The EPBD and Continuous Commissioning

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*Tools and methods for linking EPDB and continuous commissioning*

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Abstract

The building sector is responsible for more than 40 percent of the European energy consumption. At the same time, the potential to save energy by appropriate building operation management, i.e. by taking measures involving very low or no investment costs, ranges from 5 – 30%. This applies particularly to the non-residential building stock.

Today, after the certification, usually there is no continuous evaluation of the building performance in order to reach or maintain an energy-efficient operation. As a result the performance of buildings is often poor and does not represent the energetic / economic optimum.

Continuous Commissioning™ (CC™) is a relatively new approach that addresses these problems and that was first established in USA. The term denotes an ongoing process for the quality assurance of building performance. The Energy Performance of Buildings Directive (EPBD; Directive 2002/91/EC) which prescribes energy certificates for new and existing buildings might offer some opportunities in this field as well.

This report show potential links between CC and the EPBD by evaluating different assessment technologies for the performance of buildings (that can be used for CC) with respect to their practical application and potential connections to the EPBD. Measurement based techniques are considered as well as model based techniques and functional performance tests. As a result, it can be stated that – for existing buildings - there is hardly an obvious connection between the requirements for energy certification according to the (EPBD) and the methods used during continuous commissioning.

If asset ratings were applied, the certification could deliver the actual state of the building and a theoretical target value for energy performance. However, asset ratings for existing buildings – which are investigated in Building EQ – are only prescribed in a few countries. Most Member States will have operational ratings for existing buildings which in their present definition are not suited for any kind of detailed analysis.

One major drawback is the diversity of the different national implementations in the Member States. That is, there will be no common data set for all Member States that can be exploited for performance analysis. Consequently, there will be no common basis for a European tool to be developed in the Building EQ project. The consortium therefore has to develop an “artificial” data set which must be consciously chosen.

On the other hand, this report shows that there exist a lot of valuable assessment techniques like: Benchmarking, Visualisation, model based techniques and Functional Performance Tests (FPT).

Inside the framework of Building EQ methods and tools will be developed, which make use of these techniques and which can support a continuous commissioning process. Furthermore the benefit of asset ratings for CC (independent from the national regulations for existing buildings) will be investigated.
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1 Introduction

The building sector is responsible for more than 40 percent of the European energy consumption. At the same time, the potential to save energy by appropriate building operation management, i.e. by taking measures involving very low or no investment costs, ranges from 5 – 30%. This applies particularly to the non-residential building stock.

At present, however, technical systems in buildings are not usually monitored to guarantee their performance or to check the energy efficiency of their operation. Maintenance is limited to ensuring that the primary functional aim is fulfilled e.g. warm or cool rooms. Even in new buildings, an energy optimised operation is often not achieved. Often technical systems in buildings operate far below their energetic/economic optimum. At the same time, the system owner or operator lacks the technical know-how and/or capital necessary to make any improvements.

The Energy Performance of Buildings Directive (Directive 2002/91/EC) which prescribes energy certificates for new and existing buildings might offer some opportunities in this field. With the increasing dissemination of energy certificates the awareness of building owners concerning energy efficiency will rise. Furthermore the EPBD is considering the building envelope and the HVAC systems as parts of the same entity and could thereby establish a basis for global optimisation of building performance.

Another quite new approach, that first was established in USA, is continuous commissioning. The term denotes an ongoing process for the quality assurance of building performance. It is designed to develop targets and to verify and document their achievement. Continuous commissioning is seen as a prerequisite for an energy efficient long term operation of buildings.

Building EQ tries to find possible links between the regulations of the EPBD and the continuous commissioning process in order to get the most out of both approaches.

The general structure of this report is as follows:

- Chapter 2: General introduction to the energy use of commercial buildings, performance metrics and consideration of practical issues
- Chapter 3: Introduction of the concept of continuous commissioning and possible links to the EPBD
- Chapter 4: Overview over methods for the measurement based performance evaluation of buildings
• Chapter 5: 
  Overview over methods for the model based performance evaluation of build-
  ings and introduction of the concept of fault detection and diagnosis FDD).

• Chapter 6: 
  Introduction of Functional Performance Tests (FPTs)

• Chapter 7: 
  Conclusions and recommendations for the methods to be evaluated in the 
  Building EQ project.
Energy use in public and commercial buildings

The energy use in public and commercial buildings varies of course a lot depending on building services systems, building envelopes, activities in the building (utilisation), size etc. Building envelopes has changed over time and building services systems have become more and more advanced. Even the indoor activities have changed. The question arises, has the changes lead to improved energy performance of buildings? The answer depends on the definition of energy performance, which depends on regional conditions. However the implementation of the European Performance of Buildings Directive may lead to a European consensus.

Energy statistics from public and commercial buildings in Sweden shows that specific use of heat has decreased rather dramatically since the oil-crisis three decades ago, while use of electricity has increased. Cooling together with more strict indoor climate requirements (temperature) is the main reason for the increase of electricity. The use of cooling is considerable nowadays even in the cool northern European countries. Computers and other electrical equipment is one reason why many modern office buildings has a heat surplus even when the outdoor temperature is just around 0 °C!

It is obviously a big challenge to break the trend of increased use of electricity but the question is how? Continuous commissioning may not be the whole answer, but together with mind full projecting of new buildings, it is absolutely possible to break and turn the trend.

There are a lot of easy and cost effective energy saving measures which are easy to do, such as adapting airflow rates to required levels (actual air flow rates are often higher than required) and adjust operational hours to required times. These adjustments are just some examples of measures, without cost. To get a picture of the whole energy saving potential of the building with its services systems, a hierarchical model of the building as an entirety is essential.
Hierarchical energy use: quantities to be measured or modelled

It is possible to divide a building and its services systems in such away that a change in a subsystem or component on one level affects only the energy use at that level, or on higher ones. Figure 1 shows such a division. The levels range from the building seen as an entirety down to a component in a subsystem, e.g. a fan. The first division is between the building service systems (to the left in the figure) and the building itself (to the right). The system part is primarily physical objects, such as the building structure and envelope.

Figure 1 Division of a building and its services systems into subsystems and components

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A simplified graphical representation of energy flows in buildings or facilities respectively is given in Figure 2.

The overall systems can be viewed from different levels:

- The whole system
- A subsystem, involving several components
- Components that are considered as critical, considered alone.

Accordingly the analysis can either be a top-down approach or a bottom-up approach.

- **Top-Down**
  The top-down approach consists in “going down” from the “system” level to the component “level”, passing through some subsystems. The whole system performance is first verified and the inquiry is extended to lower and lower levels, according to observed malfunctioning and to questions to be answered.
  The final goal is not to verify if a component is “good” or “bad” in itself, but to check if it’s correctly integrated in the system considered.

- **Bottom-Up**
  The bottom-up approach consists in starting from a single component and going back progressively to the whole building. It might be more appropriate for

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initial commissioning, in order to follow the construction (not to arrive too late). It allows a safer identification of local defaults, but it might also generate a waste of efforts by lack of global vision of the problem.

When the analysis is based on measured values the typical approach is top-down since normally only the whole energy use of the building is measured, divided into heating and electricity. When the analysis is based on either an energy audit or modelling a bottom-up approach is more common. In energy audits the approach is typically an iterative mix of both approaches.

For Building EQ a top-down approach seems to be appropriate as the project deals with existing buildings and the initial saving potential is not clear. Thus detailed analysis on system or component level is only recommended if a malfunction or inefficiency is visible on a “higher level” (like total energy consumption). By choosing this approach some opportunities for energy savings might be missed but in general the corresponding cost does not justify a detailed test for every system or component.

![Figure 3: Rationale for the top-down approach in performance analysis of existing buildings. Theoretical maximum of energy cost savings are unknown initially. The cost of “information”, i.e. the level detail in which the building and its system is known (acquisition of stock data, theoretical calculations, measurements), increases with information. Maximum cost savings (result of energy cost savings and cost of information) do not necessarily correspond to maximum information.](image-url)
2.2 Performance metrics

2.2.1 General definition

When comparing the performance of different buildings it is important that the data are presented in a way that the buildings really can be compared. One way of doing this is to use standardised performance metrics.

Deru and Torcellini\(^3\) gives the following definition for performance metrics:

“A metric is a standard definition of any measurable quantity, and a performance metric is a standard definition of a measurable quantity that indicates some aspect of performance. Many other terms are used with a similar meaning, such as performance indicator, performance index, and benchmarking. Performance metrics need certain characteristics to be valuable and practical. A performance metric should:

- Be measurable (or able to be determined from other measurements).
- Have a clear definition, including boundaries of the measurements.
- Indicate progress toward a performance goal.
- Answer specific questions about the performance.”

This definition is applied to energy performance of buildings and performance metrics for different levels according to Figure 1.

They defined three levels of performance metrics (see Figure 4).

- Tier 1 provides a high level view of building performance and can be derived from monthly and annual data such as those on utility bills. (Level 2 in Figure 1)
- Tier 2 provides a detailed breakdown of the energy use and typically requires hourly or sub hourly sub metering. (Level 3-6 in Figure 1)
- Performance indicators are above Tier 1 metrics, and they aggregate complex information to show planning level trends toward goals.

Similar definitions are given by Kenneth, Gillespie, et.al.\(^5\).

In the framework of Building EQ (Workpackage 3) project specific performance metrics will be defined in order to provide an optimal comparability between the demonstration projects in the different countries.

2.2.2 Application of performance metrics

The energy use can be expressed in different ways. In some countries the delivered energy to the building is used and the energy carriers are not weighted at all, whereas in other countries the energy use is expressed as nationally weighted energy or as primary energy. The way to express the energy use is a cultural factor and can sometimes lead to confusion.

If the whole building is studied the physical parameter may be the treated floor area or treated (heated) building volume. For an office building the number of workplaces may give a better insight of the energy use than the floor area if this includes a lot of not really used spaces. For hospitals the number of beds has traditionally been used in some countries, but changes in the medical care with “fast treatments” and much shorter stays in the hospital have made this parameter a bit obsolete.


If a specific energy end-use is studied e.g. the energy used for air transport and treatment (heating, cooling, humidification) of the ventilation air the design, or maximum, airflow rate may be a good physical parameter to use.

The physical parameter used is also a cultural factor, which depends on among other things the country and the building category studied.

To make comparisons of annual energy use between buildings possible the following prerequisites must be fulfilled:

- The energy data is monitored/calculated in a similar way.
- In most climates heat energy data must be adjusted to a standard (“normal”) year for the location of each building.
- In climates where cooling energy is “climate-driven” cooling must also be adjusted to a standard year for the location of each building.
- If the buildings have very different time of use (use pattern), say normal office hours and around-the-clock use, all energies must be adjusted to a standardized use pattern.
- The physical factor, e.g. a floor area, must also be defined in a similar way between the buildings.

Building energy performance is a key value, mostly based on used energy per area unit. Some countries use cubic meters as a comparison base. The energy performance can also be based on energy use per produced unit (manufacturing industries) or energy used per hotel guest night (hotels) or other adequate comparison basis. Experience from building owners and energy experts’ points out division of square meters as difficult. The more complex the building, or group of buildings is, the more difficult, specially common areas such as glazed common areas in shopping centres, garages, etc. Moreover, there are various kinds of area terms, such as net lettable area, gross internal area, etc. It is of out most importance to be aware of and have knowledge about the various area terms when comparing performance metrics of different buildings.

2.2.3 Typical measured data available

The measured energy use of non-residential buildings is typically restricted to the energy use controlled by the buildings owner. These energies are usually collected at level 2 in Figure1:

- Total heating use of the building, usually read on monthly basis.
- Electricity use of the building services systems and other electrical energy controlled by the buildings owner (i.e. stairwell lighting), read on monthly or quarterly basis
Building owner sometimes have information on electrical energy use of the occupier or tenant on a monthly or quarterly basis. However, this is only the case if sub meters for each tenant are installed. If the tenants have their own energy subscriptions and meters, it can be difficult to get information about the energy use since the building owners have no juridical right to take part of their tenants energy bills. Frequent information about energy use (at least on an a monthly basis) is a condition for meaningful energy management.

Lack of sub-meters makes it often difficult to get a detailed knowledge about energy end users. Hopefully, building owners will realize the advantages with sub meters and will be encouraged to install these a soon as possible. The fastest accept to extended use of sub meters will most likely be in countries with Operational Rating as energy performance certification criteria.

Buildings with BEMS give building owners access to a lot of data from the building services systems. However, these data are unfortunately rarely saved in any accessible databases.

### 2.3 Examples of measured buildings

#### 2.3.1 Swedish office buildings

A multi-year project, STIL 2, is ongoing in Sweden with the purpose to audit the energy use, particularly electricity use, in all types of non-residential buildings. During six years about one thousand buildings, in ten different building categories, will be audited, one or two building types per year. Year seven the audit process will start again with the first building category. Before 2007 the audit project was called Stegvis STIL (Stepwise STIL).  

During 2005, the first year, 123 office and administration buildings were audited. About 60% of these were located in the valley of Lake Mälaren, which is in, and east of, the capital city Stockholm; about 25% were in the colder middle parts of Sweden; and about 15% were in parts of Sweden south of Lake Mälaren. Due to the large part of the buildings in the Lake Mälaren area, where district cooling is available, 29 buildings (24%) had district cooling. Totally 91 buildings (74%) had some form of air-conditioning including the ones with district cooling. The heat delivered to the buildings was totally dominated by district heating, 90% of the delivered heat energy or 111 (90%) of 123 buildings. Of the delivered heat energy about 2,5% each came from the three sources: oil boilers, direct resistance electric heating, and heat recovery from water chillers.

All buildings have balanced mechanical ventilation systems, typically with air-to-air heat exchangers. A few buildings have return air dampers as an “old-time alterna-
tive”. Nearly three quarters of the buildings have air-conditioning system, either in the form of traditional North European air-water systems, where spaces are cooled via the supply air and heated via hydronic radiators, or in form of modern all-air systems where spaces are cooled via hydronic systems, with mainly chilled beams, and heated via hydronic radiators. In the last case the ventilation system is only responsible for an outdoor airflow rate that satisfies the requirements on the indoor air quality.

Figure 5 shows the annual energy use per building divided into operational electricity and heating per m² of used floor area (BRA). The operational electricity excludes electricity for heating, but includes district cooling as if it was coming from electric water chillers with the annual seasonal performance factor (SPF) of 3.5. The heat energies are normalized to a standard year for each location of the building. This division is motivated thermodynamically to show energy used for heating purposes on the y-axis, and energy used for work (operational electricity) on the x-axis.

The floor area is the Swedish standardized used floor area (BRA – Bruksarea), which is the floor area inside the external walls less area for shafts for ventilation, pipes and wiring and inner walls thicker than 300 mm. The STIL 2 study shows that this area is 96.5 % of the floor area inside the external walls.

One building, a PC-hotel with very extreme electricity use for office equipment and cooling, is excluded from the figure.
Figure 5 Measured energy performance in 2005 of 122 office and administration buildings inside the STIL 2 project. Heating is normalised to a standard year for each location. Electricity for heating purposes is added to the heating energy. For buildings with district cooling this is added as electricity to the electrical energy with a SPF of 3.5.

Figure 5 shows that there is a great difference in energy use between the buildings. This really shows that each building is an individual and that future energy efficiency measures (including continuous commissioning measures) must be matched for each building separately.
From Figure 5 it can also be concluded that there is no apparent connection between buildings using much electrical energy and little heat energy. Electrical energy would yield a lot of internal heat gains and thereby offset heat energy use.

In Figure 5 “iso primary energy lines” can be drawn where 1.0 kWh electricity corresponds to e.g. 2.5 kWh heat. In principle buildings laying on the same iso-line use the same amount of primary energy. For Figure 5 this is not really true since electricity for heating is included in the general heating energy.

The STIL 2 study distinguished between around twenty energy end-uses in the audited office buildings. These use more or less only electricity. Table 1 shows the median value and the upper and lower quartiles for these energy end-uses. Sometimes the number of buildings with a certain energy end-use is too small compared to the total number of buildings to yield any meaningful statistics. In this case the mean value is given instead.

Table 1 Annual energy use in 2005 for audited energy end-uses for all of the audited 122 office and administration buildings in the STIL 2 study, excluding the PC-hotel.

<table>
<thead>
<tr>
<th>Energy end-use</th>
<th>Median [kWh/year &amp; m² BRA]</th>
<th>Lower quartile [kWh/year &amp; m² BRA]</th>
<th>Upper quartile [kWh/year &amp; m² BRA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating thermal</td>
<td>94.3</td>
<td>66.7</td>
<td>117.4</td>
</tr>
<tr>
<td>Heating electricity</td>
<td>6.3 (mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating Total</td>
<td>98.0 (mean)</td>
<td>68.5</td>
<td>126.2</td>
</tr>
<tr>
<td>District cooling</td>
<td>7.1 (mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>District cooling converted to electricity (SPF=3.5)</td>
<td>2.0 (mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fans</td>
<td>16.4</td>
<td>10.3</td>
<td>20.8</td>
</tr>
<tr>
<td>Circulation fans</td>
<td>2.0 (mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pumps</td>
<td>3.5</td>
<td>2.0</td>
<td>6.4</td>
</tr>
<tr>
<td>Water chillers</td>
<td>9.3 (mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condenser fans and pumps</td>
<td>0.7 (mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lifts</td>
<td>0.7 (mean)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor lighting</td>
<td>20.6</td>
<td>15.2</td>
<td>28.2</td>
</tr>
<tr>
<td>Main frames/servers</td>
<td>3.5</td>
<td>0.3</td>
<td>14.1</td>
</tr>
<tr>
<td>PCs</td>
<td>6.0</td>
<td>4.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Printers</td>
<td>0.9</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Copiers</td>
<td>1.4</td>
<td>0.8</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Table 1 shows data for 122 audited buildings whereas Table 2 shows data for only the buildings that have each of the different energy end uses. This number varies from all buildings (e.g. indoor lighting) to only 10 out of 123 buildings.

To illustrate the difference between Table 1 and Table 2 one can look at the energy end-use district cooling. The average building, out of 122, in Table 1 has a mean use of district cooling of around 7 kWh/year & m² BRA. The median for only the 29 buildings that has district cooling is 24 kWh/year & m² BRA with an upper quartile of nearly 45 kWh/year & m² BRA.

Table 2 Annual energy uses 2005 for audited energy end-uses for the audited office and administration buildings, which have each energy end-use, in the STIL 2 study.
<table>
<thead>
<tr>
<th>Buildings which have each energy end-use</th>
<th>Median [kWh/year &amp; m² BRA]</th>
<th>Lower quartile [kWh/year &amp; m² BRA]</th>
<th>Upper quartile [[kWh/year &amp; m² BRA]]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condenser fans and pumps</td>
<td>0.9</td>
<td>0.4</td>
<td>1.8</td>
</tr>
<tr>
<td>Lifts</td>
<td>0.4</td>
<td>0.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Indoor lighting</td>
<td>20.6</td>
<td>15.2</td>
<td>28.3</td>
</tr>
<tr>
<td>Mainframes/servers</td>
<td>7.6</td>
<td>1.5</td>
<td>19.6</td>
</tr>
<tr>
<td>PCs</td>
<td>6.0</td>
<td>4.0</td>
<td>8.7</td>
</tr>
<tr>
<td>Printers</td>
<td>0.9</td>
<td>0.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Copiers</td>
<td>1.6</td>
<td>1.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Tea kitchens etc.</td>
<td>2.6</td>
<td>1.6</td>
<td>3.4</td>
</tr>
<tr>
<td>Catering kitchens</td>
<td>0.6</td>
<td>0.3</td>
<td>2.8</td>
</tr>
<tr>
<td>Laundry equipment</td>
<td>0.4</td>
<td>0.2</td>
<td>2.0</td>
</tr>
<tr>
<td>Air compressors</td>
<td>2.0</td>
<td>1.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Car engine heaters</td>
<td>1.4</td>
<td>0.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>7.3</td>
<td>3.3</td>
<td>12.1</td>
</tr>
<tr>
<td><strong>Non-Heating Electricity Total</strong></td>
<td><strong>83.5</strong></td>
<td><strong>60.6</strong></td>
<td><strong>121.5</strong></td>
</tr>
</tbody>
</table>

An energy end-use that is rather special for the Nordic countries (Finland, Norway and Sweden) is electric car engine heaters. Even in the 33 buildings that have them, they only use a few kWh/year & m² BRA but they contribute to a substantial part of the electric load on cold winter days. This is particularly true if they are time controlled to start about one hour before the work ends and the car has been cold down during the day. Nowadays smarter control algorithms are available.
2.3.2 British office buildings

In the United Kingdom guides for typical annual energy uses in office buildings have been available since more than fifteen years. The data is partly based on general statistics and partly on more thoroughly audited pilot projects. The buildings are divided into four generic types:

- Office type 1: Natural ventilated, cellular
- Office type 2: Natural ventilated, open-plan
- Office type 3: Air-conditioned, standard
- Office type 4: Air-conditioned, prestige

These office types are rather British, particularly the natural ventilated ones, and not always easily compared, or translated, to other countries. In this chapter data are only given for office type 3, which might be compared to the Swedish offices shown above. One exception is that the Swedish offices have a higher share of cellular offices, and thereby a lower density of occupant per floor area than British offices. In the UK humidification (electric steam generators) is back again, whereas this energy end-use is still totally unknown in Sweden since the first oil price crisis in 1973.

Natural gas is the totally dominating energy carrier for heating in the United Kingdom, where district heating or cooling are totally unknown.

The British floor area is the treated floor area (TFA), which is defined as the gross internal area (GIA) less the floor area for plant rooms and other areas not directly heated (e.g. stores, covered car parking, and roof spaces). The gross internal area (GIA) is the total building area measured inside the external walls. As stated above this area is a few percent larger than the Swedish BRA. For Office type 3, TFA is typically about 90% of GIA. This means that the British TFA is a smaller floor area than the Swedish BRA and consequently the British benchmarks yield a somewhat higher number than the Swedish ones shown above.

---

Table 3 shows the annual energy end-uses for a typical, and a good practice, type 3 air-conditioned standard British office building.

Table 3   Annual energy end-uses for typical and good practice for the British Office type 3: Air-conditioned standard.

<table>
<thead>
<tr>
<th>End-use</th>
<th>Good practice [kWh/year &amp; m² TFA]</th>
<th>Typical [kWh/year &amp; m² TFA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating and hot water – gas or oil</td>
<td>97</td>
<td>178</td>
</tr>
<tr>
<td>Cooling (water chillers) – electricity</td>
<td>14</td>
<td>31</td>
</tr>
<tr>
<td>Fans, pumps &amp; controls – electricity</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Humidification (where fitted) – electricity</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td>Indoor lighting – electricity</td>
<td>27</td>
<td>54</td>
</tr>
<tr>
<td>Office equipment – electricity</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td>Catering – gas</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Catering – electricity</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Other – electricity</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Computer room (where appropriate) - electricity</td>
<td>14</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total – gas or oil</strong></td>
<td><strong>97</strong></td>
<td><strong>178</strong></td>
</tr>
<tr>
<td><strong>Total – electricity</strong></td>
<td><strong>128</strong></td>
<td><strong>226</strong></td>
</tr>
</tbody>
</table>

Energy end-use intensities between Swedish and British offices have been compared a few times earlier (Bordass & Jagemar\(^8\), Ask et al\(^9\) (2001)). New Swedish offices turn out to use 25 % to 30 % less both heat energy and electricity per floor area than British one. If instead the energy is expressed per work place the British offices use 45 % to 50 % less heat energy and electricity. This is because the occupant density is more than twice in the UK compared with Sweden.

---


Figure 6 shows a comparison between heating and operational electricity benchmarks for British Office type 3: Air-conditioned standard and the median and the area into which 50% of the 122 audited Swedish office buildings energy use is falling. One reason for the lower heating energy use for the Swedish office buildings may be a long tradition of heating energy conservation since the first oil prices crisis. Sweden has no tradition of conservation of electricity. Instead much of the oil decrease has realised by substituting oil to electricity or district heating based on a variety of energy carriers.

As seen in Figure 6 the benchmarks for the British Good Practice office is close to the majority of the Swedish audited offices. The benchmarks for the British Typical office, on the other hand, represent about twice the energy use of both heat and electrical energy compared to the Swedish office buildings.
3 The Energy Performance of Buildings Directive and continuous commissioning


The purpose of the directive is to make the energy use in buildings more effective and by that contribute to reducing the amount of green house gases. The import dependence of energy can be reduced in this way and the providing safety regarding energy increased.

