

## Comparing building performance assessment in the UK the USA and Sweden - lessons and opportunities for harmonisation

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Increasing interest in how buildings and their systems perform - both design predictions and in-use assessments - has produced a large number of assessment procedures throughout the world. This paper compares various established methods for assessing or regulating buildings energy efficiency. Conclusions are drawn about the potential to simplify and improve energy standards for the assessment of buildings by designers and managers, and to reduce the duplication of published guidance work. System benchmarks, such as electrical power density (in watts per square metre) and efficacy (for example in watts per litre per second), are becoming more widely used and could transcend national boundaries more easily than building energy consumption benchmarks. This paper compares a selection of approaches and draws conclusions about the type of approach and the benchmark standards set.

### Objectives and approaches considered

Energy standards help building designers and managers to achieve energy efficient design and operation. A selection of widely used standards listed in table 1 is considered to compare their approach and the benchmark levels. The objectives of this paper are

- to help building designers or managers identify a suitable energy assessment method
- to identify any conflicts in the approaches used by the various methods, or the benchmark levels
- to highlight opportunities for harmonisation in the interest of users and those creating the standards.

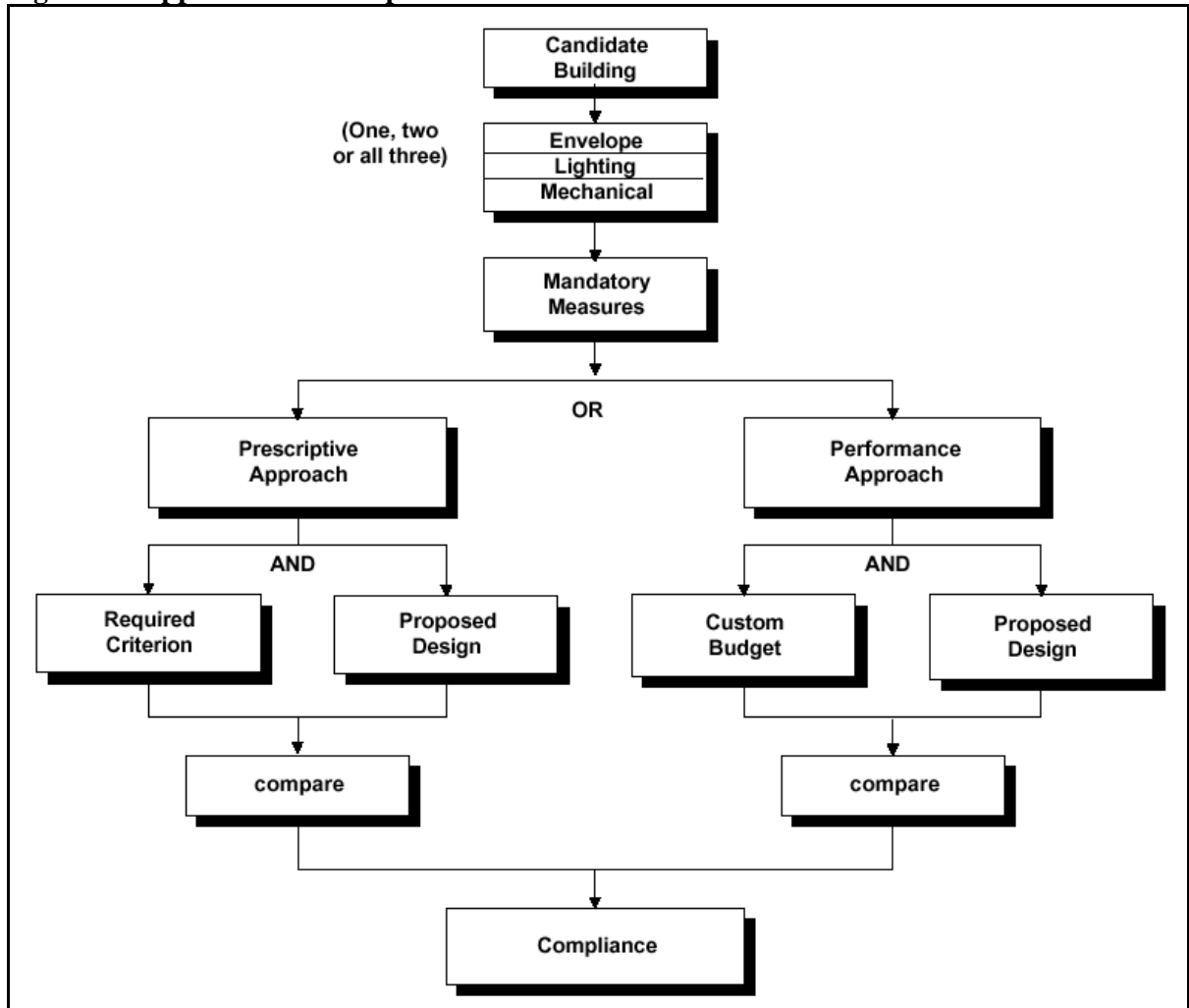
**Table 1 Overview of energy standards considered**

