# Energy Efficiency Indicator for High Electric-Load Buildings. The Case of Data Centres. **(Preprint)**

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## Keywords

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## Abstract

Energy per unit of floor area is not an adequate indictor for energy efficiency in high electric-load buildings. For data centres we propose to use a two-stage coefficient of energy efficiency CEE = C1 * c2, where C1 is a measure of the efficiency of the central infrastructure and c2 a measure of the energy efficiency of the equipment. The appropriateness of the CEE-concept is analysed by discussing three

aspects: can C1 and c2 be measured, is it possible to determine potentials of energy efficiency improvements, can CEE be integrated in the framework of a legislation and policy programme favouring energy efficiency.

## 1. Introduction and problem setting

A commonly used measure of the energy efficiency 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 is 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, 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 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. One may therefore use another indicator, e.g. 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 considers it in a separate approach.

In the last couple of years ICT [1]-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 1000W/m2. The Authority of the Canton of Geneva faced several applications of construction-permits for data centres, with the potential to increase considerably the electricity consumption of the Canton of Geneva and therefore compromising the energy-policy of the Government aiming to reduce electricity consumption in the Canton. In a study commissioned by the Authority of the Canton of Geneva the authors of this paper explore how to measure the energy efficiency of data centres and how to integrate it in a policy-framework aiming at promoting energy efficiency of all large energy consumers as well in the phase of planning and construction as in the phase of operation of the energy consuming facilities.

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 would 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.

## 2. 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) as proposed to the Canton of Geneva 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 1) divided by the electricity purchased from the utility or produced on-site (T).

[1] Information and Communication Technology

CEE = u / T = C1 * c2

with

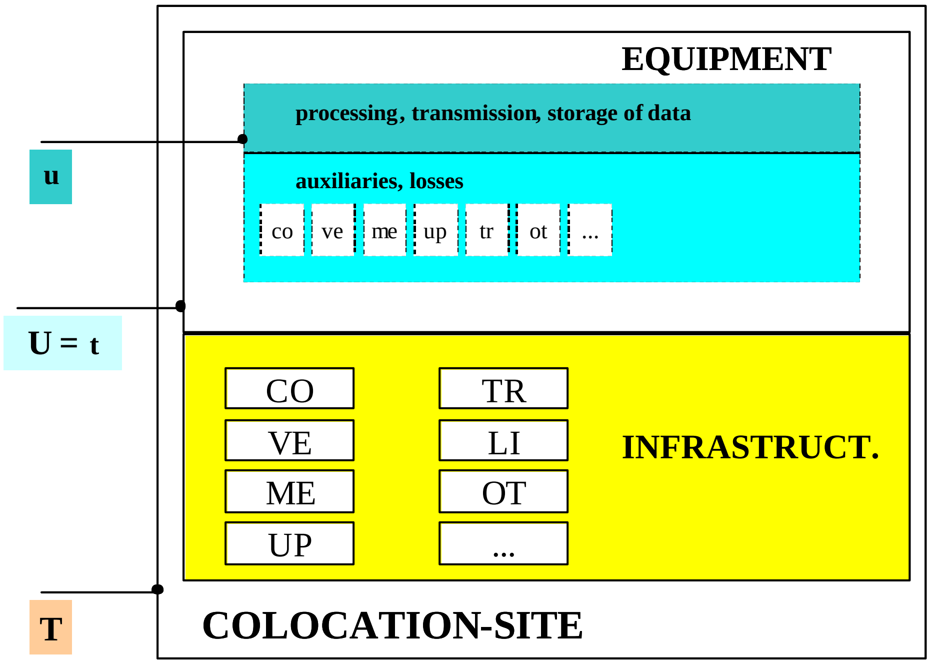
C1 = U / T = U / (U + CO+VE+ME+UP+TR+LI+OT)

and

c2 = u / t = u / (u + co+ve+me+up+tr+ot)

Abbreviations can be found in Appendix 1.

**Figure 1. Schema of a collocation site and its electricity consuming parts.** (See appendix for explanation of the abbreviations.)




C1 is a measure of the energy efficiency of the infrastructure's design and operation and is commonly used in the 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 feasibility of CEE is investigated in section 3 from the technical point of view of the data centres. The policy considerations in section 4 are valid not just for data centres, but also for other groups of important energy consumers.

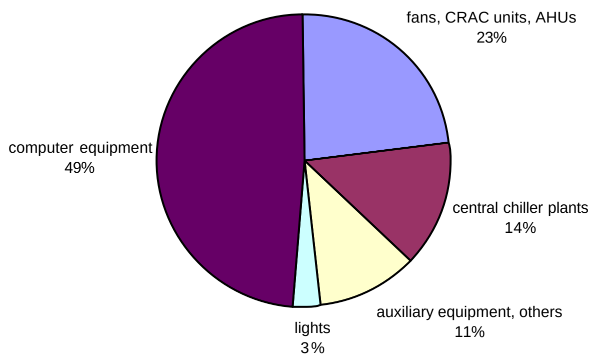
## 3. Energy efficiency in data centres

The technical feasibility of the CEE-concept in the case of data centres 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.

