality and validity of commercial building sector energy consumption, both at a macro level, and perhaps more relevantly, at the energy use intensity level, varies. In the US there is a large and regularly updated database known as the "Commercial Buildings Energy Consumption Survey", or CBECS, that provides a wealth of information about the commercial sector's energy use and is the most comprehensive national dataset of its type in the world. The CBECS database is established via a detailed survey of commercial building characteristics and energy use. Every four years a representative sample of buildings in the US is surveyed, and exact energy/fuel usage information is collected from the energy suppliers. The latest survey, conducted in 1999, reports data from a sample of 5,430 buildings, which are chosen to be representative of the national commercial building stock totalling over 6 billion square meters (EIA 2002).

In France the private organization CEREN carries out annual surveys that are mainly financed by the French Energy Agency ADEME and energy supply companies. Around 20,000 commercial entities are surveyed annually, but the disaggregation is oriented on economic sector and not building information. The survey is predominantly based on telephone interviews. A serious drawback is the confidentiality of the data, which are only available to the energy suppliers financing the survey and ADEME. To what extent the French system will continue in the future in its current form is uncertain due to the planned liberalization of the energy markets in France (Schlomann et al 2000).

International Efforts Regarding EUI Data Comparison

Recently two different efforts have been undertaken to assemble and compare energy performance of commercial buildings in different parts of the world. In June 2000, IEA, in cooperation with the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI), organized a workshop on "Indicators of Commercial/Service Sector Activity, Energy and CO_2 Emissions, and Policy Impacts". Data on commercial sector energy use, and normalization to a variety of economic indicators, were presented by experts from a number of countries. A number of reports and presentations are available from the Fraunhofer ISI.

Subsequent to this workshop, an effort was expanded through the Asia Pacific Energy Research Centre (APERC), looking in more detail at "Energy Efficiency Indicators" for the APEC (Asia Pacific Economic Cooperation) region countries (APERC 2001). This APERC report gave a good summary of trends in energy performance in commercial sector buildings in the APEC region, including time series information on the improvement in efficiency levels, and changes from different policies or other drivers. Some of the data presented in the APERC report shows how the energy intensity has varied over the past two decades in four APEC countries. It is especially interesting to see the effect of dramatic increases in energy costs in Canada over the period, and the resulting significant drop in EUI.

In April 2004, a group of international practitioners gathered for the International Conference on Improving Energy Efficiency in Commercial Buildings (IEECB) in Frankfurt Germany (IEECB 2004). Several different sessions had papers on energy use monitoring and benchmarking. An informal meeting was organized to discuss effective ways of sharing international best practices in monitoring and benchmarking measured commercial building energy performance. Participants also discussed the relative effectiveness of different activities in motivating building energy performance improvement.

A recurring theme found through all of the efforts to date is that commercial sector energy use is growing at a significant rate, and it is important to better understand relative building performance and the impact of different programs and policies. It now appears that more energy policy makers are beginning to understand the value of this kind of comparison.

Difficulties in Comparing Relative Energy Use

As noted above, there are significant variations in the availability and quality of commercial sector building energy performance data. Many practitioners have developed their own data sets, and certain industry groups and companies share and compare benchmarking data, but very little has been assembled to compare this information in different regions of the world.

Part of the difficulty in comparing the relative performance of buildings in different parts of the world is that there is a wide variety of building types and space uses, as well as different expectations for comfort and expected amenities. There are also wide variations in climate conditions, which drive construction style and building energy consuming equipment, particularly equipment for heating, ventilation and air-conditioning (HVAC).

Further complications occur when one attempts to normalize the energy use data, into a "benchmark" EUI, most typically expressed as total building energy consumption per unit floor area per year. For this paper, all data have been converted to the units of kWh/square meter/year. In calculating the EUI, it is important to have accurate information for both the energy consumption (all fuels), as well as the floor area.

