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HISTORY AND CURRENT PERSPECTIVES ON TERMODECK

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INTRODUCTION

The TermoDeck system of Advanced Fabric thermal Storage originated in Sweden over 20 years ago following the world's first oil shock. By the time of the second oil shock in 1979, the first generation of TermoDeck buildings were operational, and during the following decade the Scandinavian market expanded to 216 projects totalling over 800,000m² gross floor area (Table 1).

Table 1

Initial market development of TermoDeck in Scandinavia

Year	Number of projects	Total m²
1979	12 projects	46370
1980	14 projects	38590
1981	21 projects	79220
1982	19 projects	41800
1983	18 projects	50760
1984	27 projects	120720
1985	24 projects	108000
1986	28 projects	89170
1987	20 projects	121000
1988	33 projects	108900
Total	216 projects	804530

Although these projects were primarily commercial sector offices, post offices, banks etc., other more conservative market sectors also proved suitable for this technology, e.g. schools health centres and hotels (Table 2).

Table 2

Initial market type distribution of TermoDeck

Project types	Total
Offices including post offices, bank etc.	181
Industrial	6
Health Centre	10
Schools	12
Hotels	7
Total	216

Sine the late 1980's the total number of projects world wide has increased to nearly 350 projects in locations from within the Arctic Circle to within the tropics, specifically Jeddah and Riyadh. Initially this market expansion was attributable to client interest in energy conservation, but gradually further arguments developed directly form clients' experience. The popularity of year round internal environment and low inherent maintenance. These arguments are increasingly attractive to commercial property interests and also to tenders for PFI projects with 25 year operating contracts. Independent assessments of internal comfórt criteria have been undertaken for one of the first UK buildings, but since its publication is imminent, this paper will therefore concentrate on the energy conservation and design development issues.

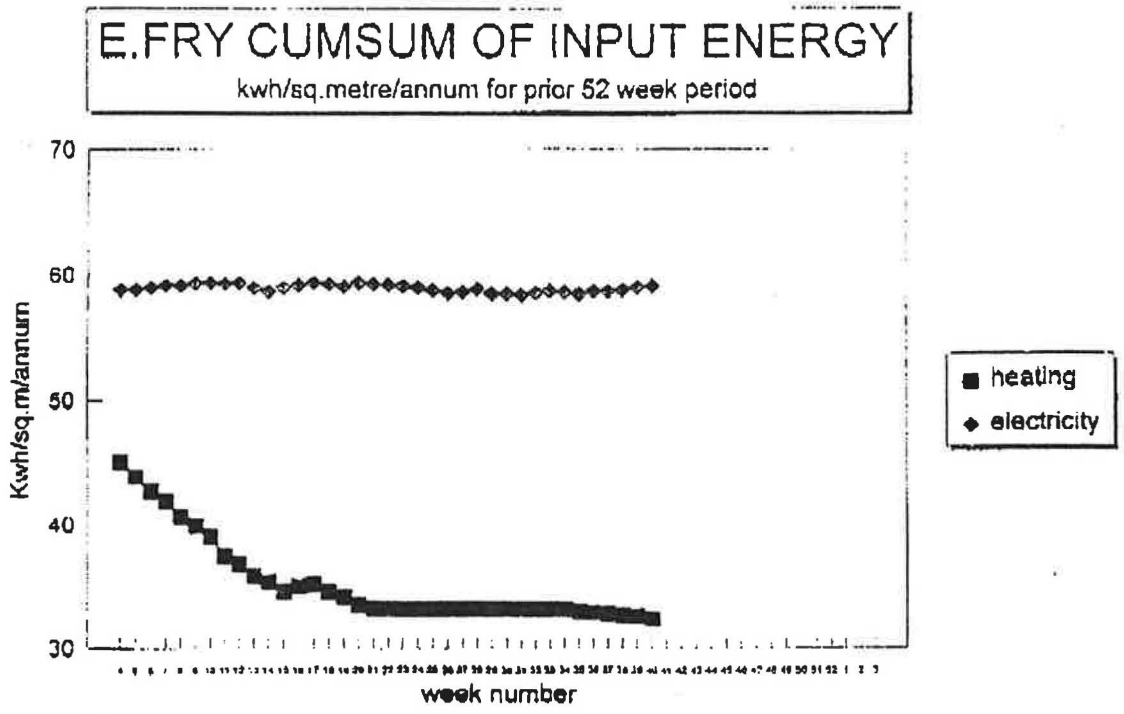
HVAC ENERGY CONSUMPTION IN TERMODECK BUILDINGS

For locations in temperate maritime climates (such as the UK), the prevailing design philosophy advocates natural ventilation, as opposed to mechanical ventilation or air conditioning. Whilst this design philosophy is generally valid for conventional HVAC schemes used in commercial buildings, it can be shown that TermoDeck buildings with mechanical ventilation have significantly lower delivered (and prime energy) consumptions and lower maintenance requirements than even the best natural ventilation designs.