### 3.1. Energy efficiency of the infrastructure (C1)

The analysis by Mitchell-Jackson (2001) of the power loads in a data centre 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 (Figure 2).

**Figure 2. Breakdown of computer room power by end use (Mitchell-Jackson 2001).**




A coefficient similar to C1 is used in more than 10 computer centres in Switzerland (Jund, 1996). Unfortunately only two annual power-load measurements (one in summer and one in winter) are performed and most of the detailed information is confidential. Nevertheless, some interesting information can be derived from the data:

- Between 45 and 65% of total electricity is used by the computer equipment itself.
- Cold production is the dominant consumer of the infrastructure with a share of 20 to 30% of total electricity purchased (T).
- Electricity consumption for ventilation is highly variable with a share between less than 5 and more than 15% of total electricity purchased.
- Electricity transformation and UPS systems require about 10% of the total electricity purchased.
- Lighting and miscellaneous contribute with only a few percents.

A concept to measure the energy consumption of the different components of the infrastructure in a data centre is proposed in Appendix 2. In most of the existing data centres this concept can be realized with reasonable investments, but in some data centres, e.g. smaller data centres which share some infrastructure (e.g. production of cold) with other users, substantial investments would be needed.

By choosing smart technical solutions the electricity consumption of the infrastructure may be substantially reduced (Appendix 3). The two most important measures to reduce power loads and electricity consumption of the infra structure are

- free-cooling, and
- cold-water circuit temperature.

Operating the HVAC system with maximum free-cooling capacity, elevated room air temperature (26°C instead of 20°C) and the cold water circuit at elevated temperatures (13/19°C instead of 6/12°C) allows for a reduction in electricity consumption of the HVAC-system in the order of 50%. The share in electricity consumption for computers in optimised data centres may reach more than 70% whereas it is less than 50% in centres that are equipped with an inadequate (oversized) or inefficient infrastructure (Table 1).

**Table 1. Infrastructure electricity consumption in relation to the total yearly electricity consumption for an optimised, a conventional and an inefficient layout and operation of the infrastructure in data centres.**

| | 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 | 4.0 | 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 |
| Computers | 74.2% | 62.2% | 50.3% | 48.5% |
| HVAC | 14.8% | 21.8% | 27.7% | 36.9% [1]) |
| Light | 2.0% | 3.0% | 4.0% | 3.4% |
| Power distribution unit | 2.0% | 4.0% | 5.0% | [2]) |
| UPS | 5.0% | 7.0% | 10.0% | [2]) |
| Others | 2.0% | 2.0% | 3.0% | 11.2% |
| Total | 100.0% | 100.0% | 100.0% | 100.0% |

[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)

In terms of C1, defined as the ratio of electricity consumption by the computers to total electricity consumption, the energy efficiency of the infrastructure is then of the order of 50% to 60% in a non-optimised data centre -- to be compared with the efficiency of 75% in the optimised data centre.

## 3.2. Energy efficiency of the ICT-equipment (c2)

The Coefficient of Energy Efficiency (CEE) on the level of ITC-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 therefore try to determine the different losses and derive u by the difference between t, the total electricity entering the equipment rooms, and these losses.

A decomposition by type of equipment is given by Mitchell-Jackson (2001): 60 % server, 18 % switches, 9 % disks, 8 % routers. In all these equipment the most important energy losses are occurring at the following stages:

- electricity used for transformation and correction of electrical power (tr)
- electricity used for ventilation, evacuation of heat by air (ve)
- electricity used for uninterruptible power supply (up), if the uninterruptible power is not organized centrally.

Power supplies for widely used equipment are usually produced in few standard sizes, e.g. 200 W, 250 W and 300 W for personal computers and low-end servers units or 600 W for larger routers and switches. In the configuration process of the equipment these power supplies are selected for the maximum number of extension boards in the supplied device. The result is that power supply units are normally largely oversized. Own measurements of servers, routers and switches show that the workload (ratio of effective load to nominal or rated load) lies typically between 50% and 30%. If power supplies are used in a redundant configuration in order to increase security, the workload is even lower. More information about the typical workload of the equipment is important, because the efficiency of power supplies is strongly dependent on this workload. Preliminary results (Marti et al., 2002) of measurements of power supplies up to 1 kW show that the efficiency between 50% and 30% workload is of the order of 50% - 60%, but below the efficiency may decrease very fast.

The heat loads occurring mainly at the level of the power supply and the processors (typically 33 Watts per square centimetre for a Pentium-processor) must be evacuated. The small fans on processors or in power supplies have an electrical power consumption in the range of 1.5 to 4 W (own measurements and measurements by Windeck and Gieselmann (2001). Measurements on several servers show that the electrical consumption of the ventilation is of the order of 10 % of total consumption in a standalone server and of 25 % in a rack-optimised server. The higher proportion in the rack-optimised server is due to the flat and compact construction which leaves only small air ducts for the evacuation of the heat.

