Energy efficiency indicators for high electric-load buildings

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Abstract
A commonly used measure of the energy efficiency of commercial buildings is the annual energy consumption per unit of floor area. This indicator is adequate for most of the buildings, where energy and electricity consumption is dominated by HVAC and lighting leading to an electric load of the order of 10-100 W per square meter. But, in some parts of some buildings energy consumption is dominated by specific processes like cooking, washing or data processing (computer rooms) and the electric loads may locally be of the order of several 100 W per square meter. If these high electric-load zones represent a substantial fraction of the building, then the measure of energy consumption per unit of floor area is no more a good measure of energy efficiency of the building. Alternative indicators of energy efficiency are presented for restaurants and computer centres and the use of these indicators in energy efficiency programmes is discussed.

Introduction and problem setting
Energy efficiency policies are an aspect of the battle against CO_2 emissions and the climate change brought about by the greenhouse effect. These problems are featured on the political agenda of all industrialized countries. This raises the question of how to make such policies as effective and efficient as possible. One crucial topic of this policy debate concerns the choice of intervention instruments that could and ought to be adopted in order to promote energy efficiency.

As a matter of fact, different *policy tools* can be alternatively implemented by the government to achieve the same policy objective (energy efficiency). On the level of energy-consuming equipment, three broad categories of instruments can be identified:

- instrument eliminating the least efficient appliances and equipments from the market (e.g. voluntary agreement on target-value, mandatory standards on minimal energy efficiency),
- instrument guiding the choice of consumers towards more energy-efficient appliances and equipment by means of better information and economic incentive (e.g. labelling, quality label, appliances tax) and promoting new patterns of usage of appliances and equipments (e.g. education programs, incentive tax on electricity), and finally,
- instruments to develop and launch more efficient appliances and equipment on the market (e.g. financial support of private R&D, public purchasing and technology procurement).

Each policy instrument is inextricably linked to specific target groups, administrative resources, implementing agencies and institutional procedures. Thus, each policy tool generates its own "political economy" and constitutes a quasi-independent system of action in and of itself (Varone & Aebsicher, 2001).

Besides the equipment-level, energy efficiency policies target components of equipment (or of buildings and systems), buildings and systems of equipment/components. Instruments and categories of instruments similar to the ones described above for the equipment level are applicable, but the more complex a system gets the more target groups and measures (policy mix) are needed for a comprehensive policy approach.

All the policy instruments have in common that they should rely on *energy-efficiency indicators*. It's quite obvious that indicators are necessary to establish a target value, to fix a standard, to define the level of a tax, to define the content of a label, etc. Such indicators are intended to simplify (reduce complexity), quantify (reduce uncertainty) and monitor (over time and individual cases) the performance of individual pieces of equipment, larger technical systems, or even a whole sector of economic activities (Spreng & Wils, 2000). But what are good indicators for measuring and monitoring energy efficiency performance? This is the general question we address in this paper and illustrate it with the discussion of energy indicators in restaurants and computer centres.

Addressing such a broad question is not trivial and includes several further (research and policy) issues. Should policy makers develop and apply energy efficiency indicators measuring technical efficiency only or should they also include "life style" and behavioural components (e.g. for restaurant, choice of the consumer to be considered)? What fundamental qualities of energy efficiency indicators (e.g. measurability, robustness, simplicity, cost-effectiveness, acceptability through target groups) do we have to take into account in order to facilitate reasonable communication between the target groups of state intervention and the regulators? How can we conceive energy-efficiency indicators that look beyond the boundary of engineering expertise (for a very specific piece of an equipment) without neglecting sector-specific characteristics but, at the same time, which allow a more comprehensive approach (the primary interest for policy makers and implementers)? All these partial issues are central when discussing the best way to increase the awareness of the energy efficiency and environmental impacts of commercial activities like restaurants and computer centres. In one word: to define an energy efficiency indicator is not only a technical challenge but also a pre-structuring of the subsequent policy choice. The political inherency of energy efficiency indicators is given by the fact that such indicators will then influence the behaviour of target groups (who should conform to the target values, standards, etc. based on such indicators) because "what gets measured gets down".

In actual practice and policies, a commonly used measure of the energy performance of a commercial building is the annual energy consumption per unit of floor area. In order not to compare apples and oranges one often corrects energy consumption for climate differences and classifies buildings according to their HVAC (e.g. fully air-conditioned building, building with mechanical ventilation, building with no cooling and no mechanical ventilation) and/or according to the economic sector or building type (e.g. office building, hospital, school). For all these buildings energy and electricity consumption are dominated by HVAC and lighting and the mean electric load is typically of the order of 10-100 W per square meter.

In some parts of some buildings energy consumption is dominated by specific processes like cooking, food conservation, washing or data processing (computer rooms). Mean electric loads may locally be of the order of several 100 W per square meter. If these high electric-load zones represent a substantial fraction of building energy consumption, then the measure of energy consumption per unit of floor area is no longer a good measure of energy efficiency of the building. One may therefore use another indicator, such as energy per meal or per guest for a restaurant, or exclude this process-induced energy consumption in the calculation of energy per unit of floor area and consider it in a separate approach.

In this paper, mainly for illustration purposes, we discuss energy efficiency indicators for two rather different sectors: The first case study analyses restaurants, where we look at existing data in 4 world regions with quite different culinary cultures (Switzerland, France, California and Japan) and explore the use of different energy efficiency indicators. The second case study investigates computer centres, where we propose to use an indicator measuring the efficiency of the central infrastructure. For each sector three points are successively treated: a brief description of energy use, the presentation of one or several indicators to measure energy efficiency and a brief summary of how these indicators are used today or planned to be used in the future.

Case study restaurants

ENERGY DEMAND AND ENERGY USE

Energy consumption in restaurants is of the order of 1% (Japan) and 2.5% (Switzerland) of total energy demand. In Switzerland electricity is commonly used for cooking (in restaurants and at home); in Japan most of the cooking is done by gas. The future energy demand of restaurants in Switzerland is evaluated by means of a bottom-up approach of the type: energy demand – (floor area) * (energy per unit of floor area). In the module "electricity" two types of restaurants are distinguished: a traditional restaurant with a mean specific electricity consumption of 750 MJ/m^2.year and a restaurant with a higher electricity consumption of 1 500 MJ/m^2.year, due to more electricity-consuming equipment, higher intensity of use of the equipment and greater comfort (e.g. air conditioning). Thanks to improved planning, more energy-efficient equipment and more precise operation of the equipment and technical systems, the specific energy consumption of each of these types of restaurants can be cost-effectively reduced by 13% and 27%, respectively. An increasing fraction of new and renewed restaurants is of the second type with a specific electricity consumption of twice that of traditional restaurants, and therefore the mean specific electricity consumption is increasing – despite technical improvements – due to the structural change from traditional to high electric load restaurants (Aebischer, 1999).

