PERFORMANCE INDICES FOR FABRIC THERMAL STORAGE

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This paper reviews the development of performance indices for fabric thermal storage from the original BRE office research data to the two mixed mode design options currently available, each having different design priorities, namely. naturally ventilated or mechanically ventilated. Naturally ventilated mixed mode designs appear to be less suitable for UK locations and also appear to have significantly greater annual energy consumption. In addition to the comparison of energy consumption criteria, the paper also reviews recent Scandinavian indoor climate classifications. It recommends linking an appropriate UK indoor climate classification with an environmental energy index as an easily understood reporting procedure for a future national database.

INTRODUCTION

Fabric Thermal Storage (FTS) techniques are being designed into environmentally aware buildings, primarily to remove the need for air conditioning, and secondarily to reduce the HVAC system capital and maintenance costs and improve the environmental health and comfort of occupants. Advanced versions with high standards of thermal insulation and heat recovery mechanical ventilation further reduce the installed HVAC capacity and annual energy usage.

The current scarcity of monitored feed back raises serious concerns about the design claims of many "green" commercial buildings. The environmental pollution benefits and comfort standards claimed for many of the mixed mode buildings frequently fail to materialise in practice.

The original BRE low energy office project, designed in 1978, was the first 'mixed mode' design to receive extensive publicity. The fabric thermal storage component was provided by exposed concrete slab ceiling soffits giving a moderately heavy construction (response factor 6) and was insulated to achieve a measured fabric heat loss of 1.9 W/m²K.). The specific fan power of the heat recovery mechanical ventilation system was 4.1 kW/(m³.s) with a measured ventilation loss of 0.09 W/m²K. All windows were opened for summer ventilation and locked in winter, with the balanced mechanical ventilation system operating during occupation periods (Figure 1). All rooms had LPHW convector heaters supplied from two non condensing gas boilers.

Corrected Energy Use	1981/2	1982/3	1983/4	1984/5	1985/6
MJ/sq.m	528	460	530	476	476
kWh/m².a	145	128	147	132	132
* kg/CO_2/m².a	29	25.6	29.4	26.4	26.4
* Calculated using 0.20kg/CO_2/k/Wh of gas consumption					

This table gives the BRE low energy office heating energy usage for 1981 - 1986. In addition the reported electrical energy consumption was 63 M/m².a (17.5 kWh/ m².a or 12.25 kg CO_2/ m².a).

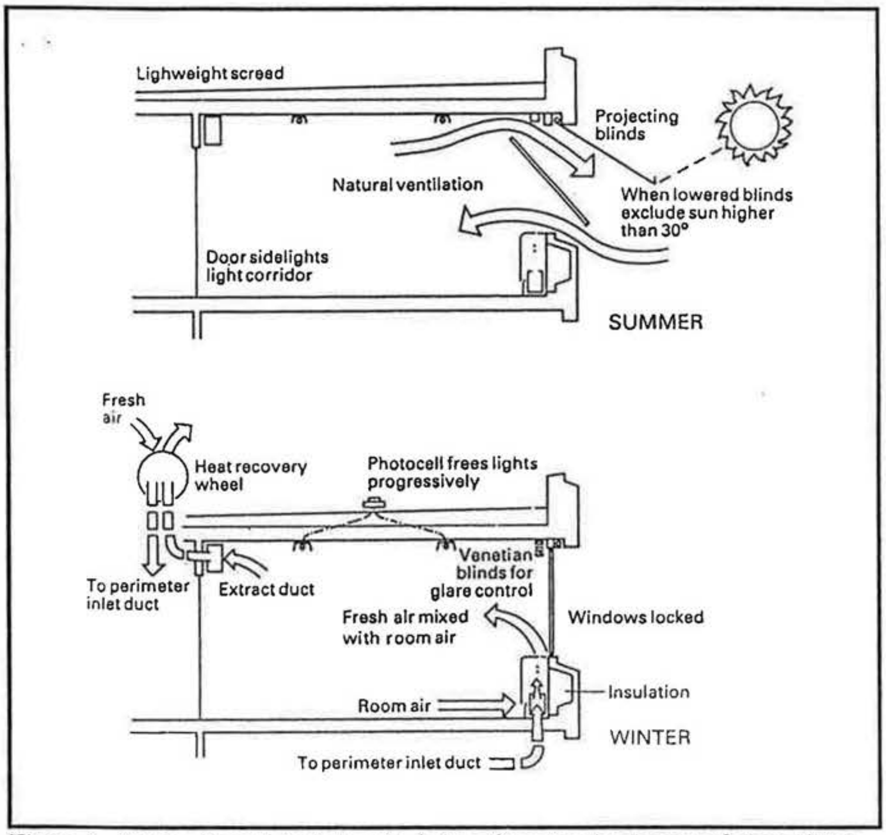

Figure 1 - Section through typical south-facing office showing how comfort conditions are achieved in summer and winter