Energy rating system		Application			
		Design tool whole building	Design tool for systems	Benchmark existing buildings	Benchmark systems
California Title 24 (1)	USA	Yes	Yes	No	No
ASHRAE 90 (2)	USA	Yes	Yes	Yes	Yes
ASHRAE 100 (3)	USA	No	No	Yes	Yes
ECON19/TM22 (4,5)	UK	Yes	Yes	Yes	Yes
EPIM (6)	UK	Yes	No	No	No
CIBSE Energy Codes (7,8)	UK	Yes	Yes	No	No
SCANVAC R2 (10)	Sweden	No	Yes	Yes	Yes

A generalised approach to compliance is illustrated in Figure 1 from the California Title 24<sup>1</sup> code. The standards may apply to various building elements or systems, there may be mandatory aspects to the standards, then for the remaining aspects there may be alternative approaches involving prescriptive requirements for each element (limiting U-values or component efficiencies for example), or a performance based approach where the whole building has to meet an energy budget which is

typically calculated for the building by modelling an equivalent building whose systems individually comply with the prescriptive approach.

**Figure 1 - Approaches to compliance**



This investigation has been directed at lighting and air distribution (fan power), services for which system benchmarking is highly effective.

## Lighting

### *California Title 24*

Title 24 is a detailed energy code and compliance is required generally for new buildings and major refurbishment in the state of California. There are mandatory requirements for lighting controls including room controls, controls for daylit areas and "bi-level" switching (allowing operation at 50% output or dimmed). The prescriptive installed power approaches include limiting the installed lighting for the whole building, or by area such as Hotel lobby (2.2 W/ft<sup>2</sup> or 24 W/m<sup>2</sup>) and General commercial work low bay (1.0 W/ft<sup>2</sup> or 10.8 W/m<sup>2</sup>). A further option includes a standard for installed power based on illuminance (quality) categories.

**ASHRAE 90.1-1999, USA**

ASHRAE 90<sup>2</sup> is a US-wide energy code which can form the basis of local regulation. A version is available using SI units. For lighting there is a whole building approach in which interior lighting power allowance is derived from the building floor area and the lighting power densities - for example offices are 14 W/m<sup>2</sup> and a Warehouse is 13 W/m<sup>2</sup>.

Alternatively, the interior lighting power allowance can also be made up from different areas within a building for example as shown in Table 2 which shows that the lighting density for each Space Type normally does not change. Open plan offices have 14 W/m<sup>2</sup> and enclosed (cellular) offices have 17 W/m<sup>2</sup>.

**Table 2 Lighting power density using the space-by-space method**

Selected building types and space types are shown

Space type	Building Types:	Lighting Power Density (W/m <sup>2</sup> )		
		Office	Hospital Healthcare	Hotel
Office—Enclosed		17	17	17
Office—Open plan		14	14	14
Conference Meeting/Multipurpose		16	16	16
Food Preparation		23	23	23
Restrooms		10	10	10
Corridor/Transition		8	17	8
Stairs—Active		10	10	10
Active Storage		12	31	12
Inactive Storage		4	4	4
Electrical/Mechanical		14	14	14
Building-specific		Banking 26 Laboratory 20	Emergency 30 (etc. various)	Guest rooms 26
Additional power allowance		Yes	Yes	yes

Additional lighting power is allowed for specific purposes as follows:

- decorative chandeliers 10.8 W/m<sup>2</sup>
- VDU lighting 3.8 W/ m<sup>2</sup>
- retail highlighting - 17 W/m<sup>2</sup> or 42 W/m<sup>2</sup> for fine merchandise.