It is often very challenging to collect complete energy consumption data for a building. Electricity usage is generally the easiest, as many electric utility providers make available summaries of a customer's consumption history, generally available as monthly summaries, or sometimes even in smaller interval periods, such as hourly electric load profiles. Other fuels are more difficult, as liquid fuel and coal deliveries are often not calibrated to measure consumption for a specific period, and normalization for annual consumption can be difficult.

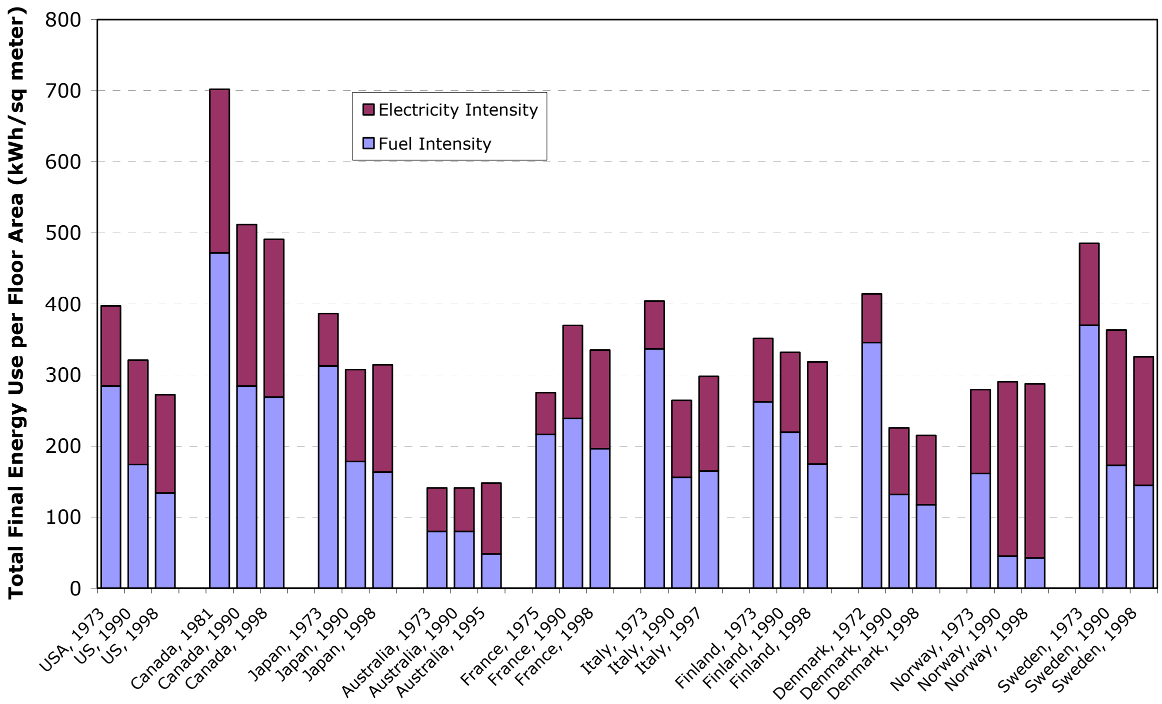
Similarly, the floor area used as the denominator for EUI calculations is often calculated in different ways. All around the world there are very different definitions for floor area, as tenants often pay rent per unit of floor area. There is often wide variation in floor area estimates, depending on whether one measures usable floor area as that inside the interior walls of a building, the gross area based on the exterior dimensions of the building, or other permutations. Also, in some cases common areas like lobbies, elevator shafts, bathrooms and mechanical rooms are left out of floor area, which has a large effect on the calculated EUI. In a recent effort to compare building energy performance across countries in Europe, the GREENEFFECT project has developed a set of conversion factors to adjust for the different "national floor area definitions" that prevail in the different countries (Therburg 2004).