In 1988 the insulation standards were improved. The new U values (W/m²degK), [walls (0.45), roof (0.3), floor (0.39), windows including frames (0.22)] almost halved the fabric heat loss, as shown in the table below. During the next two heating seasons the building was naturally ventilated using two independent heating systems, electric panel heaters and the refurbished LPHW system with condensing boilers and new controls.

1988/89	Gas condensing boilers and latest control technology	67 kWh/m².a	≡ 13.4 kg/CO_2/m².a
1988/89	Commercial electric panel heaters using BRESTART control optimiser	42 kWh/m².a	≡ 27.6 kg/CO_2/m².a

The innovative design of the first BRE low energy office and its subsequent refurbishment to a naturally ventilated, highly insulated building, effectively established the annual energy targets and definitive operating mode against which all subsequent mixed mode designs are being judged.

MIXED MODE DESIGN OPTIONS

Two mixed mode design philosophies now exist in the UK market, each with a different ventilation priority and fabric thermal storage mechanisms. These are:-

1. naturally ventilated buildings with basic FTS and supplementary mechanical ventilation
2. mechanically ventilated buildings with advanced FTS and supplementary natural ventilation.

Naturally ventilated design priority

These mixed mode buildings feature a highly glazed, airtight envelope with higher standards of thermal insulation than the current building Regulations Part L. They are designed for maximum performance using natural ventilation with mechanically operated BEMS controlled windows at high level, with or without open atria with BEMS controlled roof exhausts. Exposed decorative concrete ceiling soffits, provide the FTS component. Particular attention is given to effective solar shading. The HVAC designs are similar to the first BRE office and comprise conventional perimeter heating systems with gas fired condensing boilers, and also have a balanced mechanical ventilation with heat recovery for use during severe winter conditions, and to enhance the summer night cooling (Figure 1).

Mechanically ventilated design priority

The alternative mixed mode building design also features a highly insulated thermally heavy and airtight envelope with more conservative fenestration areas (25 - 35%) and a different HVAC philosophy. This primarily uses a mechanical ventilation system with low fan energy power utilising both heat recovery and advanced fabric thermal storage with the supply air ducts or heating/cooling pipes integrated into the exposed ceiling slabs. This combination ensures very stable optimum (dry resultant) temperatures. Given highly insulated windows (centre glass U value better than 1.5 W/m^2degC) and effective solar shading (SC = 0.25 or better), the perimeter heating/cooling technology of conventional HVAC design can be dispensed with in temperate climates and radically reduced in severe continental climates. These systems are suitable for either new or existing buildings. For example:

a) all air HVAC for new buildings (Figure 2)
b) air/water HVAC with embedded pipe systems for refurbished buildings (Figure 3).

Both feature small openable windows for supplementary natural ventilation (if desired by individual occupants) without significant penalty to the annual heating consumption, since the majority of the internal thermal energy transfer is low temperature radiant energy from the high thermal capacity floor/ceiling plates.