Fossil fuels, district heating and wood are used for space heating in Switzerland. Most other energy services use electricity:

- Ventilation and air conditioning (in Switzerland no cooling is needed due to outdoor temperature, however, in some types of restaurants cooling is needed to evacuate the heat load of people and more and more for reasons of comfort; mechanical ventilation needed to comply with regulated air exchange rates for hygienic reasons).
- Lighting (different illumination levels and lighting systems in different types of restaurants).
- Other services (food conservation and preparation, washing and drying of dishes and cloths).

The experience in Switzerland shows that energy per unit of floor area is a good indicator (specific energy consumption) for planning and modelling purposes (and possibly the best for building standards). However, in restaurants there are special requirements for VAC and lighting services and for other end-uses besides HVAC and lighting, which are independent of the building characteristics and not directly related to the floor area. New policy approaches (benchmarking and voluntary agreements on energy efficiency targets) require that the efficiency of these special energy uses can be measured and monitored and therefore alternative indicators are needed.

ENERGY EFFICIENCY INDICATORS

2.2.1. Switzerland[1]

In the last ten years several audits and surveys of energy consumption in restaurants were conducted:

- Five very different restaurants were analysed in detail in the early nineties (RAVEL, 1993).
- A survey of 202 restaurants in Zurich was conducted by the utility of the city of Zurich (EWZ). Not considered were restaurants attached to a hotel or to a bakery and fast-food restaurants. Recorded were electricity consumption, type and characteristics of equipment and time of use of equipment (Wittwer, 2003).
- Infel did a compilation of surveys by different utilities.
- Staff restaurants (canteens) of a large bank were monitored over several years. The following uses of energy were measured separately: cooking (electricity and gas, if used), lighting, and VAC (Gmünder, 2003).
- In the study by Balmer and Hintermann (2000) one highly frequented middle-class restaurant was analysed in detail, including measurements of energy need for the preparation of different dishes and estimates of energy embodied (grey energy) in the different comestible goods.

Energy per floor area is the most commonly used indicator, but the measurement of the floor area is not well defined. Sometimes it includes the restaurant (dining hall) and sometimes only the kitchen (and the food-storage area) is included. Alternative indicators are energy per cash-flow (total or cash-flow of the kitchen only), energy per employee, energy per seat, energy per guest and energy per meal. McDonald's Switzerland uses the indicator electricity per transaction (transaction = order = TAC). Between 1998 and 2001 it raised from 1.1 kWh/TAC to 1.3 kWh/TAC (McDonald's, 2002).

Table 1. Energy efficiency indicators used in different studies in Switzerland.
(Energy per guest in the highly frequented middle class restaurant is derived from energy per meal under the assumption that 50% of the guests have a meal). Source: staff restaurant (Gmünder, 2003); retail store, home for aged, hospital, fast food, gastro[2] (RAVEL, 1993); highly frequented middle-class (Balmer/Hintermann, 2000); Infel mean, Zurich (Wittwer, 2003).

Type of restaurant	Number of entries	Energy/seat MWh/seat.year	Energy/guest KWh/guest	Energy/meal KWh/meal
Staff's restaurant, canteen	6 (5)			2.2 (1.4)
Retail store	1	1.2	0.4	3.1
Home for the aged	1	0.6	0.6	2.3
Hospital	1	0.9	1.0	3.0
Fast food	1	3.0	0.5	1.2
Gastro	1	2.3	1.9	4.6
Highly frequented middle-class rest.	1	2.1	0.9	1.9
Infel mean	?			5 (best: 1.5)
Zurich	200			3 - 4

The Zurich survey of 200 restaurants was analysed in detail by EWZ, the utility of Zurich. A composite index to measure relative energy efficiency is proposed: energy per (floor area of the kitchen x cash-flow of the kitchen) measured in Wh/(m^2.CHF). Values < 2 Wh/m^2.CHF are found in energy efficient objects; values > 7 Wh/m^2.CHF indicate a large saving potential (Wieland, 1995). This approach is used by EWZ in consulting their clients. Unfortunately we do not have access (yet) to this analysis or the underlying survey data.

It is interesting to understand the variation in the ranking of the different types of restaurants for the three energy efficiency indicators:

- The fast food restaurant has the highest energy consumption per seat, but the second lowest value for energy per guest, because the number of guests per seat (frequency, turnover) is very high. The lowest value for energy per meal is probably due to several factors: many guests (42%) have a meal, high turnover, energy needed to prepare a fast food dish requires less energy than most of the "traditional" meals (see section "Total energy use for different meals") and the preparation is instantaneous (no energy needed to keep warm, no standby-losses!).
- The restaurant in a retail store has rather low energy consumption per seat and per guest. The relative high value of energy per meal is probably due to the low percentage of people having a meal (meal/guest = 13%). In reality, a substantial fraction of the energy is not needed for preparing the meal, but for cooling and heating drinks and for lighting and VAC-demand of people coming for a drink. If we attribute 0.2 kWh to a guest coming for a drink, then energy per guest having a meal would be 1.7 kWh or 40% less than the 3.1 shown in Table 1.

1. Have contributed to this section: Roger Gmünder, Ökoeffizienz, Switzerland oekoeffizienz@bluewin.ch, Gabriele Wittwer, EWZ, Switzerland Gabriele.wittwer@ewz.stzh.ch
2. "gastro" stands for "restaurant gastronomique", which means a restaurant serving meals of high standard.

Table 2. Use of electricity in the restaurants in Zurich (Source: Wittwer (2003), Gmünder (2003), Balmer/Hintermann (2000)).