The directive determines requirements for:

- calculation methodology for building energy performance
- minimum requirement regarding energy performance of new buildings and buildings comprehensively refurbished
- energy performance certification of buildings
- regular inspections or advisories regarding heat boilers
- regular inspections of HVAC systems

An EC-directive is binding for each member state regarding the results that must be fulfilled. However, national authorities are responsible to determine form and course of action of the realization. The main parts of the directive must have been implemented nationally by 4th January 2006, but the parts regarding energy certification of buildings can be delayed until 4th January 2009 due to national lack of experts.

3.1 Energy certification of non-residential buildings


- Operational Rating (OR) – based on measurement of annual delivered energy;
- Asset Rating (AR) – based on calculation of annual energy needs via a building energy model.

Both methods use the amount of energy actually consumed (OR) or estimated (AR) to meet the different needs \textit{associated with a standardised use of the building}, which may include, inter alia, heating, hot water heating, cooling, ventilation and lighting.
The rating of the building is done on either an energy indicator or an environmental indicator. In both indicators the denominator is the floor area of the building inside the external walls. The numerator in the energy indicator is the sum of the annual energy use either expressed with national energy weighting factors or with primary energy factors. The numerator in the environmental indicator is typically the annual carbon dioxide emissions caused by the different fuels.

The two rating methods means that the information needed to do the rating varies a lot:

- Operational rating based on annual energy use
  - Annual measured delivered energy divided into the different fuels used;
  - Correction factors for these energy quantities to a standard year for the location;
  - Knowledge of the use pattern of the building and of factors to correct this, if needed, to “standard use”;
  - National energy weighting factors or primary energy factors of each fuel;
  - Floor area of the building inside the external walls.

- Asset rating based on annual energy use
  - Detailed information of the building shell;
  - Detailed information of the building services systems including set points, operational hours etc.;
  - Detailed information of the energy supply systems of the building (boilers, water chillers, CHP-equipment, etc.);
  - Detailed pattern of standard use;
  - Calculated annual energy use per fuel based on point 1 to 4 via a more or less sophisticated building energy simulation programme;
  - Floor area of the building inside the external walls.
3.2 Overview over the national implementations

A detailed description of the different national implementations of the EPBD in the Member states is given in the Annex. This chapter gives only a condensed overview.

3.2.1 Data acquisition

In general, detailed data concerning the status of the implementation in the European countries is hardly available. The websites of the EPBD-platform provides the best information by giving an overview for each country. However, only 4 papers are dated after July 2007. Most information were done beginning of 2007.

Since legislation is in progress in many countries, it is obvious that the collected data in this report can be already revised.

3.2.2 Certification

In 9 countries certification for new buildings is already in force. For existing buildings most countries will introduce an energy certificate in 2008-2009.

Concerning the calculation method only 6 countries will apply asset rating mostly for new buildings and in some cases with simplified calculation methods using default values. In Denmark and Austria certification based on energy demand is obligatory for all buildings.

A few countries give information if calculation methods are based on CEN-standard such as Austria, Germany and Czech Republic.

3.2.3 Inspection

Inspection for boilers is covered by existing law in 16 countries. Partly, these regulations have to be amended. Execution orders for inspection of air conditioning systems are under discussion in almost all countries. Information about the interval of inspection is very few, e.g. in Germany every ten years for air conditioning systems and every two years for boilers in Flanders (Belgium).

3.2.4 Requirements on existing buildings

Requirements for existing buildings have to be applied when major renovation is undertaken. Mainly, there are requirements on the maximum U-value for each building component (14 countries) and in 7 cases on energy demand. Regulations about when a renovation is "major" differs between the countries.
Continuous Commissioning (CC)"

"Ongoing-" or "Continuous Commissioning" is a term that comes from the USA. Originally, "Commissioning" denoted a task that is performed after a building is constructed and before it is handed over to the building owner to check operational performance. Today (at least in USA, but also in some other countries) "Commissioning" stands for a general quality assurance procedure.

The final report of the IEA ECBCS Annex 40 gives the following definition for commissioning:

"Commissioning is a quality-oriented process for achieving, verifying, and documenting whether the performance of a building’s systems and assemblies meet defined objectives and criteria."

To overcome the common understanding of commissioning as a task performed during hand-over, the Annex 40 report distinguishes between different kinds of commissioning:

- **Initial Commissioning** (I-Cx)
  Systematic process applied to the production of a new building and/or an installation of new systems.

- **Retro-Commissioning** (Retro-Cx)
  First time commissioning implemented in an existing building in which a documented commissioning process was not previously implemented.

- **Re-Commissioning** (Re-Cx)
  Commissioning process implemented after I-Cx or Retro-Cx when the owner hopes to verify, improve and document the performance of building systems.

- **On-Going/Continuous Commissioning** (On-Going Cx / CC)
  Commissioning process conducted continually for the purposes of maintaining, improving and optimizing the performance of building systems after I-Cx or Retro-Cx.

Most experts in building performance analysis probably would agree that a continuous commissioning process is a prerequisite for the energy-efficient long term operation of a building.

The "Continuous Commissioning Guidebook" of the FEMP gives the following definition for continuous commissioning:

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11 "Continuous Commissioning" and "CC" are registered trademarks of the Texas Engineering Experiment Station
13 "Continuous Commissioning Guidebook", Claridge et.al., Energy Systems Laboratory, Texas A&M University, Federal Energy Management Program, USA, 2002

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“Continuous Commissioning is an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities.”

A more detailed definition of continuous commissioning from Annex 40 stresses the aspect of quality assurance which strives to meet the requirements of the owner:

“CC = Clarifying Owner’s Project Requirements (OPR) from viewpoints of environment, energy and facility usage, and auditing and verifying different judgments, actions and documentations in the Commissioning Process (CxP) in order to realize a performance of building system requested in the OPR through the life of the building.”

Typically, the commissioning process is described as a multi-level process. The “Continuous Commissioning Guidebook” of the FEMP describes the general phases for CC as follows:

- Develop the CC plan
  - Develop a detailed work plan
    (description of task, definition of targets, specification of monitoring, etc.)
  - Identify the entire project team
  - Clarify the duties of each team member

- Develop performance baselines
  - Document existing comfort conditions / problems
  - Document existing system conditions / problems
  - Document existing energy performance

- Conduct system measurements and develop CC measures
  - Identify current operating schedules, set points and problems
  - Develop solutions to existing problems
  - Develop improved operation and control schedules and set points
  - Identify potential cost effective energy retrofit measures

- Implement CC measures
  - Obtain approval for measures from building owner’s representative before implementation
  - Implement solutions to existing operational and comfort problems
  - Implement and refine improved operation and control schedules

- Document comfort improvements and energy savings
• Document improved comfort conditions
• Document improved system conditions
• Document improved energy performance

• Keep commissioning continuous
  • Maintain improved comfort and energy performance
  • Provide measured annual energy savings

Although there are rules or even standards for energy auditing in many Member States, the complete list of tasks described above is seldom performed\textsuperscript{14}. Especially the documentation of cost and energy savings is often neglected.

However, results from USA show that by introducing CC an average of 20% of energy savings could be achieved while the implemented measures had a pay back time of a few months up to 2 years. If these results could be transferred to Europe is one of the issues to be investigated in Building EQ.

3.3.1 Assessment of building performance

Besides the management of the different parties involved in the commissioning process (like building owner, operation staff, user or tenant, HVAC specialists) different methods for the assessment of building performance has to be considered during CC.

Generally they can be split several categories:

• Measurement based methods
  Methods that rely on measured data like monthly energy consumption or hourly indoor temperatures. A very important and useful technique in this category is visualization.

• Model based methods
  Methods that use different kind of models to generate benchmarks either for “normal” or “optimal” building operation.

• Functional performance tests
  passive or active on-site testing of systems or components

Each of these categories is described in detail in the following chapters.

\textsuperscript{14} This is an actual result of the IEA ECBCS Annex 47 „Cost effective Commissioning for Existing and Low Energy Buildings”. There are significant problems to populate an international database on fully documented Re-Cx projects.
3.4 **Connections between EPBD and continuous commissioning**

While continuous commissioning is an ongoing process over the entire life time of a building, certification according to the EPBD will (in most cases) only be performed once. The EPBD does not prescribe an ongoing evaluation of building performance. Accordingly, the certification can only be one part of a continuous commissioning process.

In the case of asset ratings, the certification can deliver the actual state of the building and a theoretical target value for energy performance. Thus, it could be integrated in phase I of the CC (“Development of CC plan”).

However, asset ratings for existing buildings – which are investigated in Building EQ – are only prescribed in a few countries (Denmark and Austria so far). Most Member States will have operational ratings for existing buildings which in their present definition are not suited for any kind of detailed analysis.

The only systems explicitly dealt with in the EPBD are the inspection of air-conditioning systems and of boilers. The last is nationally implemented either as inspections or as information depending on each country’s needs. Again, the kind of inspection and the intervals in most Member States are not suited for a continuous commissioning process.

However, the work put into certification of a building is a good basis for continuous commissioning. The certification process is actually a good starting point considering that a benchmark and energy saving suggestions are given. Furthermore, the certification process will affect many building owners to install energy sub-meters to determine energy end-users; which is a prerequisite for good continuous commissioning.
4 Measurement based building performance assessment

To ascertain if and when a building is in need of energy efficiency measures, or to decide which of a group of buildings are in need of such measures, it is of utmost importance to know the history of the energy use. The more detailed the information is (i.e. divided into different end-users and time intervals), the more useful it will be during the energy management programme. Every single building should be continuously compared to itself. This is typically done on a monthly basis and on annual basis, which gives indications of whether the energy performance of a building deteriorates over time.

Since part of the use of energy is dependent on outdoor climate, it is usually necessary to take into account the climate during the measuring period in relation to the same period for a "normal" year. Recalculating the measured use of climate dependent energy to the corresponding use for a "normal" or "typical" year does this. By doing this, it is possible to compare the energy used in a building for corresponding periods in selected years. April of year 1 can then be compared to April of year 2, and so on, independent of whether the actual climate was different in April for the years in question. Variations in normalised use of energy for different years consequently indicate sources other than external climate.

There are alternative ways of normalising the use of energy. One, which is very convenient for the user and can be employed to keep track of heating, electricity and cooling, is known as the energy signature model, Section 4.2 below.

4.1 Benchmarking (annual data)

Benchmarking is to compare mainly the measured annual energy use with different relevant benchmarks. At a first glance this seems a very simple technique. However, it is easy to compare apples with oranges. The first thing is that the measured energy use shall comprise the same energy end uses as in the benchmark.

Part of national EPBD implementation has lead to national benchmark registers. These registers will be more and more substantiated, as more and more building energy performance certificates will be registered.

There are also national registers besides the EPBD registers. Some of them are very general which makes them less useful for real benchmarking. Other registers are far more precise and well defined but mostly with a limited number of different buildings.

As mentioned above, benchmark of buildings seems easy at a first glance but it is easy to compare apples with oranges by mistake when benchmarking. Buildings that may seem identical can, due to different conditions, be very separate in energy performance even if both are equally energy efficient.

Example:
Two school building (A & B) have identical building envelopes, dimensions and build-
ing services systems. Building A has operational hours 08.00-16.00 working days. Building B has operational hours 08.00-22.00 working days and 09.00-16.00 weekends because of evening and weekend courses. It is obvious that Building B will use more energy than Building A, but is not less energy efficient!

4.2 Energy signatures (monthly/weekly data)

An Energy signature is a visualisation technique based on aggregated e.g. weekly or monthly values. The reason for this time “step” is that the heat energy must be a “short time” average where the influence of the daily heat storage in the building is smoothed out. The simplest form of energy signature is related to dry outdoor air temperatures only. Further developed forms may include for example solar insolation or wind speed.

When using the energy signature for heating statistics, it is convenient to include also domestic hot water. It is important though, not to use too short periods of time when calculating. Variations in the use of domestic hot water can cause distortion. The thermal mass of the building (heat storage) evens out and delays the measured use. Therefore, a period of a week or a month is adequate, with a month as the recommended period. A month is convenient for taking into account the practical aspects of working with energy statistics and collecting the necessary data. An Energy signature is a useful tool for regular internal benchmarking with the same building. Since the energy signature clearly shows if something becomes wrong with the building or with the building services systems, it constitutes a useful operation alarm for continuous commissioning.

Example: How to use energy signature in practice:
Measured use of energy (separated heat and electricity) and measured average outdoor temperature are the only needed measurements. The actual average energy demand is calculated using the quotient of the measured use of energy and the number of hours for the individual month.

After calculating the actual average energy demand for each month the energy signature can be printed as shown in Figure7. However, in this figure the monthly energies have not been divided with the number of hours per month. In the figure are plotted the values from measured use of energy and measured average outdoor temperature. The actual energy signature for the building is the straight line, which is adapted as well as possible to the individual monthly values. A convenient way of doing this is to use the least square method for the months with outdoor temperature depending heating and cooling needs. This has been applied when plotting the energy signature based on the monthly values of the year 1993, 1994 and 1995. It is obvious that the energy for the three warmest months of the year are not outdoor temperature de-
ependent regarding heating, but outdoor temperature dependant regarding electricity (electrical water chillers).

Looking deeper into the building characteristics, it is clear that the values for heating during the summer gives the heat needed for service hot water. For buildings with a large share of heating used for service hot water in relation to the total use of heating, it may be necessary to divide the energy signature into two parts.

Figure 7 shows that the heating data for 1996 and 1997 are different from the ones from previous years. The reasons are mainly changes in set-points in the heating system and a minor refurbishment of the district heating sub-central.
4.3 Visualisation techniques

Visualisation analysis of measurements is a useful tool for continuous commissioning. Characteristics of the operation of a system or component can be examined. Malfunctioning of building services systems etc. are detected by looking at graphs, manually or automatically. Visualisation techniques are very helpful for detection of malfunction and diagnosis.

This chapter gives an overview over the following techniques:

- **Time series plots** show the classical diagram of a measured value over the time.

- **Scatterplots** (x-y plot) show the interdependence of two measured values (also called variables in this context). Furthermore it is possible to group by another variable. Scatterplots of more than two variable can be composed to so called scatterplot-matrices.

- **Carpetplots** show the time dependence of one variable by colour coding. The name is related to the fact that sometimes the resulting diagrams look carpets.

- **Boxplots** show the statistical distribution of one variable divided up into groups by another variable.

Scatter-, carpet- and boxplots are especially suited for analysing, since they reveal the characteristics of the energy consumption and the system temperatures. Classical time series plots however are a valuable reference for a closer examination of the time dependency.

Important additional features visualisation are filters and groupings.

A selection or grouping of measured values / variables by certain variables is called filter in the context of this chapter. An example is the selection of all measured values above a certain outdoor air temperature. Therefore with a filter the behaviour of the system under selected conditions can be studied.

**Grouping** the data means, that the data is divided up (grouped or split) by a certain variable e.g. weekday and weekend. Therefore it is possible to compare different operational modes.
4.3.1 Time series (hourly data)

Hourly values for variable energy end-users, such as computers, lighting, etc are useful for continuous commissioning. If the measured values are plotted, a good picture is given of how well the energy saving settings on the computers work or the lighting control, etc. An example of measurements, based on hourly values for lighting power, is shown in Figure 8 below.

![Figure 8](image)

Figure 8: Total lighting power of six office rooms during working days divided by room floor area, 95% confidence interval is also shown (medel ± konf). The plot clearly shows that the occupancy sensors or the occupants turn off the light in some of the rooms during lunch. The light is turned off when no one is there in all rooms but one. Measure: check the occupancy sensors and fix the one that does not respond.

An advantage with short time series is that the boundary conditions are easy to get a grip on, for example number of guest nights during a specific week in a hotel or if quick preliminary results are required after implementation of energy saving measures, etc.

4.3.2 Scatter plots - XY-plots (hourly data)

Scatter plots are similar to time series graphs in that they use horizontal and vertical axes to plot data. Scatter plots show how much one variable affects another.

Scatter plots in continuous commissioning enlightens relations between for example heating/cooling power and outdoor temperature, air flow rate and number of people, air temperature in air treatment system as a function of outdoor air temperature. Figure 9 shows an example of measured hourly air temperatures in an air-handling unit. Energy signatures are also typical scatter plots, see Section 4.2.
Figure 9 shows that the setpoint of the supply air temperature has been changed several times during the monitoring period. One reason for these changes is that the air is heated more than expected in the ducts from the air handling unit to the supply air terminals. To be able to maintain the design room temperatures the supply air has to be 15°C at the air terminals. The exhaust air temperature is a measure of the average room temperature in the building. This temperature varies a lot over the year. During the coldest nights it is just above the setpoint 21 °C but this is decreased during times even up to nearly 20 °C depending on outside temperature. The reason for this was mainly operational problems with the old heating system in this otherwise totally refurbished office building.
4.3.3 Scatter plot matrices

Scatter plot matrices show the dependency of more than two variables from each other by displaying a matrix of scatter plots. An example for an air treatment system is shown below.

![Scatter plot matrix for an air treatment system.](image)

Figure 10 Scatter plot matrix for an air treatment system. The matrix shows (from top to bottom): supply air temperature, outdoor air temp, supply air temperature after heat recovery, outdoor air damper, exhaust air damper, outdoor air bypass. The plot reveals that the dampers work correctly, but that the two temperature sensors for supply air, which should actually show the same temperature, are deficient. They had to be re-calibrated. This special kind of scatter plot shows the coefficients of correlation in the upper part of the matrix. It is also possible to display frequency distributions of the variables in the fields with the names. The graph is made with the software “R” (www.r-project.org).
4.3.4 Carpet plots (hourly data)

As mentioned above, measured data in great quantities is impossible to get a grasp of if presented in tables. Carpet plots have become better known lately, even though still not common. A plotted coloured variable is visualized over a period of time in a diagram; which gives a significant pattern that looks like a carpet.

In carpet plot usually the time of day is drawn on the ordinate (y-axis). On the abscissa (x-axis) the day (or date) is drawn. The value of the variable under observation is encoded as a colour value at the coordinate of time and date.

Figure 11 below shows a small peace of a carpet diagram, based on measured values for electricity use in an office building. It is easy to see that the use of electricity is higher during working hours than during nights and weekends.

Figure 11  Carpet plot of hourly measured values for electricity use in office buildings: Friday to Tuesday.

Why this pattern is called a carpet plot appears clearly in Figure 12, below.

Figure 12  Electricity use during January, February and March 2005 in a part of a Swedish office building in Stockholm, with six work places, pantry and conference room. The carpet shows 2160 hourly values. The electricity use varies between almost 9 kW during a few days in January and approximately 1 kW during nights at the end of March.
4.3.5 Day of week plots (hourly data)

Another effective way to illustrate data, that are varying both depending on the time of day and the day of week, are three-dimensional day of week diagrams. Figure 13 shows an example of the average power of computers depending on the time of day and the day of week from the tutorial of the Universal Translator software\(^{15}\) & \(^{16}\).

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Figure 13 example for a day of week plot of the average power of computers depending on the time of day and the day of week from the tutorial of the Universal Translator software

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\(^{16}\) UT home page: www.utonline.org
4.3.6  Box plots

A boxplot (also known as a box-and-whisker diagram or candlestick chart) is a way to display statistical data analysis in a graphical way. Median, 1\textsuperscript{st} and 3\textsuperscript{rd} Quartile and Min. and Max. are usually depicted. Sometimes other values like the 5\textsuperscript{th} and 95\textsuperscript{th} percentile are used instead of Min. an Max.

With boxplots different types of data distributions can be distinguished visually. The appearance of the box helps to indicate variance, skewness and identify outliers.

Figure 14  Boxplot for the distribution of the room air temperature in every hour of the time of day in a German office building for the time period Jul. – Sep. 2007.
Model based building performance assessment

Mathematical models of the building and systems play an important role in identifying energy saving potentials in buildings as they are principally able to deliver reference values for the “normal” behaviour of the building as well as the system parameters for the optimal performance.

Therefore, they can be used for fault detection and diagnosis (FDD) as well as for optimisation. FDD and optimisation has to be considered as coupled process as optimisation can only be performed if the operation of the system is faultless.

Model based FDD and optimisation is common in fields where the processes are technically or economically sensitive, such as in nuclear technology, aeronautics, chemical industry. Up to now, however, they has not played a role in practical building operation (Katipamula and Brambley 2005, part I), (Katipamula and Brambley 2005, part II). This chapter provides an overview of the available model based approaches for FDD and optimisation and evaluates them with respect to their application potential in the area of building technology.

5.1 Model-based Methods for Fault Detection and Optimisation in Building Operation

Within the context of this report, fault detection and optimisation are changes or alterations to the building operation and mostly pertain to the area of controls involving very low or no investments. Measures, such as exchanging or refurbishing the building envelope or the system technology (both of which have large energy savings potential), are not considered here.

Fault detection and the optimisation of technical systems, as described above, have the prerequisite that “normal” operation (here considered to be the fault-free or optimal system operation) is known and can be compared with the actual operation.

Figure 15 shows a simplified schematic of the processes involved in fault detection and optimisation. In general, data are gathered from the system, edited and compared to suitable values representative of “normal” or optimal operation. A simple example is the specific electricity consumption of a building in kWh per square meter useful floor area for the previous year. This value is compared to the consumption of the previous year in order to determine any possible changes. If any significant variations are observed, an investigation is carried out to determine the causes. If need be, the system is modified. In order to guarantee continuous fault-free operation over the long term, this process must be run continually or at least in regular intervals.
Within the framework of this report, mathematical representations of real systems that provide quantitative statements about the system performance are called models. The German DIN V 18599, that provides a model for the energy demand of buildings and for the efficiency of its generation, can be used as an example here.

5.2 Differentiating between fault detection and optimisation

In order to investigate the possible areas of application more closely, a further differentiation must be made between the partial processes of fault detection and optimisation. The area of “Fault Detection and Diagnosis” is shortened to FDD in this report.

5.2.1 Fault Detection and Diagnosis (FDD)

Faults are conditions or events in building operation that hinder achieving both: a comfortable indoor climate and an efficient energy supply at the same time. A simple example here is a clogged filter due to lack of maintenance. The resulting increased head loss leads to either supply problems (a too low volume flow at constant pressure) or to an increased energy consumption (increased head loss at constant volume flow).

Faults are thus defined as an unintentional worsening in the scheduled operation.

The cause of faults can lie in insufficient planning or implementation, false operation or poor maintenance. Typical mistakes in building operation are, for example:
• Scheduling problems
  Drives like pumps and fans are operated during the entire day and on the weekend, even when they are not required and even without the operator’s knowledge.

• Simultaneous heating and cooling
  Due to incorrect set points, the same zone is simultaneously supplied with heating and cooling energy, thereby increasing the energy consumption.

• Faulty controls
  The desired comfort or planned energy efficiency is not reached due to programming mistakes in the system control, despite correct specification, or the sensors or actuators are not positioned correctly.

• Deactivated or falsely set controls
  When problems appear, the controls are often taken out of operation or rudely adjusted, in order to compensate for other defects in the system.

• Calibration is lacking
  Sensors which are used for controlling systems give invalid values due to lack of calibration or calibration that was falsely performed. As a result, these values negatively influence the indoor climate and/or energy consumption.

• Lack of maintenance:
  Due to lack of maintenance, the function or efficiency of the components is limited.

• Lacking hydraulic balancing
  Pipe and duct systems are often not hydraulically balanced, especially after reconstructions or changes in use. Generally this results in increased energy consumption and/or decreased comfort.

• Under- or Over-Dimensioning
  Many HVAC systems are under- or over-dimensioned. This leads to inefficient operation.

FDD aims to recognize and diagnose faults quickly, systematically and – as far as possible- automatically before additional damage to the system occurs or before the system fails. This is achieved by a combination of continuous monitoring and analyzing the data for faults. To this purpose, numerous methods, applicable for single components as well as for entire buildings, have been developed and tested in the scientific field (Annex 25 1996), (Annex 34 2001), (Annex 40 2005), (Katipamula and Brambley 2005, part II). In section 5.4, these will be considered in more depth.
5.2.2 Optimisation

Within the context of this report, the optimisation requires a functional and controllable system after basic faults have been removed. Within the framework of the optimisation, the energy efficiency of the system and/or the indoor climate is improved under consideration of the current boundary conditions. These are, for example, weather, comfort requirements or the presence of people.

As apportioned to FDD, optimisation can be described as targeted improvements of the scheduled operation or its adjustment to the currently imposed boundary conditions.

Some typical approaches for optimising building operation are:

- Optimising operating schedules:
  With consideration to the current and perhaps future (predictive controller) requirements, the operating schedules of systems like heating and air-conditioning systems can often be appreciably reduced. Especially with consideration to the primary building mass, interesting options for energy and cost savings can emerge.