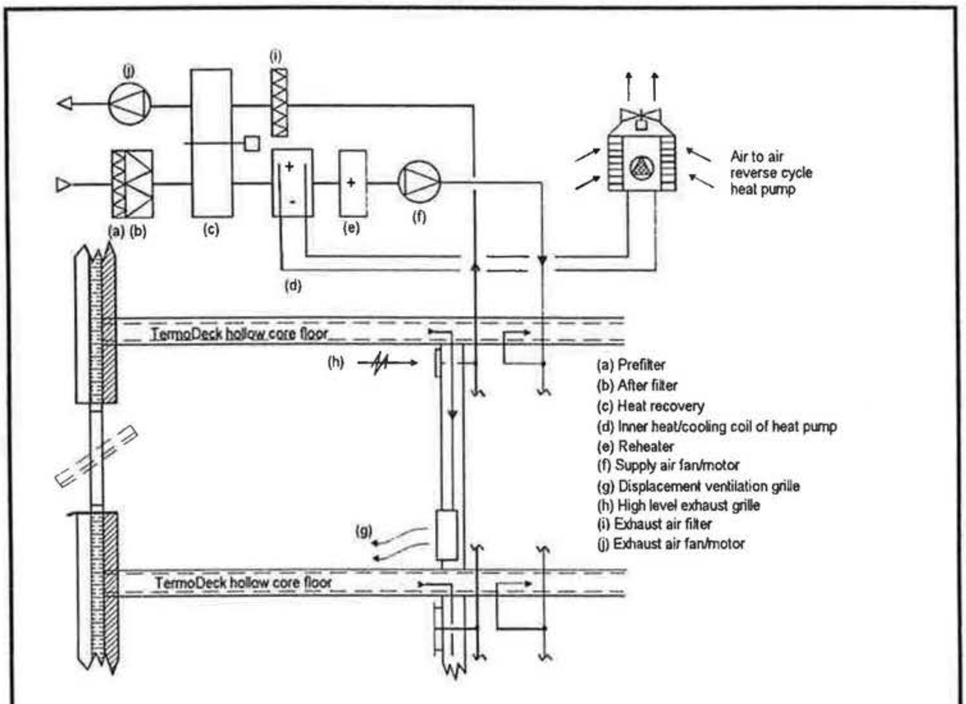

Figure 2 - Mechanically ventilated mixed mode design using all air system

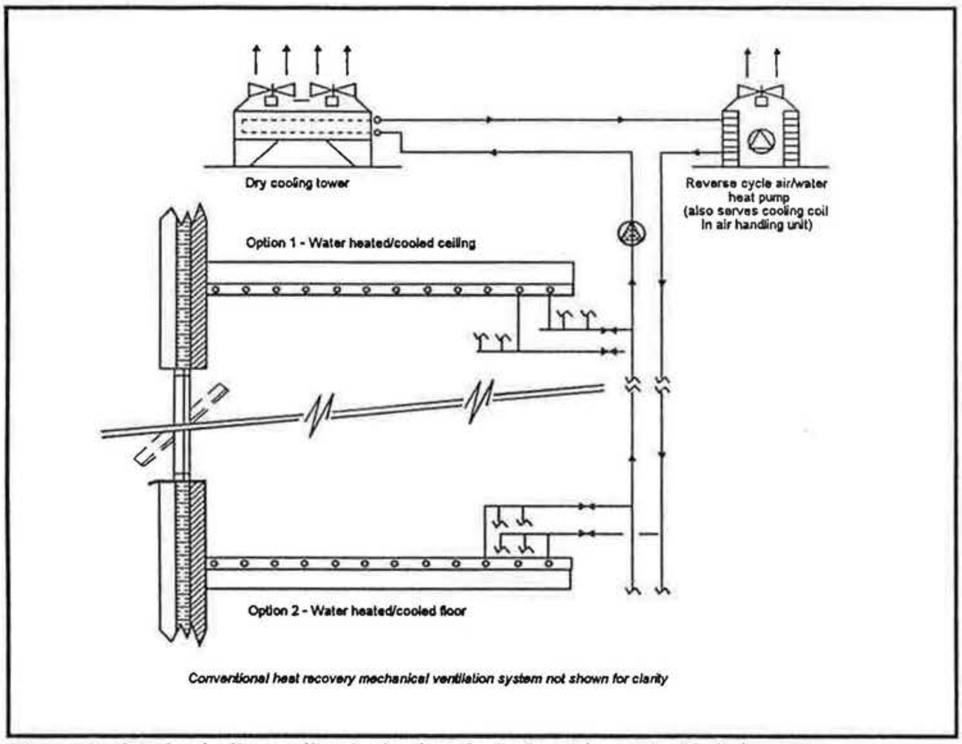

Figure 3 - Mechanically ventilated mixed mode design using embedded pipe systems

COMPARATIVE UK THERMAL COMFORT CRITERIA

To date, no comparative energy studies of the thermal performance for indoor air quality and comfort standards for the two types of mixed mode commercial buildings has been published. The primary difficulties are:-

a) There is no nationally agreed indoor climate classification.
b) There is no national database available.