The efficiency of USP-system depends mainly on the type and size of the system, the operating mode (bypass, USP-operation) and the load. In a typical system in the small capacity range of few hundred VA the efficiency of a UPS -system with 50 % load is around 85 - 90 % (in double transformation operation) or 90 - 95 % (in bypass operation).

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 of 40%, which is lower than the 50-60% of C1 in a data centre with not optimised infrastructure.

Remains the question, how to measure c2. In a typical data centre the number of equipment is of the order of several thousands. It is therefore not conceivable to measure the losses in all these equipment individually. But it seems not impossible to define a limited number of classes of equipment characterised by the type of power supplies they use and by some geometrical criteria – responsible for the fraction of electricity used to evacuate the heat -, where most of the equipment would fit in. In order to determine the losses in the power supplies we need to know the efficiency curves (efficiency in function of workload) of the different classes of power supplies and the distribution of the workload of the equipment. Efficiency curves can be measured relatively easily (Marti et al., 2002). In order to determine the distribution of the workload the following information is needed:

- nominal or rated load of all the equipment in the data centre (some of the operators of data centres do not exclude the establishment of such a data bank in their centre);
- measurement of the actual load by class of equipment, by rack or by group of racks;
- typical distribution of the ratio actual load to rated load for different classes of equipment.

The first two points define the mean value of the ratio actual load to rated load for groups of equipment. The third information is important, because of the non-linearity of the efficiency curves.

An efficiency of 40% suggests that important improvements are possible. Indeed, by running the power supplies at a reasonable load, important losses may be avoided. But much higher efficiencies could be reached by central AC/DC conversion and DC power distribution – an approach still in use in the telecommunication business and de facto the situation in a more centralized data processing environment, where many small equipment are replaced by a large server or a mainframe computer[2]. The recently introduced blade servers (servers which have the dimension of an ordinary electronic board) go in that direction: one power supply for 6 to 12 servers. Important improvements in evacuating the heat are possible by better design of the equipment, by optimising the configuration of the racks and of course by evacuating the heat by means of a water circuit. But like in the case of the power supplies, the scope of the individual user is rather limited. The same is true for operators of data centres unless he considers radical changes in the business-model, e.g. by transforming a collocation data centre in a managed data centre (see Appendix 4) with the possibility to concentrate data processing in larger units.

## 4. Policies to favour energy-efficiency in data centres and other important energy consumers

Presupposed that it is technically feasible to measure CEE (C1 and c2 or only C1) and to define values for C1 and/or c2 that can be reached by technical and entrepreneurial measures, alternative policy designs for the inclusion of the CEE-concept in the energy-efficiency programme of the canton of Geneva are presented and compared. In contrast to the technical discussion in section 3, the argumentation considers all kind of large energy consumers, e.g. high electric-load buildings, and not just data centres.

### 4.1. Policy scenarios

Three scenarios (S2-S4) are proposed which are based on target values or mandatory values (standards) for C1 and/or c2. These values are used in the process to get the construction and operation permission and in

[2] see Appendix 4: Typology of data centres

the later phase of monitoring the energy consumption. A first scenario (S1) describes the legal procedure effective today.

- The scenario "procedural permission (S1)" is a description of the approach defined in a recent revision of the legislation in the Canton of Geneva. It postulates the involvement of the promoter of a new building in a four stage permission-procedure (preliminary authorization, final authorization and operation permissin), which includes the elaboration of an energy concept.
- The scenario "voluntary agreement on target values (S2)" basically envisages an energy self-regulation. Both decision and control are de facto delegated to data centres or to other large consumers. It is inspired from the two approaches "Energiemodell Zürich" und "Energiemodell Schweiz" summarised in (Aebischer et al., 2002).
- The scenario "formal authorization based on mandatory values (S3)" corresponds to a rather traditional understanding of authorization procedures, such as building permits. It proposes to make energy decisions according to the procedures already in place for construction regulation. In other words, formal authorization increases the public sector's power while it is only sporadically wielded by it or is delegated to private actors (for example the data centres themselves, indirect control by environmental NGOs).
- The scenario "integrated control (S4)" goes a step further in the direction of strict legal and administrative monitoring of the conditions for authorization. It increases the role of the state, since it implies rigorous state control and sanctions to ensure that conditionally authorized installations and equipment then actually conform to set standards. Here, private economic and/or environmental actors no longer play a role.