Lastly, similar types of commercial buildings are often used and operated quite differently. In the US, school building energy use varies widely, though the reasons can often be explained by different hours of operation per week, number of months per year, types of HVAC and other systems, presence or not of swimming pools or cooking facilities, and many other items. Similarly, office buildings have very different types of loads, with some only open and conditioned 35-45 hours per week while others have much longer operating hours, with heavy computer equipment in place drawing electricity (and generating heat that needs to be removed through air conditioning). These differences in building uses and amenities have a significant effect on EUI, and can distort averages and EUI distributions for some building types.

EUI Comparisons and International Trends

Figure 1 shows the evolution over time of EUI data for the commercial sector in ten countries. In many countries EUI levels declined over the 20 year period preceding 1990, largely because of reduced space heating requirements. Much of the improvement has been due to improvements in boiler efficiencies and a corresponding growth in electrical internal loads that has resulted in a fall in delivered energy fall although not always such a strong fall in primary energy. Since 1990 there is a much more mixed picture, with many countries experiencing a plateau in EUI levels with continuing declines in fuel use offset by growth in electrical loads.

Figure 1. Evolution of Service Sector Annual Energy Electricity and Fuel Use Per Unit of Floor Area in 10 Countries



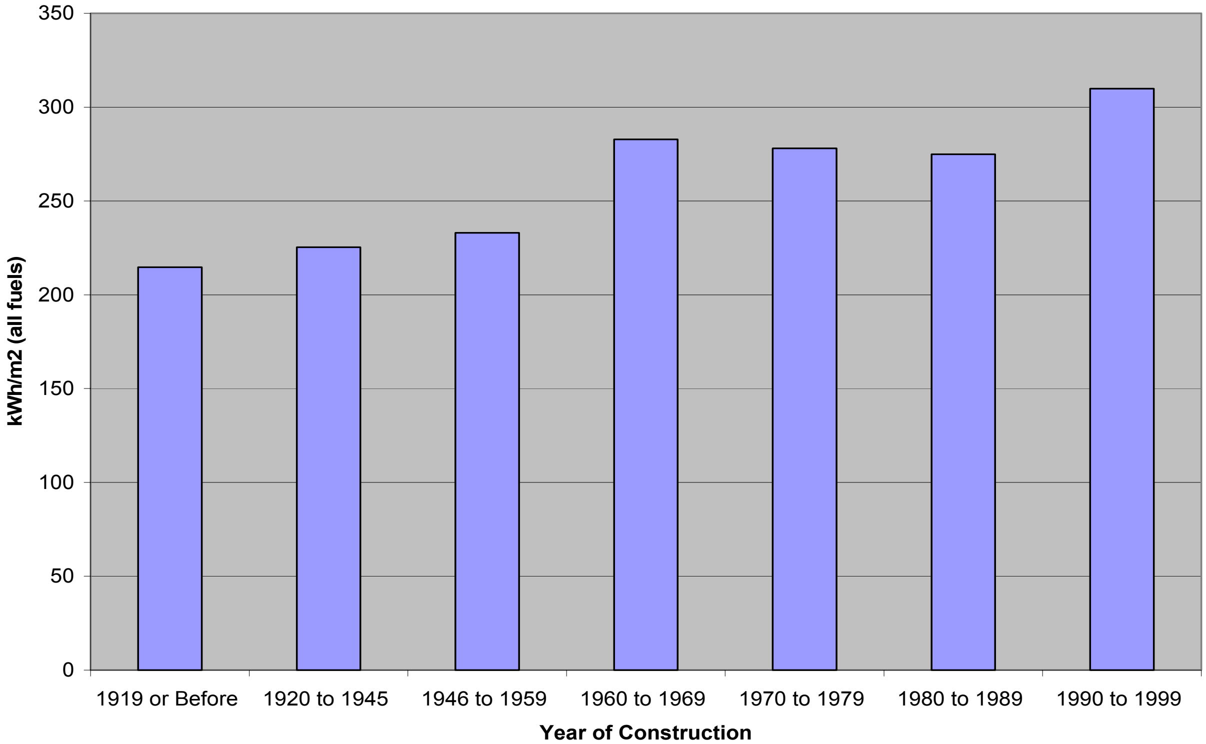
Source: IEA 2004