The thermal comfort criteria for sedentary comfort used in the current CIBSE Guide (1980, Volume A) emphasises the "adaptive" nature of subjective thermal comfort relative to world-wide outdoor temperatures (Reference 5).

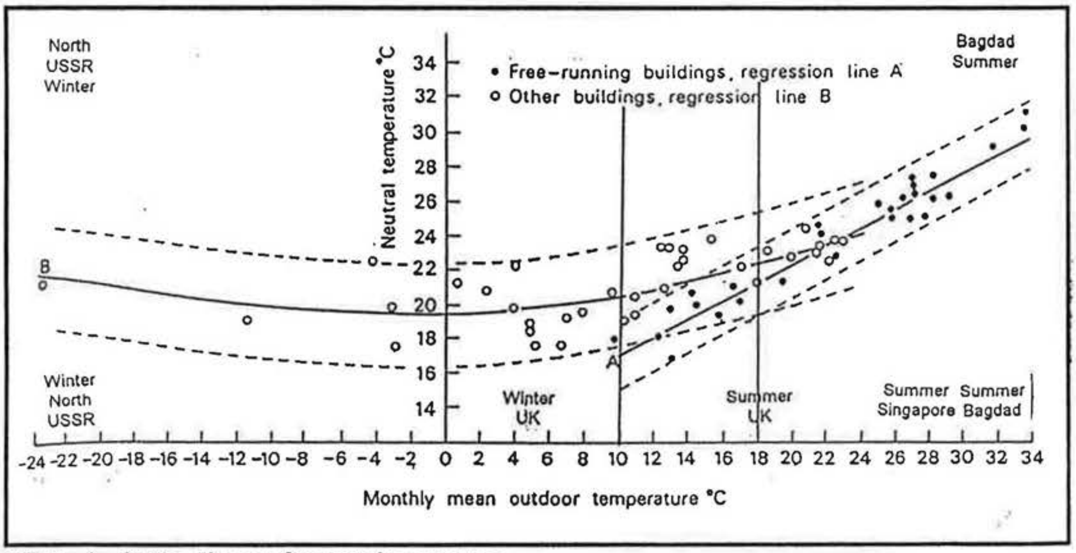

Figure 4 - Scatter diagram for neutral temperature

Humphreys distinguishes between thermal comfort experienced in "Free Running Buildings and Other Buildings", see Figure 4.

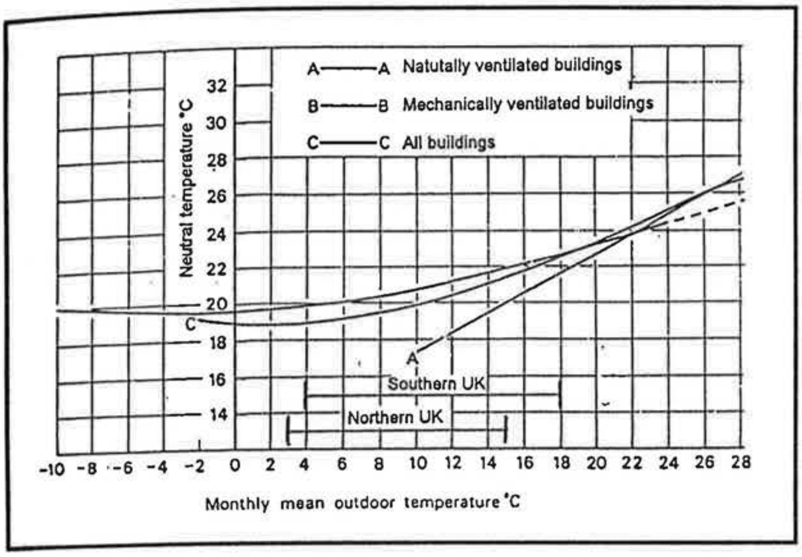

Figure 5 -Scatter diagram for UK mixed mode design

When applied to mixed mode buildings in UK locations, the "free running" building comfort temperature (°C) relationship relates to the natural ventilation design priority mode and the "Other" building comfort temperature (°C) relationship relates to the mechanical ventilation operating mode, see Figure 5. The mechanical ventilation operating mode would appear to be the preferred mode from a thermal comfort perspective.