**Table2. Scenario overview (including scenario 1, the current reform) grouped by activities and responsibilities of different actors**

| **Scenarios grouped by stages of procedure** | **Prior consultation** | **Formal decision** | **Possible appeals** | **Monitoring** | **Sanctions / regulatory instruments** |
|---|---|---|---|---|---|
| **Procedure for energy concept (S1)** | - Four-step procedure for the energy concept | - Authorization granted by ScanE[3] if the procedure is followed | - Right to appeal based on current legislation | - Checked 36 months after request for operating permit | - Procedure to attain compliance |
| **Voluntary agreement on target values (S2)** | - Participation of NGOs, SIG[4] and experts in establishing energy indexes and target values | - Authorization granted/refused by ScanE<br><br>- *Target values* negotiated between the ScanE and an individual data centre, a group of data centres or a group of large consumers | - Right to appeal based on current legislation<br><br>- Right to appeal based on the negotiated agreement | - Periodic *voluntary* statement given by data centres on the development of their energy indexes and the degree of success in reaching the target values<br>- *Optional* establishment of a database | - Procedure to attain compliance<br>- Fines |
| **Authorization based on mandatory** | - Participation of data centres, | - Authorization granted/refused by ScanE | - Right to appeal based on current | - Periodic *compulsory* statement given | - Procedure to attain compliance<br>- Fines |

[3] ScanE (Service cantonal de l'énergie) is the energy office of the canton of Geneva
[4] SIG (Services industriels de Genève) is the utility of the canton of Geneva

| | | | | | |
|---|---|---|---|---|---|
| **values (S3)** | NGOs, SIG and experts in establishing energy indexes and threshold values<br>- Mandatory value set in the regulatory framework | based on a predefined index *(threshold value)* | legislation | by data centres on the development of their energy indexes and the adherence to threshold values<br>- *Optional* establishment of a database | |
| **Integrated control (S4)** | - Participa-tion of data centres, NGOs and experts in establishing energy indexes and threshold values<br>- Mandatory value set in the regulatory framework | - Authorization granted/refused by ScanE/DIAEE[5] based on a predefined index *(threshold value)* | - Right to appeal based on current legislation | - Checks *(on the ground*, in the data centres) by ScanE on the development of energy indexes and the adherence to threshold values<br>- *Compulsory* establishment of a database | - Procedure to attain compliance<br>- Fines |

The CEE index can be used in all the scenarios as an indicator of the target value and/or as a monitoring index.[6] Its status and its usefulness, however, vary from case to case. In the second scenario, its final value can be negotiated before it becomes a target value. In scenarios 3 and 4, its value is measured for each case and is then compared to the target value set in the regulations. It becomes a criterion for granting authorization, and afterwards, monitoring the CEE index allows measurement of how well the fixed objectives are attained.

The described scenarios in their present state do not contain any instruments for economic incentives (e.g. incentive tax or subside, a system of financial reward and punishment according to the energy efficiency of the data centres, electricity tax). It is however perfectly possible to include such instruments and to combine them with the authorization procedure which lies at the heart of the proposed scenarios. Two (complementary) categories of incentive instruments are discussed in (Aebischer et al., 2002).

## 4.2. Criteria for Evaluating Scenarios

While we do not propose to present an exhaustive analysis of all the implications raised by the scenarios, we do evaluate them with the help of some criteria, among them the following:

- Appropriateness of energy and economic objectives (overall relevance of the procedure)
- Contribution to realizing objectives of cantonal energy policy (effectiveness of the procedure from an energy perspective)
- Simplicity and administrative costs of implementation (efficiency of the procedure)
- Implications for the regulatory framework (altering laws, setting rules for procedures and target values, etc.)

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[5] DIAEE (Département de l'intérieure, de l'agrigulture et de l'environnement) is the department in charge of energy and environment

[6] Nevertheless, different definitions of the CEE index – limiting it to C1 or expanding it to include C2 – can change the scenarios. We have defined the CEE index here as containing both components.

- Equal treatment of data centres and other large consumers (equity of the procedure)
- Possibility for affected private actors to participate, for example by prior consultation or appeal (openness of the procedure)

Limiting the CEE index to C1, or extending it to include c2, affects which scenario is the best choice. For example, the complete index (C1+c2) would likely reduce the flexibility of the involved actors, raise the administrative costs of monitoring and of managing the authorization cases, and affect the types of regulatory instruments that could be used.

**Table 3. Scenarios grouped by main criteria for evaluation**

| **Criteria for evaluation** | **Procedure for energy concept (S1)** | **Voluntary agreement on target values (S2)** | **Authorization based on manda-tory values (S3)** | **Integrated control(S4)** |
|---|---|---|---|---|
| 1. Energy efficiency | - | + | ++ | ++ |
| 2. Simplicity and reproducibility of the procedure | -- | - | + | - |
| 3. Equal treatment of large consumers | - | + | ++ | ++ |
| 4. Acceptability to large consumers | ++ | + | - | - |
| 5. Overall relevance | - | + | + | - |

Explanation: ++ criterion fully met, + criterion met, - criterion not met, - - criterion not met at all

This comparative (albeit not all-encompassing) table shows that the scenario of the type S3 presents the best solution, mainly for the following reasons: Setting threshold values, first of all, makes implementation, monitoring, and the authorization process more efficient, predictable and easier to evaluate. It reduces the risk of unfair treatment that might result from a process focused purely on procedure. While this scenario does require important administrative resources for monitoring, overall it engenders less regulation than scenario S4. Furthermore, threshold values reduce the administrative costs of a procedure based on presenting and evaluating concepts without stable, formal norms. In the absence of thresholds, target values could be set or negotiated with the involved actors. It is nevertheless clear that such a solution could not entirely replace a type S3-scenario in terms of energy efficiency

## 5. Conclusions

The CEE-concept is a useful approach for analysing the energy consumption in a data centre and identifying ways towards a more rational use of energy. Between 40% and 50% of the total electricity consumption is used by the central infrastructure and more than 50% of the remaining electricity entering the equipment rooms is used in the power supplies and by ventilators. Thus only between 30% and 20% of the electricity purchased or produced onsite is used to power the electronic components and mechanical drives of the ICT-equipment. This is in good agreement with the measurement of the electric power flow in a large computer centre (Spreng and Aebischer, 1990).