There are exterior lighting allowances based on linear or square metre limits.

**ASHRAE Standard 100-1995, USA**

ASHRAE 100<sup>3</sup> is a system efficiency standard for existing buildings and, dating back to 1995 it has possibly been overtaken by current normal standards. Its approach to lighting is that a building's lighting power (adjusted for the level of automatic control) must be less than the lighting power allowance which is specified for each usage area with allowance for room shape. This must be achieved separately for interior and external lighting.

The controls factor is given for various combinations of control rising to a maximum of 40% for Occupancy sensing and daylight sensing with continuous dimming. Further requirements are that fluorescent lamp ballasts have specified minimum efficiencies; and the minimum number of control points, their types and accessibility are specified.

Examples of exterior connected lighting power allowances are 82 watts per linear metre of building exit doorway and 2.7 watts per m<sup>2</sup> of external surface to be illuminated.

### ***Energy Consumption Guide 19, UK***

Energy Consumption Guide 19<sup>4</sup> (ECON19) Energy Use in Offices provides annual energy consumption benchmarks for existing buildings - both at whole building and system level. Recent editions include system benchmarks for W/m<sup>2</sup>, hours of use and kWh/m<sup>2</sup> for Typical and Good Practice benchmarks as shown in table 3.

**Table 3 Lighting benchmarks for offices, ECON19**

Office type:	Type 1 Naturally ventilated cellular		Type 2 Naturally ventilated open plan		Type 3 Standard air conditioned office		Type 4 Prestige air conditioned office	
	Good Practice	Typical	Good Practice	Typical	Good Practice	Typical	Good Practice	Typical
Connected power Wm2	12	15	12	18	12	20	12	20
Occupied hours per year	2500	2500	3000	3000	3200	3200	3500	3500
Fraction on (%)	45%	60%	60%	70%	70%	85%	70%	85%
Lighting energy use kWh/m2/yr	14	23	22	38	27	54	29	60

The connected load of 12 W/m<sup>2</sup> can be related to 400 lux and 3 W/m<sup>2</sup> per 100 lux in the office areas.

This approach can therefore relate system installed powers to annual energy consumption benchmarks, and procedures for investigating this in existing buildings are specified in the CIBSE Office Assessment Method<sup>5</sup>. These procedures have no explicit allowance for exterior lighting.

### ***Energy Performance Indicator Method, UK***

EPIM provides a broad assessment of efficiency at the design stage based on installed loads and controls. In the Energy Performance Indicator Method<sup>6</sup> (EPIM) the lighting contribution to the total building electricity use is calculated from the connected power of lighting, the typical annual equivalent hours of *full load* operation (taken to be 2000 hours for a naturally ventilated office and 3000 hours for an air conditioned office) and a control and management factor which has different values depending on the extent of monitoring and targeting, the proportion of the building with time and occupancy control and the proportion of the building with daylighting available which is fitted with daylighting controls.

While the lighting performance is not separated, the overall building energy-related CO2 emissions are compatible with ECON19 targets. The inclusion of variability with time, occupancy, daylight and daylight control is achieved without undue complexity.

### ***CIBSE Energy Codes part 1 and 2 1999, UK***

The CIBSE Energy Codes provide a tool to assist with low energy design of buildings. The two Codes<sup>7,8</sup> use the same approach for lighting. The annual lighting energy is calculated from the floor area of each zone, the installed lighting load (as in table 4), the lighting diversity factor for month (derived from annual diversity factor which are tabulated for required illuminance levels, room orientation, glazing percentage and glazing transmission factor). Allowances for occupancy diversity and task lighting are also included.