Humphreys concludes the indoor temperature required for thermal comfort is related to the prevailing outdoor monthly temperature. "Varying the indoor temperature with the seasons being more economical on energy and more satisfactory to the occupants", e.g. in southern England the mean temperature varies from +4°C in January to 18°C in July. Curve B (Figure 5) suggests 20°C and 23°C for the respective indoor temperatures are the most satisfactory. Occupants in naturally ventilated buildings (curve A) appear to prefer cooler indoor temperatures than is possible in the UK climate without supplementary cooling.

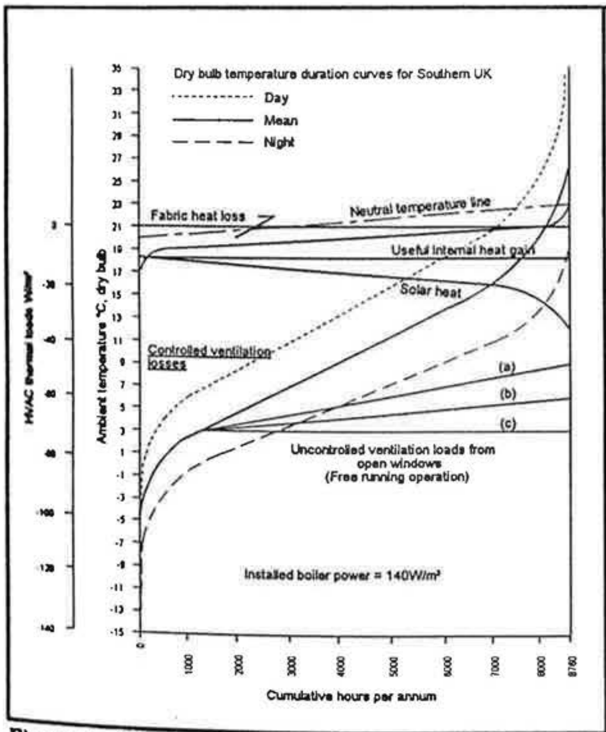

Figure 6 - Mixed mode operation for a naturally ventilated building

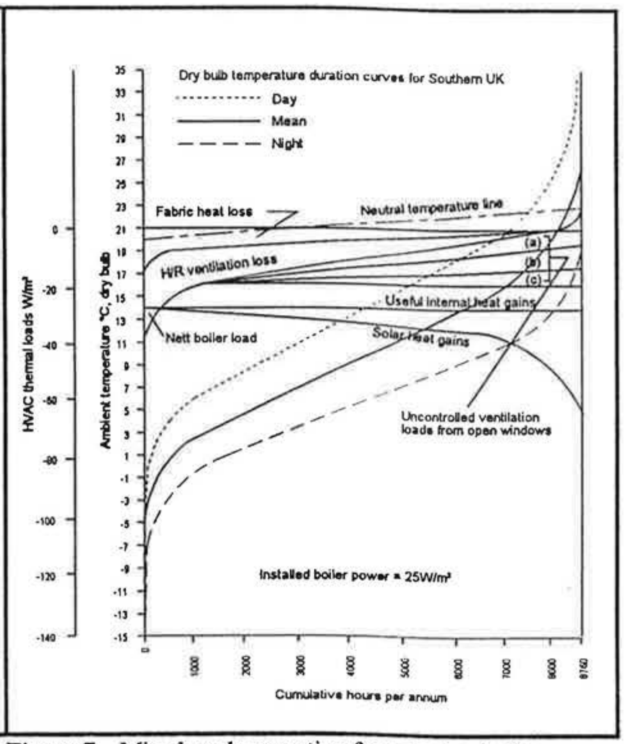

Figure 7 - Mixed mode operation for a mechanically ventilated building

Whereas, in buildings with mechanical ventilation the occupants prefer higher internal temperatures in summer. The lower temperatures preferred by occupants in naturally ventilated modes could explain the heating consumption of uncontrolled window ventilation experienced during spring and autumn (Figure 6). Mechanical ventilation with heat recovery and advanced FTS are essentially self heating and consequently, less sensitive to uncontrolled opening of window (Figure 7).

