HVAC System Efficiencies for EPBD Calculations

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SUMMARY

Whole-building energy performance calculations are required by the EPBD as part of compliance with minimum standards for new buildings and of the energy performance certification process for existing buildings. These are integrated calculations that include the effects of the building design and of the installed or proposed HVAC and lighting systems. The performance of HVAC – and especially air-conditioning - systems can vary very widely and it is therefore important to estimate system efficiencies realistically. On the other hand, the calculation process itself should not be unduly onerous. This paper explains how these contradictory pressures have been dealt with in the development process of the HVAC component UK compliance tool for non-domestic buildings, SBEM (Simplified Building Energy Model) and summarises its main features..

INTRODUCTION

Energy-related building codes for new construction have traditionally focussed on building envelope issues and, in many countries, only on heating energy use. In recent years, however, there have been substantial increases in demand for electricity for lighting and air-conditioning, especially in commercial buildings. At the same time climate change and carbon emissions from all fuels have become a focus of energy and environmental policy. As a result this traditional emphasis on heating and insulation has come to look incomplete.

This is reflected in the requirements of the Energy Performance of Buildings Directive (EPBD), which calls for the use of integrated energy calculations that take account of all energy sources and all building-related end-uses of energy. These integrated calculation methods are to be used as the basis of building codes for new construction throughout Europe, though Member States have some flexibility to define the calculation process. In many countries the same calculation method will be used for the Energy Performance Certification of buildings when they are constructed, sold or let.

Crucially, these integrated calculations have to reflect system efficiencies as well as envelope performance. There are many alternative types of HVAC system of very different efficiency and so the impact of system selection and specification on carbon emissions can be as large as that from building envelope decisions, especially for new buildings. This is especially so for systems that provide cooling or ventilation in addition to heating. Increasing insulation requirements and moves to impose minimum efficiencies for boilers and other heat generators have already reduced heating demands, more of which are met by internal heat gains. Since the cost-effectiveness of increasing insulation thicknesses is subject to the law of diminishing returns, the economic benefits of further improvements are now relatively small.

Thus the realistic representation of HVAC systems in these calculation tools is of substantial importance. It is far from clear how best to do this as there are somewhat conflicting requirements for simplicity and consistency of use on the one hand, and technical robustness on the other. This paper describes the approach that has been adopted in the UK Simplified Building Energy Model (SBEM) and places this in the context of developing practices in other Member States.

OBJECTIVES

Calculation procedures for EPBD applications should ideally satisfy a number of somewhat contradictory requirements:

- Technical Credibility
  - Technically sound calculation process
  - Produce realistic results
- Discrimination
  - More efficient systems should give better figures
- Repeatability
  - Different users should get the same results
- Transparency
  - Both the data and the process should be auditable
- Ease of use and manageable data requirements
  - To reduce errors and cost

In practice it is difficult to satisfy these simultaneously and it is necessary to balance the competing requirements against each other. This balance is likely to be different for different applications - for example, the relative importance for design purposes may be different from that for Energy Performance Certification.

PRINCIPLES, OPTIONS AND EUROPEAN STANDARDS

The calculation of HVAC system efficiency can be addressed at several levels of complexity. At one extreme, the simplest methods may miss out or over-simplify important factors. On the other hand, complex methods such as detailed system modelling can be very data-intensive and time-consuming to apply. Poor data quality may introduce greater uncertainty than is associated with the modelling itself. [1] In existing buildings obtaining precise information is time consuming, costly and sometimes impossible. Absolute precision is not the most important consideration, especially if it compromises the other attributes such as repeatability. Given the uncertainties of data, of calculation and of the way that buildings are operated, any decision that is driven solely by small apparent differences in performance is fragile.

The important outcomes are the actions that result. For new buildings these are the design decisions that designers are encouraged to consider. For existing buildings they are: the selection (or at least consideration) of possible improvements and decisions on the selection from a range of options of buildings available to purchase or rent.

The calculation of heating and cooling *demands* of spaces and the associated energy *consumption* of HVAC systems that satisfy these demands are obviously closely linked processes. However, the two calculation processes have somewhat different constraints.