- Optimising set points:
  The adjustment of set points (e.g. supply temperatures of the heating and cooling) is closely related to the first point described above. Adjusted operating schedules require, as a rule, an “intelligent” control of the system set points in order to avoid a loss of comfort.
  Furthermore, the distribution losses in the system, the COP of energy generation or the fan efficiency are significantly influenced by the given set points (temperatures, volume flow, mass flow).

- Selecting the best supply
  Systems with more than one supply unit (e.g. several chillers) are not necessarily operated so that the generator with the currently highest efficiency is always chosen. Dependent on the boundary conditions (e.g. weather, indoor comfort, presence of persons), large energy savings can be reached with a suitable control strategy.

By the implementation of optimisation strategies, it can be differentiated between two principally different cases:

- Off-line optimisation
  In this case, the building operation, is optimised externally. This means that the building is simulated off-line, where certain user profiles and suitable weather data sets are assumed. The optimised control parameters are then passed back (at first manually) and used for the building operation.
  The aim here is to determine general control strategies for the systems in the building in order to minimize the annual energy consumption or the annual energy costs.
• On-line optimisation
  Predicative or learning controllers aim to optimise the system by making use of the current or future building situation, e.g. the current boundary conditions in terms of weather, indoor climate or presence of persons. From this information, the real operation can, theoretically every hour, be optimised. In practice, this type of optimisation requires a large technical effort, and as part of the building automation, necessitates a close coupling with the sensors and the actuators.

In the scientific field, numerous approaches have already been developed and tested for optimising the operation of HVAC systems (Wetter 2004). In section 5.5 this is considered in more depth.

In the practice, the system operation is often optimised manually. Even during manual optimisation computer models are sometimes referred to for assistance in a trial and error approach.(Claridge 2004).
5.2.3 FDD and Optimisation as Process

As shown in both of the previous sections, FDD is a necessary prerequisite for achieving a fault-free operation and is therefore a pre-step to the optimisation. As a result, a two-step process exists, which is schematically shown in Figure 16.

![Diagram](image)

Figure 16 Process structure by fault detection and optimisation in building operation

The process begins with data acquisition which can be a part of the building automation in the ideal case. Information about the building in the form of measurement data, set points and status information as well as stock data are gathered.

The fault detection and diagnosis are part of the first step. The fault detection can take place either manually (e.g. by the operating personnel) or automatically. When a fault is detected during operation, a fault diagnosis is carried out whereby the cause for the fault is investigated. Whether or not a fault is judged to be critical or not depends on the given boundary conditions with respect to energy, costs and indoor climate. These factors are weighted according to their importance from the viewpoint of the building operator or owner.

When all critical faults are remedied, the optimisation can take place to generate specifications for the set points of the system operation. Before these set points are fed into the building automation system, a plausibility test should be carried out. This test should determine if all requirements have been considered and question whether all of the named requirements make sense.
To ensure the energy efficient operation over the entire building lifetime, it is decisive that this process be performed continually at regular intervals in order to be able to react promptly to any changes. These changes can be intentional (e.g. building renovation, reconstruction of part of the building) as well as unintentional (e.g. degradation of an energy supplier due to a fault.)

5.3 Models

Models are understood to be representations of systems where conclusions can be drawn about the system performance under given boundary conditions. In a suitable model it is attempted to reduce the complexity as much as possible without losing the details which are necessary and important for the system description. The complexity is reduced as much as possible to simplify the model development and the model validation as well as to achieve fast calculation time. Models can be considered on different levels. The actual systems are depicted in terms of mathematical formulas as physical or as conceptual models as shown in Fig 5.3. In most cases, these mathematical formulas must be implemented using numerical methods.

![Figure 17 Model and validation levels (Palomo del Barrio and Guyon 2002)](image)

In order to be able to better describe different types of models and their applications, a short description of the general make-up of models is given in the following.

The central parts of a model are the mathematical calculations for connecting inputs, outputs and parameters that are part of the model structure. The the representation of the inputs and outputs and the parameters at the border of the model shown in Fig 5.4 indicates that these are influenced by outer forces. Input parameters and parameters are specified by analysts or taken from other models or processes. In the same way, the output data can be used for other models or for evaluation by the analysts. The module structure, on the other hand, remains unchanged.
An important aspect of this representation is that all of these types of models can also be used as sub-models. Sub-models make up parts of the model structure in larger models.

Dependent on the type or the physical relevance of the parameter, it should be differentiated between the following types of models:

- **White Box Modell**
  Physical model with exclusively physical meaningful parameters (internal structure of the model is modelled)

- **Black Box Modell**
  Non-physical model (e.g. statistical/stochastic) without physically relevant parameters (internal structure is not modelled)

- **Gray Box Modell**
  Model form combining both the white and black box models

Before the individual types of models are described in more detail, the calibration of models is presented first in the following section.

5.3.1 Calibration of Models

Models can generate the building and system specific values for the “normal” or optimised operation. These calculated values are used for comparison and are of special interest for fault detection and optimisation.
As a rule, it is necessary that the parameters of the model be fitted to the actual, or real, system. This process is called “model calibration”.

In creating the model, it can be differentiated between two different types with respect to the parameter specification. These are called forward modelling and inverse modelling (ASHRAE 2001).

- **forward modeling**
  In forward modelling, it is assumed that all of the necessary modelling parameters are adequately known so that a realistic model of the actual system can be created. For most of the models, this assumption is valid for only some of the parameters. Therefore, this type of modelling is limited, for the most part, for use in the planning phase of new systems. The term “forward” here shall imply that there is no back coupling to measurements. Most of the models that fall under the forward modelling category are based on fundamental principles and therefore require parameters like material characteristics, which are well-known.

- **inverse modelling**
  As opposed to forward modelling, some or all of the parameters are estimated in inverse modelling using measurements of the input and output quantities of the system. These estimates can be performed manually or automatically. Here the aim is to fit the calculated parameters to the measured values of the system in the best possible way. This process is called model calibration.
  As a general rule, only simple models are suitable for determining the parameters using the inverse modelling procedure. This is especially true for models where the parameters are estimated in an automated procedure. Here so-called “black box” models that do not contain any physical parameters are used.

In the practice and in scientific investigations respectively, one often finds models made up of a combination of the above-named modelling methods. Many models contain parameters that can be determined sufficiently based on the know-how of analysts (forward) as well as parameters that are determined using measurement data (inverse). Typical examples for parameters that are suitable for forward modelling are the thermal conductivity of building components such as the external wall or the roof. An example for a parameter that is suitable for inverse modelling is the effective building mass.

In order to make reliable prognoses about the behaviour of real systems, it is imperative to calibrate models that are to be used for fault detection and optimisation. As a result, inverse modelling is always chosen (at least for parts of the modelling) for models that are used in the area of fault detection and optimisation. Certainly the
degree of the automation in the calibration process, or estimation of the parameters, can vary greatly depending on the model and the available measurement data.

Figure 19 shows a schematic of the calibration of a black box model. For the calibration, a so-called training data set is used. This data set contains the measured input and output quantities of the real system over a given time period. The model parameters must now be adjusted so that the model can replicate the relationship between the input and output quantities of the training data set with sufficient accuracy.

As a rule, calibration is an iterative process by which the output parameters of the system can be calculated with the assistance of the model structure, the measured inputs and the known, or estimated, parameters. The calculated outputs of the model are compared to those quantities in the training data set. If significant variations occur, the parameters must be fitted appropriately and the system output then newly calculated. If the discrepancy is small enough and thus the model output acceptable, then this process can be aborted. In some cases, the model structure may have to be adapted. This must be performed manually in most cases. At the end of this process, the calibrated model is available for use in fault detection and optimisation.

Dependent on the model type, the type and number of parameters and on the available measurement data, the parameter fitting can be performed automatically or manually. (See following section).

It must be taken into consideration that the calibration is not a one-time procedure, rather it must be repeated, if need be, as soon as the system shows signs of any significant changes.
5.3.2 Overview of Model Characteristics

In the previous chapters various model structures to represent technical systems were described. This paragraph summarises the most important characteristics of model production, calibration and application for fault detection and optimisation. See Table 4 for an overview.

<table>
<thead>
<tr>
<th></th>
<th>White-Box</th>
<th>Grey-Box</th>
<th>Black-Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehension of physics</td>
<td>+</td>
<td>o</td>
<td>-</td>
</tr>
<tr>
<td>Number of parameters</td>
<td>-</td>
<td>o</td>
<td>+</td>
</tr>
<tr>
<td>Complexity of creation</td>
<td>+ / -</td>
<td>+ / o</td>
<td>+</td>
</tr>
<tr>
<td>Calculation Speed</td>
<td>+ / o</td>
<td>+ / o</td>
<td>+</td>
</tr>
<tr>
<td>Necessary Training Data</td>
<td>+</td>
<td>o / -</td>
<td>-</td>
</tr>
<tr>
<td>Complexity of Calibration</td>
<td>+ / -</td>
<td>+ / -</td>
<td>+</td>
</tr>
<tr>
<td>Extrapolation</td>
<td>+</td>
<td>o</td>
<td>-</td>
</tr>
<tr>
<td>Portability to other Systems</td>
<td>+</td>
<td>+ / -</td>
<td>- *</td>
</tr>
<tr>
<td>Usable for FDD</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Usable for Optimisation</td>
<td>+</td>
<td>o</td>
<td>-</td>
</tr>
</tbody>
</table>

* only with new training data

Essentially, White and Black Box models are opposites. Whilst White Box models have very good analytical capabilities, they are often more costly to produce and calibrate; the reverse is true for Black Box models. It is not necessarily true, however, that White Box models (when of simple structure and consequent reduced prediction accuracy) are more difficult to produce than Black Box models.

To gain an understanding of the system, White Box models are initially very sensible. It is hence advisable to search for a way to allow a White Box model to be produced with the simplest of assumptions, which can be enhanced later, either with greater detail or with a matching Black Box model (Lebrun 2001).

On the other hand, Black Box models are most suitable for rapid and easy identification of patterns (e.g. usage profiles for buildings) and the recognition of outliers from the "normal" pattern. The patterns identified can additionally be used as input values for other, more detailed models. In particular, for complex processes, of which the "internal structure" is unknown, or not known in detail, Black Box models can prove to be helpful.
5.3.3 Tools for the creation of models of buildings and HVAC

An comprehensive overview over calculation tools for buildings is given on the internet site of the United States Departments of Energy (DOE, Building Technologies Program)\(^\text{17}\). Over 200 Softwaretools are documented there.

Tools for creation of models fall into various categories. Along with simulation environments that are specially designed for building simulations, there are general simulation tools and general numeric tools. The individual categories are covered in brief below

**Specialised Simulation Environments**

Generally this is a matter of a combination of the component library and solvers. Typical examples of these traditional building simulation programs are: DOE2\(^\text{18}\), ESP-r\(^\text{19}\) or TAS\(^\text{20}\).

Many of these simulation programs operate with models having a medium to high level of detail, i.e. they are multiple zone models with algorithms for heat transfer in multi-layer building components, ventilation, solar and internal gain, HVAC systems and control. It must be appreciated, however, that HVAC system models often do not have the same level of detail and scope as building models.

In many cases what is required is the ability to simulate a period of a year with a time resolution of an hour or less. This carries a considerable calculation cost, which has led to a situation where, at the beginning of the development, numerical aspects played a significant role and the simulation programs (models) were specifically optimised for high calculation speeds. A high level of modelling flexibility or a specially clear and comprehensible implementation of the physical principles was of no concern. This has the disadvantage that the implementation of changes and enhancements at a later stage is both difficult and costly (compare Figure 20).

![Figure 20](http://ourworld.compuserve.com/homepages/eds/)
Due to the increased calculation performance of computers, the costs of the calculation requirements of many projects/cases is now very much less than the cost of the production of the simulation models and the integration of new models. This means that today a high level of modelling flexibility, or a particularly clear and comprehensible implementation of the physical principles is of rather more interest. A modelling structure for this is the so-called “equation-based approach”, where the physical equations are also transferred to the simulation program as a component of the simulation model. This enables them to be matched to the current problem in terms the level of detail and in relation to the linkages (Sahlin 2000). The disadvantage of equation based structures is the high calculation expense (see Figure 21).

Figure 21 Task distribution for equation based methods

At scientific conferences in relation to buildings (construction physics, IAQ (indoor air quality), HVAC, air conditioning, building simulation) a large number of new mathematical/physical models (in the form of equations) have been presented (Sahlin 2000; Sahlin, Eriksson et al. 2004). The advantage of equation based simulation structures is that such new models can be directly integrated into simulations. This means that the community that can take part in the further development of the simulation tools can be substantially widened. For the integration of new physical models, no special numerical knowledge is necessary.

With TRNSYS21, that was developed in 1973 (Klein 1973) for the simulation of solar installations, certain elements of equation based models were put into practice. It allows the free linkage of subordinate models and the integration of algebraic equations. Modelling with equations was not seen as the primary interest here, but merely as an enhancement opportunity.

The only example of an equation based simulation tool produced specially for buildings and installations simulation is IDA-ICE22.

21 http://sel.me.wisc.edu/trnsys
General Simulation Tools

In principle these tools allow any system to be represented. Typical examples of this group are: Matlab/Simulink\(^{23}\), Dymola/Modelica\(^{24}\), Mathmodelica\(^{25}\), IDA-SE or EES\(^{26}\). Generally, these tools belonged to the “equation based” type and were used successfully for buildings and in particular in the field of buildings control (Adam, André et al. 2006).

Whilst Matlab-Simulink is a quasi industrial standard (in particular in the sphere of control), in the last few years Dymola/Modelica has become more significant.

Equation-based tools often allow the integration of traditional components, so that in critical cases the calculation performance can be improved.

General Numeric Tools

In the sphere of Black Box models in particular, further numeric tools, above all, are required to provide the appropriate algorithms for the calibration of models and the optimisation of systems.

This principally concerns differing minimisation algorithms (linear, non-linear) and special statistical processes (e.g. robust linear regression). These tools will therefore generally be used not for the simulation of dynamic systems, but for data analysis, the calibration of models and optimisation. Examples are: Matlab\(^{27}\), R\(^{28}\), scipy\(^{29}\), GenOpt\(^{30}\) or octave\(^{31}\).

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23 http://www.mathworks.de
25 http://www.mathcore.com
26 http://www.fchart.com
27 http://www.mathworks.de
28 http://www.r-project.org
29 http://www.scipy.org
30 http://gundog.lbl.gov/GO
31 http://www.octave.org
Since the mid 1970s, model-based fault detection for technical systems has become increasingly important in science and technology. The exploration of space, air travel and the chemical industry were the main reasons for this development (Isermann 2006), (Venkatasubramanian 2003, part I), (Venkatasubramanian 2003, part II), (Venkatasubramanian 2003, part III).

Automated fault detection and diagnosis in building operation is a relatively recent discipline. A number of approaches have been tried, mainly in the field of science, but only during the last 10 years or so. A good overview of the subject is to be found in (Katipamula and Brambley 2005, part I; Katipamula and Brambley 2005, part II).

It must be noted that fault detection and diagnosis are two separate processes. While fault detection is aimed at the detection of deviations from the "normal" behaviour of a system, fault diagnosis is designed to find the cause of the deviation. However, in order to be able to deduce the cause of the faults from the symptoms, it must first be established what effect certain operating faults have on observed or measured signals. Fault diagnosis therefore requires more information than can be provided by a model alone. In the simplest case, allocation of symptom and fault must take place even if the model is capable of representing faulty behaviour (creating a fault model). That is why models are mainly used for fault detection.

FDD in a building can be applied at various levels. For example, correct operation and efficiency of individual components such as chillers or heating coils can be monitored. FDD can also be applied to specific systems (e.g. a heating system with all its components, such as generator, storage, distribution etc.) or to the entire building. There are various methods, depending on the level at which it is to be applied.

Ideally, applications would complement each other, so that monitoring of individual components and also monitoring of overall efficiency and comfort are carried out. However, the current situation is far from achieving this goal.

Up until now, most FDD methods were developed for individual components whose design and thermodynamic behaviour are already known (see (Katipamula and Brambley 2005, part II)). Special FDD methods are developed on the basis of individual faults (e.g. loss of coolant in a compression chiller). This detailed knowledge of the system is typical of FDD at component level and distinguishes it in principle from FDD operating at system or building level.

At system or building level, system structure and parameters are often not completely known (think, for example, of the effect of occupants' behaviour on energy consumption in a building). An accurate representation of the system or of individual faults is only possible to a limited extent. For that reason, visualization techniques or statistical methods (models) are often used, thereby allowing detection of outliers. In more complex systems, fault analysis is often carried out manually by an analyst.
From a practical point of view, to reduce the number of measuring equipment to a minimum, it is particularly important to be able to deduce lower level faults from higher level signals for the entire building.

5.4.1 Method classification

(Isermann 2006) provides a comprehensive general overview of existing methods of fault detection and diagnosis for technical systems and proposes a classification system. (Katipamula and Brambley 2005, part I) and (Venkatasubramanian 2003, part I) provide other methods of classification. However, under their classification systems, fault detection and diagnosis methods are not clearly separated, and therefore Isermann’s classification seems more suitable for this report. His classification will be explained here, followed by examples of application to building technology.

Fault Detection

Isermann first of all classifies each method according to the way in which reference values for the process are produced:

- Threshold values / trends
  This relatively simple procedure checks whether a selected measurement (signal), or its time derivative, breach a given threshold value. Frequently statistics such as mean values are used.

- Signal models
  Signals emanating from processes frequently display oscillating behaviour (harmonic or stochastic). For signals of this kind, black box models, for exam-
Building EQ – The EPBD and Commissioning

ple on the basis of correlation analysis, Fourier analysis, ARMA models or wavelet analysis, can be created. If changes in the signals are connected to faults, these can be detected with this method. The difference from process models lies in the fact that for the most part only output signals, but not input parameters are included.

- Multivariate data analysis
  It is possible to use multivariate data analysis, such as principal component analysis (PCA), for processes in which the creation of a model-based analysis would be difficult due to size or complexity. This procedure is especially suited to processes in which measured signals show a high correlation. The basic idea of PCA is to reduce the data volume by using existing performance data to create a few “artificial” variables that are uncorrelated and display the “trends” of the greatest variances of the data volume. This allows changes in these new “main components” to be detected.

- Process models
  Fault detection by means of process models offers a variety of options. Most often calibrated models are used to create reference values for the process output variable. If model predictions and the process output signal differ, this may point to a fault.
  Other approaches compare parameters of the real system to those gained from a parameter estimation with a model. Furthermore models can be used to calculate states such as temperatures to be compared to measured values.

Fault diagnosis

The objective of diagnosing faults is to detect the location, type and scope of the underlying fault from the symptoms. This assumes knowledge of the relationship between symptoms and faults. Two cases can be determined in this way:

- Causality of fault and symptom not known
  In this case classification methods can be called upon for diagnosing faults. These methods seek to classify faults arising based on similar symptoms. The categories must be identified through experiments or via “learning”, thereby creating an unstructured knowledge database.

- Causality of fault and symptom known
  Where the causal relationship between the fault and symptom is known, the fault can be detected via inference methods. Depending on whether the symptoms observed are discrete (or binary) or of a continuous nature, different procedures can be deployed for deducting or evaluating them.

32 By linear combination of the measured variables
Figure 23 gives a rough overview of the various methods that exist, which is also obtained from (Isermann 2006).

5.4.2 FDD in the field of building technology

As already mentioned, the research on and application of techniques for fault detection and diagnosis in buildings is a relatively new discipline. The increasing interest in research within this field over the last 10-15 years is demonstrated by the setting of priorities by the International Energy Agency (IEA) in various annexes to the Energy Conservation in Buildings and Community Systems (ECBCS) programme.

IEA ECBCS annexs

The “Building Optimisation and Fault Diagnosis Source Book” was published in 1996 as a result of IEA ECBCS Annex 25 (“Real Time Simulation of HVAC Systems for Building Optimisation, Fault Detection and Diagnosis”, 1991-1995) (Annex 25 1996). The subject of FDD in buildings is described here as a new or future task. The Source Book gives a comprehensive overview of the most common faults in building technology systems, and FDD methods in general. Based on the objective of analysing faults with the help of process models or simulation, numerous component models have been developed and assembled. The following systems were observed – oil-fired boilers, chillers, heat pumps, ventilation systems and storage. One of the many recommendations was to keep models as simple as possible, which led to the frequent use of static models. The annex gives a good theoretical overview (probably for the first time in this scope), but without evaluating the methods via field studies. This was the impetus for the follow-on project.
This follow-on project was IEA ECBCS Annex 34 (“Computer-Aided Evaluation of HVAC System Performance”, 1997-2001) (Annex 34 2001), the results of which were summarised in 2001 in the report “Demonstrating Automated Fault Detection and Diagnosis Methods in Real Buildings”. This contains numerous case studies of FDD in buildings using various tools. More than 26 tools were tested in over 20 buildings. In contrast with Annex 25, this includes FDD methods that may be used not only with regard to components but also in respect of the whole building. These are some of the conclusions at which the authors arrived:

- The diagnosis of faults in building technology on the basis of available measurement data from routine operation is difficult. It is often only possible to detect faults. FDD is an option particularly for individual components that are mass-produced and where the normal “behaviour” and characteristics are well known.

- It should be possible for the user to adjust the threshold values for detecting faults.

- FDD tools must take into account the different operating conditions of a system in order to avoid false alarms. Measurement data should therefore be available for these operating conditions.

- The integration of fault detection with regard to components and an overall analysis in respect of the whole building are recognised as one of the next research projects.

- The costs of installing and configuring an FDD tool must be considered by way of a cost-benefit analysis as these may be considerable.

A further follow-on project was initiated by IEA ECBCS Annex 40 (“Commissioning of Building HVAC Systems for Improved Energy Performance”, 2001-2004) (Annex 40 2005). The annex is the result of the experience of many researchers in the field of FDD in buildings, that most buildings serving as demonstration projects (e.g. in IEA Annex 34) were never run correctly or efficiently. It was therefore evident that a project should be initiated involving the commissioning of equipment in building technology.

Commissioning is not intended as a one-time process but a continuous or repetitive procedure, which is required for a building to be permanently run on an energy-efficient basis. Thus, one of the terms introduced is “continuous commissioning”, which has since been copyrighted as a word (Texas Engineering Experiment Station, TEES, tees.tamu.edu). In the context of this process in turn FDD methods are being used.

As well as the use of concepts and models, which were already developed in the preceding projects, a higher meaning pertains to the practical constraints in Annex 40. Questions such as the organisation of the commissioning process, the use of building automation systems for FDD and the visualisation of data are dealt with in detail.
The authors of the final report found that the building automation system is an important module for continuous FDD, due to the diversity of information that it provides. At the same time, communication problems due to the variety of different protocols in the field of building automation are perceived as a hurdle.

It is also stated that only few FDD tools are actually used in practice.

The current IEA ECBCS Annex 47 (“Cost Effective Commissioning of Existing and Low Energy Buildings”, 2005-2008) takes up these questions and tries to develop methods and tools that are suitable for use in practice.

This short summary of the IEA ECBCS annex tends to show the development of FDD in buildings from the theoretical “model-driven” perspectives of the early 1990s up to the “application-driven” viewpoints for the use of the methods in practice and the surmounting of the problems associated with it today.

Status quo

Katipamula (Katipamula and Brambley 2005, part I; Katipamula and Brambley 2005, part II) gives a current summary of the situation of FDD in buildings, which is also independent of the IEA ECBCS annexes. In a review article he evaluates over 100 publications on the topic.

He finds that most of the studies completed at the time of the publication (2004) were concerned with individual components or systems. In his article he only presents works which deal with compact air-conditioning equipment, heat pumps, compression chillers and air handling units.

Most of the studies deploy simplified physical models (white box) or black box models in the form of regression models, neural networks or ARX models. Detailed white box models are rarely used.

It is mainly classification methods that are used for diagnosis, giving the character of the residuals (difference between the output signals of the model and the real system). The procedures are used to detect faults with characteristics that are known from experiments or simulations. Although most authors (irrespective of the procedures selected) report that the procedure they used was able to detect the faults sought, Katipamula objects that most surveys were only carried out in the laboratory and not in the field.

Moreover, Katipamula arrives at the following results:

- Only very few products for FDD exist on the market and these are usually very specialised (for individual components) and not automated.
- The (automatic) generation of fault threshold values for detecting faults has not yet been studied in depth, but represents an important aspect in automation.
- The calibration of models requires training data on correct operation. To apply the model on a broad basis it is necessary to develop the model either during
the manufacture of the components in the factory, or automated during operation (online). There is still a need for research, particularly on the second approach. Deployment in existing buildings is seen as problematic because measuring data for correct operation is required for the calibration of the model. In existing buildings it is much more likely that equipment and components were not being run correctly before an energy audit.

- Most of the studies mentioned work with procedures for fault diagnosis, whereby significant faults arising singly can be detected. Detection of several faults arising at the same time is thereby not possible. There is also a need for research in this area.