	Lighting	Coffee	Food/drink con-serv./cooling	VAC	Food pre-paration	Washing dishes	Washing clothes
Zurich	17%	4%	18%	8%	20%	18%	15%
Highly frequented middle-class rest.	7%	2%	20%	6%	50%	12%	3%
staffs restaurant	15%		20%	15%	45%		5%

All these indicators have advantages and disadvantages that have to be discussed in the context of the intended application (policy measure) and the relevant target groups. Such a detailed discussion is beyond the topic of this paper, but a few hints can be given:

- Energy per seat is useful in the planning phase, when no information about the operation is available.
- Energy per guest helps to catch variations in energy consumption due to variation in business activity.
- Energy per meal finally addresses the energy needed for the preparation of different dishes and catches therefore the specific service offered and the choice of the guest for one or the other meal. One problem with this indicator is the energy "needed" by guests who do not have a meal, but come for a drink. A measurement of the energy per guest having a drink is hardly feasible, but an estimation of mean values for energy per drinking-guest in various types of restaurants should be possible.

Energy per meal is a particularly interesting indicator because it includes behaviour and lifestyle of the consumer. It may explain differences in energy consumption of restaurants due to differences in culinary cultures in different world regions and finally it opens the way to include energy embodied in the different food products.

Energy per meal varies strongly with the category of the restaurant, partly due to the different kind of typical dishes, the variety of dishes in the same restaurant and the way that the food is prepared. Therefore a pertinent classification of the restaurants is most important. But also for a given category of restaurants, the variation of energy per meal is largely due to the age and type of equipment and due to the use of the equipment and the behaviour of the cook and the auxiliaries (Figures 1 and 2).

Some of the variation can be explained by looking what for the energy is used (Table 2).

Use of energy efficiency indicators for restaurants in policy programmes in Switzerland:

- Information, help desk, consulting by EWZ, the utility in Zurich.
- Consulting, defining of targets of energy efficiency to be reached in the framework of the programme SwissEnergy.
- Target setting, monitoring of energy efficiency by the Canton of Geneva (in planning phase; energy efficiency indicator to be used not defined yet).
- Demonstration of new equipment (pilot kitchens).

France

A survey was carried out on hotels of different categories (2**, 3***, 4****) in 1999 by Inestene (Le Strat et al., 1999) for the account of the ACCOR Group. All the energy uses of every hotel were studied and the restaurants were part of this survey. The aim of this work was to identify the uses consuming a lot of energy. In a follow-up project the possibilities to reduce energy consumption of hotels is investigated.

The following energy uses are considered and measured separately: cooling for food conservation, cooking (electricity and gas) and dishwashing; not included are lighting, air conditioning, ventilation, space heating, central preparation of hot water, others. The energy consumption for the meal preparation is represented by the following graph for 36 restaurants of hotels belonging to four chains: Sofitel (4****), Novotel (3***), Mercure (3/2***) and Ibis (2**).

The mean values of energy per meal in total and separately for conservation of food, cooking and dishwashing and the standard deviation between each hotel and the average of the categories is shown in the following table.

The higher the category of the hotel, the more the restaurants consume energy for the preparation of meals. Only the 2** hotel-restaurants consume less than 4 kWh per meal

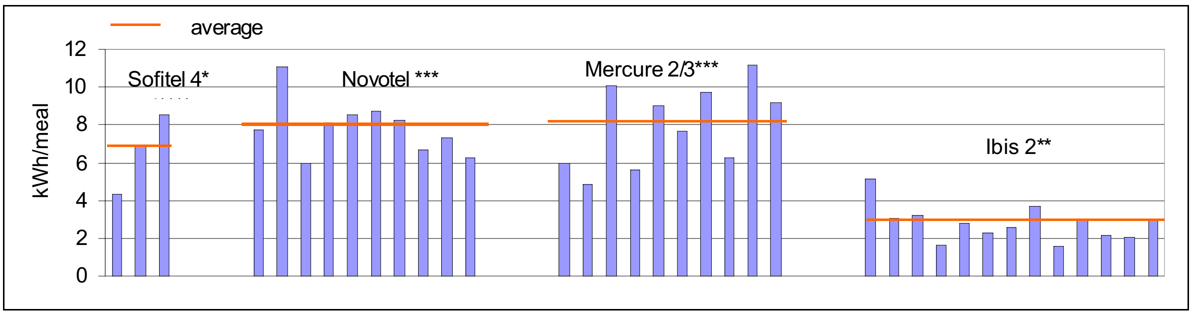

Figure 1. *Energy per meal for 36 hotels belonging to four categories in France (Source: Le Strat et al., 1999).*

with an average of 2.8 kWh/meal. All the other restaurants consume more than 5 kWh per meal with an average between 7 and 8 kWh/meal. The difference in energy per meal in the 2** restaurants and in the other types is due mainly to the huge difference in energy use for conservation of food. One reason is the reduced variety of food available in these 2** restaurants and probably some organisational differences with a central storage outside the individual restaurant.

Energy for cooking per meal is between 2 kWh/meal and 4 kWh/meal, which is of the order of total energy per meal in the Swiss data. During visits to the restaurants, we observed that the stoves operated from the arrival of the cooks up to their departure. There is no energy management in the kitchens and the cooks rule like kings. One of our aims was to sensitise the hotel employees to optimise their behaviour.

California

The data are taken from the 1996 California Commercial End Use Survey (CEUS) for the Northern California region (Pacific Gas and Electric service territory). These data were obtained through onsite surveys. The survey was collected for forecasting purposes; however, it has been useful for benchmarking building energy use as well. The sites are primarily located in the heavily populated regions in the Greater San Francisco Bay Area and Central Valley. The buildings in the sample are either all-electric or gas-electric and include 9 restaurants categorized as Bar/Tavern/Nightclub/

Table 3. Energy per meal (total and decomposed into conservation, cooking and dishwashing) in four types of restaurants in France (Source: Le Strat et al., 1999).

category of hotels	conservation kWh/meal	cooking kWh/meal	dishwashing kWh/meal	total kWh/meal	standard deviation
2**	0.44	2.08	0.25	2.77	0.94
2**/3***	3.81	3.89	0.25	7.95	2.18
3***	3.67	3.99	0.21	7.86	1.47
4****	2.53	3.92	0.13	6.58	2.13

Other, 21 as Fast Food/Self Service, and 34 as Table Service, for a total of 64 restaurants.

The climatic environment, and consequently, the amount of heating and cooling, varies greatly for this sample. While we do not have end-use breakdowns of energy use to separate the heating and cooling energy from the cooking energy, this can be compensated for by accounting for variation in climate. This may be achieved by grouping sites according to climate zone or through adjustments based on climate variables such as heating-degree days or cooling-degree days.