In the absence of any suitable measure of the service delivered by a data centre the coefficient CEE is also an appropriate measure of the energy efficiency of a data centre. The efficiency of the central infrastructure (C1) can be measured and – even if a measurement of the losses occurring at the equipment level is not granted – at least a reasonable estimation of the c2 seems possible. Technical measures to improve the efficiency of the central infrastructure are known and target values for C1 can be proposed. A detailed monitoring and analysis of the energy efficiency of the central infrastructure in several data centres is needed before the predefinition of mandatory values (standards) can be envisaged. Alternative approaches should be considered in order to improve energy efficiency on the equipment level: declaration and labelling of power supplies, use of an automatic power management of servers – similar to PCs, incentives to favour the use of more efficient servers.

From the policy point of view, CEE can be widely used in several scenarios provided that target values or mandatory values can be defined – at least for one of the components of CEE. On the other hand the policy analysis can not answer the question whether CEE or an other definition of energy efficiency is the best indictor to be used for a specific group of important energy consumers. A technical analysis of each of the specific groups has first to be performed.

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## Appendix 1: Abbreviations used in the definition of CEE

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.

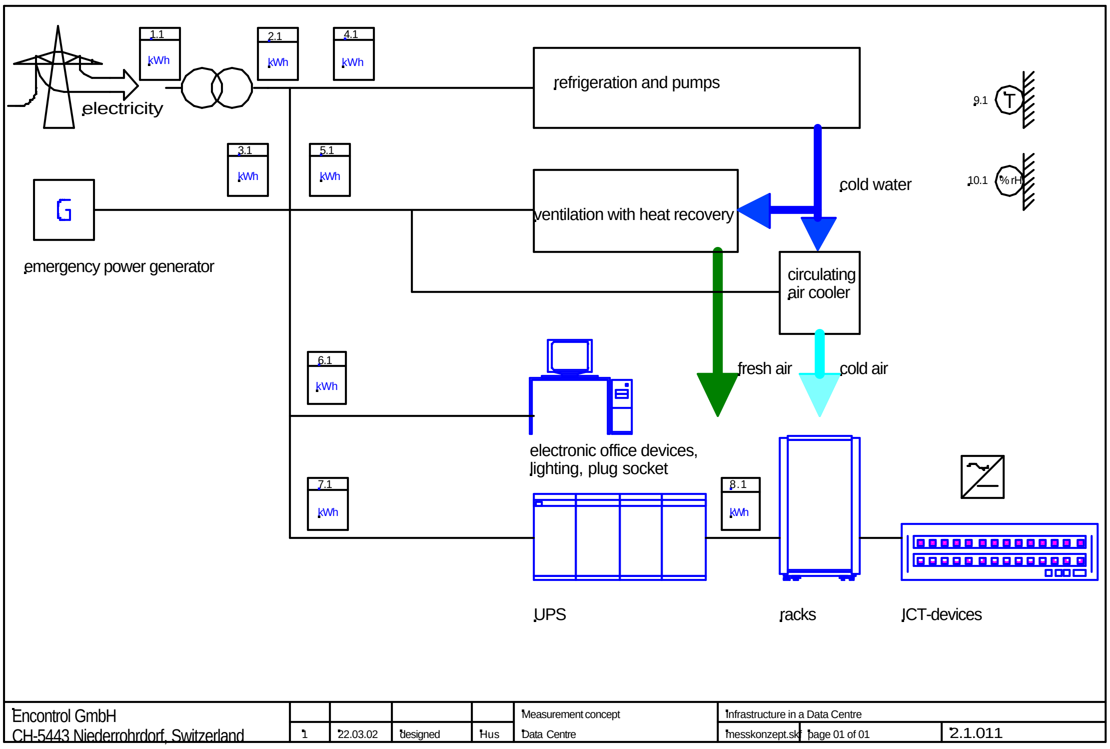
| | |
|---|---|
| U = t | total el. power load / consumption of equipment |
| CO | electricity used for production of cold, refrigeration |
| VE | electricity used for ventilation, evacuation of heat by air |
| ME | electricity used for other mechanical work, e.g. pumps |
| UP | electricity used for uninterruptible power supply |
| TR | electricity used for transformation and correction of electr. power |
| LI | electricity used for lighting |
| OT | electricity used for others (miscellaneous consumers and losses) |

Depending on the measurement concept and due to its inferior relevance "lighting" (LI) is often including in "others" (OT).