- In general, the amount of measured data available in buildings and its quality is low. The development of cost-effective and reliable sensors is therefore an important step to the spread of FDD in buildings. The gradual introduction of open communication standards in building technology is seen as a major opportunity.

- There is not enough information on the cost-benefits relationship of FDD in buildings.

In Katipamula’s view there is a great need for research in the field of FDD in buildings, particularly with regard to practical use and automation.
5.4.3  FDD products available on the market

Table 5 shows a summary of FDD tools that have been developed in the context or scope of the IEA Annex and which are currently available on the market.

Table 5  Overview FDD Tools

<table>
<thead>
<tr>
<th>Tool</th>
<th>Level</th>
<th>FDD-Method</th>
<th>Coupling with BAS</th>
<th>remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>component</td>
<td>system</td>
<td>building</td>
</tr>
<tr>
<td>Energy Witness</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>ENFORMA</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
</tr>
<tr>
<td>PACRAT</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Universal Translator</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>EMMA-CTA</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Energy Expert</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>DABO</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>ABCAT</td>
<td>x</td>
<td>(x)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>WBD</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>CITE-AHU</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

Further Information / provider:
1) Interval Data Systems (www.intdatsys.com)
2) Architectural Energy Diagnostics (http://www.enformadiagnostics.com)
3) Performance and Continuous Re commissioning Analysis Tool (PACRAT), Facility Dynamics Engineering (www.facilitydynamics.com)
4) Universal Translator, PG&E (www.utonline.org)
5) EMMA-CTA, FAULT DETECTION AND DIAGNOSTIC OF AIR HANDLING UNIT, CSTB (http://software.cstb.fr)
7) Diagnostic Agent for Building Optimisation (DABO) Natural Resources Canada (www.nrcan.gc.ca)
8) Automated Building Commissioning Analysis Tool (ABCAT), Texas A&M University, (www.esl.tamu.edu)
10) Commissioning the Installation and Technical Equipment-Air Handling Units (CITE-AHU), NIST / CSTB (www.bfrl.nist.gov)
None of the abovementioned tools are more than 10 years old, and few are more than 5 years old. This illustrates, once again, that the discipline is relatively new. There are no figures for the distribution (number of licences) for the individual tools.

Alongside the characteristics mentioned in Table 5, most tools demonstrate extended functions for acquiring and processing data (creating “virtual” or calculated data points and filtering data). Administration or database functionalities, such as the gathering and presentation of tariffs, costs or cost centres, are often provided in addition.

The overview illustrates the following points:

- Visualisation is the only functionality common to all tools. In the product description this function is often also emphasised as an “intuitive” interface with the user. The type of visualisation usually clearly goes beyond the pure time series presentation (e.g. XY diagrams or carpet plots). Other functionalities in common across many tools are filters or data groupings.

- Almost all tools have interfaces for direct coupling to building automation. This functionality is often also emphasised by the providers as an important characteristic. Only in this way is continuous monitoring possible.

- Almost all tools use either rule-based methods (based on if-then statements) or black box models for fault detection. The rule-based methods are often used for individual components or sub-systems (e.g. ventilation system), in which a manageable number of rules (or faults) can be defined based on a fixed set of measuring data (e.g. CITE-AHU has around 60 rules to detect faults in ventilation units). Black box models are mainly deployed in the form of regression models (e.g. PACRAT) or neural networks (e.g. WBD). They are used to identify a baseline of the consumption, which is used to detect unusually high or low consumption, i.e. the baseline represents “normal” (i.e. available) energy consumption and can therefore be used to identify aberrations but not for optimisation.

- White box models are only used with one tool (ABCAT). Though these are very often used for American-style ventilation systems. The model illustrates a ventilation unit with an associated zone (static). Heating and cooling of the zone are carried out exclusively via the air handling unit (“all air system”). Although the approach of a simple, physically based model appears appealing in principle, the model cannot be easily transferred to European systems, which display a high degree of design variance.

5.4.4 Summary

Overall, a picture is emerging of technology under development in the field of FDD in buildings, with numerous different approaches and little systemisation to be found in
the area of research. The variety of approaches that were studied in the research, the suitability of which is often only studied in the laboratory or in simulation calculations, is not reflected in practice.

There is a limited number of tools and many are still in development. For fault detection, they are very much focused on visualisation, simple rules for diagnosing faults in sufficiently well-known systems and black box models for determining unusual energy consumption.

It is worthy of note that physically based (white box) models have until now hardly played any part in practice, but have been - and still are - a main item of research. The obvious difficulties in integrating the system models for FDD in existing equipment clearly underlines the fact that the models used should be as simple as possible. Nevertheless white box models are of considerable interest, as in principle they not only detect deviations from “normal” operation but can also be used for optimisation.

The difficulty in introducing FDD into building operation, however, does not lie in the lack of available and validated models of building technology components and systems. What is missing is the systematic integration of individual approaches into an overall operations monitoring, which is not only able to monitor individual components but also the efficiency of the whole system.

FDD (particularly the diagnosis) with regard to the whole building or larger sub-systems, is clearly more difficult than for individual components, because knowledge of the system may not be complete. Only few approaches exist which study this question.

Another problem lies in the implementation. One of the greatest problems is presented by the acquisition and quality of data. Even in those cases in which a building automation system is available to supply data, sensors for structured collection of energy consumptions are often missing. Furthermore, the data technology linking to building automation systems is often associated with costs in the region of €5,000–10,000. The linking or even the integration of the FDD to/into the building automation system is viewed as an important step for its further dissemination.
5.5 Optimisation

Once the building operation is failure-free, optimisation measures can be implemented. In this regard, in addition to the question of how low is the optimum level of energy consumption, the question of how to achieve this is also crucial.

With optimisation, not only does there have to be a variance from optimum operation but also parameters indicating how the actual system can achieve this status, so, in contrast to failure recognition, it is usual to work with models based on basic physical principles. This is the only way of establishing the full extent of the optimisation potential, (Lebrun 2001).

Optimisation itself refers to the search for the parameters of the model which best achieve a given objective function, e.g. the minimisation of energy consumption or energy costs. In this respect, there are usually predetermined constraints which must be taken into account, such as the provision of a specified room temperature or the required operating periods.

In relation to optimisation problems, a distinction is drawn between local and global. In the case of global optimisation, the absolute minimum of all the permitted parameters must be found. Global optimisation is much more difficult. Here, subject to the available computational capacity, solvability depends greatly on the topology of the objective function.

In many cases, there are additional incidental or ancillary constraints which must be complied with during optimisation. Ancillary constraints may be formulated as equalities or inequalities, or require the permitted parameters to have a specific magnitude (e.g. natural numbers). Optimisation and fit methods are now being used in many areas, e.g. engineering science, statistics, physics, economics.

The following section first sets out the optimisation methods used in the building sector before going on to describe their use in the building sector.

5.5.1 Methods of Optimisation

Firstly, a suitable method must be found for determining the objective function, e.g. "energy consumption". In addition, incidental or ancillary constraints must be complied with, e.g. the principal functionality of the building must be ensured, i.e. specific temperature, lighting, ventilation requirements, among many other factors, must be safeguarded. Most buildings contain various different energy sources and their importance in relation to overall energy optimisation must be determined. Primary energy or energy costs are suitable for the overall energy parameter, both of which depend on the respective building and building environment (Ellis, Griffith et al. 2006). These optimisation processes involve minimisation problems, since the minimum objective function is being sought.

The effort involved in solving optimisation problems depends largely on the characteristics (form) of the objective function. In the case of continuously differentiable objective functions, there is a range of standard optimisation procedures, thus allowing for
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a simple and speedy solution\textsuperscript{33}. Where the independent variables of objective functions and constraints are linear, we talk about a linear program\textsuperscript{34}. In the case of a quadratic program, on the other hand, the objective function is quadratic, depending on the independent variables, but the constraints (inequalities are also possible) are linear. Reliable algorithms are available for solving both linear and quadratic programs.

Optimisation processes are divided up according to the type of objective function, e.g. scalar and vector (multi-criteria problem), linear (linear program), integer (integer program), quadratic (quadratic program), non-linear, stochastic, convex\textsuperscript{35}, concave. And for many types there are special methods. Non-linear programs (NP)\textsuperscript{36} are more difficult to solve than linear and quadratic ones, because both the basic solvability and the convergence characteristics are unknown.

A difficult area is the search for global minima or maxima (i.e. the optimisation of the objective function) in the case of non-linear problems, if the functions are not continuously differentiable and convex or concave. One example of this (in three-dimensional space) would be a horizontal surface containing holes of varying depths (i.e. not continuous, not differentiable). For such cases, it is only possible to use methods whereby the whole surface is systematically or randomly scanned. The search is even more difficult where the objective function is not unique, i.e. at a point within the parameter space, the objective function may assume more than one value depending, e.g., on the route used to get there.

In the field of building optimisation, it is mainly scalar objective functions which are used. There are also, however, examples of vectorial optimisation problems. These problems are also known as pareto optimisation. In this case, the values of a vectorial objective function\textsuperscript{37} must be optimised simultaneously. The difficulty exists in that the components of the objective function do not all reach an optimum level simultaneously. From the optima for the individual components, a single (overall) optimum point can then be determined. This may be achieved, e.g., by attaching varying weights to the individual components (i.e. referring back to non-vectorial optimisation). In the case of buildings, both energy and cost optimisation problems, in the planning and operational phase, are initially inherent multi-variable and multi-criteria problems (i.e. multidimensional, vectorial) (Ellis, Griffith et al. 2006). In most cases, however, it is advisable to refer back to scalar problems.

\textsuperscript{33} E.g. Newton Procedure, possibly only local extreme values
\textsuperscript{34} The word “program” is used to mean “optimisation methods” or “optimisation problem” (particularly in English). This is due to the developmental history of optimisation methods. It was first used for military problems (in America), where programs of actions were optimised. Program is often used in conjunction with optimisation problems with ancillary constraints.
\textsuperscript{35} For a continuously differentiable function, convex means f is convex when its derivation f’ is growing, and tightly convex when f’ is growing tightly monotone (analogous concave). A general formulation for non-differentiable functions is possible.
\textsuperscript{36} Non-linear programs (NP): objective function and ancillary constraints are not linear in the independent variables.
\textsuperscript{37} (i.e. several objective functions)
Generally, in the building sector, little is known about the characteristics of the objective function. Only in exceptional cases are there integer-based project definitions. Even the analytical characteristics of the objective function are generally unknown in the building sector, so one is unable to fall back on the methods of linear or quadratic programming.

Constraints for dependent variables can be taken into account by way of penalty or limitation functions (Wetter 2004).

Irrespective of the topology of the objective function, there is no optimisation method which can find a global extreme (minimum), with certainty or with a certain degree of probability. For certain types of objective function (e.g. linear or continuously differentiable, highly convex or concave) the global convergence of certain optimisation methods has proven itself. In relation to the building sector, these conditions for the objective functions do not generally exist, i.e. there is no method for achieving global optimisation, with any certainty.

Most global optimisation methods use a specific system to find local extremes (minima). There are many different methods which are also used for non-linear, non-differentiable and even non-continuous global optimisation problems. Some of these, which can be used in the building sector, will be looked at in more detail below.

For optimisation in the building sector, determining the objective function is generally time consuming and there are no established analytical characteristics for the objective function. For this reason, it seems advisable to avoid optimising too many parameters at a time and to restrict the parameter space to a reasonable size in order to keep the computational effort to a minimum and avoid futile local optimisation points.

**General Pattern Search GPS (General Pattern Search Algorithm, e.g. Hooke Jeeves)**

GPS algorithms are methods by which the domain of the objective function is systematically examined for extremes (minima). For this purpose, regular networks are defined and successively subdivided (Hooke 1996). In this regard, the search usually follows the coordinate axis in the domain of the objective function. If the objective function can be reduced with a step in one direction, the search continues in this direction, with increasing step sizes. If this ceases to result in a reduction of the objective function, the search starts again from the last (lowest) objective function value along all the coordinate axes (original step size). If no further reduction of the objective function can be achieved in any direction, the step size is reduced and the search

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38 Within the overall parameter space
39 The idea of challenging the search criterion is also interesting. Sometimes it is more advantageous to find an area with as many closely grouped local minima as possible, than to find a strictly limited global minimum.
40 Since for convex (concave) functions, no local minima exist in addition to the global, in relation to these functions, for all optimisation procedures for which proof of local convergence exists, global convergence is proved at the same time. With respect to objective functions in the building sector, it is not generally possible to draw any conclusions relating to convexity from building simulation programs.
41 Parameter space in the case of building simulations
is repeated. With the program GenOpt (Wetter 2004), which has been used many times in the building optimisation field, some improvements to the original algorithm of 1961 have been taken into account. In order to find the global minimum, the Hooke – Jeeves is started from many different starting points (Multi-Start). The advantages are: GPS algorithms (and therefore also the Hooke – Jeeves algorithm) require hardly any knowledge of the problem, i.e. they can also be used for discrete and non-continuous problems. The disadvantages are: Convergence towards the global optimum depends on the starting point. In the case of Multi-Start HJ the required computational period is relatively long.

Particle Swarm Algorithm (PSA)

The Particle Swarm Optimisation algorithm, first referred to in 1995 by Eberhart and Kennedy (Eberhart and Kennedy 1995) is a stochastic, population-based, heuristic optimisation method. Here a fixed, finite number of individuals or particles are tracked. These particles move within the parameter space, the objective function is evaluated at each location. The movements of the particles are modelled according to the social behaviour of e.g. flocking birds or schooling fish. Each particle tries to move in the direction of its own best location with the lowest objective function (cognitive behaviour) and in the direction of an even better location of another particle (social behaviour) (Wetter 2004, Simulation-Based...; Wetter 2004, GenOpt...). The advantages are: 1. PSAs require hardly any knowledge of the problem (e.g. gradients), i.e. they can also be used for discrete and non-continuous problems. 2. PSAs belong in the class of stochastic procedures and can therefore also be used for problems where traditional optimisation methods fail. The disadvantages are: 1. PSAs do not always give rise convergence towards the global optimum within an acceptable period of time. 2. The crucial disadvantage of PSAs is the relatively long computational period required for problems where traditional methods may also be used. Methods which use gradients in the search of the optimum, are many times faster.

It has already been shown that where such heuristic search procedures are combined with traditional methods, convergence can be improved without reducing the capacity to find the global optimum (Wetter and Wright 2003). PSA algorithms have already been successfully used in the building sector. Their effectiveness was comparable to GPS and GA (see below).

Evolutionary Algorithms (GA Genetic Algorithm)

Evolutionary algorithms are also heuristic procedures based on the principles of biological evolution. They are suitable for optimisation processes with a non-differentiable and non-continuous objective function. The genetic algorithm is very popular because it is easy to implement. Evolutionary algorithms are used where traditional optimisation methods do not achieve their purpose due, for example, to non-continuous and non-differentiable objective functions. GAs have proven to be especially effective where the condition of the local minima displays a regular structure within the parameter space. GAs are robust optimisation methods because they work with a large number of permitted solutions and, as a result, in the search for the op-
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timum, various routes can be tried and information about the various routes is even distributed via the entire population.

Typically, the following elements from evolutionary theory are implemented: 1. Selection, 2. Recombination (crossover) and 3. Mutation. The fewer individuals that survive (high selection pressure) and are incorporated into the new generation, the faster the procedure converges. At the same time, the probability increases that the global optimum will not be found. In many cases, it has proven to be advantageous to represent the numbers as so-called grey encoded binaries (Wetter and Wright 2003). In doing so, neighbouring (natural) numbers only differ from one another by one binary digit (Press et al 2003).

Simplex Algorithm from Nelder Mead

An additional optimisation algorithm which is often used for non-differentiable and non-continuous objective functions, and is therefore also used in the building sector, is the Simplex Algorithm from Nelder and Mead (Nelder and Mead 1965). This procedure is also known as the Downhill Simplex Procedure or the Simplex Algorithm. The name of the procedure is based on the simplex used, which is the simplest body (or polytope) in a n-dimensional space. The algorithm is iterative; the vertex with the highest value for the objective function (in the case of minimisation) is replaced by a new one.

The Downhill Simplex Algorithm displays approximately linear convergence with a very good level of stability in the case of non-differentiable and non-continuous functions. The result for functions with distinctive local minima depends on the starting values.

Newton Procedure

The Newton Procedure is a numerically iterative procedure for determining zero points of a continuously differentiable function. The procedure is not suitable, or of only limited value, for non-differentiable or non-continuous functions. Its use in the building sector therefore tends to be limited.

The Newton Procedure used for optimisation is based on the vanishing first derivative at the optimum of a twice continuously differentiable function. For the procedure to be used, the derivative need not be analytically known, it can also be determined numerically (e.g. finite differences). For \( f: \mathbb{R}^n \rightarrow \mathbb{R} \), the calculation of the inverses on the Hessian Matrix (second derivation in the denominator) can be left out in favour of implicit procedures. These procedures are faster and sometimes more stable than the normal Newton Procedure. They are known as Quasi-Newton Procedures. As an example for this sort of procedure, we refer to that of Davidon, Fletcher and Powell (DFP Procedures).

Particularly good convergence properties are achieved by the so-called Conjugant Gradient procedure (CG), however, it is only applicable in areas with a positively de-
fined Hessian Matrix. More suitable numerically are procedures with a Preconditioned Conjugant Gradient (PCG).

In the case of twice continuously differentiable functions, the Newton procedures feature high convergence speed. In the case of objective functions, with unknown analytical characteristics, it is advisable to test first whether a Newton procedure converges.

Additional Optimisation Procedures

Another, very stable group of optimisation algorithms belongs to the so-called Simulated Annealing. This stochastic optimisation algorithm is suitable for global optimisation processes of non-differentiable and non-continuous functions, the algorithm is therefore suitable for building problems. Convergence is slower than gradient-based methods.

In other areas with optimisation problems similar to those of the building sector, a large number of other algorithms are used, such as e.g. Sequential Qadratic Programming (SQP), great deluge algorithm, metropolis threshold accepting algorithm, stochastic tunnelling. And in each case there are a multitude of sub-variants and variations of the algorithms for specific applications. Furthermore, numerous combinations of different optimisation algorithms exist (e.g. PSA combined with Hooke-Jeeves (Wetter 2004))

5.5.2 Summary of Optimisation Procedures

Since continuously differentiable objective functions are substantially easier to optimise, it is worthwhile formulating building simulations mathematically in such a way that the corresponding objective function meets this condition. The literature contains an example of a building simulation program developed specially with this aspect in mind (Wetter 2004). Since, however, in the case of building control systems, on-off switches are generally used, a consistent description with continuously differentiable functions is difficult and sometimes artificial. In addition, the numerical determination of objective functions in the building sector can lead to discontinuities (Wetter 2004).

Due to these characteristics of the objective functions in the building sector, the robust, stochastic optimisation procedures are often used (see Table 6), although the number of iteration steps or building simulations is being increased in this regard.

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42 Often in the case of building simulations
### Table 6: Examples for various types of optimisation problems and possible solving methods

<table>
<thead>
<tr>
<th>Optimisation Problem</th>
<th>Solving Method</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Program</td>
<td>Simplex Algorithm(^43), Inner-Points-methods</td>
<td>In building optimisation rarely used</td>
</tr>
<tr>
<td></td>
<td>Integer Program</td>
<td>Heuristics: Local Search, Taboo Search, GA, Simulated Annealing, Exact methods: Branch-and-Bound (\sim), Branch-and-Cut (\sim)</td>
</tr>
<tr>
<td></td>
<td>Quadratic Program</td>
<td>Newton-Type e.g. Quasi-Newton CG</td>
</tr>
<tr>
<td><strong>Non-linear Optimisation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>one Variable</td>
<td>Golden Section …</td>
<td>In building optimisation rarely used</td>
</tr>
<tr>
<td><strong>Multi Variable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without constraints(^44), continuously differentiable</td>
<td>Newton-Type e.g. Quasi-Newton CG</td>
<td>In building optimisation rarely used since constraints usually make sense</td>
</tr>
<tr>
<td>Without constraints, local, discontinuous functions</td>
<td>GPS, Down-Hill-Simplex, PSO, GA, (^45)</td>
<td>In building optimisation rarely used since constraints usually make sense</td>
</tr>
<tr>
<td>With constraints, continuously differentiable, local</td>
<td>SQP, Newton-Type with penalty functions</td>
<td>Use in building optimisation not safe because usually analytical properties are not known, should be tested since fast</td>
</tr>
<tr>
<td>With constraints global, continuously differentiable</td>
<td>Multi start: Newton-Type, SQP, GPS combination Newton-Type</td>
<td>(^46) Use in building optimisation not safe because usually analytical properties are not known, should be tested since fast</td>
</tr>
<tr>
<td>With constraints global, discontinuous</td>
<td>PSO, GA, Multi start GPS, Down-Hill-Simplex, Multi-start Newton-Type</td>
<td>Usually used in building optimisation</td>
</tr>
</tbody>
</table>

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\(^43\) Not to be confused with the Downhill-Simplex-Algorithm

\(^44\) alternatively global for convex / concave functions

\(^45\) Newton-Methods can be tested, possibly successful if optimum is not at the discontinuity

\(^46\) Information on global or local optimum hardly available
5.5.3 Implementation of the Optimisation

We differentiate between two different types of operation optimisation implementations. (1) **Offline-optimisation** works by simulating and optimising the control parameters independently of the current situation of the building. Thus this is not a continuous process related to the building (see Figure 24). (2) By contrast **online-optimisation** is a continuous process coupled directly to the controller. Current building state and possibly some predictions (e.g. daily power or climate predictions) are considered for the optimisation (see Figure 25).

![Diagram showing process structure for offline optimisation of the building operation](image)

There are hardly any identical non-residential-buildings. However they consist mainly of adapted similar components in different combinations. The building control system must be adapted individually. Therefore it is reasonable to use this individual adaptation of the control system to automatically couple with or generate an individual optimisation. If this is successful the optimisation costs are expected to be lowered considerably. Therefore in the future optimisation will be closely linked to the building control. This allows for the optimisation to be carried out in a more continuous manner to incorporate changing conditions (like weather, utilisation, prices …).
5.5.4 Offline-Optimisation

The main idea of Offline-Optimisation is that a stable building operation can be achieved by classical control techniques, as the dynamic behaviour of buildings is sufficiently stable. The main issue thus is optimizing by determining central control parameters (e.g. setpoints, PID settings, time-schedules). Since building dynamics does not change rapidly, these optimal control parameters and strategies should not change remarkably over longer periods of time.

Hence optimisation does not need to be implemented directly into the Building Automation (BA). Experience shows, that this type of optimisation needs to be redone on a regular basis just like in Continuous Commissioning (CC).

Offline optimisation is mostly used in science and planning. Regular recurrence of operation optimisation is rarely the case in the field. Below we present some examples of offline optimisation:

Texas A&M University developed a (rather simple) building simulation model called AirModel. It includes some kind of basic optimisation methods for certain American systems like cold deck and hot deck temperature (Haves, Salsbury et al. 2001, 2002, 2003 #547). This tool uses simple GPS-algorithms. It searches step by step for the (energy) optimal setpoint temperatures and assures that the comfort criteria are met. This software is especially adapted to the American HVAC-systems. The tool is hardly applicable for European systems. (Wetter and Wright 2003) and (Wetter 2004) describes and compares the coupling of EnergyPlus with different optimisation algorithms (e.g. GPS and GA). The optimisation also includes building envelope parameters like window dimensions. These types of parameters can only be adjusted during building design. It is pointed out there, that no definite advice can be given for the choice of the optimisation algorithm in connection with buildings.
Also (Holst 2003) optimises the building envelope parameters with GenOpt (Wetter 2004) and EnergyPlus. The importing capabilities of EnergyPlus make it possible to generate the building model in only two hours. With approximately 120 iterations the optimum among about $3 \cdot 10^{10}$ possibilities was found. Energy savings of 22.5 % were realised in the process.

Some research has been done on coupling different simulation programs, like TRNSYS, EES and Matlab-Simulink in order to model and optimise building operation. (Baumann 2003). In that paper no optimisation was applied to the simulations. Although it was stated there, the modelling was intended for optimisation. A complete search of the parameter space is done on different cutting planes to characterize the objective function.

In (Xing 2004) some special points on building operation (cooling) optimisation are investigated. However this paper only deals with standard American systems and the modelling was done with EnergyPlus. Therefore the outcomes are not readily portable to European systems. The optimisations were done with GenOpt and Matlab. This is research work. The integration of these methods in tools applicable for field use needs to be done. Just like many other investigations about optimised cooling-systems the peak load reduction for cost reduction is a major issue here.