**Table 4 Lighting power densities, CIBSE Energy Codes**

Illuminance (lux)	Lighting Power Density (W/m <sup>2</sup> )									
	Halogen downlight (50W/12V)	SON high bay reflector	MBF high bay reflector	Fluorescent tube (white)				Task light		
				Open trough	Industrial	Enclosed	Enclosed surface	Tungsten	Fluor.	
-	-	-	-	-	-	-	-	-	1.1	0.28
150	22	3	5	6	4	7	7	-	-	-
300	40	6	10	12	9	14	15	-	-	-
500	N/A	10	19	20	15	23	26	-	-	-
750	N/A	15	26	28	22	32	37	-	-	-

### ***CIBSE Interior lighting Code, UK***

This Interior Lighting Code<sup>9</sup> has target ranges of Installed power density (W/m<sup>2</sup> per 100 lux) for different lamp types and room index to be used with recommended lux levels.

### ***UK Building Regulations***

The UK Building Regulations for energy are currently undergoing consultation for major revision. For lighting, control and lamp efficiency or connected load requirements introduced and upgraded in 1995 are likely to be considerably strengthened. The EPIM method described in 2.5 above may be incorporated as a Carbon Performance Index.

### ***Lighting comments***

Most of the methods include basic installed lighting power per unit area limits or allowances. These generally get more onerous with time - the 1995 AHRAE 100 allowances at 20 to 30 W/m<sup>2</sup> for offices are possibly no longer useful, and current ASHRAE 90 allowance at 14 W/m<sup>2</sup> is can be compared with ECON19 "Good practice" and Title 24 levels of 10-12 W/m<sup>2</sup>.

The need for explicit allowance of room (shape) factor appears to vary strongly between the methods - this introduces significant extra work for the user and the value is not obvious.

The US systems explicitly allow for external lighting. This would seem to be useful to reduce the imbalance between buildings with external lit facades, entrance and possibly car parking.

The ECON19 and ASHRAE 90 "simple" approach consider whole-building average lighting power density, which is a useful starting point in many cases.

The way in which codes are expected to be used differs - Title 24 is intended to be assessed by a professional engineer and certified accordingly - with the advantage of full support of California State in enforcing the requirements. The potentially complex allowances and whole-building approaches require considerable expertise and professional trust. The CIBSE Energy Codes and more detailed ASHRAE 90 procedures also require detailed appraisal, but these organisations can not themselves enforce the codes.

The ECON19 and EPIM approaches can relate installed loads to annual energy benchmarks and annual energy consumption in use, without the use of complex calculations. It is a point of debate whether the simplifications required for this leave the results as useful when not used by highly experienced engineers.

## Ventilation

### *Ventilation approaches*

Specific fan power - the connected electricity load of all system fans per unit of system air flow rate - is used as a limit in many approaches. This can be measured as total system fan power in kW related to the supply air volume, as kW per m<sup>3</sup>/sec. This can also be measured as watts of fan power per litre/sec which is the same numerically as kW/(l/s).

**Sweden - SCANVAC<sup>10</sup>** provides limiting specific fan power in kW/(m<sup>3</sup>/s) for different classes of system. The constant volume system limits range from 4 kW/(m<sup>3</sup>/s) for the least efficient class, down to 1 kW/(m<sup>3</sup>/s) for the so-called "efficient" class.

**US ASHRAE 90.1-1999**, restricts specific fan power as shown in Table 5.

**Table 5 Fan power limitation ASHRAE 90.1-1999**

Supply air volume	Allowable nameplate motor power	
	Constant Volume	Variable volume
Less than 9.4 m <sup>3</sup> /s	1.9 kW per m <sup>3</sup> /sec	2.7 kW per m <sup>3</sup> /sec
9.4 m <sup>3</sup> /s or greater	1.7 kW per m <sup>3</sup> /sec	2.4 kW per m <sup>3</sup> /sec

**California Title 24** has fan power allowances, for fans over 19 kW, of 2.6 W/(l/s) for VAV fans and 1.7 W/(l/s) for other fans.