Disappointingly newer buildings are not generally more efficient than older ones. Figure 2 shows the EUI levels for the buildings in the 1999 CBECS data segmented by year of construction. In this it appears that commercial buildings constructed from before 1919 up to 1959 on average use appreciably less energy per m^2 than their more recent successors. Structural differences in service levels and building use may explain some of this phenomenon, but overall, it appears that new designs are not matching energy performance expectations.

On average the type and function of the building has a large impact on its EUI. Figure 3 shows the spread in average EUI across a range of building types based on function, which suggests that meaningful international comparisons should be done on the basis of building type rather than just average building stock.

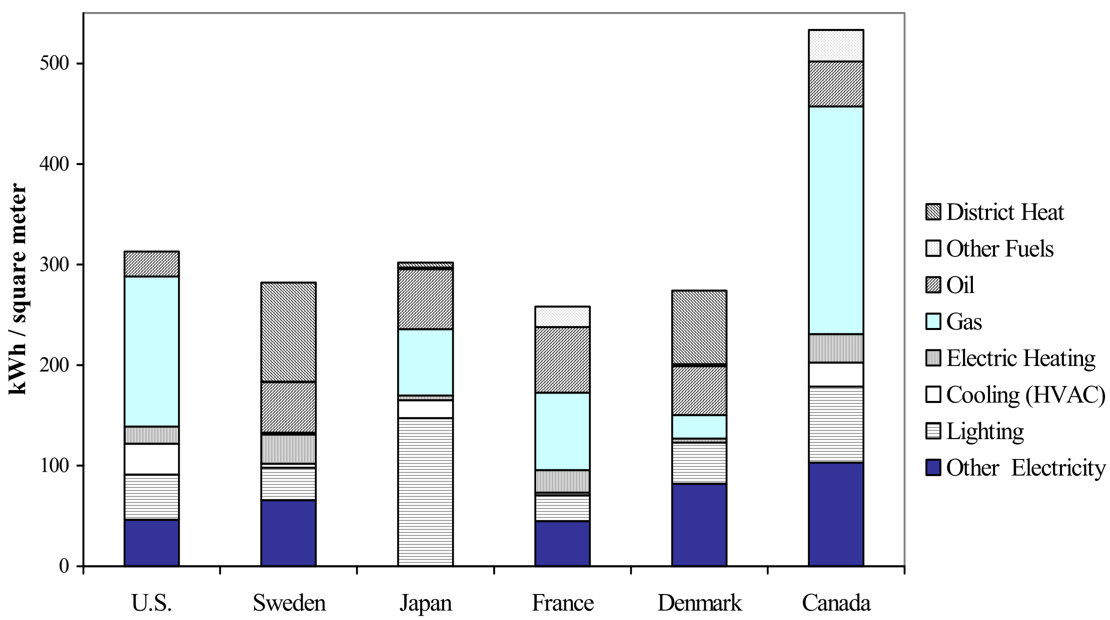
Interestingly, however, climate while an important parameter is not as dominant a factor in distinguishing average EUI as is often assumed. Figure 4 shows the EUI results from the simulation of a typical 4000 m2 office block when sited in five different EU countries. Despite large differences in climate, which lead to significant differences in the split between heating and cooling demand, total energy demand does not fluctuate as much because heating and cooling load variations tend to cancel each other out. These results are just based on detailed thermal simulations; however, they are indirectly supported by an analysis of the regional data in the US CBECS dataset, which shows comparatively minor fluctuations in EUI as a function of building location within the US.