One more optimisation tool for the design stage is described in (Ellis, Griffith et al. 2006). Once again, EnergyPlus is used for modelling. Again therefore the outcomes are only partially portable to European Systems.

Many different concepts especially for optimisation of building operation are outlined in (Henze 2007). These were applied to American systems. The modelling is performed in (Matlab-Simulink, TRNSYS-GenOpt, EnergyPlus). Field examples are given, but all the methods and algorithms used are at a development stage. There is still a lot of work to be done to develop ready to use tools from there.

Another variant of offline optimisation is hardware in the loop \cite{Note1} optimisation. For that, real equipment (e.g. control hardware) is connected to a simulation environment. Thus testing and optimising of real hardware components can be done in a quick and cost efficient way under controllable circumstances.

\footnote{The denomination refers to the so called control loop}
Hardware in the Loop (HIL) methods are mostly used during development of control systems. E.g. when the real building (or any other system) does not yet exist or the behaviour of the controller is to be tested for many different buildings (circumstances) (Bianchi 2006).

The example of Figure 26 shows a hardware in the loop arrangement where the building and the HVAC system are replaced by a simulation (possibly with an A/D converter). The measurements required by the controller are the state values of a simulation. The controller outputs are looped back into the simulation (e.g. with an A/D converter). Then some kind of optimisation method can be applied. The objective function is evaluated by the simulation. Depending on the execution speed of the simulation so called real-time and not-real-time applications are distinguished. For energy optimisations in buildings it is worthwhile to speed up simulation time compared to real time in order to quickly test and optimise the behaviour for different climates and independent of the real outdoor climate. An additional advantage of HIL is that different hardware versions can be tested and optimised under identical circumstances.

5.5.5 Online-Optimisation

While offline building optimisation methods are already partially used in practice (mainly design stage) online optimisation is rarely realized e.g. for restricted sub controls like night set back optimisation.

Optimisation needs to be automated and integrated in the building automation (BA) system in order to lower the expenses.
If an optimisation routine is integrated into a control system it is called adaptive or learning control. It is called a Model Predictive Control (MPC) if models are used to adjust the control. I.e. in the building sector adaptive controls are usually MPCs. Further distinction can be made according to the type of model in use, e.g. Non-Linear-Model-Predictive-Control (NMPC).

MPC is usually used in systems with highly variable control dynamics like e.g. (supersonic) airplanes. Buildings do not display highly variable control dynamics.

MPC is already in use in other areas e.g. combustion processes or paper processing. In these fields, without MPC satisfactory control quality cannot be achieved. The dynamics of these systems is slow enough to optimise in real-time. That is also true for buildings.

In (Henze 2007) online optimisation is called “time dependent treatment of operation optimisation”. Under this generic term further subdivision is made into: Model-Based Control (MBC), model-free-learning control or Reinforcement-Learning Control (RLC) and Hybrid-Learning Control (HLC). Successful online optimisation in building operation is described by (Henze 2007). The easy implementation of RLCs is their advantage. For practical use, though, RLC was not suitable due to the extremely long training periods needed.

5.5.6 Conclusion

In building operation optimisation the objective function has properties that complicate optimisation. They might not be continuous or differentiable. Therefore the use of classical high efficient gradient-based optimisation methods like Preconditioned Conjugant Gradient (Newton) algorithm (PCG) is not always possible.

Where these gradient-based methods were unable to find solutions, then stochastic optimisation methods like General Pattern Search (GPS), Particle Swarm Algorithm (PSA) or Genetic Algorithm (GA) worked. Combinations of different optimisation methods improved them. However it is impossible to give guidelines on which optimisation method is best fitted.

Non-residential-buildings are diverse. Most newer buildings have an individually adapted control system. Therefore in the future an individual optimisation could eventually be generated from that individual control system. If this is successful the optimisation costs are expected to be lowered considerably. Therefore in the future the optimisation will probably be some kind of MPC.

Today building optimisation is usually carried out offline. Models are used to find optimal control parameters for different modes of operation. This is done independently of the building after calibration has been carried out. This kind of optimisation is called offline optimisation here since it is not conducted continuously. It is used more often than online optimisation because optimisation can be effected independently of the building and the building automation system. Hence offline optimisation is more applicable for scientific research.
5.6 Connections to EPBD

As described in this chapter, models of buildings and HVAC systems play an important role in fault detection and diagnosis as well as in optimisation of building performance. Models can either be built from measured data (black box) or from physical insight (white box).

One connection between the EPBD and model based approaches could be the asset ratings. Asset ratings are theoretical calculations of the energy demand of buildings for “standard” utilization patterns (white box model). Many Member States prescribed asset ratings for the certification of new buildings only few (Denmark and Austria) prescribed them also for existing buildings.

Depending on the national implementation and calculation methods, asset ratings can deliver quite detailed information of the building structure and the HVAC system which will be sufficient not only for static calculations but also for dynamic simulation.

Accordingly, asset ratings could be a base for a quite detailed analysis of building performance. In fact, with the implementation of the EPBD the basic idea of considering building envelope and HVAC systems as parts of one entity that has to be optimised jointly was implemented in Europe for the first time.

The major drawback is that in most Member States asset ratings will only be applied to new constructions. In most countries existing buildings will be certified on the basis of operational ratings. As these ratings only consider the measured annual energy consumption for the last years, they are not sufficient for any kind of analysis, except a very simple benchmark.

In this context, it should be mentioned that all of the model based approaches described in this chapter rely on more or less detailed measurements of energy consumption and/or system behaviour, i.e. ongoing monitoring. The EPBD doesn’t prescribe any kind of monitoring (not even for new constructions) and thus misses the chance to ease the introduction of ongoing performance evaluation or continuous commissioning.
5.7 Literature for chapter 5


Sreedharan (2001). COMPARISON OF CHILLER MODELS FOR USE IN MODEL-BASED FAULT DETECTION. Berkeley, Department of Mechanical Engineering, University of California, Berkeley.


6 Functional Performance Tests (on-site)

This section gives an overview over the concept of Functional Performance Tests (FPT) and tries to evaluate if and how FPT can be used in the framework of Building EQ or in connection with the EPBD, respectively. Much of the information in this chapter is taken from the material provided by IEA ECBCS Annex 40 and Portland Energy Conservation, Inc. (PECI; www.peci.org).

Principally a FPT is a procedure in which the correct and efficient function of a single component (e.g. a boiler) or a subsystem (e.g. heating system, possibly comprising generation, storage, distribution and emission) is evaluated by performing on-site measurements. In most cases functional testing is performed manually using handheld test instruments on selected equipment that is not part of the long-term monitoring.

Each component has a well-defined function inside the whole HVAC system. Any malfunction can compromise the correct behaviour of the whole system. The malfunction may be due to:

- Design faults
- Selection or sizing mistake
- Manufacturing fault or initial deterioration
- Installation fault
- Wrong tuning
- Control failure
- Abnormal conditions of use

The test can be “active” or “passive”, according to the way of analysing the component behaviour: with or without artificial perturbation. Active tests are mostly applied in initial commissioning, i.e. at the end of the building construction phase. Later in the Building Life Cycle a passive approach is usually preferred, in order to preserve health and comfort conditions inside all the building occupancy zones.

There are many descriptions for FPT provided by manufacturers or national standards that are usually (but not necessarily) performed during the initial commissioning. In Germany there exist e.g. the VDI 3809 (Functional testing for heating plants) and the DIN EN 12599:2000 (Functional Testing for air handling units and air conditioning systems).

However, in building practice they are seldom applied as can be seen from many monitoring projects. Moreover, the existing functional tests are mostly dedicated to initial commissioning and not to a continuous commissioning process.
FPTs are seen as a necessary effort for revealing faults and optimisation potentials on the system and component level. This is because the available long-term-measurements (e.g. from a BAS) usually does not provide deep insight on the system and component level as the cost for this “complete” monitoring is not justified by possible savings. Accordingly manual spot or short term measurements - which show a much better cost-benefit ratio - have to be performed when and where necessary. On the other hand, some functions or faults might only be detected by active testing and not by passive monitoring.

The official Annex report *Commissioning of Building HVAC Systems for Improved Energy Performance* summarizes the work of IEA-ECBCS Annex 40. Here functional performance testing is described as just a part of the whole commissioning process. Functional performance tests may be performed as needed as part of the continuous commissioning process. This is the way FPTs are considered in the framework of Building EQ.

The question which level is to be chosen should be answered by prior analysis based on passive monitoring and possibly the results of the certification according to EPBD (theoretical calculation of system performance). FPTs should only be considered for systems and components that obviously show a malfunction or low efficiency according to this prior analysis.

For active testing a risk analysis in relationship with acceptance criteria should be considered as the test might influence the performance of the system and thus the indoor conditions.

### 6.1 Specification of FPT

FPT is, as mentioned above, just one part of the whole Commissioning process. It has only to be started on the basis of strict specification, given in the Design Documents. Test results and interpretation have to be incorporated into the As-built Records. All information sources should be used in order to guarantee a successful FPT.

Verification checks are also an important prerequisite to functional performance testing. In the field, verification checks are often referred to as pre-start checks, start-up checks, or prefunctional tests. Regardless of the specific terminology used, these items consist of necessary checks prior to activating a system or immediately subsequent to its activation, to ensure that it is safe to operate and ready for the more rigorous processes associated with a functional test.

Typical examples of this type of check include:

- Verifying that the component actually installed is the component described in the As-Built records
- Verifying piping and wiring connections
- Verifying calibration and sensor locations
• Verifying safety settings
• Flushing and static pressure testing of piping systems
• Verifying belt tension
• Verifying electrical parameters like voltage and amperage
• Verifying pressure and flow ranges for utility and support systems

To be successful, it is essential to understand the background behind how the system will respond to a test, as well as what could be causing the observed responses. Information and testing procedures are viewed from a system perspective, rather than a component perspective. This is especially critical for functional performance testing and for the overall success of the system. The performance of the system is dependent on four areas of interaction:

• The individual components in the system
• The components with each other as a subsystem
• The subsystem with other subsystems in the building
• The building with its environment.

In the framework of IEA ECBCS Annex 40 a general specification format was developed for FPT. The specification format can be applied to any level and is structured as follows:

• Presentation of the system considered
• Operating principles
  Information about working principals of the system, expected performance, existing calculations (including simulations), interaction with other systems (as-built)
• Manufacturers Data
  data and performance sheets of the HVAC-equipment (as-built)
• Problems to be considered
  Most relevant or assumed malfunctions to be evaluated
• The test itself
• Summary of the test specifications
  The summary consists of a list of different testing phases with verification objects and expected results and a definition of verification points, experimental conditions and acceptance criteria. Furthermore information about required equipment, required time, and required preliminary operation is included.
• Preparation phase
  A FPT can be performed at any time, all along the building life cycle. The starting point is an evaluation of all information and data actually available at the time considered. Performance criteria have to be fixed in accordance with that information. In order to gather all necessary data, in most cases complementary instrumentation has to be prepared. The "preparation" may also include some adaptation of the BEMS data logging and storage system, in accordance with the relevant variable to be collected.

• The test method
  A summary of the test method has to be prepared. Each method has to be selected and validated on the basis of a theoretical analysis. The description includes: operational conditions and time required to conduct the test, measuring techniques and instrumentation required, pre-requisites, data pre-processing, data processing and result analysis.

• Additional possibilities
  • Model calibration and use of some components as "measuring devices"
    Many HVAC components have sufficiently well-known characteristics in order to be used as measuring devices. Manufacturers themselves are very often offering adapted sensors or adapted location for such sensors as part of their products.

One result of Annex 40 are a number of specifications for FPT for different kinds of systems and equipment. Further specifications are being developed in the follow up project IEA ECBCS Annex 47. All of these can also be used in the framework of Building EQ.

6.2 Using models for FPT

As described in chapter 5, models play an important role for FDD and optimisation as they are able to deliver reference values for the “normal” behaviour as well as the optimal behaviour of a system. Accordingly, they can also be used for FPT.

Talking about FPT, models are usually used on the component or system level. Models that comprise the whole building usually are dedicated to design (White-Box Models) or continuous evaluation of energy consumption (Black-Box models) rather than for functional testing.

The following steps comprise a "use case" for a general purpose, component-level, model based commissioning tool that can be used both for initial commissioning and for performance monitoring during routine operation (Annex 40):

• For automated functional performance testing, the model is configured using manufacturers' performance data and system design information. In general,
the model parameters will be determined by a combination of direct calculation and regression.

- An active test is performed to verify that the performance of the component is acceptably close to the expected performance. This test involves forcing the equipment to operate at a series of selected operating points specifically chosen to verify particular aspects of performance (e.g. capacity, leakage).

- The test results are analysed, preferably in real time, to detect and, if possible, diagnose faults.

- If necessary, the test is performed again to confirm that any faults that resulted in unacceptable performance have been fixed. Once the results of this test are deemed acceptable, they are taken to define correct (i.e. acceptable) operation.

- The model is re-calibrated using the acceptable test results.

- The tool is used to monitor performance during on-going operation. This will typically be done in passive mode, though active testing could be performed at particular times, e.g. every weekend, after routine maintenance, after system modifications or retrofit, on change of ownership, etc.

These steps describe an ideal case the effort of which is probably too big to be applied to every component. However, for major components such as heat or cold generators with a significant capacity this might be a reasonable approach. Even though it is questionable if this approach should be introduced by a commissioning provider as “external service” or rather by the manufacturer as an integrated feature of the component.

### 6.3 Connection to EPBD?

FPT in the sense of this report could be interpreted as a kind of inspection, i.e. a regularly evaluation of the function and efficiency of the equipment of a HVAC plant. The EPBD prescribes the following inspections:

- inspection of hot water boilers used for heating of buildings
- inspection of air conditioning systems used to control air temperature inside buildings, possibly in combination with the control of building ventilation, air humidity and air cleanliness.

In its "considerations", the EPBD states that "regular maintenance of boilers and of air-conditioning systems by qualified personnel contributes to maintaining their correct adjustment in accordance with the product specification and in that way will ensure optimal performance from an environmental, safety and energy point of view".
Although the link to FPT seems to be obvious, the “understanding” of functional testing is quite different between the EPBD and a continuous commissioning approach like in Building EQ. The EPBD prescribes functional tests on the component level as well as a re-evaluation of the design of the systems. These tests or evaluation respectively, should be done on regular basis and according to national standards. E.g. the inspection interval in the German EnEV is set to 10 years. While this interval might be acceptable for the re-evaluation of the design, it is much too long for a reasonable application of FPT in a continuous commissioning process.

Furthermore the national standards (e.g. VDMA 24186, part 1,3 and 4 for inspection of HVAC systems in Germany) often give no detailed description as explained in 6.1 but only a list of general tasks to perform.

### 6.4 Resources for FPT

Resources for detailed descriptions of FPT that can be used as a kind of “cooking recipe” can be found mainly in the USA.

- **IEA ECBCS Annex 40**
  The final report of Annex 40 gives a list of FPT that were developed within the Annex (http://www.commissioning-hvac.org/)

- **The Portland Energy Conservation, Inc. (PECI) published an online-collection of different FPT that follows more or less the specifications described in 6.1. A Functional Testing Guide (FTG) as well as a Control System Design Guide is available (http://www.peci.org/ftguide/index.htm).**

  An example of these kind of tests is given in the Annex.
7 **Recommended methods in connection with continuous commissioning**

While continuous commissioning is an ongoing process over the entire life time of a building, certification according to the EPBD will (in most cases) only be performed once. The EPBD does not prescribe an ongoing evaluation of building performance. Accordingly, the certification can only be one part of a continuous commissioning process.

The two ways for energy certification is either a theoretical calculation of the energy performance of an existing building using a standardised use pattern, Asset Rating, or measured data for an existing building, possibly corrected to a standardised use pattern, Operational rating.

In the case of asset ratings, the certification can deliver the actual state of the building and a theoretical target value for energy performance. Thus, it could be integrated in phase I of the CC ("Development of CC plan").

However, asset ratings for existing buildings – which are investigated in Building EQ – are only prescribed in a few countries (Denmark and Austria so far). Most Member States will have operational ratings for existing buildings which in their present definition are not suited for any kind of detailed analysis.

Furthermore, also the inspection of air-conditioning systems, larger than 12 kW cooling capacity prescribed in the requirements of the EPBD are not designed as regular functional performance tests (FPT). The inspections take place only once during lifetime of the certificate. In the worst case this is once every ten years. Consequently, they are not suited for a continuous commissioning.

One major drawback is the diversity of the different national implementations in the Member States. The data in Annex 8.1 shows that almost no country or region has similar implementations of the energy certification of existing buildings. That is, there will be no common data set that can be exploited for performance analysis.

Consequently, there will be no common basis for a European tool to be developed in the Building EQ project. The consortium therefore has to develop an “artificial” minimal data set which must be consciously chosen in order to be available for many countries.

Most larger and serious building owners of non-residential buildings have some in-house process to follow the energy performance of their buildings. Particularly buildings with more recent building energy management systems (BEMS) have great possibilities for optimizing the energy performance but these possibilities are very rarely realised. In these cases a continuous commission process has large possibilities to achieve and maintain an energy efficient buildings operation. Consequently, continuous evaluation of the energy performance of the building and its systems is a crucial ingredient for energy efficiency.
This report has shown that there exist a lot a valuable assessment tools and methods like:

- **Benchmarking** for comparing the energy performance of the building and its systems with other buildings in a first step.
- **Visualisation** for identifying funny working systems or components during normal operation.
- **Model based techniques** for e.g. set-point optimization.
- **Functional Performance Tests (FPT)** for identifying systems and components with faulty functions during standardised tests.

The application of these methods generally asks for more detailed measurements and/or a more detailed building modelling than described in the national/regional implementations of the EPBD. In general continuous measuring, ideally on an hourly basis, is necessary for implementation of the methods mentioned above.

As mentioned above, asset ratings can be a good starting point for continuous commissioning. Some of the national implementations can deliver a quite detailed building model (e.g. Germany) when asset ratings are performed.

Hence, the benefit of asset ratings for CC (independent from the national regulations for existing buildings) will be investigated.

Furthermore, inside the framework of Building EQ project methods and tools will be developed, which can support a continuous commissioning process and which consequently can be seen as an enhancement to the EPBD and its different national implementations.

In order to reach a good cost-benefit ratio, a top-down approach will be defined that puts effort only where and when it is necessary. The approach should define a systematic method for fault detection and diagnosis in non-residential buildings.

The analyses will be based on a minimal data set. This set consists of data that must be measured monthly and hourly. The monthly data are generally energies for both the whole building and for selected energy end-uses. The hourly data are generally flows and temperatures in the building and its building services systems.

In order to identify faults and for diagnostics the application of visualization techniques and model based techniques (Black Box and White Box) will be investigated. In the case of using models, simple model structures will be preferably investigated.

This approach will be more elaborated in Work Package 3 and its reports.
8 Annex

8.1 National implementation of the EPBD

This Annex is concentrated on the implementation of the energy certification process in the various EU-countries. The implementation of the four countries inside the project Building EQ is described more detailed.

Table 7 gives an general overview over the legal context in the different countries, while Table 8 summarizes the requirements for the certification.
### Table 7  Overview over the certification in the Member States

<table>
<thead>
<tr>
<th>Country</th>
<th>new buildings</th>
<th>public buildings</th>
<th>existing buildings</th>
<th>based on calculation or consumption?</th>
<th>existing buildings: asset rating?</th>
<th>existing buildings: operational rating?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>01.01.2008</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td>calculation, energy level based on final end energy demand</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Belgium-Flemish</td>
<td>01.01.2008</td>
<td>2008</td>
<td>in case of sale 2008, in case of rent 2009, non-res 2009</td>
<td>public buildings based on consumption, other calculation methods are under discussion</td>
<td>n.i.</td>
<td>x</td>
</tr>
<tr>
<td>Belgium-Brussel</td>
<td></td>
<td></td>
<td></td>
<td>calculation method still under discussion</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Belgium-Walloon</td>
<td>2008, as soon as min. requirements are in force</td>
<td>2008-2009</td>
<td>2008-2009</td>
<td>calculation method still under discussion</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Bulgaria</td>
<td></td>
<td></td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Cyprus</td>
<td>beginn 2008</td>
<td></td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td>n.i.</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Denmark</td>
<td>is already obligatory, 14 classes, not more than 5 years old</td>
<td>30.09.2006</td>
<td>based on energy demand</td>
<td>x</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Estonia</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td>n.i.</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Finland</td>
<td>see Annex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>01.07.2007</td>
<td>01.01.2008</td>
<td>01.11.2006 sold buildings 1.7.07 rented buildings</td>
<td>performance classified on primary energy and co2-emissions, calculation based on consumption for non-res.b., residential b. very simplified asset rating or by operational rating</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Germany</td>
<td>01.01.2002</td>
<td>01.07.2009</td>
<td>1.7.08 dwellings &lt;1965 1.1.09 dwellings &gt;1965 1.7.09 non-residential</td>
<td>based on calculation for new buildings and existing dwellings &lt;1977 with less than 4 flats being not renovated</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Country</td>
<td>new buildings</td>
<td>public buildings</td>
<td>existing buildings</td>
<td>based on calculation or consumption?</td>
<td>existing buildings: asset rating?</td>
<td>existing buildings: operational rating?</td>
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<tr>
<td>Greece</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td>n.i.</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Hungary</td>
<td>2007</td>
<td>2007</td>
<td>2007</td>
<td>asset method has been selected</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Ireland</td>
<td>01.01.2007</td>
<td>01.07.2008</td>
<td>01.01.2009</td>
<td>operational rating for public buildings, label displays primary energy use in classes A-G, software “DEAP” for new buildings</td>
<td>n.i.</td>
<td>x</td>
</tr>
<tr>
<td>Italy</td>
<td>see Annex</td>
<td></td>
<td></td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
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<tr>
<td>Latvia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Lithuania</td>
<td>01.01.2007</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Luxembourg</td>
<td></td>
<td></td>
<td></td>
<td>new buildings: asset rating 4 years after certification, certificate is accomplished by energy consumption indicator existing residential buildings: operational</td>
<td>n.i.</td>
<td>x</td>
</tr>
<tr>
<td>Malta</td>
<td></td>
<td></td>
<td></td>
<td>under discussion</td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Netherlands</td>
<td>01.01.2008</td>
<td>01.01.2009</td>
<td>housing companies 01.01.2009, other buildings 1.1.08</td>
<td>based on very simplified methods, no decision about how to deal with different building types</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Norway</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>have not been presented</td>
<td>n.i.</td>
</tr>
<tr>
<td>Poland</td>
<td>01.01.2008</td>
<td>01.01.2009</td>
<td>01.01.2009</td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Portugal</td>
<td>mid 2007</td>
<td>jan 2008 or 2009</td>
<td>01.01.2009</td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Romania</td>
<td>01.01.2007</td>
<td>01.01.2007</td>
<td>01.01.2010</td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
</tr>
<tr>
<td>Slovenia</td>
<td>begin 2008</td>
<td>begin 2008</td>
<td>begin 2009</td>
<td>new buildings: asset rating existing buildings: asset rating with simplification in input data public buildings: optional by operational</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Country</td>
<td>new buildings</td>
<td>public buildings</td>
<td>existing buildings</td>
<td>based on calculation or consumption?</td>
<td>existing buildings: asset rating?</td>
<td>existing buildings: operational rating?</td>
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<tr>
<td>Slovak Republic</td>
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<td>01.01.2008</td>
<td>01.01.2008</td>
<td>n.i.</td>
<td>n.i.</td>
<td>n.i.</td>
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<tr>
<td>Spain</td>
<td>31.10.2007</td>
<td></td>
<td>01.07.1905</td>
<td>new buildings: calculation based on simplified or complex methods existing buildings: under preparation</td>
<td>n.i.</td>
<td>n.i.</td>
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<tr>
<td>Sweden</td>
<td>Starts 2009-01-01. Based only on operational rating after two years of use</td>
<td>finished 2008-12-31</td>
<td>multi-family buildings finished 2008-12-31. All other buildings start 2009-01-01 when sold or rented</td>
<td>all buildings based on consumption with the energy uses by the activities in the building excluded</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.i.</td>
<td>n.i.</td>
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<td>Country</td>
<td>requirements new buildings</td>
<td>description requirements</td>
<td>requirements existing buildings</td>
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<tr>
<td></td>
<td>end energy consumption</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>end energy demand</td>
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<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<td></td>
<td>primary energy consumption</td>
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<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>CO₂-Emissions</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>max U-Value</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>average insulation level</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>boiler, chiller</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ventilation</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<td></td>
<td>other criteria</td>
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<tr>
<td>Austria</td>
<td>x</td>
<td>sophisticated calculation system, combining 9 building codes allowing differentiated description of building, details or default values based on experiences of 100,000 buildings</td>
<td>x</td>
<td>same method than new buildings but simplified and with lower requirements</td>
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<td>min. requirements depending on type and function of building</td>
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<td>Belgium-Walloon</td>
<td>x</td>
<td>same calculation methods as Flemish, first draft available</td>
<td>x</td>
<td>for &gt;1000 m² requirements are function of type and extent of renovation</td>
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<tr>
<td>Country</td>
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<td>boiler, chiller ventilation</td>
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<td>boiler, chiller ventilation</td>
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<td>other criteria</td>
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<tr>
<td>Bulgaria</td>
<td>x</td>
<td>requirements for Ht' only for non-residential buildings with normal temperature</td>
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<tr>
<td>Cyprus</td>
<td>x</td>
<td>developed a simple methodology for calculation for residential based on relevant EN-standard, for non-resid. adequately modified, evaluating also methods from other countries</td>
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<td>Czech Republic</td>
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<td>energy performance integral part of planning permission</td>
<td>x</td>
<td>requirements are only to apply when renovation exceeds 25% of surface or consumption increase 25%</td>
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<td></td>
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<tr>
<td>Denmark</td>
<td>x</td>
<td>two classes with energy demand 75% or 50% of normal house</td>
<td>x</td>
<td>calculation method same as new buildings, cost efficient energy saving measures must be shown when renovation is higher than 25% of building</td>
<td></td>
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</table>
## Building EQ – Building EQ – The EPBD and Commissioning