The energy values are for annual use and were obtained from utility billing data. The number of seats and floor area were contained in the survey; however, the data on meals was recorded as average meals per day. Thus the number of meals per year was estimated by using scheduling information to estimate the number of days per year that each res-

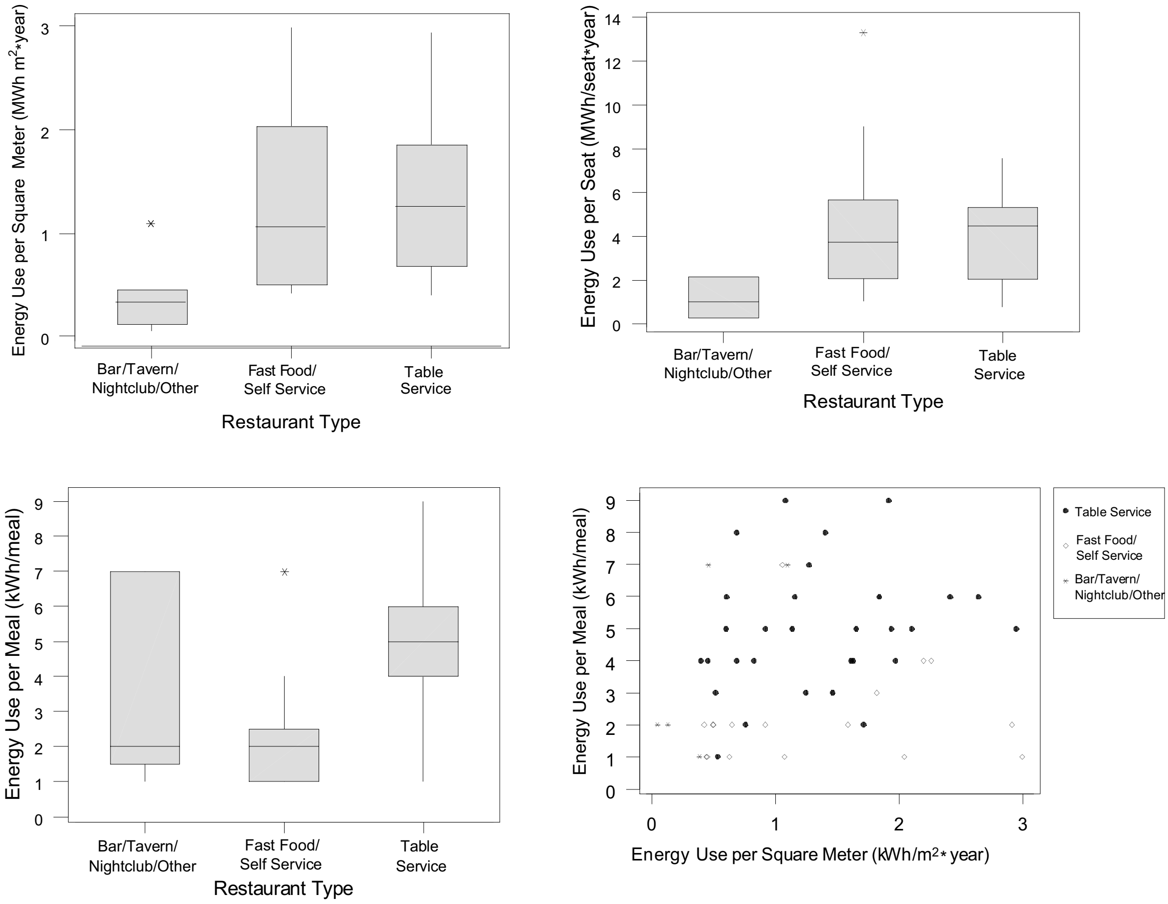

Figure 2. *Energy Use Metrics (Source: 1996 California Commercial End Use Survey).*

Table 4. Energy efficiency indicators in the three types of restaurants in California (Source: 1996 California Commercial End Use Survey. About 15% of energy is used for space heating/cooling, source: Pacific Gas and Electric Company, 1999).

Restaurant Type	N Obs	Variable	N	Minimum	25th Pctl	Median	75th Pctl	Maximum
Fast Food/Self Service	19	kWh/meal	17	0.74	1.43	1.88	2.43	7.14
		MWh/m^2	19	0.42	0.50	1.05	2.04	2.99
		MWh/seat	16	1.05	2.20	4.33	5.90	29.51
Table Service	30	kWh/meal	30	0.84	3.58	4.93	6.15	8.96
		MWh/m^2	30	0.39	0.69	1.26	1.84	2.95
		MWh/seat	30	0.76	2.06	4.49	5.22	7.57
Bar/Tavern/Nightclub/ Other	8	kWh/meal	5	0.86	2.19	2.22	7.22	7.37
		MWh/m^2	7	0.04	0.13	0.32	0.45	1.09
		MWh/seat	3	0.26	0.26	1.01	2.15	2.15

taurant operates and multiplying by the average meals per day reported in CEUS. The figures below show the distribution of energy use by restaurant type for each of three metrics: energy use per square meter, energy use per seat, and energy use per meal. The last graph shows energy use per square meter against energy use per meal.

Energy use per square foot is the most common metric used. Some additional information is given by Kinney and Piette (2002).

Japan

A questionnaire survey was carried out by The Energy Data and Modelling Center, The Institute of Energy Economics, Japan and Jyukankyo Research Institute with sponsorship of the Ministry of Economy, Trade and Industry, Japan in 2000 (The Energy Data and Modelling Center, 2001). The data are available for 40 restaurants classified into 6 categories, café, Japanese restaurant, Chinese restaurant, casual dining restaurant called "Family Restaurant" in Japan, fast food and others. The type of energy used is categorized into "space heating", "space cooling", "lighting, motor & others" and "other heating demand ". Freezing and refrigeration for food conservation are included in the "lighting, motor & others". It can be guessed that the large part of the "other heating demand" for restaurants is used in the kitchen for cooking, boiling and frying. Energy consumption per guest, seat and square meter for each category is shown in Figure 3 disaggregated into the main uses. Energy consumption per meal is calculated with the assumption on fraction of guests having a meal shown in Table 5.

Energy for space heating and space cooling is – with the exception of cafés – a small fraction (10 – 20%) of energy used in restaurants. Chinese Restaurants, which are very popular in Japan, have typical cuisine menus that need a large quantity of heat for cooking. Japanese restaurants - including sushi bars, noodle shops, pork cutlet shops and culinary art style restaurants – have a lower heating demand for cooking. Casual dining restaurants, serving a variety kind of cuisines from Japanese to Western food, have a heat demand between that of Chinese and Japanese restaurants. Fast food restaurants show similar characteristics as in the US and in Switzerland: relatively high demand per square meter and per seat, but low energy demand per guest. The relatively high demand per meal may be an artefact of the assumption of 0.4 meals per guest taken from Swiss data.