Heating and cooling demands can be adequately calculated at monthly intervals, for example by using the monthly heat balance and utilisation factor approach of EN13790[2]. Hourly demand calculations are used as design tools but regulatory applications are unusual in Europe. The EN13790 monthly procedure (now adapted to include sensible cooling as well as heating) is becoming the most widespread approach. [•]

For most HVAC systems, calculations using hourly (or shorter) time-steps are more natural, since this interval is better aligned to the inherent time constants of the systems. Hourly calculations can

[•] EN13790 also permits the use of hourly calculations and includes a simplified hourly procedure.

either be full system simulations or simpler “bin methods”. For some types of system – especially those providing only heating – an annual seasonal efficiency can be adequate. However, even here, the determination of annual seasonal efficiencies can become cumbersome for complex systems, such as those with bivalent heating. While the results from hourly demand calculations could be easily aggregated into monthly figures for a monthly system calculation the reverse procedure is much more difficult.

Definitions

The definition of “system efficiency” for HVAC systems is less straightforward than appears at first sight, because of the difficulty of attributing energy for fans, pumps and controls to the different end-uses (heating, cooling, ventilation). The EPBD standards resolve this by separating the energy associated with these, mainly transport, components from the losses associated with the generation of heating or cooling from fuels or electricity. The energy associated with fans and pumps (and controls) is treated as a separate item denoted as “*auxiliary energy*”. The consequent definitions for system heating and cooling efficiency then become more straightforward - but are now different from the more familiar meanings that include the auxiliary energy.

“Auxiliary Energy”: is the energy used by the fans pumps and controls of a system, irrespective of whether this supports heating, cooling or ventilation.

For heating, the “System Coefficient of Performance”, SCoP, is the ratio of the total heating demand in spaces served by an HVAC system divided by the energy input into the heat generator(s) - typically boilers. It takes account, for example, the efficiency of the heat generator, thermal losses from pipework and ductwork, and duct leakage. It does not include energy used by fans and pumps

For cooling the “System Energy Efficiency Ratio” SEER: is the ratio of the total cooling demand in spaces served by a system divided by the energy input into the cold generator(s) - typically chillers. It takes account of, for example, the efficiency of the cold generator, thermal gains to pipework and ductwork, and duct leakage. It does not include energy used by fans and pumps. Since many cooling demand calculations only estimate sensible cooling, the definition may be extended to include allowances for deliberate or inadvertent latent loads.

prEN15243

prEN15243[3] is the draft standard that deals with the calculation of HVAC system efficiencies. It contains a number of informative annexes that illustrate different approaches, but it does not prescribe specific calculation procedures. It permits HVAC system performance to be calculated either monthly or hourly. The draft standard provides a framework that can be used to assess whether particular methods are appropriate to particular circumstances.

The standard identifies nearly 40 mechanisms that can affect the relationship between the cooling demand of a building and the energy used by an HVAC system in meeting that demand. These are mapped against 20 or so types of HVAC system to show which mechanisms may apply to which system types. It then requires any calculation procedure to declare which system types it claims to cover, and how it addresses each of the applicable mechanisms. It does not prescribe how each mechanism should be handled (although there are “informative” suggestions). So, for example, the effect of heat gains to cold ducts could be calculated in detail or included as a fixed allowance (or ignored). Different degrees of sophistication may be appropriate to different situations. The draft standard simply demands that the user should know and thus be in a better position to judge whether a particular procedure is appropriate to his needs.

Table 1. Overview of mechanisms identified in prEN15243

10 within-room mechanisms
9 mechanisms relating to terminals
1 mechanism covering auxiliary energy
7 mechanisms relating to other distribution features
9 mechanisms relating to heat and cold generation

Table 2. System types identified in prEN15243

Code	System name	Does not always include heating provision and may be used with separate heating system (including room heaters which may be within terminals)	Does not include integral provision of ventilation and may be used with separate (cooled) ventilation system
A	**All-air systems**		
A1	Single duct system (including multi-zone)		
A2	Dual duct system		
A3	Single duct, Terminal reheat		
A4	Constant Volume (with separate heating)	✔	
A5	Variable Air Volume (with separate heating)	✔	
B	**Water-based systems**		
B1	Fan coil system, 2-pipe	✔	✔
B2	Fan coil system, 3-pipe		✔
B3	Fan coil system, 4-pipe		✔
B4	Induction system, 2-pipe non change over	✔	
B5	Induction system, 2-pipe change over		
B6	Induction system, 3-pipe		
B7	Induction system, 4-pipe		
B8	Two-pipe radiant cooling panels (including chilled ceilings and passive chilled beams)	✔	✔
B9	Four-pipe radiant cooling panels (including chilled ceilings and passive chilled beams)		✔
B10	Embedded cooling system (floors, walls or ceilings)		✔
B11	Active beam ceiling system	✔	✔
B12	Heat pump loop system	□	✔□
	Packaged Air Conditioning Units		
C1	Room units (including single duct units)	✔	✔
C2	Direct expansion single split system	✔	✔
C3	Direct expansion multi split system (including variable refrigerant flow systems)	✔	✔