### Country Requirements

<table>
<thead>
<tr>
<th>Country</th>
<th>Requirements New Buildings</th>
<th>Description Requirements</th>
<th>Requirements Existing Buildings</th>
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<td>Estonia</td>
<td>governed by function and type of building</td>
<td></td>
<td>requirements are not similar to new buildings</td>
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<tr>
<td>Finland</td>
<td>x</td>
<td>x</td>
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<td>France</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>requirements on technical installation, windows, lighting</td>
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<td>Country</td>
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<td>Germany</td>
<td>x</td>
<td>residential buildings: calculation based on demand (DIN 4108, 4701)</td>
<td>x</td>
<td>requirements only when refurbishment</td>
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<td>non-res-buildings: calculation based on demand (DIN 18599)</td>
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<td>Greece</td>
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<td>energy study for the building permit necessary</td>
<td>x</td>
<td>the same as new buildings</td>
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<tr>
<td>Hungary</td>
<td>x</td>
<td>additional requirements: specific heat demand coefficient in W/m²K and max mean daily indoor-temperature, simple estimation and more detailed calculation methods</td>
<td>x</td>
<td>same as new buildings when major renovation over 1000m²</td>
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<td>Ireland</td>
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<td>requirements strengthened 1.7.06 when renovation or extension</td>
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<td>Country</td>
<td>requirements new buildings</td>
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<td>other Criteria</td>
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<td>not yet adopted</td>
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<td>in case of refurbishment same as new buildings</td>
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<td>Lithuania</td>
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<td>energy performance less than class C</td>
<td></td>
<td>energy performance less than class D for large buildings after renovation, class is not obligatory for buildings for sale or rent</td>
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<tr>
<td>Country</td>
<td>requirements new buildings</td>
<td>description requirements</td>
<td>requirements existing buildings</td>
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<tr>
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<td>Norway</td>
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- Annex 10 -
<table>
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<tr>
<th>Country</th>
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<td>boiler, chiller</td>
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<td>average insulation level</td>
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<td>x</td>
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<td></td>
<td>requirements regardless of building function, energy rank is not regulated</td>
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<tr>
<td>Portugal</td>
<td>x</td>
<td>x</td>
<td>additional requirements: heating and cooling needs, mandatory solar water heater, min. efficiency for heating and cooling</td>
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<td></td>
<td>non-res. build &gt;1000m²: if consumption exceed certain level, energy saving measures must be implemented</td>
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<td>major renovation: see new buildings</td>
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<td>Romania</td>
<td>x</td>
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<tr>
<td></td>
<td>when renovation or extension</td>
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<tr>
<td>Slovenia</td>
<td>x</td>
<td>x</td>
<td>co2-emissions and primary energy as an additional indicator but no requirement</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>when major renovation, only part which is renovated, same requ. as new buildings</td>
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<tr>
<td>Country</td>
<td>requirements new buildings</td>
<td>description requirements</td>
<td>requirements existing buildings</td>
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<tr>
<td>Slovak Republic</td>
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<td>additional requirements: specific heat use and total delivered energy</td>
<td>x</td>
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<tr>
<td>Spain</td>
<td></td>
<td>additional requirements: lighting, solar thermal, photovoltaik, simplified procedure or complex one</td>
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<tr>
<td>Sweden</td>
<td></td>
<td>No asset rating of new buildings. End energy consumption excludes energy uses for the activity in the building. Two climate regions. Different consumption levels for residential and non-residential buildings</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Country</td>
<td>requirements new buildings</td>
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<td>requirements existing buildings</td>
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<tr>
<td>United Kingdom</td>
<td>x</td>
<td></td>
<td></td>
<td>calculation methods applied throughout the UK</td>
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</table>

apart requirements on CO2 emissions there are different requirements in each country, calculation methods applied throughout the UK.
8.1.1 Austria

Legal content

On May 24th 2006 the Austrian Parliament passed the Energy Certification Providing Act. The obligation for providing energy certificates for new buildings will come into force on January 1st 2008 and for existing buildings on January 1st 2009. Energy certificates have to be issued according to the technical rules which to be set by the Austrian federal provinces by December 2007.

Calculation procedures

A sophisticated calculation system has been developed amalgamating the nine existing building codes allowing a differentiated description of the buildings. The user of this system can do the calculation either using all available details or in case of existing buildings - using default values based on the experience of more than 100,000 already existing energy certificates. As far as they have already been available all CEN-standards have also been implemented and will guarantee a high compatibility of the Austrian calculation methodology to a future harmonised European methodology.

Requirements for new buildings

Requirements for new buildings include mainly

- maximum annual final energy demand per m² of floor area,
- maximum u-values of different elements of the building,
- building air-tightness,
- prevention of thermal bridges,
- requirements on the quality of boilers, aeration systems and chillers as well as on systems for storage and distribution.

Residential buildings have to fulfil special requirements. The Bundesländer may fix additional requirements.

Requirements for existing buildings

Requirements are mainly the same as for new buildings. The simplified methodology for existing buildings basically does not differ from the above-mentioned one but uses mainly default values.

The requirements will be strengthened on 1st January 2010.

Inspection

In Austria, the regular inspection of heating systems has been in use for many years. Cooling devices have so far not been regularly inspected, so it was necessary to de-
velop requirements as well as calculation methods, which will come into force by 1st January 2008.

Future planning

It is intended to strengthen the requirements for residential and non-residential buildings and to introduce the use of renewable energies by law. As for independent experts, Austria has many consultants and institutions but usually many of them have not been concerned with heating, aeration and cooling. Therefore a common system of information and formation has been put in place.

8.1.2 Belgium

Legal content

In Belgium the implementation of the Energy Performance of Buildings Directive (EPBD) is the responsibility of the Regions: Flanders, Brussels and Walloon.

In Flanders the energy performance decree came into force 1 January 2006. An execution order of the Flemish government of 11 March 2005 lays down the actual energy performance requirements and the calculation procedure. Other execution orders will follow. In Walloon and Brussels the implementation of the EPBD is still under discussion. Drafts are partly available.

Calculation procedures

In Flanders software has been developed to calculate and check the compliance with the energy efficiency and indoor climate requirements. Use of this software, which needs further completion, will be mandatory.

The Walloon Region intends to use the same calculation method as the Flemish Region and will propose adoptions in collaboration with the other Regions.

Requirements for buildings

Flanders: New requirements are in force with respect to every building for which a building permit is requested after January 2006. There are requirements with respect to thermal insulation, the overall energy performance level and the indoor climate.

Walloon, Brussels: The type and level of requirements is governed by the function and the type of building and may cover

- max. U-value
- max. primary energy consumption
- other criteria (summer comfort, ventilation,…)

Certificate

Flanders: An operational rating system will be used for the certification of public buildings, which should all have a certificate in 2008. Energy performance certificates for buildings that are being sold or rented will be introduced in 2008 (residential
buildings) and 2009 (non-residential buildings). The legislative instruments and supporting software tools are being developed.

Walloon, Brussels: The requirements regarding the certification of buildings will be included in an execution order.

**Inspection**

Flanders: The regulation related to the inspection is being drafted; the end of 2006 expects the adoption. The mandatory inspections and advisory support will start in 2009.

Walloon, Brussels: Inspection will be included in an execution order, which is under discussion.

**Future planning**

The main execution orders should be published in 2007.

8.1.3 Bulgaria

**Legal content**

On 19 February 2004, the National Assembly of Bulgaria adopted the Energy Efficiency Act regarding the transposition of the EPBD in national law. The execution orders are the responsibility of the Government.

**Calculation procedures**

The calculation procedures have come into force since 1 March 2005. These are:

- technical requirements for energy conservation and heat retention in buildings;
- methodology for defining annual energy consumption, taking into account: heat losses through the building structures and windows, heat gains of internal source and solar radiation, climatic data, and other specific requirements for buildings;
- specific requirements and procedures for new and for existing buildings;
- technical rules and norms for design of thermal insulation, including values of the coefficients thermal transmittance;
- rules for water vapour penetration, water tightness, air leakage and solar protection during the summer period;
- technical criteria for determination of the main indicators for energy consumption which are different for: Residential building - annual energy consumption for heating per 1 m²; Non-residential building – coefficients of specific transmission thermal losses through the building envelope and elements;
and for Low temperature non-residential building - annual energy consumption for heating per 1 m³.

**Requirements for new buildings**

The type and level of requirements are governed by the function and the type of building - residential buildings and non-residential buildings (education, hospitals, offices, hotels, schools) and may cover:

- Maximum U-value;
- Requirement on average insulation level;
- Maximum primary energy consumption per m² of floor area.

**Requirements for existing buildings**


**Certificate**

Energy certification can be only done after obtaining the building permit.

**Inspection**

The organization of the inspection of the boilers is carried out in two main directions according to defined parameters of the installations: high-pressure boilers and low-pressure boilers.

Inspection of boilers is covered by the execution order and is mandatory from 1 April 2006. The procedures for inspection of air conditioning systems are still under discussion.

**Future planning**

Amendment of the Energy Efficiency Act and the related ordinances.

8.1.4 Cyprus

**Legal content**

For the transposition of the EPBD in Cyprus, the House of Representatives have approved three legal documents. The approval of the legislation has been delayed, mostly due to elections during 2006 and the resultant changes in the composition of the House of Representatives. However, the Government aims at full implementation of all provisions of the EPBD by 4/1/2009.

**Calculation procedures**

The enactment of the legislation concerning the minimum energy requirements for all new buildings is foreseen for July 2007, with the possible start of certification of new
residential buildings at the beginning of 2008. For this purpose a simple methodology for the calculation was developed, based on the relevant EN standards.

Regarding new non-residential buildings, the intention is, at least for the initial stage, to use the same simple methodology as that adopted for new residential buildings, adequately modified in order to include the evaluation of lighting systems. In the meantime, the MCIT is evaluating more comprehensive energy performance methodologies that have been developed by other countries.

**Inspection**

Inspection of boilers and air-conditioning is covered by an existing law and will be made mandatory during the next 2 years.

### 8.1.5 Czech Republic

**Legal content**

On 29th March 2006, the Parliament adopted the amendment of Act on Energy Management by including requirements for existing buildings. The amended regulations specifying the methods of implementation of all the articles of EPBD Directive are currently at the stage of debate.

**Calculation procedures**

The calculation methodology proposed in the draft implementing regulation to the Act is based on published CEN Standards and applicable Czech Technical Standards. It is assumed that a unified calculation procedure will be used for new, renovated and existing buildings as well. In parallel with the draft implementing regulation to the Act a national calculation tool is under preparation.

**Requirements for new buildings**

The compliance with the requirements for the energy performance of a building shall be demonstrated by comparing the energy performance of the assessed building with the building as constructed, and by compliance with appropriate comparative parameters comprising:

a) The thermal/technical properties of building structures (max. U-values);

b) The properties and operation of building technical equipment and lighting.

These minimum requirements are set at the same level, as laid down by the hitherto applicable national legislation.

**Requirements for existing buildings**

The requirements for renovated buildings are the same as for new buildings. These requirements apply when the renovation of the building envelope exceeds 25% of the external surface area, or when changes to the building technical equipment causes a 25% increase in the overall energy consumption.
Certificates of buildings

The certification will be obligatory after 1st January 2009 for new buildings, renovated buildings (larger than 1,000 m²) and public buildings (larger than 1,000 m²). Other buildings when rented or sold, shall be provided with the energy performance certificate, only if they are new or renovated after 1st January 2009.

Inspection

The inspection of boilers and air conditioning systems is governed by the amendment to Act on Energy Management. The inspection of boilers shall be mandatory from 1st January 2007 and the inspection of air-conditioning systems from 1st January 2009 on.

Future planning

It is expected that the implementing regulations for existing buildings will be adopted and come into force at the turn of 2006/07. Any revision of the requirements is not expected before the end of 2009.

8.1.6 Denmark

Legal content

Denmark has implemented the EPBD since January 1st, 2006. Denmark has for many years had fairly strict energy requirements in the building regulations, obligatory labelling scheme for buildings and obligatory inspection scheme for boilers. Denmark has now tightened the energy requirements in the building regulations further and developed new labelling and inspection schemes.

Calculation procedures

The Danish calculation procedure is described in "Energy demand in building". It also includes a PC calculation program, which is to be used by all other programs to ensure identical calculation of energy demand of buildings.

Requirements for new buildings

The new energy requirements are not only an implementation of the EPBD. They also impose stricter energy performance requirements in accordance with current Danish action plans. For all type of buildings the new energy requirements also include two classes of low energy buildings. Both classes have an energy demand of 75 % respective 50% or less compared to a normal house.

The energy frame is supplemented by specific requirements for U-values, minimum boiler efficiency, pipe insulation, heat recovery, fan power efficiency etc.

Requirements for existing buildings

The requirements for existing buildings undergoing renovation are the same as the requirements to new buildings and with the same enforcement schedule.
Cost efficient energy saving measures are required if renovation of the building shell, or the energy installations is higher than 25 % of the value of the building or if more than 25 % of the building shell undergoes renovation.

Certificates of buildings
In the case of new buildings the building needs to have a sufficient energy label to fulfil the energy requirements in the building regulations to be granted a permit for use.

In the case of existing buildings being sold or rented out, the buildings must have an energy label of not more than 5 years old. In blocks flats the labelling is done on the building, but with an individual sub label for each flat stating the heating demand.

There are 14 classes on the labelling scale from A1 to G2, where A1 is the highest.

Inspection
The inspection of boilers and heating systems were implemented on September 1, 2006. It is expected that the new scheme for inspection of air conditioning is to be implemented from January 1, 2007.

Future planning
Irrespective of the EPBD the Danish government and parliament has had for many years ongoing plans for energy savings in buildings.

8.1.7 Estonia

Legal content
The draft Act regarding the transposition of the EPBD in national law was approved by the Parliament on 27.09.2006.

Calculation procedures
The Minister of Economic Affairs and Communications will adopt the calculation procedures.

Requirements for new buildings
The Government will adopt the minimum energy performance requirements. The requirements come into force for building permits requested after 1 January 2008.

The type and level of requirements are governed by the function and the type of building (dwellings, office buildings, schools …) and may cover:

- Maximum acceptable U-value;
- Maximum energy consumption per m² of floor area.

Requirements for existing buildings
For building renovation and for extensions to existing buildings the Government will adopt minimum requirements separately, which are not similar to requirements applied to the new buildings. These requirements should be in force before 1 January 2008.

Certificates of buildings
Certification is mandatory for all buildings from 1 January 2009.

Inspection
Inspection of boilers will be covered by the Minister’s regulation and is mandatory from 1 January 2008. The procedures for inspection of air conditioning systems are still under discussion.

Future planning
It is expected that the execution order for the inspection of air conditioning systems will be adopted by the Government before the end of 2008 and will come into force from 1 January 2009. A revision of the requirements is foreseen before the end of 2009.

8.1.8 France

Legal content
After the vote of the parliament, the French Government has promulgated, on 13 July 2005, the program Law defining the scope of the energy policy, regarding the main points for the transposition of the EPBD into French legislation.

Calculation procedures
Calculation procedures pre-existed: they had been introduced by the preceding regulation on new buildings. They had been based on the same principles as prEN 13790. The new calculation procedures were adopted by the Government on 24 July 2006. There are specific procedures for dwellings and for other buildings.

Requirements for new buildings
The type and level of requirements are governed by the function of the type of building (dwellings, office buildings schools, …) and may cover:

- Maximum U-values for windows, walls, roofs and ceilings;
- Requirement on average insulation level;
- Maximum primary energy consumption per m² of floor area;
- Maximum interior temperature in summer.

Requirements for existing buildings
The French Government is going to adopt minimum requirements for new building components when building renovation is done and for extensions to existing buildings. These minimum requirements concern in particular:

- Boilers fired by non-renewable liquid or solid fuel;
- Electric heating systems;
- Air-conditioning and ventilation systems;
- Hot water production systems;
- Windows and glazed walls (with or without closing);
- Equipments of energy production using renewable energy sources;
- Insulation materials of opaque walls;
- Lighting systems.

**Certificates of buildings**

The energy performance certificate labels both following aspects:

- The energy consumption of the dwelling or building;
- The impact of this consumption on greenhouse effect.

Energy consumption is either calculated according to one of the declared assessment methods or with an operational rating based on invoices (consumption noted over the last 3 years).

**Inspection**

The Government will lay down different measures to establish a regular inspection of boilers and air conditioning systems. However, these procedures are still under discussion.

8.1.9 Greece

**Legal content**

By early 2007, the Parliament is planning to adopt the Decree regarding the transposition of the EPBD in national law.

**Calculation procedures**

Greece is in the process of setting the regulations for the EPBD (general design/inspection principles and minimum requirements for the building cell, lighting, boiler/heating system, air conditioning etc). The country is planning to form the calculation procedures in parallel to the regulations. It is foreseen that they will be adopted
by the Government within 2007. There will be specific procedures for dwellings and for other buildings.

Software tools are expected to be developed by the market and verified by appropriate government bodies thereafter.

**Requirements for new buildings**

The Government of Greece is completing a study on minimum requirements for all new buildings. The requirements will come into force for building permits requested after 1 January 2009.

The type and level of requirements are function of the type of building (dwellings, office buildings, schools …) and may cover:

- Maximum U-value;
- Requirement on average insulation level;
- Maximum primary energy consumption per m² of floor area;
- Boiler and air conditioner efficiencies.

New buildings should produce an energy study for the building permit to be issued.

**Requirements for existing buildings**

The procedure followed for new buildings covers also existing buildings.

**Certificates of buildings**

The requirements regarding the certification of buildings will be adopted by the Government by mid 2007. The general certificate model to be used will be the A-G label. Certification will be obligatory for buildings with a building permit after 1 January 2009.

**Inspection**

The plan for Inspection of boilers has been prepared and is under review by the Ministries of Development and Environment. It will replace existing boiler inspection procedures undertaken by the Ministry of Environment. The examination of air conditioners will start during the first part of 2007.

**Future planning**

A study on minimum requirements for Air-conditioners will start in spring 2007 and is expected to be handed to the relevant Ministries for review by autumn 2007.
To date, the national regulation was issued in May 2006. The rules are in force from 1 September 2006, from this date a building permit is mandatory for new buildings and also for buildings over 1000² floor area undergoing major renovation.

**Calculation procedures**

The calculation procedures have been adopted and the related national regulation is in force.

**Requirements for new buildings**

Also the national regulation on minimum requirements for all new buildings is in force.

The type and level of requirements are governed by the function, the type of building and the surface to volume ratio and including:

- Maximum U-value of each building element;
- Requirement on specific heat demand coefficient of the building (W/m³K), which includes transmission heat losses (incl. thermal bridge effect) and passive solar gains;
- Maximum primary energy consumption per m² of floor area.

The first level (maximum U value of elements) is generally in force. On the second level the specific heat demand coefficient depends on the surface to volume ratio. The calculation method facilitates the application of a simple estimation and a more detailed calculation (including solar access) of passive solar gains. The simplified estimation is intended to be on the safe side. Requirements on each level must be fulfilled.

Maximum primary energy consumption per floor area depends on the surface to volume ratio and the use of the building.

**Requirements for existing buildings**

The same rules for new buildings apply to major renovation of existing buildings over 1000² floor area. The limitation of the U value of building elements automatically limits the selection of elements, which can be used for renovation.

**Certificates of buildings**

It is expected that the ministerial order will be issued by the end of 2006. It is to be mentioned that asset method has been selected, thus the calculation method for design and certification overlap.

**Inspection**

Discussions are in progress.

**Future planning**
It is expected that the certification will be implemented in 2007, while the execution order for the inspection of air conditioning systems is unlikely to be started before the end of 2008.

8.1.11 Ireland

**Legal content**

The amended EC Energy Performance of Buildings Regulations 2006 was published in December 2006 and came into operation from 1 July 2006.

**Calculation procedures**

Specific procedures will be developed for existing dwellings and for non-residential and public buildings. A more user-friendly software tool is being developed and will be finalised by April 2007. A calculation procedure for new non-residential buildings will be adopted during 2007.

It is expected that an operational rating may be used for the energy rating of public buildings and pilot projects will be carried out to test and evaluate this approach.

**Requirements for new buildings**

The type and level of requirements are a function of the type of building (dwellings, office buildings schools, …) and cover:

- Limitation of Heat loss through the building fabric
- Limitation of CO2 Emissions
- Controls for space heating and hot water supply systems
- Insulation of hot water storage vessels, pipes and ducts

**Requirements for existing buildings**

From 1991, the Government of Ireland adopted minimum requirements for new building components when building renovation is done and for extensions to existing buildings.

**Certificates of buildings**

The requirements regarding the certification of buildings have been set out in an Action Plan. Certification will be obligatory for new residential buildings from 1 January 2007. For new non-residential - including public - buildings, a Building Energy Rating (BER) will be needed from 1 July 2008. Existing buildings (residential, non-residential and public buildings) when rented or sold must have a Building Energy Rating (i.e. an energy performance certificate) from 1 January 2009.

**Inspection**
An information and promotional campaign for boilers is being developed and will be implemented from January 2008 in Ireland.

The inspection of air-conditioning systems is covered by the existing regulations. These regulations were adopted in June 2006 and will be mandatory from January 2008. The procedures for inspection of air conditioning systems are still being developed.

**Future planning**

A software tool is being developed (“PASSES”) for assessing the feasibility of alternative energy systems in new buildings. User-friendly software is being developed of new dwellings. A study of the methodology to calculate the energy performance of non-residential buildings is being initiated.

8.1.12 Latvia

**Legal content**

The Government of Latvia has not yet adopted the EPBD. It has been granted an additional 3-year integration period.

**Calculation procedures**

The calculation procedures have not yet been adopted by the Government.

**Requirements for new buildings**

The Government has not yet adopted the minimum requirements for all new buildings. There are requirements for maximum permissible transmission heat loss coefficient of external envelope structures of buildings and requirements of maximum permissible heat loss of buildings depending on type of building. These requirements are included in Latvian Building code. By amendment to the code from September 26th the requirement to indicate specific heat losses of the whole building and specific heat losses for 1 m² of floor space is included.

**Requirements for existing buildings**

In case of the refurbishment of existing buildings the requirements are the same as for new buildings.

**Certificates of buildings**

The Government has not yet adopted the certification procedure.

**Inspection**

The Government has not yet adopted the inspection procedure requirements for boilers and air conditioning certification procedures.

**Future planning**

The future planning is based on using the additional 3-year EPBD integration period.
8.1.13 Lithuania

Legal content
The main provisions on the energy performance of buildings and the certification of the energy performance of buildings are described in The Law Amending the Law on Construction adopted 17 November 2005.

Calculation procedures

Requirements for new buildings
The energy performance class of new buildings (building part) must be not less than C. This requirement is valid for all new buildings, for which the set of the design terms (references) was issued before after the Regulation came into force.

Requirements for existing buildings
The energy performance class of large buildings (building part) with a heated area of more than 1000 m² after major renovation must be not less D. This requirement is valid for all buildings after major renovation, for which the completion of the design terms was issued after the Regulation came into force. The requirements for energy performance class are not obligatory for buildings (building part) for sale or rent, but evaluation procedure will be mandatory from 1 January 2009.

Certificates of buildings
Certification requirements for new buildings came into force from 1st January 2007. Certification requirements for existing and refurbished existing buildings will come into force from 1 January 2009.