Energy for services other than meals is included. This leads to uncertainties and to an overestimation of energy per meal in cafés, where few meals are served. Interesting is the varying ratio of heat/others: 6 in Chinese restaurants, 2 in Japanese restaurants, but < 1 in casual dining restaurants and in fast food restaurants.

In Japan, energy per square meter is usually and conventionally used for restaurants as for other business categories in the commercial sector. The indicator is presently used just for information and rough benchmarking. Each indicator explaining appropriately each business type's activity should be created for standards or labelling.

TOTAL ENERGY (INCLUDING EMBODIED ENERGY) USE FOR DIFFERENT MEALS

This extended view of energy consumption is interesting mainly for consumer information.

Balmer and Hintermann (2000) performed a very detailed analysis of the energy use for the preparation of different dishes in a highly frequented middle-class restaurant. In addition to the direct energy use – measured for storage/cooling/washing energy, cooking energy – the indirect (grey or embodied) energy[3] was estimated by using data from Kram-

Table 5. Energy (space heating and cooling excluded) per meal in different types of restaurants in Japan (derived from energy per guest with the assumptions of meal per guest shown in this table).

Type of restaurant	number of entries	meal/guest assumption	lighting,motor & others kWh/meal	heat (other than space heat) kWh/meal	total energy (excluding HVAC) kWh/meal
Café	2	0.1	4.6	3.4	8.0
Japanese Rest	12	0.9	1.2	2.3	3.5
Chinese Rest	6	0.9	0.7	4.3	5.0
Casual Dining Rest	9	0.6	2.6	2.2	4.8
Fast Food	7	0.4	1.6	1.2	2.8
Oth ers	2	0.8	3.1	4 2	7.3

3. The indirect energy use embodies all energy used to produce (e.g. fertilizer, machines), to process and to transport (fuel energy) food until it comes to the restaurant.

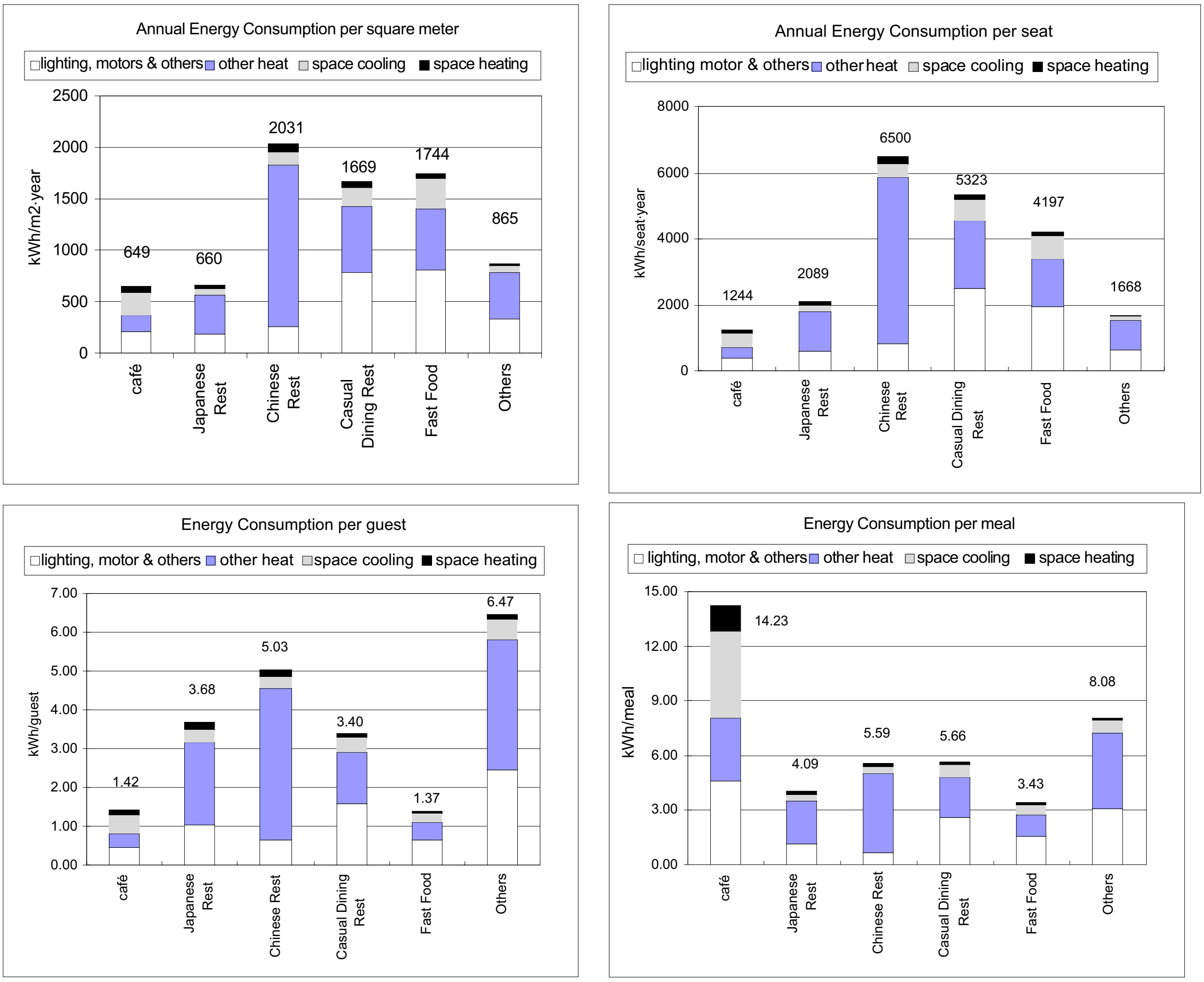

Figure 3. *Energy efficiency indicators in different types of restaurants in Japan (energy per meal is derived from energy per guest; see assumptions in Table 5. Source: The Energy Data and Modeling Center, 2001).*

er and Moll (1995). In order to calculate the cooking energy, the energy use of the different involved kitchen appliances was split up for each particular meal. Not specifically included are storage, cooling and washing in the restaurant, because the energy use of these processes evenly distributes to all meals (0.17 kWh per meal).