COMPARISON WITH INTERNATIONAL THERMAL COMFORT CRITERIA

Recent European guidelines may prove suitable for comparing thermal performance of UK buildings. The Scanvac guidelines (1993) use four thermal climate groups, and three indoor air quality and noise level classes.

The Finnish Classification (1996) has three categories (shown in the table below) and specifies;

a) target values used for specifying the target level of indoor climate at an early stage of a construction project
b) design values to be used specifically for the dimensioning of heating, ventilating and air conditioning plant
c) procedures to ensure compliance with the target and design of the building when it is in operation.

Room temperature	Target values °C			Design values °C		
Category	S1	S2	S3	S1	S2	S3
WINTER	21 - 22	21 - 23	20 - 24	21	21	20
SUMMER	22 - 25	22 - 27	22 - 23 (35)*	24	26	27 (35)*
* Room temperature should never exceed 35°C, and not exceed 27°C when the outdoor temperature is below 15°C						

At the European level, a CEN Standard "Ventilation for Buildings - Design Criteria for the Indoor Environment" is being developed which embodies many of the features published in the Scanvac and Finnish guidelines, shown in the following table.

Room Temperature	°C		
Category	A	B	C
WINTER Operative temperature °C	22° ± 1.0	22° ± 2.0	22° ± 3.0
SUMMER Operative temperature °C	24.5 ° ± 0.5	24.5 ° ± 1.5	24.5 ° ± 2.5

Pending publication of the CEN Standard, the performance indices and procedures described in the Finnish Classification could be used for appraising mixed mode buildings.

Appendices 1 and 2 list the full range of criteria included in the Finnish Classification method. A comparison of room temperature criteria specified in the Finnish system and the draft CEN Standard will serve to illustrate their similarities. Both Scanvac and the draft CEN use operative temperatures, whereas the Finnish Classification uses the air temperature in the occupied zone.

VENTILATION AND INDOOR AIR QUALITY

All three guidelines/standards recognise that the volatile organic chemical emissions from building material cannot be corrected by increased ventilation alone, and they seek to improve indoor air quality by discouraging release of volatile organic compounds from paints, adhesives, photocopiers and general cleaning chemicals.

The draft CEN Standard provides calculation procedures to determine the ventilation rate required for comfort taking into account:-

a) the expected occupancy
b) the sensory pollution load from smokers
c) the sensory pollution from the building
d) the quality of the external air (at the fresh air intake)
e) the desired indoor air quality category (i.e. A, B or C).

In the Finnish Classification the design calculation procedure is simplified as shown in the following table.

Ventilation Air Flow			
Category	S1	S2	S3
l/sec.person	16	12	8
l/sec.m²	2	1.5	1.0

The outdoor air ventilation rate for the selected air quality category ensures the concentrations of indoor pollutants in each category (see Appendices 1 and 2) are not exceeded, subject to no specific pollutant source in the room.

To achieve the highest indoor air quality standard specified in the Finnish guideline, the current CIBSE ventilation air flows for non-smoking environments need to be doubled. In many urban locations natural ventilation systems would have problems satisfying the lower air quality and acoustic categories whereas mechanical ventilation systems are capable of achieving the higher thermal air quality and acoustic categories.