Inspection
Inspection of boilers of an effective rated output of more than 100 kW capacity is covered. Inspection of boilers of an effective rated output of 20 kW to 100 kW and air conditioning systems will start in 2008.

Future planning
Certification requirements for existing and refurbished existing buildings will come into force from 1 January 2009.

8.1.14 Luxembourg

Legal content
The existing regulation of 1995 sets up the requirements for new buildings and the refurbishment of building stock. As a first step, the legal process for the implementation of the EPBD in residential buildings is in place. The regulation of 1995 will proba-
bly stay into force for all non-residential buildings as long as the EPBD will not be incorporated into a national regulation for these non-residential types of buildings.

**Calculation**

The new regulation implements

- a methodology to calculate the energy performance of new residential buildings;
- a methodology to calculate the energy performance of existing/residential buildings if they are subject to major modifications or extensions.
- an energy performance certificate.

**Requirements for new buildings**

The minimum requirements consist of

- maximal U-values of building elements
- building air tightness, shading measures (summer)
- insulation of hot water pipes and qualitative requirements for ventilation systems.

Beside those minimum requirements the main innovation of the new regulation consists of the prescription of specific maximum primary energy demand values and heating energy demand.

**Requirements for existing buildings**

Existing buildings undergoing modifications or extensions are subject to the new regulation. The minimum requirements are the same as for new buildings. The primary energy and heating energy requirements have only to be fulfilled in the case of an extension and if the energy reference volume of an extension exceeds 75 m³.

**Certificates of buildings**

Each time a building permit (new buildings and refurbishment of existing building) is required the energy performance certificate have to be attached to the demand. Four years after an energy performance certificate has been issued for a new residential building, or for residential buildings undergoing modification or extension, the certificate is accomplished by an energy consumption indicator for heating and/or domestic hot water.

Residential buildings must be classified on the energy performance certificate into different categories of efficiency with respect to the primary energy consumption indicator, the heating energy consumption indicator and the CO2 emissions indicator.

**Inspection**

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The regular 4-year inspections of gas-powered boilers are covered.

**Future planning**

The incorporation of the energy performance directive into the national law related to non-residential buildings is at this time under development.

8.1.15 Malta

**Legal content**

Malta has requested the extension of another 3 years in the implementation. The Government has adopted minimum requirements for all new buildings in November 2006. The requirements came into force for building permits requested as from 2 January 2007.

**Calculation procedures**

No specific calculation procedures have yet been adopted. In the case of residential buildings, a draft calculation procedure that takes into consideration the heating requirements has been prepared.

**Requirements for new buildings**

The type and level of requirements cover:

- Maximum permitted U-values of building components such as roofs, walls, floors and apertures – independent of the category of building type;
- Limitations for the size of windows and roof lights - according to the type of glazing used and different building categories;
- Control of solar overheating by limiting the area of glazing according to orientation, type and shading factors; OR Maximum permitted level of summer overheating per m² of floor area if alternative calculations based on the CIBSE method are used to prove equivalence;
- Introduction of zone timing and temperature controls for space heating and cooling systems.
- Automatic thermostat controls on hot water systems
- Separate metering for different categories and sizes of heating and cooling equipment.
- Limitations on maximum power consumption of high efficiency control gear for lighting.
- Time switching controls for artificial lighting.
- Provision for the conservation and reuse of rainwater.

**Requirements for existing buildings**
The minimum requirements are applied to building permits requesting major renovation works, extensions or change of use.

Certificates of buildings
The requirements regarding the certification of buildings are still under discussion and have not been adopted yet.

Inspection
Procedures for the inspection of boilers and air conditioning systems are still under discussion.

Future planning
It is expected that the draft legislation in connection with the inspection of boilers and air conditioning systems will come into force by not later than 2 January 2009.

8.1.16 Netherlands

Legal content
In December 2006 the Decree Energy performance of Buildings’ (BEG) as well as the ‘Regulation on Energy Performance of Buildings’ (REG) was legally implemented. For Housing companies this will be one year later on the provision of certification of their complete building stock. The permanent certification for public buildings will be mandatory by January 1st 2009.

Status of the implementation
The Netherlands already meets the Directive on a number of issues. The missing issues are being adapted and incorporated into Dutch law. Like the European Union, the Dutch government has an active policy to keep the administrative costs for citizens minimised.

Calculation procedures
Currently a substantial part of the EPBD has already been integrated into Dutch law. The methodology for new buildings already complies with the current Energy Performance Standard (EPN). The same methodology applies to major renovations of existing buildings. For other existing building stock the actual Energy Performance Advice (EPA) methodology is being simplified.

Requirements for new buildings
In the current national building regulations, proof that the requirements are met must be given before the completion of the building. The main requirement is to comply with a given maximum value for the Energy Performance Coefficient (EPC).

Requirements for existing buildings
Existing buildings, the Dutch Building Law ensures that in case of a major renovation a minimum level of energy performance is met. For small renovations there are minimum requirements concerning ventilation and insulation.

**Certificates of buildings**

The issuing of the Energy Performance Certificate is established in the ‘Decree Energy performance of Buildings’ (BEG). In the ‘Regulation on Energy Performance of Buildings’ (REG) that is to be issued in 2007, the above will be developed in further detail. In the REG the representative requirements of the Certificate will be outlined, as well as the required minimum information on the Certificate.

**Inspection**

In the Netherlands small boilers are usually checked every year for maintenance reasons. A tool will be developed with which the energy performance of the boiler can easily be determined. For large boilers the Netherlands complies with current legislation in the Environmental law. The approach to air conditioning systems will be developed similarly to the above-described method for boilers.

**Future planning**

The Netherlands are striving for complete implementation of the EPBD by January 1st 2007. The formal obligation to comply with the Directive will be met as soon as there are a sufficient number of qualified and accredited inspectors for the Energy Certificate.

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**8.1.17 Norway**

**Legal content**

On 13.06.2006, the Government of Norway presented for public inquiry a proposal for new energy requirements for new buildings with a proposed date for implementation of 01.01.2007. Other parts of the transposition of the EPBD in national law are pending. The requirements for new buildings will come into force for building permits requested after 1 February 2007.

**Calculation procedures**

The calculation procedures are part of the proposal for new energy requirements. The same procedure – net energy demand - is proposed for all building categories. The certification procedure will be based on the same principle, but may also take the delivered energy into account.

**Requirements for new buildings**

The level of requirements is expressed as maximum net energy demand per m² of floor area for 13 building categories. An alternative way is to show that a set of 11 energy saving measures are planned, for instance maximum U-values for wall, roof, floor and windows, maximum area of transparent elements, air tightness, energy re-
covery of heat etc. The Norwegian proposal also requires the use of renewable energy, replacing electricity, oil and gas for heating purposes, if cost-efficient.

**Requirements for existing buildings**
The requirements for new buildings will also apply for major renovations, affecting more than 50% of the building area.

**Certificates of buildings**
The requirements regarding the certification of buildings have not been presented by the Government.

**Inspection**
The requirements regarding the inspection of boilers and inspection of air conditioning systems have not been presented by the Government.

**Future planning**
It is expected that a proposed scheme for certification of buildings and inspection of boilers and air conditioning systems could come into force from 2008 for some building categories.

8.1.18 Poland

**Legal content**
Council of Ministries will consider, in September 2006, a new version of the Act on buildings and apartments energy assessment system and inspection of installations within a scope of energy efficiency.

**Calculation procedures**
Legislation discuss the Ordinance about the scope and form of energy certificate for building and apartments, introducing one assessment method for all types of buildings (new and old - modernized and non-modernized but rented and sold).

**Requirements for new buildings**
The requirements are the following:
- maximum permissible insulation level
- infiltration coefficients for windows and doors, and fenestration areas

The type and level of requirements are same regardless of building functions and types (dwellings, office buildings schools, …).

The energy rank is not regulated it is a result of application of specific solutions fulfilling primary (listed above) requirements.

**Requirements for existing buildings**
Requirements for existing, modernised or extended buildings will be same as for the new ones.

**Certificates of buildings**

From 1st of January 2008 all new buildings should have an energy certificate. From 1st of January 2009 all existing buildings that are sold, rented or modernised should have an energy certificate.

**Inspection**

Inspection of boilers and AC units is covered by the fore mentioned project Act that is planned to be mandatory from 1st January 2009.

**Future planning**

It is expected that execution order for the certificate and inspection will be adopted by the Government on an end of February 2007 and to become into force from 1st January 2008 for new buildings and from 1st January 2009 for the others.

**8.1.19 Portugal**

**Legal content**

On 4 April 2006, the Official Journal published three Decrees regarding the transposition of the EPBD in national law.

**Calculation procedures**

The calculation procedures are included in the Building regulations for residential buildings and in the HVAC regulations for non-residential buildings.

A software tool shall be available from INETI (at a nominal cost) in September 2006.

**Requirements for new buildings**

The new requirements are mandatory for building permits requested after 3 July 2006. The type and level of requirements are function of the type of building (dwellings, office buildings, schools, etc.) and cover:

- Maximum Heating and Cooling needs per m² of floor area (residential only);
- Maximum U-value;
- Minimum shading requirements for all windows;
- Minimum requirements for thermal bridges;
- Maximum consumption for production of hot water, including mandatory installation of solar water heaters (all buildings);
- Maximum primary energy consumption per m² of floor area (all buildings);
- Minimum efficiency and quality requirements for heating and cooling components (non-residential buildings).

Requirements for existing non-residential buildings larger than 1000 m²

If the primary energy consumption of a building exceeds a certain level, fixed by type by the HVAC regulations, an energy plan must be prepared and all measures with payback shorter than 8 years must be implemented over three years.

**Certificates of buildings**

Certification is mandatory for all new buildings requesting a use permit after mid 2007. For public buildings, a certification is needed from 1 January 2008 or 2009, depending on size. Other buildings when rent or sold must have an energy performance certificate from 1 January 2009.

**Inspection**

Inspections of boilers and air-conditioners are covered by the HVAC regulations. The procedures for inspection of boilers and air conditioning systems are still under discussion.

**Future planning**

Training courses for accredited experts are being prepared for launch in October 2006.

8.1.20 Romania

**Legal content**

On 15 December 2005, the Parliament of Romania has adopted the Law regarding the transposition of the EPBD into national law.

**Calculation procedures**

The calculation procedures will be adopted by the Government until the end of 2006. There are specific procedures for dwellings and for other buildings.

**Requirements for new buildings**

The type and level of requirements are function of the type of building (dwellings and non-residential buildings) and may cover:

- Maximum U-value - for building element and whole building
- Requirement on average insulation level – G coefficient [W/m3K]

**Requirements for existing buildings**

Requirements for new building components when building renovation is done and for extensions to existing buildings are the same as for new building.
Certificates of buildings

Certification is obligatory for new buildings with a building permit after 1 January 2007. For public buildings, a certification is needed from 1 January 2007. Residential buildings when rent or sold must have an energy performance certificate from 1 January 2010.

Inspection

Inspection of boilers is covered by the law and is mandatory from 1 January 2007. The procedures for inspection of air conditioning systems are still under discussion.

Future planning

It is expected that the execution order for the inspection of air conditioning systems will be adopted by the Government before the end of 2007 and to become into force from 2008.

Legal content

In Slovenia EPBD the Energy Act is now in the parliamentary procedure and it is expected to be promulgated till the end of 2006. Secondary legislation (regulations) based on those acts is also being prepared.

Calculation procedures

Methodology of calculation of integrated energy performance of buildings is under development and it will be integral part of Regulation on efficient use of energy in buildings. The existing approach for determination of energy demand for heating, which was part of regulation of 2002, will be extended with the calculation of energy demand for hot water preparation, air conditioning, ventilation and lighting for all types of building. CEN standards for support of implementation of EPBD will be applied as much as possible (pragmatic approach). Due to the considerable variety in local climate, additional effort will be put into the preparation of climatic data. It is planned that these regulations will be promulgated in January 2007.

Requirements for new buildings

The minimum requirements will be expressed in terms of annual heat demand for space heating and cooling (useful energy) and in terms of annual energy demand for buildings operation (final energy).

Additional requirements are proposed on the level of the element (Umax) and on the system level (heat and cooling demand). CO2 emissions as well as primary energy will be demonstrated as an additional indicator, not as a specific requirement.

Requirements for existing buildings

Requirements will have to be satisfied in case of major renovation of the building, where definition from the directive will be applied. Only that part of the building,
which is being renovated, will have to satisfy requirements. The same requirements as for new buildings will apply.

Certificates of buildings

Energy certificates for new buildings will be based on calculated values (asset rating) using the calculation methodology defined in Regulation on efficient use of energy in buildings, described above. Also for existing buildings the energy performance certificate will be based on calculated values with some simplifications in input data. The certificates based on operational ranking are considered as an optional solution for public buildings with obligatory display of energy performance.

Inspection

Regular inspection of boilers is already in place in Slovenia in the framework of the Environmental Protection Act. The regulation with additional tasks and protocols for regular inspection of boilers requested under EPBD is planned to be promulgated at the end of 2007.

Regular inspection of air conditioning systems is planned to be established at the beginning of 2008.

8.1.22 Slovak Republic

Legal content

On 8-th of November 2005, the National Council of the Slovak Republic has approved the Act regarding the transposition of the EPBD in national law. The execution order for this Act was published in December 2006.

Calculation procedures

The final calculation procedures should be adopted after the preparation of the EN standards. The procedures are not definitive set, yet. There will be not different procedures for dwellings and for other buildings.

Requirements for new and existing buildings

The type and level of requirements are function of the type of building and may cover:

- Maximum U-value required separately for existing and new building after the national standard
- Requirement on average insulation level is not set, but requirement for the heat use for heating depending on building form factor
- Maximum total delivered energy per m² of floor area as a global indicator

Certificates of buildings
The requirements regarding the certification of buildings are given in the proposed Regulation. Certification is obligatory for new buildings and major renovated buildings with a building permit as well as for public buildings and rent or sold buildings after 1 January 2008.

**Inspection**

On 13-th of December 2006, the National Council has approved the Act on regular inspections of boilers, heating systems and air-conditioning systems. This law fully become into force from 1st January 2008. The three execution orders are in preparation phase.

**Future planning**

Nothing concrete is being planned.

8.1.23 Spain

**Legal content**

The EPBD was transposed in Spain by means of three royal decrees, which were approved between March 2006 and January 2007.

**Calculation procedures**

The calculation procedure for the buildings energy efficiency is expressed by the estimated energy consumption necessary to satisfy the building energy demand in occupational and standard running conditions.

This can be calculated by a simplified prescriptive option or by a general option, described in the following section, using an official software tool or by any alternative method validated by the Government.

**Requirements for new buildings**

The type and level of performance requirements depend on the climatic zone (in total, there are 12 in all the Spanish territory) where there is building work, and they cover:

- Maximum U-values for different building elements;
- Solar factor for windows, roof lights, etc;
- Minimum Efficiency performance for thermal installations;
- Minimum Efficiency performance for lighting installations;
- Minimum natural lightning contribution;
- Minimum solar contribution to Domestic Hot Water;
- Minimum photovoltaic contribution to electric power.
The compliance with requirements on ‘Energy demand limitation’ could be checked using a simplified procedure or by using a complex procedure.

**Requirements for existing buildings**

Existing buildings must comply with the same minimum requirement as new ones when building rehabilitation, enlargement or renovation is carried out: also large buildings (floor area over 1,000 m²) where more than 25% of the building envelope undergoes renovation.

**Certificates of buildings**

Provisions regarding the energy performance certification of new buildings have been adopted at national level. Autonomous Communities can regulate and complete the national system giving more detail provisions of the control and inspections.

As for the calculation of energy demand, the ‘National Basic Procedure’ for energy certification foresees two possible ways: a simplified one and another complex one. The last one requires the use of a software tool.

**Inspection**

Inspection of boilers is already covered. HVAC systems are included to the recently revised regulations.

**Future planning**

It is expected that the Royal Decree approving the Certification for new buildings will be approved by the Government soon.

8.1.24 United Kingdom

**Legal content**

*England & Wales:* In March 2007 and June 2007, regulations were implemented.

*Scotland:* In Scotland EPBD was implemented in 2004, 2006 and 2007.

*Northern Ireland:* It is planned to make the new regulations by Autumn 2007 and to bring them into effect through a phased implementation beginning early next year.

**Calculation procedures**

The procedures for a national calculation methodology for building energy performance applying throughout the UK have been established. This is based on calculating CO₂ emission per m² for an actual design and comparing this with the CO₂ emissions per m² for a notional building, which corresponds to the 2002 building standards.

**Requirements for new buildings**

*England and Wales:* The building complies with the regulations if it satisfies the following tests:
CO2 emissions per m2 lower than the target
Limits on design flexibility for building fabric and energy systems.
Limits on solar gains for non air-conditioned buildings
Construction quality - including air tightness and commissioning tests
Satisfactory provision of operating and maintenance instructions

*Northern Ireland*: The building complies with the regulations if it satisfies criteria very similar to those listed for England and Wales above.

**Requirements for existing buildings**

The regulations meet minimum energy efficiency standards defined at the elemental level. For certain types of major improvement works in buildings with floor areas over 1,000m2 there is a further requirement for additional improvements to energy efficiency.

**Certificates of buildings**

Energy performance certificates (EPCs) will include environmental (CO2) ratings on an A-G scale. These ratings will be produced by elements of the national calculation methodology. The information for these calculations will typically be collected through site surveys using plans and specifications where they are available.

**Inspection**

The UK has decided to pursue the option of provision of advice on boilers rather than inspections, continuing the extensive programme of information, grant schemes and regulation it has been following for a number of years. The inspections of air conditioning equipment will start from January 2009.

**Future planning**

The implementation of EPBD and its impact will be kept under review by the three regional governments as part of their programmes for achieving national goals for energy efficiency and carbon emissions reduction.
8.2 Countries inside Building EQ

8.2.1 Finland

Implementation

In the beginning of the year 2008 the following laws and regulations will be put into effect in Finland:

- the law on energy certificate,
- the law on the inspection of the air condition system refrigeration in buildings and
- the regulation of Ministry of the Environment for the energy certificate and the calculation of energy efficiency of buildings.

With these laws and regulations the energy directive (2002/91/EY) will be put in force. A part of the national building codes in Finland have also been reformed in connection of the implementation of the energy directive:

- D5. Calculation of power and energy needs for heating of buildings. Guidelines

The energy certificate is needed only when the building is taken into use, sold or rented. It is mandatory for new buildings and most existing buildings. For existing buildings having less than six apartments and existing detached houses the energy certificate is voluntary. The certificate is not demanded for holiday houses (smaller than 50 m² and in use less than four months per year). Besides, the requirements are not related to industrial buildings, protected buildings and churches.

The law on energy certification will come into operation in the beginning of the year 2008. After that new buildings will need an energy certificate when applying for a building permit. However, for existing buildings an energy certificate will be needed after the beginning of the year 2009 and then only in situations when the building is sold or rented.

Requirements for new buildings

The main designer (usually the architect) will give the energy certificate for a new building and the energy certificate is mandatory for new buildings. The certificate is based on the calculated energy consumption of the building.

The calculation principles of the energy certificate have been defined for three categories:
1. small residential buildings, max. six apartments in building
2. over six apartment residential buildings or building group and
3. other than residential buildings.

The group 1, for small (maximum six apartment) buildings the calculation method used will be National building codes, D5. Calculation of power and energy needs for heating of buildings.

For other buildings National building codes D5 guidelines, suitable SFS-En standard or some other calculation method can be used.

**Requirements for existing buildings**

The energy certificate for existing buildings can be given by

- house manager or chairman of the house board in context of house manager’s certificate
- energy expert / energy auditor in the context of the energy audit and
- person who fulfils defined competence requirements.

For existing buildings the energy certificate is based on the measured energy use in the building. The energy certificate includes the audit (or a site visit) of the building in which the energy efficiency and energy saving potentials are scanned and reported.

**Certificates**

The buildings are divided into ten categories for which the levels for energy consumption have been defined in unit kWh/brm²/year. The annual energy consumption is the sum of heating energy, property electricity and cooling energy. The heating energy consumption is weather corrected to the city of Jyväskylä in Finland.

The energy consumption levels are divided into classes A-G. The building classification is based on handbook of Statistics Finland. The building categories are the following:

1. Small apartment buildings
2. Large apartment buildings
3. Office buildings
4. Commercial buildings
5. Educational buildings
6. Kindergartens buildings
7. Health care buildings
8. Recreational buildings
9. Swimming halls
10. Other buildings
Figure 27 presents an example of the conclusion page of the energy certificate.

The following certificates are valid for ten years

- energy certificates for detached houses and max. six apartment buildings
- energy certificates which have been done in context with the energy audit of the building
- separate energy certificates

The energy certificates is valid for four years

- larger than six apartment buildings and
- office/commercial buildings in context of building permit.

Shorter validity time for energy certificate is for

- certificates which include to the house manager’s certificate, valid as house manager’s certificate.
Energy experts
The person who gives separate energy certificate should have suitable degree in civil engineering or building services. The person should have adequate knowledge of regulations and of preparing the energy certificate. The competence for acting as an energy expert is tested with official test.

Periodical Inspections
The inspection of the air conditioning systems in buildings is related to the whole building or a part of its air conditioning system, having a cooling capacity higher than 12 kW and based on use of compressors. The systems mentioned should be inspected at least once during a ten year period. The system which utilises district cooling does not need to be inspected according the law.

From the inspection the building owner should be given a certificate in which is mentioned the condition and efficiency of the equipment and also some recommendations for improving the energy efficiency of the equipment.

The inspections are carried out by authorised contractor or maintenance company.

8.2.2 Germany
Implementation
The EPBD is implemented in the legal context of the Energy Saving Act, which originally came into force in 1976 and has since then been used to set up the requirements for:

- the thermal insulation of buildings,
- the energy performance and maintenance of heating appliances and
- the billing of heating cost according to individual consumption of the tenants.

On this basis the current Energy Saving Ordinance (EnEV 2002 – amended 2004) sets up requirements for new buildings and the refurbishment of building stock. These are mainly based on an energy balance of the whole building taking into account most of the aspects given in the annex of the EPBD. For normally heated new buildings the overall requirement is based on primary energy, an energy certificate (Energiebedarfsausweis) has to be issued for these new buildings as well as for buildings in the course of major refurbishments.
Figure 28  Legal context of German implementation of EPBD

In future, this approach will apply to residential buildings only - except those equipped with air conditioners (very few because of strict limits for solar shading).

To implement the aspects “lighting” and “cooling”, the Energy Saving Act had to be amended in September 2005. This was also necessary for the implementation of energy certificates for existing buildings, which are not subject to renovation.


**Calculation method**

The calculation procedures for existing and new residential buildings will stay in force. They are based on two German pre-standards, which are mainly transpositions of EN 832. The current versions are DIN V 4108-6: 2003-06 and DIN V 4701- 10: 2003-08.

In 2005, the German Standardisation Institute (DIN) published under the Title “DIN V 18599 (Part 1 – 10)” the results of an interdisciplinary standardisation work as the calculation method for overall energy performance of buildings including all aspects of the EPBD. The standardisation works where initiated by the federal government in order to have a universal method covering all aspects (new: lightning and cooling) primarily for non-residential buildings.

**Requirements for new buildings**

The requirements for residential buildings will be kept at the present level, as will the requirements for refurbishment of parts of the building’s fabric. For non-residential buildings the requirements will be transposed without significant changes to the new model taking into account the different uses of these buildings and the new aspects.
In general, there will be no changes in the level of requirements after the current amendment comes into force. The level of requirements will be revised later, not before people have got familiar with the new methods for non-residential buildings and the energy certificates for existing buildings. The level of requirements for new buildings is governed by the function and the type of building (residential / non-residential with detailed conditions of use) and also the Surface/Volume-Ratio.

They consist of:

- a maximum primary energy demand,
- a maximum average u-value
- maximal u-values of each element of the building’s fabric
- several requirements on quality of boilers, controls and pipe insulation
- building air-tightness and
- the prevention of thermal bridges.

**Requirements for existing buildings**

The requirements in cases of refurbishment consist of either

- a maximum primary energy demand (140% new buildings) and
- a maximum average u-value (140% new buildings) or
- maximum u-values (=state of the art) for each element of the refurbishment.

The requirements have to be met, if more then 20% of the element in question (walls, windows, roof/upper ceiling, cellar ceiling/walls) is subject to refurbishment.

**Certificates**

Certification is already obligatory for new buildings since February 2002. Existing buildings will be certificated in three steps depending on the year of construction. Thus, certificates for residential buildings older than 1965 are mandatory from July 2008 respective January 2009 for newer buildings.