Energy demand varies strongly with the dish (Figure 4). Hot meals are in general more energy intensive than cold ones; however, some cold starters need more energy than some hot meals, because of a large amount of indirect energy. Vegetarian food does not use less direct energy than non-vegetarian food, but meat-products have a lot of embodied energy, especially when they were transported by aircraft (see lamb filet in Figure 4). An important factor for direct energy use is the way to cook pasta because this usually leads to a permanently boiling water pot in the kitchen.

An even broader analysis, looking not only at energy use, but at all kind of environmental aspects in the preparation of food can be found at www.gammarus.ch/gammarus-case-stockwerk.html#Oekobilanz_Stockwerk

SUMMARY OF CASE STUDY RESTAURANTS

In order to discuss possible energy efficiency indicators for restaurants we did a rough analysis of energy consumption data in four world regions. These data samples are of different size, different quality, grouped in different types of restaurants and most importantly the system boundary of the samples are not identical. They can therefore not be compared in a strict scientific manner. Some first conclusions are nevertheless possible:

- Similar variations in the ranking of different types of restaurants are observed in the data of all four regions when looking at the three indicators energy per seat, energy per guest and energy per meal.
- In all regions fast food restaurants have a lower energy demand per meal than other restaurants (Figure 5).
- Energy per meal in a fast food restaurant is in all regions of the same order of magnitude (2 kWh/meal).
- Energy per meal in other restaurants is – with the exception of France – in the mean about 2.5 times higher than in fast food restaurants. The high value of energy per meal in French restaurants may be due to the special data sample (all restaurants are attached to hotels); but some influence of the "French cuisine" cannot be excluded.

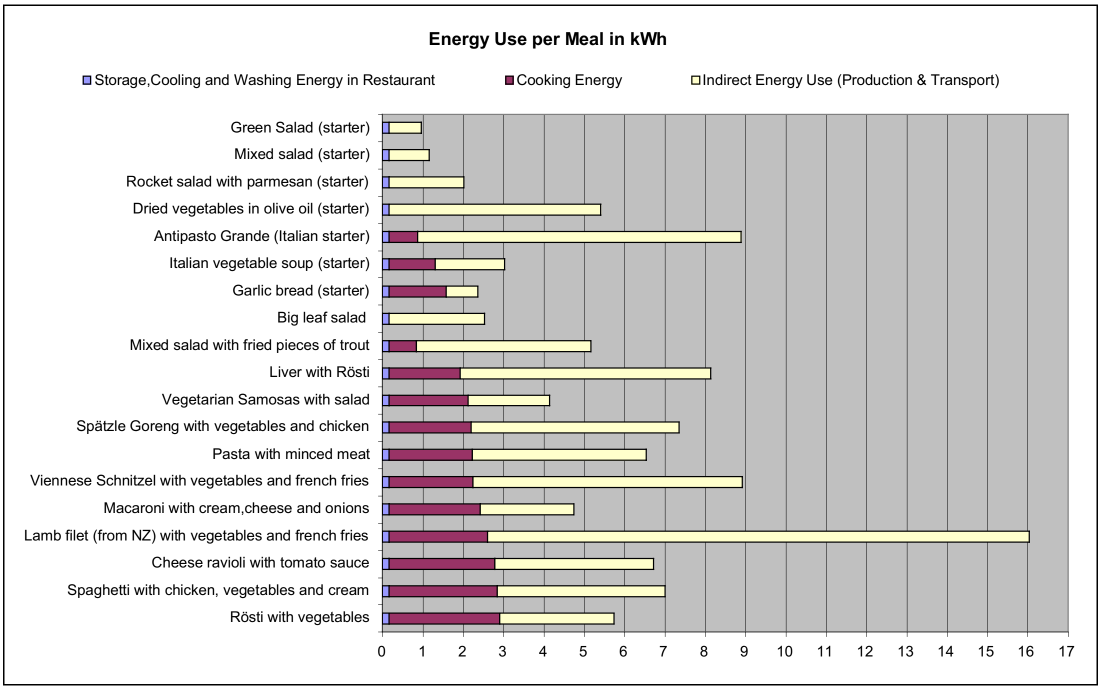

Figure 4. *Total energy use of different meals (Source: Balmer and Hintermann, 2000).*

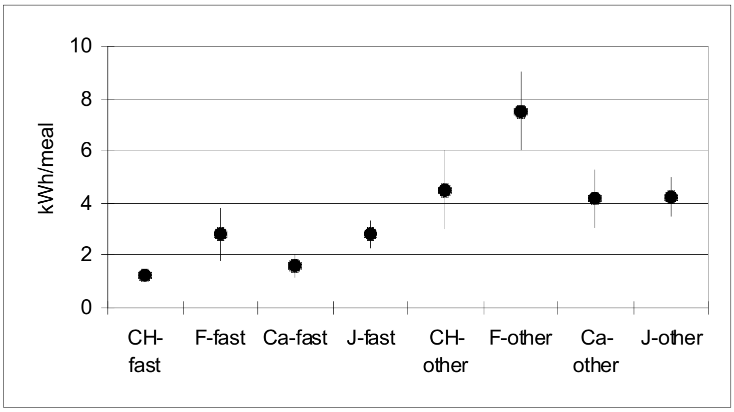

Figure 5. *Energy (space heating/cooling excluded) per meal in fast food (fast) and in other restaurants (other) in Switzerland (CH), France (F), California (Ca) and Japan (J) (The French restaurants in the 2** IBIS hotels are considered as fast food restaurants; the error bars show typical variations but are not (for all samples) statistically determined values).*

Energy per surface area is in all the regions the most commonly used measure of energy efficiency in restaurants. Some general information on alternative approaches can be found in Kinney and Piette (2002). The composite indicator energy per (floor area of the kitchen x cash-flow of the kitchen) used for consulting purposes by the utility in Zurich is unique.

Energy per meal is an interesting candidate to be used as a measure of energy efficiency because it refers to the primary service of a restaurant and at the same time it addresses the most energy intensive processes in a restaurant: the conservation of food, the preparation of the meal and the washing of the dishes. The practicability of this indicator for benchmarking purposes or in voluntary commitment processes has nevertheless first to be shown. Is it possible to define adequate categories of restaurants? Is there a good enough correction for guests that do not have a meal? Much more data and good analysis is needed to answer these questions.