INTERNAL HEAT GAINS

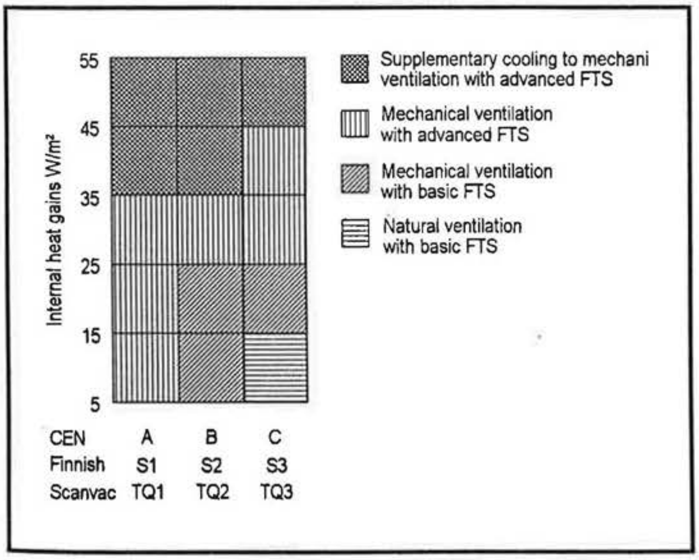

Figure 8 - Thermal quality performance comparisons for summer operation

In summer, the internal space temperatures and the classification category achieved, with mixed mode designs, are very sensitive to internal heat gains. Mechanical ventilation maintains lower day temperatures than natural ventilation by utilising the fabric thermal storage capability of floor/ceiling slabs. Natural ventilation only achieves the lowest thermal comfort category provided the summer internal heat gains never exceeded 15 watts/m² over the occupancy period. Figure 8 shows the relationships between internal gains and the thermal performance category for mixed mode buildings in summer.

CAPITAL COST SENSITIVITY

The total capital costs of both mixed mode buildings are comparable for most commercial buildings. The additional capital costs of higher thermal insulation standards, tighter building construction standards, solar protected glazing etc. are balanced by the capital savings from omitting false ceilings and installing smaller (and less sophisticated) HVAC services. A typical example of the installed boiler power is shown in Figures 6 and 7.

To achieve the indoor climate and thermal performance categories suitable for commercial city offices with higher internal heat gains requires the addition of refrigeration. Air conditioning has lower cost implications for mechanical ventilation with advanced FTS because the inherent thermal capacity allows more free cooling, and smaller direct expansion refrigeration systems with higher evaporating temperatures and sized for 24 hour operation. These energy efficient cooling systems have the potential to achieve lower annual energy consumption (and global warming pollution) than many naturally ventilated offices.

ANNUAL ENERGY CONSUMPTION

Annual energy consumptions need to be compared on the basis of similar internal climate categories. Only a few impartially measured energy consumptions of mixed mode buildings are currently publicly available and none are linked to the quality of their internal climate.

In order to revitalise energy conservation in the commercial market sector all buildings should record and publish their HVAC systems energy consumption in terms of $kg/CO_2m^3.a$, either in their annual report or a national database. This would provide a single value index which reflects the public concerns on global warming. Energy conservation values would then quickly become a self motivating business objective for designers and facility managers.
Linking each building's internal climate target classification with its annual CO_2 contribution would ensure that all energy consumptions are equally compared. Each building's target classification, the internal climate category (i.e. A, B or C) achieved, together with the measured annual CO_2 consumption ($kg/m^2.a$) may be recorded jointly i.e. A80 or B146 or C146 etc. etc.

CONCLUSION

Fabric thermal storage techniques enable designers to reduce the thermal and electrical loads of commercial buildings. For these techniques to achieve their market potential which their energy conserving and indoor climate enhancement warrants, the HVAC industry requires:-

a) a national database of energy consumption for all categories of commercial buildings
b) an industry standard for indoor climate classification to link with the above national database
c) a "top down" management commitment to energy conservation throughout the commercial market sector.

These requirements could be the basis for each company to annually publish the maximum energy demands and consumptions for their commercial buildings, ideally transparently in their annual reports.

APPENDIX 1 - Target values of indoor climate

		Category		
Factor	Unit	S1	S2	S3
Room temperature, winter	°C	21-22	21-23	20-24†
Room temperature, summer	°C	22-25	22-27	22-27(35)*†
Floor temperature	°C	19-29	19-29	17-31
Vertical Temperature difference	°C	<2	<3	<4
Air velocity, winter 21°C	m/s	<0.10	<0.15	<0.15
Air velocity, summer 24°C	m/s	<0.15	<0.20	<0.30
27°C				
Relative humidity of air, winter	%	25-45	-	-
Relative humidity of air, summer	%	30-60	-	-
Noise level of heating and air conditioning equipment	dB(A)			
offices		<30	<35	<35
living and bedrooms		<25	<25	<28
Air change rate (residence)	1/h	>0.8	>0.6	>0.4
Ammonia (NH_2)	mg/m³	<0.02	<0.03	<0.05
Formaldehyde (H_2CO)	mg/m³	<0.03	<0.05	<0.15
Total volatile organic compounds (TVOC)	mg/m³	<0.2	<0.3	<0.6
Odour intensity	desipol	<2	<4	<5.5
Carbon dioxide (CO_2)	ppm	<1000	<1250	<1500
	mg/m³	<1800	<2250	<2700
Carbon monoxide (CO)	mg/m³	<2	<5	<8
Ozone (O_3)	mg/m³	<0.05	<0.07	<0.10
Total suspended particles	mg/m³	<0.06	<0.06	<0.06
Radon (Rn)	Bq/ m³	<200	<200	<200