THE UK APPROACH

At the time of writing, few EPBD calculation methods for non-domestic buildings have been produced. This section deals with the methodology that has been in use in the UK since April 2006. Similar procedures are used in the Netherlands and Germany – some of the British procedures mimic those already in use in the Netherlands. The current Dutch procedures for HVAC systems appear to be less detailed (in some respects) - for example, in not explicitly including duct leakage. The German standard [4] includes more detailed calculation procedures in some areas, such as the calculation of pump energy use (including for heat rejection devices).

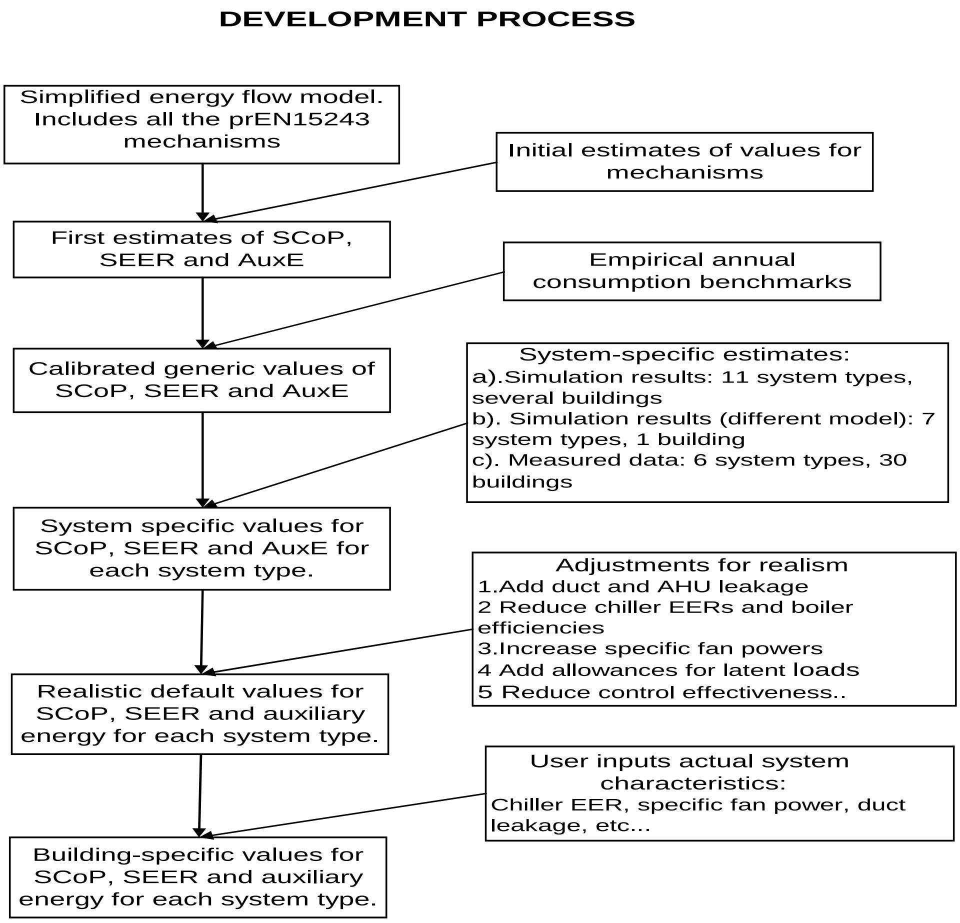
The standard calculation procedure for non-domestic buildings in the UK is the Simplified Building Energy Model (SBEM) [5, 6], although accredited hourly simulation procedures are also acceptable. The following section describes the development and basis of the HVAC system modelling in SBEM. The basic heating and cooling demand model is the monthly procedure from EN13790. [7] This imposes constraints on the way that the system performance is characterised. For consistency with the demand calculation, monthly values of the performance parameters (auxiliary energy, SCoP, SEER) are needed. •

The basis of the calculations in the UK is a comparison between the calculated carbon emissions of the proposed or actual building with those of a “notional” or reference building. The notional building has the same dimensions, geometry and use pattern as the actual building and is exposed to the same weather. However, the levels of insulation and the system efficiencies have fixed reference values. The notional building does not therefore have a specific HVAC system, but defined auxiliary energy, SCOP and SEER values.