Figure 2. US Commercial Building Energy Intensity by Year of Construction



Source: EIA 2002

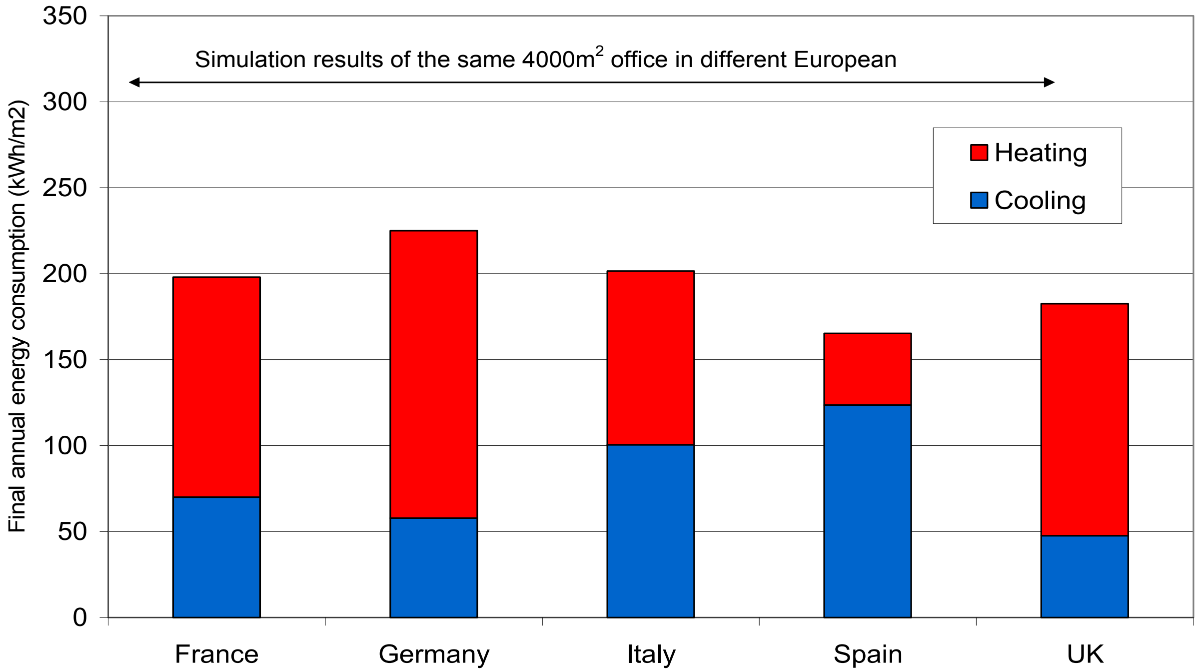
Figure 3. Annual Energy Intensities by End-Use and Building Type, 1990



(*Note: Electric heating includes HVAC and water heating. Values are weighted averages based on floor area in the U.S.A, Japan, Canada, France, Denmark, and Sweden)*

Source: Schipper 2000

Figure 4. Simulated Energy Intensities for an Identical 4000 m^2 Office Building in Various EU Countries



Source: EECCA 2003

Global Energy Estimates

Based on available data for total sector energy use, and energy intensities in certain regions, an effort has been made to develop an initial estimate, by global region, of commercial sector energy use, floor area, and EUI. The energy data were calculated using IEA totalconsumption by region as a starting point. Regional shares of "Buildings" energy use were estimated based on limited empirical data for more developed countries and extended based on best approximation to other regions. Similarly, shares of "Commercial" energy use as part of "Buildings" were also applied to arrive at the regional energy values. Floor area data were derived using limited empirical data on commercial floor area per capita and applying those values to population estimates for 2001. More confidence can be placed in the values for developed countries, as these were based on previous empirically-based data.

Globally, it is estimated that in 2001 the total final energy consumption in the commercial buildings sector is approximately 8,600 TWh, resulting in approximately 2,500 million metric Tonnes of CO2 emissions. As a rough picture of the total global energy consumption by commercial buildings, Table 1 provides snapshot total final energy consumption data for the year 2001. Note, these values are just provisional estimates and should not be treated as anything more than this; in some cases the data seem counterintuitive, and may be driven by lower expectations of building service amenities.