* room temperature shall never exceed +35°C; room temperature shall not be above +27°C when outside air temperature is below +15°C

\- stands for no specific requirements are set

† Room temperature is the air temperature in the occupied zone. Target values apply to conditions where individual control of room temperature is not utilised at the maximum capacity. Room temperature shall be measured with a thermometer or an electrical sensor in accordance with the Finnish standard SFS 5511 /4/. If the surface temperature of a room differs much from the air temperature (e.g. poorly insulated exterior constructions, double glazed windows, large windows, several external walls, floor faced by unheated space, solar radiation, floor heating, ceiling heating, cooled ceiling), the operative temperature shall be used as room temperature. Operative temperature can be calculated from the air and surface temperature, or measured, for example, with a globe thermometer in accordance with the Finnish Standard SFS 5511 /4/.

APPENDIX 2 - Design values for indoor climate

Factor		Unit	Category S1	Category S2	Category S3
T1	Room temperature, winter	°C	21	21	20
T2	Room temperature, summer	°C	24	26	27 (35)*
T3	Control range of room temperature, winter	°C	± 2	± 2	-
T4	Control range of room temperature, summer	°C	± 2	-	-
T5	Maximum temperature difference within a zone, winter	°C	**	<2	-
T6	Maximum temperature difference within a zone, summer	°C	**	<5	-
T7	Air velocity, winter	m/s	<0.10	<0.15	<0.15
T8	Air velocity, summer	m/s	<0.15	<0.25	<0.30
H1	Relative humidity, winter	%	25	-	-
H2	Relative humidity, summer	%	60	-	-
N	Noise level of heating and air conditioning equipment	dB(A)			
	offices		<30	<35	<35
	living and bedrooms		<25	<25	<28
	kitchens		<30	<30	<35

Factor		S1 l/s.p	S1 l/sm²	S2 l/s.p	S2 l/sm²	S3 l/s.p	S3 l/sm²
Q	Air flow for air quality						
	offices	16	2	12	1.5	8	1
	conference rooms	12	8	9	6	6	4
	classrooms	12	6	9	4.5	6	3
	lecture halls	12	12	9	9	6	6
	day-care centres	10	4	7.5	3	5	2
	living and bedrooms	8	1	6	0.7	5	0.5

* no mechanical cooling; temperature can be controlled with window airing; measures have to be taken that room temperature never exceeds +35°C; room temperature shall not be above +27°C when outdoor temperature is below +15°C.

** does not apply to category S1 because of room control of temperature

\- stands for no specific requirements are set

REFERENCES

1. Warren P, (1978), Low Energy Office at BRE, BRE News 46, Winter 1978.

2. Crisp V H C, Fisk D J, Salvidge A C, (1984), The BRE Low Energy Office, Energy Conservation Demonstration Projects Scheme.

3. Electric heating in highly insulated buildings - experiences from the BRE Low Energy Office (1990).

4. John R W, Willis S T P, Salvidge A C, (1990), The BRE Office, an assessment of electric heating.

5. Humphrey M, (1978), Outdoor temperatures and comfort indoors, Building Research and Practice, March/April 1978.

6. CIBSE Guide Volume A, (1986), Design Data Criteria for Sedentary Occupation A1-4.

7. Scanvac Guidelines, (1993), Indoor Climate and Air Distribution Systems.

8. Ruotsalainen R, Seppänen O, (1996), A Finnish Classification System for a Healthy Indoor Climate, Caddet Energy Efficiency Newsletter No.1/1996.

9. Classification of Indoor Climate, Construction and Finishing Materials, (1995), Finnish Society of Indoor Air Quality and Climate.

10. The Meteorological Office, Table of frequencies of 24 hour minimum temperature versus 24 hour maximum temperatures from 1/1/1983 to 21/12/1992 at East Malling, Kent.

11. TermoDeck - Passive Climate Control.

12. Braham, G D, Fabric Thermal Storage, An Update, CIBSE National Conference 1994