Each serviced space in a building is assigned to an HVAC system. Each month the heating and (sensible) cooling demands and auxiliary energy are calculated and converted to energy demands by applying the appropriate SCoP and SEER. Each system type is associated with a vertical temperature gradient which is used to adjust the demands according to the height of the space and whether or not it is provided with de-stratification fans. There is also an adjustment to reflect the degree of direct radiant heat (or cooling) that falls on the occupied area. For most spaces and system these adjustments are small, but they can be significant in high, well-ventilated spaces.

The development procedure we adopted is summarised in Figure 1 and is described in more detail below. Because of the short timescale for implementation of the EPBD, there was limited time (or resources) for supporting research.

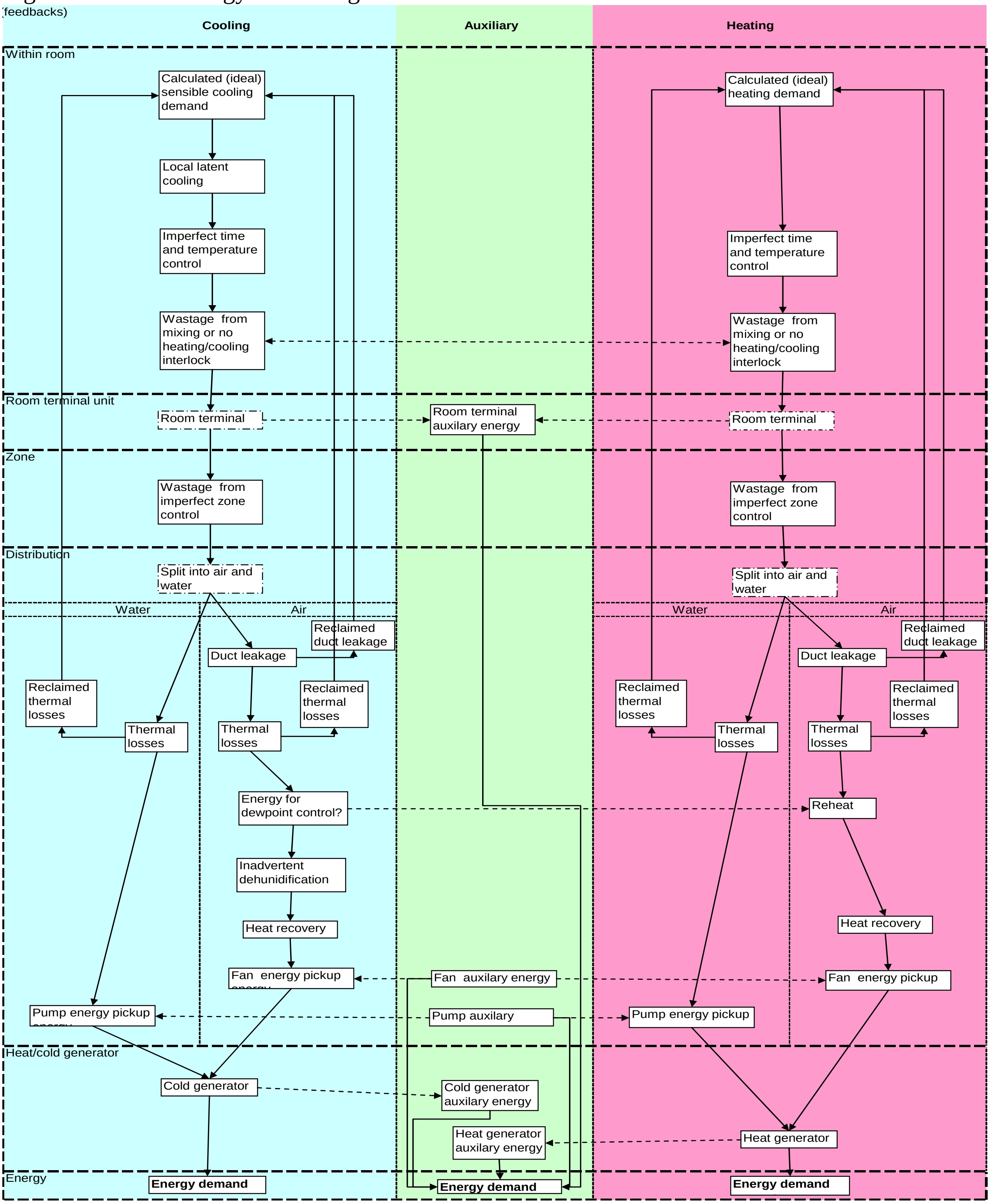
Figure 1 HVAC Model Development Process



• At present the parameters in SBEM are the same for each month. Values that varied monthly would be more realistic, and will be developed – especially for auxiliary energy – but the practical difference in terms of annual consumption estimates is actually rather small.