Case study computer centres[4]

ENERGY DEMAND AND ENERGY USE

A computer centre is a building or part of a building (a hall or a room) accommodating servers and other ICT equipment. There are nowhere official surveys of energy consumption in computer rooms, because it does not correspond to a specific economic activity, but is rather an element of all other activities. In a recent study (Cremer et al., 2003) we did a compilation of estimates of energy consumption in different countries (Table 6). It is of the order of a few tenths of percent of total electricity consumption and is increasing fast.

In Switzerland, energy consumption of 10 computer centres was surveyed for several years (Jund, 1996). Unfortunately only two annual power-load measurements (one in summer and one in winter) were performed and most of the

4. This section is largely based on the study (Aebischer et al, 2003) with contributions by Bernard Aebischer, Rolf Frischknecht, ESU-services, Switzerland frischknecht@esu-services.ch; Christophe Genoud, Idheap, Switzerland C.E.Genoud@lse.ac.uk; Alois Huser, Encontrol, Switzerland alois.huser@encontrol.ch and Fédéric Varone.

Table 6. Electricity demand of data centres in fraction of total electricity demand of the country and in electricity per inhabitant (Source: Cremer et al. (2003)).

Country	Year	Fraction of total electricity demand, in %	Energy demand by capita, kWh/cap	Evaluation method	Source
CH	1988	2.2%	143	Equipment	Spreng/Aebischer 1993
CH	1999	0.8%	57	Equipment, computer-networks	Aebischer et al. 2002d
USA	2000	0.3%	58	Equipment	Roth et al. 2002
USA	2000	0.6%	123	Equipment, computer-networks, phone-network	Roth et al. 2002
USA	1998?	0.6%	100	Equipment	Kawamoto et al. 2000
USA	2000	0.1%	20	Floor area	Mitchell-Jackson 2001
USA	2000	0.1%	15	Floor area	Beck 2001
NL	2000	0.6%		Floor area	Hartkamp 2002

detailed information is confidential. Nevertheless, some interesting information, like the repartition of energy (Table 7) could be derived from the data (Aebischer et al. 2002). The analysis of a data centre in the US by Mitchell-Jackson (2001) shows that slightly more than 50% of the electricity purchased is used for chillers, computer room air conditioning units, auxiliary equipment and lights. The remaining part is fed into the computer rooms. Similar results were found in the analysis of eight data centres by LBNL (2003).

In the last couple of years ICT[5]-companies promoted facilities and services where servers, routers and the like are operated in so-called data centres or server hotels. One major feature of these facilities is their particularly high electric load from 200 to more than 1 000 W/m².

A study commissioned by the Authority of the Canton of Geneva (Aebischer et al., 2003) explores how to measure the energy efficiency of data centres and how to integrate it in a policy framework aimed at promoting energy efficiency as well in the phase of planning and construction as in the phase of operation of the energy-consuming facilities.

ENERGY EFFICIENCY INDICATORS

Ideally, energy efficiency of a data centre should be measured in terms of energy consumption per unit of service delivered to the customer. However, there exists no commonly agreed method to measure the service provided by a data centre. Even if a standardised method of measuring the service did exist, its value would vary so fast – due to technological progress – that it would not be possible to define any reference value necessary to evaluate efficiency of a data centre. Using the floor area as a reference for the energy consumption does not make much sense in a data centre. Indeed, the same electricity consuming equipment may either be dispersed over a large area – leading to a low value of electricity per unit of floor area – or densely packed together in fully-equipped racks resulting in a high value of energy per m², with no difference in the specific electricity consumption per unit of energy service. As an alternative measure of energy efficiency in data centres we propose to use the CEE concept described in the next section.

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Table 7. Electricity end use in % of total electricity demand of data/computer centres (Source: Cremer et al. (2003), LBNL (2003)).

	Aebischer 1992	Aebischer et al. 2002		Mitchell-Jackson 2001	LBNL 2003
		min.	max.		
ICT-equipment	42 %	43 %	63 %	49 %	52%
Losses in UPS	6 %	10 %	10 %	11 %	9.9
Losses in trans-foring el. current	4 %				
Cooling	17 %	30 %	20 %	14 %	19%
Ventilation	28 %	15 %	5 %	23 %	16%
Lighting	2 %	2 %	2 %	3 %	3%

The CEE concept

Some ten years ago, Swiss banking and insurance companies developed an indicator of energy efficiency for their computer centres. It is defined by the ratio of the electricity used by the computer system itself to the electricity consumption of the entire computer centre, i.e. computer system and infrastructure needed to operate the computer system. In addition to this coefficient we propose to further consider inefficiencies occurring in the ICT-equipment.

The Coefficient of Energy Efficiency (CEE) measures the efficiency of electricity consumption of a data centre. CEE expresses the ratio of the electricity consumed by processors, hard disks and the like (u, so-called "useful electricity consumption", see Figure 6) divided by the electricity purchased from the utility or produced on-site (T). But, it does not measure the energy efficiency of processing, storing and transmitting information depending on the hardware, but also the software used.

$CEE = u / T = C1 * C2$

With:

$C1 = U / T = U / (U + CO+VE+ME+UP+TR+LI+OT)$

and

$C2 = u / t = u / (u + co+ve+me+up+tr+ot)$

Abbreviations are explained in Aebischer et al. (2003).

C1 is a measure of the energy efficiency of the infrastructure's design and operation and is commonly used in the

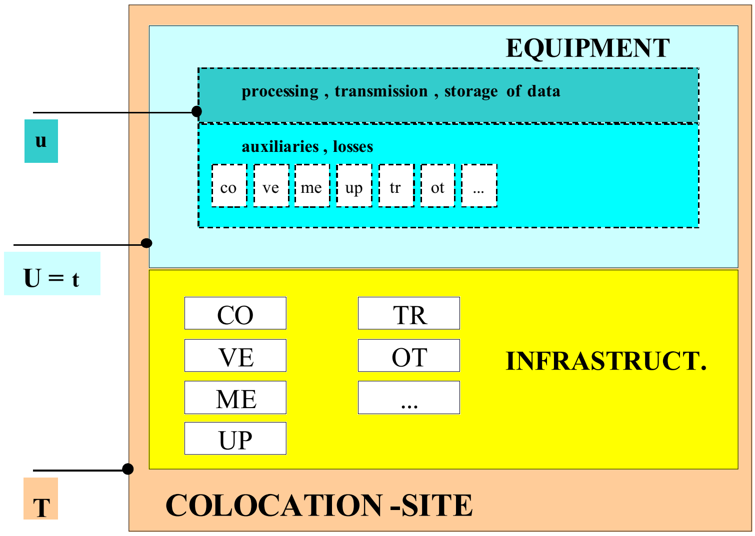

Figure 6. *Scheme of a collocation site and its electricity consuming parts. Source: Aebischer et al. (2003).*

planning process. The coefficient C2 is a measure of the losses on the level of the specific "production apparatus" itself and represents – in the case of data centres – a rather ambitious and innovative approach. The technical feasibility of the CEE-concept is explored by investigating whether the two components of CEE, i.e. C1 (measure of efficiency of the infrastructure) and C2 (measure of the efficiency of the equipment), can be determined and whether potentials and strategies to reduce the losses can be identified.