| | |
|---|---|
| u | “useful” el. power load / consumption of equipment |
| co | electricity used for production of cold, refrigeration not included in C1 |
| ve | electricity used for ventilation, evacuation of heat by air not included in C1 |
| me | electricity used for other mechanical work, e.g. pumps not included in C1 |
| up | electricity used for uninterruptible power supply not included in C1 |
| tr | electricity used for transformation and correction of electr. power not included in C1 |
| ot | electricity used for others not included in C1 |

## Appendix 2: Schematic view of the measurement concept for data centres

**Figure A2. Measurement concept to determine the components of C1 in a data centre (developed by A. Huser, encontrol GmbH)**




## Appendix 3: Design parameters influencing C1

### A3.1. Cooling equipment

A substantial part of the electricity consumption is required for cooling. The consumption can mainly be influenced by

- the temperature level of the cold water circuit and the cooling water,
- free cooling possibilities (which itself depends again on the temperature level of the cold water circuit),

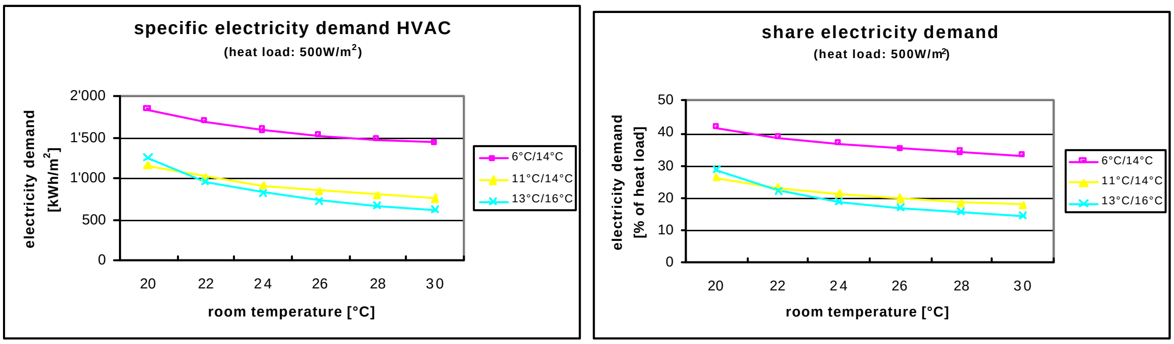
- the air temperature level in computer rooms, and
- modularity of the infrastructure.

However, the exact saving effect is hard to determine in general terms because of highly variable surrounding conditions under which data centres are operated. Nevertheless, we give a try based on the extensive experience of (Amstein + Walthert 2001) in planning and building data centres. The following sections are based on personal information provided by Mr. Adrian Altenburger, Amstein+Walthert (Altenburger 2001). He computed the electricity consumption of HVAC equipment for various operation modes of a model data centre with variable heat load.

### *Influence of cold water and computer room air temperature*

At a given computer room air temperature of 26°C a change in temperature in the cold-water inlet temperature from 6°C to 11 and 13°C, respectively, reduces the electricity demand by about 44% and more than 50%, respectively (Figure A2). This is mainly due to a better energy efficiency of the chillers (COP 4 and 3.5 instead of 2.5). However, at lower computer room air temperatures (below 22°C) these efficiency gains are over compensated by the larger increase in ventilation electricity consumption (much more air is required to cool the equipment due to the smaller temperature difference).

**Figure A2. Specific electricity demand (kWh per m$^2$ and year and percentage of heat load) for cooling and ventilation depending on the computer room air temperature and the cold-water inlet and cooling air temperature (Altenburger 2001).**




The shares of electricity required for HVAC relative to the computer electricity consumption is more or less independent of the heat load (between heat loads currently observed in Swiss data centres of 250 and 1000W/m$^2$)

### *Influence of air velocity and fan efficiency*

The energy consumption of ventilation (moving the cold air from the air conditioning units to the racks) is highly dependent on the air velocity. Optimised systems are running at low velocities of about 1.5m/s, whereas velocities of 3m/s and more [7] cause a substantial increase in electricity demand. Besides the reduction in energy consumption, low velocities lead to a better distribution of the cold air and with that reduces the risk of hot spots[8].

Fan efficiencies vary between 55 and 65%. (Figure A3) shows the variation in electricity demand for cooling and ventilation (heat load 500W/m2) using optimised and inefficient circulating air coolers. At low computer room air temperatures (<22°C) the electricity demand for cooling and ventilation differs by a factor of 1.7 between an optimised and an inefficient layout. At 26°C the inefficient layout still requires 45% more electricity as compared to the optimised solution.