Time limit for Non-residential buildings is determined to July 2009.
Certificates are based either on energy demand or consumption depending on the type of building, the amount of accommodation units and the year of construction. In general, certificates for new buildings have to be based on energy demand.

Existing non-residential buildings are free in choice between both alternatives. This does also apply to existing residential buildings with only one exception: Buildings with less than 4 accommodation units, older than 1977 and without major renovation have to be based on energy demand calculation.

Figure 29  Time limits for certification of existing buildings

Figure 30  First page of certificate for residential buildings showing the energy performance
Certificates based on energy consumption include yearly data of end energy supply for the last three years. There are no regulations about how the data are to obtain. All consumption data have to be revised by considering regional climate.

Detailed information is available only when certification is done by calculating the energy demand. Therefore, for most of the existing buildings no adequate data for continuous commissioning will be available. It is obvious that additional investments for asset rating will be done only in case of major renovation when stocktaking is done anyway.

In principle, data from certification based on demand are applicable for continuous commissioning. However, regulations on monitoring are necessary in order to enable further usage of all collected data. Up to now the EnEV does not foresee requirements on linking calculation and monitoring.

**Figure 31 Scheme of certification process**

**Energy experts**

Today exist already a high quantity of energy experts for residential buildings. The qualification ranges from engineers, architects to craftsmen or chimney sweeper with or without a training for energy saving purposes.

However, calculation for non-residential buildings has to be undertaken only by experts with academic education and a specialization in energy saving constructions.
Inspection

Inspection of boilers is covered by the Small and Medium Combustion Plant Ordinance, last amended 1997. The inspection of air conditioners is regulated in the EnEV2007 and will be mandatory ten years after start of operation. Assessors are obliged to give recommendations for possible improvement or replacement of the air-conditioning system and on alternative solutions.

Future planning

A revision of the level of requirements is envisaged in a few years.
8.2.3 Italy

Implementation and legal context

Italy starts to promote Energy Certification of buildings from 1991 with the law 10/91 “Norme in materia di uso razionale dell’energia, di risparmio energetico e di sviluppo delle fonti rinnovabili di energia” (art. 30), but this aspect of the law has been unapplied up to the promulgation of Legislative Decree 192/05 “Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell’edilizia” which aim to introduce the EPBD in the Italian contest. Another step in the implementation of the EPBD has been done with the Legislative Decree 311/06 “Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE, relativa al rendimento energetico nell’edilizia”.

The major changes introduced by the new decrees are the transfer of the Energy Certification legal implementation responsibility from the State Government to the Regional Governments. Thus a “definitive” application, in the field of Energy Certification, is subjected to the Applicative Decree each Regional Government has to prepare. In the mean time a general line guide can be prepared by the Central Government and applied in each Region until it has its own specific legislation. Today this general guideline is still under preparation, while some Regions have already provided their own specific application laws. The situation is therefore in evolution, and without a Central Government coordination it can results in many different energy certification schemes as the Regions are.

The Lombardia region and autonomous province of Bolzano have already fully implemented the certification process, while Piemonte region has only a general application law and it’s working on the practical implementation details and rules. Some other regions the autonomous province of Trento are working on the local application of the EPBD, while other Regions are still waiting for the general guidelines from the Central Government.

The other aspects of the Directive, the calculation methodologies and the minimum requisites finalized to increase the building efficiency, are instead under the responsibility of the Central Government and are only partially implemented, i.e. only for the winter heating.

Italian legislation is strongly oriented to use only the Asset Rating approach for the Energy Certification, based on CEN standards implemented by UNI⁴⁸. Other references are diffused by CTI⁴⁹ (Comitato Termotecnico Italiano). A list of technical standard is diffused on annex M of Legislative Decree 311/06. Further application of aspects that are not regulated will be based on the prEN standards that refer to EPBD.

Although this legal context the implementation of the EPBD and CEN standards is up to now only referred to some aspect of the points listed in the Annex of EPBD (see

⁴⁸ UNI, Ente Nazionale Italiano di Unificazione, Italian National Organization of Unification, site web: www.uni.com/it
⁴⁹ CTI, Comitato Termotecnica Italiano, Italian Thermotechnical Committee, site web: www.cti2000.it
The legal code that concerns other aspects is under preparation. It has to be noted that although Italy has a huge potential on the cooling energy demand, the aspect of EPBD that concern the certification of summer air-conditioning have not been applied up to now.

EUROPE  
EPBD 2002/91/CE

ITALY  
D.Lgs 192/05 and 311/06  
Law 10/91

Applicative decree, guidelines:  
• Calculation methodologies  
• Minimum requisites  
• Energy certification general

REGIONAL LAWS  
Regional laws on Energy Certification and applicative decrees

Figure 32 Energy performance requirements

The national law defines the minimum energy performance requirement for each building typology basically in term of maximum allowed primary energy use, today limited to winter heating and domestic hot water preparation. Such requirement can be further lowered by regional and community authorities and it is normally expressed as a primary energy index, (PEI). Limits for the PEI are defined considering the climate zone and the S/V ratio.

For residential buildings, excluded public schools, convents, monasteries, prisons, barracks, this Primary Energy Index is expressed in kWh/(m²*y), i.e. it is based on the useful floor area. For all other building categories PEI is expressed in kWh/(m³*y), i.e. based on the gross volume. This requirement does not apply to:

- protected historical or cultural buildings (D.Lgs 42/04);
- stand-alone buildings with a total useful floor area of less than 50 m²;
- agricultural, productive buildings that are heated for process needs or that use waste energy.

- Annex 50 -
Actually the legislation allows different energy performance assessment procedures and/or different prescriptions depending on the following cases:

- new constructions and building with a useful surface > 1000 m² if subjected to demolition, reconstruction, renovation or important refurbishment,
  - full application at the whole building;
- new added volume but less than 20% of existing building volume,
  - full application only for the new built volume;
- if only partial refurbishment of the building system, i.e. limited to:
  - envelope
  - complete refurbishment with surface is < 1000 m²;
  - partial refurbishment;
  - important maintenance;
  - extension less 20% of the volume of existing building;
  - heating system
  - new heating system in unheated building;
  - system refurbishment;
  - heat generator
  - substitution of the heat generator.
  - application limited to specific parameters.

Other prescriptions concern the thermal insulation of internal walls between apartments or connected to not-heated zones; control of the superficial and interstitial condensation, solar shading (qualitative), thermal inertia, natural ventilation (qualitative), thermoregulation, renewable energies, district network connection, maintenance of air-conditioning facilities.

Full application stays for the assessment of the Primary Energy Index via calculation (performance assessment) and for complying with several constraints on building envelope properties (i.e. thermal transmittance) and on heating system seasonal efficiency. While application limited to specific parameters respectively means:

- envelope: complying with limiting values of thermal transmittance;
- heating system: complying with limiting values of seasonal system efficiency;
- heat generator: complying with or prescription on system and boiler characteristics or limiting values of seasonal system efficiency.
Energy performance calculation method


PEI index considers the energy use due to heating, ventilation, DHW only for winter air-conditioning. Summer air-conditioning has to be defined and it isn’t considered in Energy Certificate up to now. Contribution from renewable energies (mainly solar energy) are also considered in the method.

Energy Certification

Energy Certification, which was actually in law since December 1991, has to be applied from July 2007 for:

- new buildings;
- envelope refurbishment, demolition and reconstruction (useful surface >1000 m²).

Existing buildings need to have an energy certificate only if rented or sold with following schedule:

- from 1st July 2007, buildings with useful floor are >1000 m² in case of selling/location (or other possession changes);
- from 1st July 2008, buildings with useful floor are <1000 m² in case of selling/location (or other possession changes);
- from 1st July 2008, any lodgings in case of selling/location (or other possession changes).

Energy certificate is necessary from 1st January 2007 for obtain any incentives concerning buildings, plants or energy delivery to buildings and for energy service contracts that concern public buildings.

Energy certificate is valid 10 years or until a refurbishment intervention. It must be provided for any selling or location. It must be showed to public for any public building.

Energy certificate must be prepared by a third part in building process, which has the necessary technical competence (he must be accredited by a public authority). Administrative endorsement is applied to the certifier if wrong certificate has been released. The absence of the energy certificate cancels selling or location contracts.

The energy certification procedure and the way in which technicians are accredited as authorized certifiers have to be defined regionally.
Images show the energy certificate and the energy plaque that have been adopted by Regione Lombardia. The energy certificate considers heating and DHW primary energy, useful energy for both summer and winter air conditioning and the renewable energies contribution. CO₂ emissions are also considered and qualitative analysis of energy improvement for both the envelope and the facilities concludes the certificate.
General framework for the calculation of energy performance of buildings (Art. 3), application in Italy

Table 9   methodology of calculation of energy performances of buildings and relevant aspects (EPBD Annex)

<table>
<thead>
<tr>
<th>Energy performance aspects</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) thermal characteristics of the building</td>
<td>Decreasing limit (2006, 2008, 2010) are fixed for each climate zone for the opaque and transparent envelope, depending on S/V ratio</td>
</tr>
<tr>
<td></td>
<td>Calculation based on:</td>
</tr>
<tr>
<td></td>
<td>UNI EN ISO 7345</td>
</tr>
<tr>
<td></td>
<td>UNI EN 673</td>
</tr>
<tr>
<td></td>
<td>UNI 10355</td>
</tr>
<tr>
<td></td>
<td>UNI 10351</td>
</tr>
<tr>
<td></td>
<td>UNI EN ISO 13370</td>
</tr>
<tr>
<td></td>
<td>UNI EN ISO 14683</td>
</tr>
<tr>
<td>(b) heating installation and hot water supply</td>
<td>Calculation based on:</td>
</tr>
<tr>
<td></td>
<td>UNI EN 832 (heating, residential)</td>
</tr>
<tr>
<td></td>
<td>UNI EN ISO 13790: 2005 (heating, other buildings)</td>
</tr>
<tr>
<td></td>
<td>CTI R 03/3 (DHW and heating facilities performance)</td>
</tr>
<tr>
<td>(c) air-conditioning installation</td>
<td>Not applied (only maintenance)</td>
</tr>
<tr>
<td>(d) ventilation</td>
<td>Partially considered, calculation based on:</td>
</tr>
<tr>
<td></td>
<td>UNI EN 13465 (ventilation ratio, residential)</td>
</tr>
<tr>
<td></td>
<td>UNI EN 13779 (not residential)</td>
</tr>
<tr>
<td>(e) built-in lighting installation (mainly non-residential)</td>
<td>Not applied up to now</td>
</tr>
<tr>
<td>(f) position and orientation of buildings, including outdoor climate;</td>
<td>Partially considered, Italy is divided in six climatic zone, basing on winter degree days (DPR 412/93)</td>
</tr>
<tr>
<td>(g) passive solar systems and solar protection;</td>
<td>Partially considered, calculation based on:</td>
</tr>
<tr>
<td></td>
<td>UNI EN 13561</td>
</tr>
<tr>
<td></td>
<td>UNI EN 13659</td>
</tr>
<tr>
<td></td>
<td>UNI EN 13363</td>
</tr>
<tr>
<td>(h) natural ventilation;</td>
<td>Not applied (only mentioned)</td>
</tr>
</tbody>
</table>
(i) indoor climatic conditions, including the designed indoor climate.

Heating season: 20 °C, rh 50%
Cooling season: 26 °C, rh 50%.
This set-points have to considered for 24h/day.

<table>
<thead>
<tr>
<th>Other relevant aspects</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) active solar systems and other heating and electricity systems based on renewable</td>
<td></td>
</tr>
<tr>
<td>energy sources;</td>
<td></td>
</tr>
<tr>
<td>50% of DHW needs have to be produced using renewable energies.</td>
<td></td>
</tr>
<tr>
<td>PV installation is compulsory, but no technical data are defined up to now</td>
<td></td>
</tr>
<tr>
<td>(b) electricity produced by CHP;</td>
<td></td>
</tr>
<tr>
<td>up to now it is considered only the part complying with the electrical energy need of</td>
<td></td>
</tr>
<tr>
<td>the heating system</td>
<td></td>
</tr>
<tr>
<td>(c) district or block heating and cooling systems;</td>
<td></td>
</tr>
<tr>
<td>predisposition for connection to district network have to installed</td>
<td></td>
</tr>
<tr>
<td>(d) natural lighting.</td>
<td></td>
</tr>
<tr>
<td>Not considered</td>
<td></td>
</tr>
</tbody>
</table>
8.2.4 Sweden

New buildings

The Swedish Building Code (BBR) was changed in July 2006 to reflect the requirements from the EPBD regarding new buildings. For all new buildings the annual energy use must be measured after two years of operation. The second year’s energy measured use must fall below the maximal energy performance limits in BBR. In addition there is also requirements on a maximum overall U-value. Earlier building codes only had requirements on the heating use in form of U-values and air tightness. In practice the measurement requirement means that all buildings with permits after 1 July 2007 must make energy calculations. Sweden is divided into climatic zones and there are limits for residential and non-residential buildings, respectively. Buildings with direct resistance electric heating have lower energy performance limits.

The annual amount of energy is defined as the delivered energy to a building during a standard year (often called bought energy) for heating (building and tap water), comfort cooling, and operational energy for pumps, fans, etc. It is worth mentioning that this is not fully the same definition as in the Annex in the EPBD! The difference is that Swedish directions very clearly exclude energy use caused by activity in the building, whereas the Annex includes some such as electricity for fixed lighting etc.

Existing buildings

All existing multi-family buildings and none-residential buildings with public activities must have an energy certificate before 31 December 2008 (the first buildings will probably be certified in the autumn of 2007). All commercial buildings, apart from some exceptions such as industrial buildings, religious buildings etc. and one-family houses, will be certified after 1 January 2009, when sold or rented. As mentioned new buildings will be certified after two years of use based on the measured energy during the second year.

The certificates will contain recommendations of cost effective energy efficiency measures, if there are any. The recommendations are given by certified energy experts working for accredited certifying organisations.

The certificate will also contain reference values to enable energy performance comparisons of the actual building with other existing and new buildings in the same category. The energy performance is defined as the annually amount of measured delivered energy (Operational Rating) per square meter heated area (kWh/m², year), excluding the users’ or tenants energy use.

In accordance with Swedish praxis, the weight factors for all energy carriers are set to unity. Maybe the ongoing national implementation of the Energy Service Directive will change the weight factorsmore towards primary energy factors.

Moreover, it is notable that even many new buildings today do not have separate energy meters, neither for individual buildings on a campus (mostly schools and health care buildings), nor for electricity separated into heating (when used) and other en-
ergy end-uses. It is rare with separate electricity meters for the activity, which makes it hard to distinguish between the energy use for the building (as defined in the Swedish directions) from the activity in it. It is obvious that building owners will have to install separate meters as soon as possible.

In the future, use of electrical energy on monthly basis will be known. For example, by 1 July 2009 the use of electricity will be measured on monthly basis (typically hourly basis), according to a government ordinance. At present it is measured on quarterly basis for larger users and annually for smaller. In fact, today no energy (or water) use is measured on monthly basis, unless the building owner measure it himself, which of course some do.

Heated area is defined as treated areas inside external walls were the indoor temperature never goes below 10 °C. However, this area is not defined in the general Swedish floor area and volume standard SS 121053-1999. This means that no building owner has it recorded.

In all building types, except one-family houses, the energy certificate most be publicly displayed, typically at the entrance of the building.

The certificates will contain information on special inspections of comfort cooling systems with 12 kW cooling effect or more are accomplished. Furthermore it will contain information on ventilation control (compulsory in most Swedish buildings) is accomplished, together with the number of approved or not approved ventilation systems. The certificates will also contain information on any optional radon measurements.

Information on the specific buildings will be sent to the responsible authority, Boverket (the National Board of Housing, Building and Planning) by the energy expert. All information will be stored in a national database. The database can be used for future studies, such as impact of energy saving measures carried out, etc. It is not yet specified exactly what information the certificates will contain, or what information the energy experts must send to the national database for energy certificates. Boverket has, so far, given a draft form of what information the energy experts have to send in. A compilation of it, with regard to continuous commissioning is given below:

- Heating use per energy carrier (measured and divided)
- Other electricity use (measured and divided)
- Energy performance, kWh/m² (corrected to a standard year)
- Is there solar heating? If yes, how many square meters?
- $A_{\text{temp}}$ (heated area) and/or BOA (residential area) and LOA (premises area)
- Number of floors
- Construction year
- Break down of activity per floor area
- Is OVK (obligatory ventilation control) accomplished?
- Is a voluntary radon measurement accomplished? If yes, content of Becquerel (Bq/m²)
- Type of ventilation system
- Energy saving recommendations
- Reference values of Energy Performance for similar buildings, new and existing buildings
- Is there a comfort cooling system larger than 12 kW cooling output?
- Description of energy saving measures
- Cost per saved kWh
- Reduced amount of CO₂ emissions

Figure 33  The proposed layout of the public displayed part of the energy certificate is enclosed.
On the official label the annual energy use of the building is placed on one of eight (seven) levels. These levels are so far only for testing and are:

<table>
<thead>
<tr>
<th>Level</th>
<th>Measured annual delivered energy use [kWh/year &amp; m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Liten (Low)</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>2</td>
<td>51-100</td>
</tr>
<tr>
<td>3</td>
<td>101-151</td>
</tr>
<tr>
<td>4</td>
<td>151-200</td>
</tr>
<tr>
<td>5</td>
<td>201-300</td>
</tr>
<tr>
<td>6</td>
<td>301-400</td>
</tr>
<tr>
<td>7 Stor (High)</td>
<td>401-500</td>
</tr>
<tr>
<td>8</td>
<td>&gt; 501</td>
</tr>
</tbody>
</table>

(all energy carriers’ weight = 1)

The idea is that the levels on the label shall be modified when several ongoing project for environmental classification of existing buildings are finished in the beginning of 2008. The seven level scale may also in the future be classified according to the rules in EN 15217.

So far statistics are only available for the heating energy use of buildings in Sweden. For multi-family buildings statistics are also available for the electricity use for the tenants and for the building (fans, pumps, etc). A couple of projects are ongoing to indentify the electrcyt of in non-residential buildings. Sofar data has been published for office buildings and preschools/schools respectively. In 2007 health care buildings are audited.
Sweden will not make any additional inspections of boilers in buildings, mainly because the number of boilers using fossil fuels is decreasing rapidly. The fast increasing bio-fuel boilers are currently inspected annually or every second year.
8.3 Example of FPT

This is an example of a simple FPT for a hot water pump (see: http://www.peci.org/ftguide).

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**Hot Water Pump Test**

**Heating Hot Water System**  
**Pump Test to Assess the Impact of Discharge Throttling**

**Purpose**

The purpose of this test is to document the NYMEX hot water system pump performance and assess the impact of the currently throttled valves. The system is a constant volume system with ice storage. There are several three way valves in the system and they do not have balance valves in the bypass.

The test will establish the system curve for the pumping system. This will allow the match between the pump capacity with discharge valve fully open to be assessed against the actual head required to deliver design flow. It will also allow the energy implications of the throttled discharge valve to be assessed.

**Instructions**

Initial each step if the item is completed satisfactorily or the test item associated with the step met the test requirements and passed. If the item is not satisfactory or the test step fails, record an "F" in the appropriate box instead of your initials. Document the reason for failing in the comments section as a numbered note and include the note number next to the F on the test form. If the test step has data associated with it, document it on the test form in addition to your initials and the date and time.

**Equipment Required**

1. Digital pressure gauge or a reasonably accurate gauge on the pump.
2. An amprobe or kW meter (desirable but not mandatory)

**Acceptance Criteria**

The test is being run for the purpose of gathering data to assess pump performance, thus there is no acceptance criteria.

**Precautions**

1. Exercise care when changing operating modes.
2. Verify that all components between the pump discharge and the discharge service valve are rated for the peak pressure on the pump curve with the largest impeller size installed prior to performing a shut off test.
3. Avoid sudden flow changes to minimize the potential for water hammer.
4. Exercise proper precaution while working around live wiring and terminals to take amp readings.
5. Exercise proper precaution while working around the rotating parts of the pump.

**References**

1. Pump curves for the pumps to be tested.
Hot Water Pump Test

2. A system diagram (to be developed prior to testing).
3. The Bell and Gossett Hydronic Engineering manual.
4. The Back to Basics columns in Pumps and Processes magazine; Pumps and Your Processes: They Must Work Together, January-February 2002; Using System Curves to Enhance Pump Performance; March-April 2002; Pumps and Your Processes: When They Won’t Work Together; May-June 2002

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Data [include units]</th>
<th>Completed [Initials, Date and Time]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prerequisites</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Gauges and valves are in place at the pump gauge taps. It is important that the gauges are arranged to measure pressure at the same location used by the manufacturer to develop the pump performance data.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. The test will not interfere with building operations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. The system can be operated</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Preparation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Obtain pump curves for the pump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Coordinate as necessary with the trades.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Document the as found status of the system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HW Pump 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HW Pump 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heat exchanger 1 EWT</td>
<td></td>
<td></td>
</tr>
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<td>Heat exchanger 1 LWT</td>
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<tr>
<td>Heat exchanger 2 EWT</td>
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<tr>
<td>Heat exchanger 2 LWT</td>
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<td>Outdoor air temperature</td>
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<td>5. Document the pump name plate data.</td>
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<td>Make HW Pump 1</td>
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<tr>
<td>Model HW Pump 1</td>
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<tr>
<td>Serial Number</td>
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<tr>
<td>Flow</td>
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<tr>
<td>Head</td>
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<tr>
<td>Impeller Size</td>
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<tr>
<td>Motor Make</td>
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<tr>
<td>Motor Speed</td>
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<td>Volts</td>
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### Hot Water Pump Test

<table>
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<tr>
<th>Amps</th>
<th>Hz</th>
<th>Phase</th>
<th>Efficiency</th>
<th>Serial Number</th>
<th>Service Factor</th>
<th>Other</th>
<th>Other</th>
</tr>
</thead>
</table>

#### Procedure

1. Position the system's control valves for full flow through all loads. If this is not possible document the condition at the time of test as best possible in the notes section.

2. With one pump running (normal operating mode) document the following. Note the engineering units associated with the reading; i.e. psi or ft.w.c.
   - Pump that is under test
   - Pressure ahead of the strainer
   - Pump suction pressure
   - Strainer pressure drop (the difference between the two reading just taken)

3. If the pressure drop through the strainer exceeds 3 psi/7 ft.w.c. suspend the test and inspect and clean the strainer. After the strainer is clean, proceed with the following.
   - Pump discharge pressure
   - Pump amps (all phases)
   - Pump volts (all phases)
   - Pump kW
   - Pump kW

4. Document the discharge valve position so it can be returned to the "as found" condition after the test.

5. Fully open the discharge service valve.

6. Document the following
   - Pump suction pressure
   - Pump discharge pressure
   - Pump amps (all phases)
   - Pump volts (all phases)
   - Pump kW

7. Perform a shut off test to verify the pump impeller size by briefly closing the discharge valve and and documenting the pump differential pressures. Proceed as
Hot Water Pump Test

follows:

Briefly close the discharge valve and document:

- Pump suction pressure
- Pump discharge pressure
- Return discharge valve to original position.

8. If the second pump can be operated, proceed as follows.

9. Document the discharge valve position so it can be returned to the "as found" condition after the test.

10. Fully open the discharge service valve.

11. Start the second pump and document the following:

- Pump suction pressure
- Pump discharge pressure
- Pump amps (all phases)
- Pump volts (all phases)
- Pump kW

12. Document the following on the first pump.

- Pump suction pressure
- Pump discharge pressure
- Pump amps (all phases)
- Pump volts (all phases)
- Pump kW

13. Shut down the first pump.

14. Document the following on the second pump.

- Pump suction pressure
- Pump discharge pressure
- Pump amps (all phases)
- Pump volts (all phases)
- Pump kW

15. Perform a shut off test to verify the pump impeller size for the second pump in a manner similar to what was used for the first pump. Proceed as follows:

- Document discharge valve position
- Start the second pump to prevent a chiller safety shut down due to loss of flow.
- Briefly close the discharge valve and document:
- Pump suction pressure
- Pump discharge pressure
**Hot Water Pump Test**

Return discharge valve to original position.

**Follow up and Return to Normal:**

1. Remove all test equipment.
2. Return the system to the state it was operating in at the start of the test or as requested by the operating staff.
3. Plot test results on the pump curves to determine flow rates in all operating modes.
4. Verify the impeller size for the pump that was tested based on the shut off test and document. Impeller size for the pump tested
5. Assess the impact of the throttled discharge valveCWP-2 impellers size and develop recommendations.

**List of Test Coordinators und Team Members:**

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**Test Completion Sign Off**

This test has been performed to the best of my ability per the requirements of the procedure. Deviations or problems encountered have been noted at the end of the test form.

**Date and Signature of Test Coordinator**

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