Discussion

A great difficulty in comparing relative performance of commercial buildings is that there are varied levels of expected amenities and comfort conditions in different parts of the globe. Generally speaking, it has been a trend in North America in larger commercial buildings to build "sealed" buildings, completely mechanically ventilated, often without operable windows. This

Table 1. Commercial Energy, Floor Area, and EUI, 2001

Location / Region	GWh/yr	Sq M, millions	kWh/sqm
North America	2,326,000	7,900	294
OECD Europe	2,085,000	7,400	284
OECD Pacific	651,000	2,400	274
China	668,000	2,600	261
Asia (other)	960,000	3,900	248
Former Soviet Union	659,000	2,600	253
Other	1,261,000	5,800	216
World	8,609,000	32,500	265

Source: Hinge & MacDonald 2004

obviously results in greater energy intensity in climates where natural ventilation through open windows could effect similar comfort conditions during portions of the year.

Similarly, different regions have varying expectations and typical practices for the amount and usage of electric lighting. In many parts of the world electric lighting is only used when the outside sky is dark, and ambient daylight is adequate for a large portion of the buildings' operating hours. This is obviously dramatically less energy intensive than even the most efficient electric lighting systems.

There seems to be a trend, though, with the "globalization" of much of the service sector, and homogenization of the style and types of construction, toward more similar, "Western style" buildings. It is unclear how rapidly this will affect energy intensities in different parts of the world. The recent very hot summers in Southern and Western Europe have resulted in a dramatic growth in demand for mechanical air-conditioning, and building owners are often inclined to take measures they perceive are needed to satisfy customer requirements, even if this greatly increases energy use (and peak electric demand).

There is a much greater need for compilation and reporting of actual energy consumption data, not just predicted or average consumption. A recent study for the German Federal Ministry of Economics and Technology on "Developing cost-effective surveys to record the effective energy consumption in the household and tertiary sector" surveyed what is being done in other regions of the world, and recommended a number of options for better data collection and dissemination in Germany (Schlomann et al. 2000).

While these studies have begun to compile some comparison data, there is a strong need to assemble and synthesize available data around the globe; perhaps through an expanded IEA project or task group. A European Commission supported project, the Building Energy Standards – Tool for Certification, or BESTCert, to develop a common methodology for implementation of the European Directive on Energy Performance of Buildings, just getting underway in mid 2004, includes a task to assess sources of energy consumption data, decide on building types for comparison, and then set up a variety of energy surveys (Davidson 2004).

The ability to perform meaningful comparisons is an important foundation for assuring that truly best practices in energy measures, energy programs, and continued energy performance certification are known and emulated. Certification methods and possible energy performance standards can become simpler and more effective if reliable energy performance comparison methods are available.

On the simple level of EUI, where only annual energy use and floor area are used, there are major known limitations (MacDonald 2004) that will always be present. However, EUI is the important starting point for developing more advanced comparison methods, and the energy - floor area linkage has been found to be the major predictor of variation in energy use between buildings. Advanced methods simply add to the ability to explain variation in energy performance. Adjusting for weather variation is an example of an important additional adjustment.

For more advanced energy performance comparison methods, representative samples of buildings and noticeably more data are required. Work in the US suggests that, for a given consistent economic region, all of the following factors are important: floor area, climate (weather variables), amount of building area cooled and heated, and the levels of space conditioning provided, worker density, personal computer density, extent of food service and education/training facilities, hours open each week, and for national models, average adjustments for specific types of building space uses. As suggested here, given major differences in expected service levels for lighting, etc., some service-level adjustment methods may be needed for comparison between countries or regions with major differences in these levels.