A measuring concept to determine C1 is proposed in Aebischer et al. (2003). In most of the existing data centres it can be implemented with little (new computer centres) or reasonable (existing computer centres) investments, but in some centres, e.g. smaller computer rooms that share some infrastructure (e.g. production of cold) with other users, substantial investments would be needed.

To be useful in a policy process, an indicator must give indications of potential improvements. By choosing smart technical solutions the electricity consumption of a typical central infrastructure may be substantially reduced. In a non-optimised data centre C1 is of the order of 50% to 60%, to be compared to the efficiency of 75% in the optimised data centre (in Table 8, C1 = ICT equipment / Total).

The Coefficient of Energy Efficiency (CEE) on the level of the ICT equipment (C2) expresses the ratio of the electricity consumed by processors, hard disks and the like (u, so-called "useful electricity") divided by the total electricity consumption of all the servers, routers, switches, disks and other electronic equipment (t):

$$C2 = u / t = u / (u + co+ve+me+up+tr+ot)$$

The useful electricity u cannot be measured directly. We derive u by the difference between t, the total electricity entering the equipment rooms, and the most important energy losses occurring at the following stages:

- transformation and correction of electrical power (tr) leading to typical losses of 50% (Aebischer and Huser, 2002),
- ventilation, evacuation of heat by air (ve), with losses of the order of 10% of total consumption in a standalone server and of 25% in a rack-optimised server (Aebischer et al., 2003),
- uninterruptible power supply (up), with typically 10% losses (Aebischer et al., 2003).

The energy consumption of power supplies, ventilators and UPS may then add up to more than 60% of the total electricity entering the equipment rooms, resulting in a value of C2

Table 8. Characteristics of infrastructure and relative electricity consumption of the main end uses for an optimised, a conventional and an inefficient layout and operation of the infrastructure in data centres in Geneva (Source: Aebischer et al. (2003)) (Weather conditions in Geneva: a few days below 0° Celsius in Winter and a few days with over 30° Celsius during day-time and over 20° during night-time in summer.

	optimised infrastructure [3])	conventional infrastructure [3])	inefficient infrastructure [3])	(Mitchell-Jackson 2001)
shares based on:	kWh/a	kWh/a	kWh/a	kW
free-cooling	yes	yes	no	unknown
computer room temperature	26°C	22°C	22°C	unknown
cold-water temperature	13/19°C	11/17°C	6/12°C	unknown
COP chillers	4	2.5	2.5	unknown
supply air temperature	14°C	12°C	12°C	unknown
pressure loss in CRAC	350Pa	500Pa	900Pa	unknown
fan efficiency	65%	60%	55%	unknown
ICT equipment	74.20%	62.20%	50.30%	48.50%
HVAC	14.80%	21.80%	27.70%	36.9% [1])
Light	2.00%	3.00%	4.00%	3.40%
Power distribution unit	200%	4.00%	5.00%	[2])
UPS	5.00%	7.00%	10.00%	[2])
Others	2.00%	2.00%	3.00%	11.20%
Total	100.00%	100.00%	100.00%	100.00%

[1]) 13.6% for central chiller plant, 23.3% for fans, CRAC (computer room air conditioning) units, AHUs (air handling units).
[2]) Included in "Others".
[3]) Simulation by Altenburger (2001)

of 40%, which is lower than the 50-60% of C1 in a data centre without an optimised infrastructure. Unfortunately these energy losses cannot be measured easily and therefore C2 cannot be used in a quantitative way in a policy process. For ICT equipment other indicators of energy efficiency have to be defined.

Indicators measuring the energy efficiency of the central infrastructure of computer centres are used or were used in the past by some companies or groups of companies (Jund, 1996), but as far as we know nowhere in a policy process led by a public authority. On demand of the Canton of Geneva we investigated the feasibility to use such an indicator (C1) in the construction authorisation process of new data centres and for defining targets in a voluntary commitment process applicable for new and existing data centres. A concept how to measure C1 was developed and the following target values were recommended: C1 ≥0.65 to be reached by a new data centre in the construction-permission procedure and in the follow-up monitoring process, and C1 ≥0.55 for existing data centres (Aebischer et al., 2003).

Conclusions

Energy use in the service sector is an extremely complex subject due to the many different activities and services and due to the multitude of energy consuming equipment and processes. Knowledge of technical characteristics is one side of the story but the real challenge lies in the understanding of how – and why that way – the equipment is used. A trial to develop – in analogy to modelling approaches in the household sector – a bottom-up model describing the energy use in the service sector failed mainly because of missing data and understanding on how the energy consuming equipment is used (Aebischer and Spreng, 1994). Instead of such a detailed bottom-up approach, most of the models in use today are of the building model type used successfully in the heating sector. The complexity of energy use in the service sector is – at least partly – caught by introducing a multitude of building types and structural changes at different levels of the economic activities. The almost universal use of energy per unit of area as indicator for energy efficiency in the service sector is a direct consequence.

Innovative energy policy designs need better indicators of energy efficiency. In the case study on computer centres we report on an indicator proposed to be used in the construction permission process and in the voluntary target-setting programme of the Canton of Geneva. Similarly promising indicators are needed for many other sectors and in the second case study we therefore explore some alternative approaches for restaurants. Not surprisingly, we did not find the solution, but some first interesting conclusions can be drawn.

The difficulties in fully understanding the indicator energy per meal and other indicators for energy efficiency in restaurants and the sketchy discussion about energy efficiency of ICT-equipment (detailed discussion in Aebischer et al., 2003) suggest that a pragmatic solution like the one of using C1 as efficiency indicator for computer centres is the most promising way to get a tool that can realistically be hoped to be used in near future in a policy process of target setting and monitoring. A pragmatic approach is especially recommended when considering all the other service sector activities that have to be included in such a process, if any tangible result, i.e. significant energy savings in the service sector, should come out soon.

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