**Figure A3. Specific electricity demand (kWh per m$^2$) for cooling and ventilation depending on the computer room air temperature, air flow velocity and fan efficiency (Altenburger 2001).**
**Left: Airflow velocity: 1.5m/s, fan efficiency: 65%;**
**Right: Airflow velocity: 3m/s, fan efficiency: 55%.**

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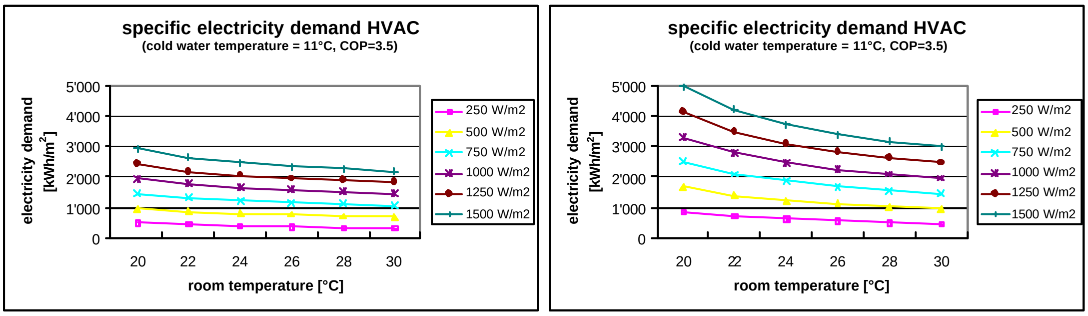
[7] Current systems are running with even higher velocities of 5m/s and more

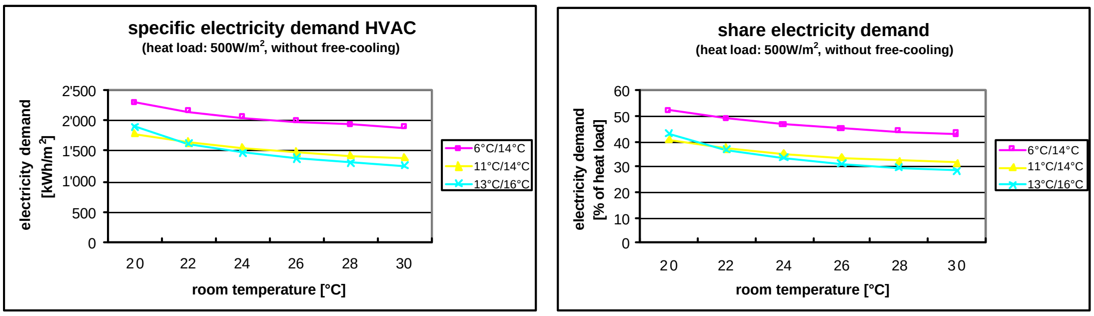
[8] Private communication by A. Altenburger, Amstein + Walthert, Zürich, 28.11.01




*Influence of free cooling and cold water pumping*

While data shown above are valid for a case where free-cooling is used as much as possible, we now turn to the situation where free-cooling is completely disregarded (Figure A4).

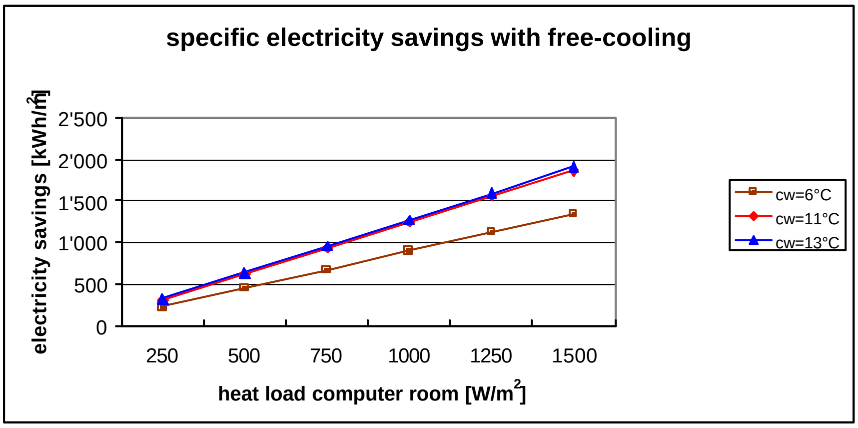
**Figure A4. Specific electricity demand (kWh per m2 and year and percentage of heat load) for cooling and ventilation without free-cooling depending on the c omputer room air temperature and the cold water and cooling air temperature (Altenburger 2001).**




We recognise that the electricity demand increases by between 24% and 30% (6°C cold water inlet temperature, 14°C cooling supply air temperature), between 53% and 72% (11°C cold water inlet temperature, 14°C cooling supply air temperature) and between 50% and 86% (13°C cold water inlet temperature, 16°C cooling supply air temperature) for computer room air temperatures between 20°C and 26°C. The share of HVAC electricity consumption related to the electricity consumption of the computers rises about 10 to 15%-points.

The electricity savings due to free-cooling increase with increasing temperature of cold-water inlet. A rise in cold-water inlet temperature level of 5K (from 6°C to 11°C) allows for an additional reduction in electricity demand by about 40% compared to the free-cooling savings at 6°C (Figure A5). A further increase to 13°C is much less effective due to the relatively small amount of additional days during which free-cooling is possible at this higher temperature level.