While all of the analysis shows that data are remarkably similar between different regions, with widely varying climatic conditions and other significant differences, there is tremendous value to providing benchmark information to building managers to help them manage buildings for optimal energy performance. A paper recently presented at the IEECB conference (Hicks 2004) showed the relative performance of commercial buildings achieving the Energy Star certification compared with the general office building stock. Table 2 shows the wide range of energy use and costs for office buildings in the US, with a factor of four in energy cost intensity for very similar types of buildings.

In addition to the benchmarking methodologies used in the US Energy Star program, consideration is being given in Europe to other methods, combining measured energy usage with simulations, which might be able to provide more valuable feedback to building owners and operators on where the opportunities lie in their buildings.

Table 2. Comparison of US Office Energy Use Intensity and Energy Cost Intensity

	Site/Delivered Energy Intensity (kBTU/ft^2-year)	Site/Delivered Energy Intensity (kWh/m^2-year)	Energy Cost Intensity (\$/ft^2)	Energy Cost Intensity (\$/m^2)
Energy Star Offices	61.4	194	$1.23	$ 13.24
CBECS Average	101.1	319	$2.03	$ 21.85
CBECS Top 25%	48.2	152	$1.02	$ 10.98
CBECS Bottom 25%	217.0	684	$3.51	$ 37.78

Without significant changes in energy performance of commercial buildings, the patterns of major increases in commercial sector energy use presented here will likely continue, with consequent resulting difficulties for reducing emissions. If important progress on improving the ability to measure and compare energy performance of commercial buildings can be made, potentially difficult commercial sector energy increases can more easily be controlled.

Conclusions

Increased energy efficiency in the commercial sector should be an important component of any national energy efficiency strategy and is a topic that requires greater attention than it has received in the past. Understanding commercial building energy consumption can be valuable for comparing performance to similar, peer buildings, as well as in establishing policies and programs.

As this paper has demonstrated, there is a wide range of data presently available on commercial sector energy usage, but there are significant challenges to accurately compare and interpret the different data sets that exist. Initial efforts have shown differences in EUI levels, and more research is needed to continue to assemble and synthesize the information, in order to provide useful information to policy makers on the types of programs and policies that are the most effective in reducing commercial sector energy use. EUI data are less sensitive to climatic variations than might be expected, as overall consumption is driven more by internal loads in the buildings, and cooling and/or heating often add somewhat similar additional loads.

As noted earlier, there is often confusion in data presented about whether EUI data was the delivered (site) energy consumed by the building, or the primary (source) energy which included loss and conversion factors for the energy used in the building. It would be very helpful to agree on "conventions and processes" for reporting energy performance data. In general, reporting delivered kWh/m^2 is most valuable and has less data reliability issues from uncertainty about conversion factors used. To avoid confusion in comparability of data, when primary energy data are presented, it is most helpful if the conversion factors and assumptions for any other "normalizations" are included. It is also helpful for data sets to keep thermal and electrical energy intensity data separate as far along the reporting chain as possible, to make it easier to convert to/from primary or delivered as required.

Comparing average EUI data for the entire commercial sector may not be tremendously valuable, as different building types have significantly different EUI levels. Comparison of EUI levels for similar building types, though, across different regions, can be quite instructive in understanding best practices.

At the IEECB conference in Frankfurt in April 2004, it was noted that there may be some international standards setting activities coming on energy data reporting, which could present an opportunity to work toward some harmonization on these issues. (IEECB 2004; in particular, see papers by Cohen and Wouters).

As the need for energy efficiency becomes more pronounced, achieving efficiency increases in the commercial sector will be impeded by its complicated mix of building sizes and uses, the complicated systems often used in commercial buildings, and the relative lack of understanding of operations factors impacting energy use and how to achieve efficiency. Improved understanding of commercial sector energy use, and the potential of improved understanding of operational improvements for saving energy in commercial buildings, would result from the ability to reasonably measure and compare energy performance among commercial buildings, in the commercial sector of national economies, and possibly in major global regions.

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