**UK ECON19** specifies benchmarks for connected load per area W/m<sup>2</sup> as derived from system specific power W per l/s and ventilation rate in l/s per m<sup>2</sup> as shown in table 6.

**Table 6 Fan system benchmarks, ECON19**

	Type 3 Standard air conditioned office		Type 4 Prestige air conditioned office	
	Good Practice	Typical	Good Practice	Typical
Ventilation rate l/s per m <sup>2</sup>	4	4	4	4
Specific fan power W per l/s	2	3	2	3
Equivalent hours per year	2750	3500	3000	3700
Fan energy use kWh/m <sup>2</sup> /yr	22	42	24	44

Note: 1 W per l/s = 1 kW per m<sup>3</sup>/s

**UK EPIM** uses the actual installed fan power and, to obtain annual energy performance, a standard operating hours and a design-dependent management and control factor.

**CIBSE Energy Code part 2** uses a calculated fan power derived from tabulated typical design fan pressures and tabulated fan and motor efficiencies.

### *Ventilation comments*

Care is required to ensure that comparisons are on a like-for like basis. For example

- It is total fan power (supply plus extract, but excluding terminal units and minor systems such as toilet fans) which is assessed. The volume flow rate is the flow rate of the supply fan(s).
- In the SCANVAC system, the volume flow rate should be 80% of the design flow rate - this can make a significant difference to system pressure and fan power.

- Scandinavian systems generally include heat recovery (with associated pressure penalty) and these are allowed for in the standards.
- High filter pressures, for special purposes, are allowed for separately.

The CIBSE energy code approach of calculating expected fan power from volume, pressure and fan/motor efficiencies, is attractive but care is needed that realistic levels are obtained.

Title 24 considers various types of ventilation system in some detail to specify which fans are included in the allowance, and where there are exemptions.

## Conclusion

The methods presented have a wide variation in complexity, and it appears that the user may often end up with the wrong level of assessment, i.e. insufficient accuracy or too much complexity of calculation.

Certification issues are critical: are the regulations intended for enforcement or to help co-operating designers or building management? The fact that Title 24 was produced by an enforcing organisation (California State) has meant that more emphasis was placed on certification - this may have useful lessons for other methods.

How can the system benchmarks (typically in watts per m<sup>2</sup>) be related to annual energy use, to enable design intentions to be verified? Some approaches, such as ASHRAE 90 and Title 24, require a full dynamic simulation, other approaches such as ECON19 and EPIM use simple products of empirical factors - the relative merits of these approaches would benefit investigation.

Actual allowance levels (limiting system W/m<sup>2</sup> for example) vary significantly between the different codes but there is broad compatibility of recent codes - the older ASHRAE100 code has higher allowances.

The whole-building energy rating standards such as the CIBSE energy codes and EPIM might achieve "value added" benefit for users by including sub-targets for component building services systems. This would help users to take action about poor indicated performance.

The large quantities of data that go towards generating each of these standards could be pooled or used to reduce the work required to update standards and at the same time to harmonise standards and reduce confusion.

## References

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<sup>1</sup> Non-residential Manual for Compliance with the 1998 Energy Efficiency Standards for non-residential buildings (Title 24). California Energy Commission July 1999.

<sup>2</sup> ASHRAE 90.1 - 1999 Energy Standard for Buildings Except Low-Rise Residential Buildings

<sup>3</sup> ASHRAE 100 - 1995 Energy Conservation in Existing Buildings

<sup>4</sup> Energy Consumption Guide 19 Energy use in Offices 1998, DETR UK

<sup>5</sup> Energy Assessment and Reporting Methodology, Office assessment method, TM22, CIBSE 1999

<sup>6</sup> Energy Performance Indicator Method (EPIM) BRE report 317/99 BRE, UK 1999

<sup>7</sup> Energy demands and targets for heated and ventilated buildings, Building Energy Code 1, CIBSE 1998

<sup>8</sup> Energy demands for air conditioned buildings. Building Energy Code 2, CIBSE 1999

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<sup>9</sup> Code for interior lighting, CIBSE 1994

<sup>10</sup> SCANVAC R2 voluntary standards for energy efficiency in building systems, Sweden