**Figure A5. Electricity savings with free-cooling depending on the cold-water inlet temperature and the heat load, (Altenburger 2001).**




The configuration of the HVAC-equipment and the computer room conditions determine by large the energy efficiency of the infrastructure. A system without free-cooling, a cold-water temperature of 6/12°C, a computer room temperature of 20°C and an inefficient ventilation system adds 64% to the electricity demand of the computers (irrespective of the specific heat load). By using free-cooling the increase is reduced by 10%-points to 54%. An increase in the cold-water circuit temperature from 6/12°C to 11/13°C contributes 16%-points reducing the share to 38% of the electricity demand of the computers. The use of an optimised ventilation system helps reducing the share by nearly 16%-points to 22.5%. Finally, a rise in computer room air temperature from 22°C to 26°C reduces the increase by another 5%-points. This lead us to a minimum electricity demand for cooling and ventilation of 17.5% related to the computer's yearly electricity consumption.

Hence, a reduction of the electricity demand of cooling and ventilation by a factor of more than two is achievable just by making use of free-cooling, rising the cold water circuit and the room air temperature, but without changing other computer room conditions.

## A3.2. Uninterruptible Power Supply (UPS)

For an uninterruptible power supply of data centres different technologies and configurations are available. On the one hand, rotary and static UPS systems may be discerned. While the former converts electric energy into kinetic energy and vice versa, the latter makes use of lead acid batteries.

On the other hand the embedding of the UPS in the system may differ. Passive-standby (also called off-line), line interactive and double conversion technologies are available. Standby UPS have a transfer time of as much as 10 milliseconds delivering a square wave or a stepped square wave, whereas line interactive technologies provide a sine wave and have a transfer time of 1 to 2 milliseconds. Online (or double conversion) technologies deliver a sine wave during 100% of the time. Because electricity is always passing through the UPS system, there is no transfer time.

(Mitchell-Jackson 2001, p. 34) assumes that 5 to 7% of the incoming power is lost in the UPS. Rotary systems usually show higher energy efficiencies at full load, about 2 to 3%, compared to static double conversion systems. According to the specification of a supplier of UPS systems, maximum efficiencies of 93 and 94.5% for battery-type UPS (60 and 400kVA, respectively), and 95 to 97.5% for rotary UPS (150kVA to 40MVA) can be reached. However, 10% energy losses are not unusual for static UPS systems operated in data centres.

Additionally, efficiency may decrease when operated at partial load. However, there are static UPS systems on the market, which show an equal or even slightly better efficiency at 50% load as compared to full load.

## A3.3. Power Distribution Unit (PDU) and other auxiliary equipment

The losses in the power distribution unit may amount to 2 to 5%, depending on the load factor. Other auxiliary equipment such as building controls, fire alarms, security systems, telephone systems and emergency power supply units (diesel, natural gas or propane) require additional power, roughly estimated by (Mitchell-Jackson 2001, p. 34) at 2%. According to her, line losses amount to additional losses of 1% assuming a light load.

The losses caused by the PDU and the other auxiliary equipment is mainly influenced by the power load factor and may vary between 5 and 8% of total load.

## Appendix 4: Typology of data centres

There are many ways to classify data centres, e.g. regarding the service provided (ISP = internet service provider, ASP = application service provider, FSP = full service provider, WASP = wireless application service provider) or with respect to ownership of equipment. Mitchell-Jackson (2001) distinguishes the following three categories:

- corporate data centres
- collocation data centres
- managed data centres

Until the mid-1990s the large majority of all data centres were of the type corporate data centres. These computer centres are owned and operated by the companies it selves. Over time, some of these corporate data centres began – mainly for economic and possibly for security reason - to be outsourced to “hosting facilities”. Liberalisation of the telecom-market, mobile telecommunication and the emerging e-economy were other drivers for the fast growth of hosting facilities.

Collocation and managed data centres are two types of hosting facilities. In collocation centres the operator owns the building and the central infrastructure and outside companies rent space and bring in their own computer equipment. Regarding managed data centres, Mitchell-Jackson says: “In managed data centres, the owner of the data centre owns not only the racks but also the computer equipment within the facility. These data centres also provide other services such as software management. From an energy standpoint, the important distinction is that the floor plan and layout for a managed hosting facility can be planned ahead of time while the equipment and actual power demands of a co-location facility are up to the customers that rent the space. The division, of course, is not as clear-cut as it may seem. The exact power needs of a managed hosting facility are not always known in advance since the rate of technological change in this industry is rapid. However, there are more unknown variables in a co-location facility” (Mitchell-Jackson, 2001, p 6).

Today, collocation seems to be the dominant form of “hosting” (Mitchell-Jackson, 2001, p 6). Experts believe that managed data centres will become more important in next years (Pittrof, 2001; Morosoli, 2001) with the evident advantage of a higher-value-added-activity and the possibility to select the ICT-equipment with the best cost/benefit characteristics. This could mean that in the near future larger computers with a much-reduced electricity-demand[9] per unit of service-output may be used.

9 IBM requests electricity savings of 95% by replacing thousands of servers by one central computer: the IBM eServer z900 (IBM, 2001)