An energy flow diagram was constructed that included all the prEN15243 mechanisms. This flow diagram was implemented as a spreadsheet. The logic diagram is shown in Figure 2

Figure 2. HVAC Energy Flow Diagram



The basic philosophy is to provide a consistent set of parameters that address all the mechanisms in prEN15243. The energy flow diagram is simplified in that some of the parameters are relatively aggregated – for example, heat pickup in chilled water distribution pipework is expressed as a percentage of the cooling energy flow handled. There are many parameters whose values are difficult to determine reliably, many of which have only a small impact on the final result. System-specific default values are used for these. The user is be able to influence the system performance in two ways: firstly by his choice of system types (which sets the values of system-specific parameters) and secondly by adjusting the value of selected parameters. [•]

We next made first estimates of typical values of the flow sheet parameters and calculated initial figures of the three performance parameters (auxiliary energy, SCoP, SEER) . With some relatively small adjustments to the initial assumptions, the consumption figures that these implied were brought into in general alignment with empirical benchmarks [8] . This provided us with calibrated generic estimates of the parameter values.

In parallel with this, we brought together several sets of existing comparisons between the energy consumptions of different types of systems in offices. These included two sets of simulation results using different models to compare different systems in identical buildings. One of the studies examined 11 different system types in a number of buildings, while the other examined 7 system types in a single building – but modelled the system components in more detail. We combined these results with measured data from 30 buildings covering 6 system types [9], to develop a set of system-specific values for SCoP, SEER and auxiliary energy. For each system type, we then adjusted the spreadsheet parameters until the spreadsheet generated the same figures.

Since the simulations assumed idealised control and other conditions, we then degraded some parameters to provide less optimistic default assumptions. In particular we added duct and AHU leakage, reduced chiller EERs and boiler efficiencies, increased specific fan powers, added allowances for latent loads, and reduced control effectiveness.

The resulting “default” consumption levels straddle the “typical” consumption benchmarks (some systems being better than the benchmark, others worse). The idealised figures straddle the equivalent “good practice” benchmark.

As mentioned above, the user has the possibility of introducing specific values for some important parameters – currently specific fan power, duct leakage, chiller and boiler seasonal efficiency - in order to claim reasonable benefit from energy-efficient system design. In addition, of course, the choice of an inherently more efficient system is rewarded by the use of default values for that system type.

The calculation of the seasonal efficiency of boilers and (especially) chillers is not entirely straightforward, especially when there are multiple chillers and a degree of oversizing. Methods of handling this have been reported elsewhere. [10] [11]

DISCUSSION

This paper summarises the development of a practical approach to representing HVAC system in energy calculation software. Clearly there are other possibilities, notably the use of explicit hourly system modelling. In principle explicit modelling is more versatile, but it requires more data (for which default assumptions could be provided) and detailed assumptions about system configurations and sizing. The latter could probably be provided via standard system templates subject to later detailed specification. Such complexity is arguably more technically complete but this has to be balanced against the greater difficulties for those charged with checking calculations and verifying installations. The model described here allows the user to influence calculated system performance by choice of system and by defining the performance of the major system components,

[•] The provision of access to over-write more of the defaults is a likely future development.

but contains many fixed default values. These may be opened up to user modification if experience justifies this.

An alternative approach would be to define explicit engineering calculation rules for the energy use by different elements of the system. This is effectively the approach taken in Germany [12]. In principle this is more transparent and more flexible than the UK approach (at least in the latter's current implementation), but this transparency is somewhat offset by the need for large numbers of look-up tables and very extensive documentation. Nevertheless, when implemented as software, the result has a rather similar appearance to that of SBEM. It is intended that SBEM will continue to develop in the light of user experience – and taking note of parallel developments in other Member States. Although a single Europe-wide methodology seems unlikely, it does seem likely that, over time, there will be increasing convergence of approach.

The current version of SBEM has been developed to a tight timescale and time and resources have meant that a number of desirable features are not yet incorporated. The software has been in use since April 2006 It can be downloaded, together with a Userguide and associated (UK-focussed) databases from www.ncm.bre.co.uk .

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