The current annual delivered energy for one of the first UK TermoDeck buildings, the Elizabeth Fry Building at the University of East Anglia is shown in Figure 1. This total annual delivered energy for the building, 91 kWh/m².a, is probably the lowest energy usage for any UK building.

Figure 1

Elizabeth Fry Cumsum of input energy



1997/98

Interestingly the University of East Anglia has two recently completed buildings which provide independent comparative evidence of HVAC energy use (see Table 3). The Queens Building is highly insulated and naturally ventilated with gas condensing boilers. The adjacent Elizabeth Fry building is also highly insulated but mechanically ventilated, using the TermoDeck design strategy. The same architects and engineers were employed for both buildings.

Table 3

Measured HVAC consumptions in two University of East Anglia low energy buildings

	Heating (gas)	Fan motor (electricity)
Natural ventilation - Queens Building	147 kWh/m².a	0 kWh/m².a
Mechanical ventilation (using TermoDeck) Elizabeth Fry Building	32 kWh/m².a	16 kWh/m².a
Differences	115 kWh/m².a	16 kWh/m².a
Conversion factor $kgCO_2/kWh$	X 0.2	X 0.6
	23 $kgCO_2/m^2.a$	9.6 $kgCO_2/m^2.a$

Table 3 compares the past year's (1996/97) annual energy consumptions. The saving of 115 kWh/m².a in heating energy is achieved by approximately 16 kWh/m².a of motive power for the supply and exhaust fans.

Using current prime energy conversion factors:-

MONITORED PRACTICE

1 $kgCO_2/m^2.a$ OF FAN ENERGY SAVES 2.4 $kgCO_2/m^2.a$ OF HEATING ENERGY

With the benefit of experience gained in designing, operating and analysing the Elizabeth Fry Building, future TermoDeck designed projects should double this saving,

FUTURE PRACTICE

1 $kgCO_2/m^2.a$ OF FAN ENERGY SAVES 4.8 $kgCO_2/m^2.a$ OF HEATING ENERGY

Low annual energy demands and consumptions, whilst desirable, clearly are not the primary concern of building occupancy. Personal comfort (both thermal and acoustic) and environmental health (indoor air quality) are of great concern to the individual. Therefore, clients are interested in year round internal temperature profiles during sustained extreme weather, in particular, summer heat waves. Fortunately the design criteria recommended for TermoDeck buildings are capable of achieving both low annual energy usage and comfortable internal temperatures throughout the year.

The design briefs for the building envelope, and the heating, ventilating and air conditioning services of TermoDeck buildings are of necessity more onerous than those for conventional commercial buildings, but generally the overall building capital costs tend to be significantly lower. Specifically the following outline specifications for the individual elements and the rationale for any variance from standard or legislative practice are itemised below (all sequences are from internal surfaces to external).

Recommended building envelope specification:-

Roof Construction

a) Exposed TermoDeck slab – the depth is dependent on structural criteria 200mm to 450mm (if plastered, then expanded metal mesh is initially fixed directly to the TermoDeck slab).

b) 300mm Rockwool slabs (usually installed as two overlapping layers), or equivalent closed cell insulation under plantroom floors.

c) Ventilated pitched roof/flat roof construction.

Increased thermal insulation is essential for the year round conservation of the stored heat/coolth within the TermoDeck element serving the top floor. Generally the TermoDeck slab temperatures are within 3°K of the room set point temperature (i.e. typically from 19°C to 25°C), whilst the roof void temperatures in the UK, range from -15°C on clear winter nights to +45°C on clear summer days.

Wall Construction

a) Dense plaster.

b) 100mm to 140mm heavyweight concrete block/cast concrete.

c) 200mm Rockwool insulation slabs (or equivalent) with a minimum of 100mm insulation over column and GRP wall ties to avoid cold bridging.

d) Air gap)
) as Architect's specification
e) External element)

The combination of external insulation and dense concrete enhances the building's thermal capacity and energy storage capability, whilst ensuring the external climate has no significant influence on the internal environment. Plastered wall finish assists in achieving the overall air tightness standard.

Floor Construction - both exposed and ground slab

i. Exposed slab (thermally active e.g. TermoDeck)

a) Selected floor finish (e.g. carpet, tiles, wood, false floor)

b) TermoDeck slab (serving floor below)

c) 100mm foamed plastic board (e.g. polystyrene)

d) Selected external cladding material

ii Ground Slab

- a) Selected floor finish as i. a) above
- b) Polythene sheet on screed
- c) Concrete slab
- d) 100 mm foamed plastic board
- e) Damp proof membrane
- f) Site concrete / hardcore.

The internal surface temperature of the heavy floor/ceiling construction of highly insulated buildings has a major influence on both the dry resultant temperature and the thermal stability.

Window specification

Preferred minimum standard U value 1.3W/m^{2}degK; shading coefficient +0.2

Triple glazed openable window comprising:-

- a) Inner unit, double glazed with one low E coating and argon filled, in a timber frame
- b) 35 – 85 mm air gap for solar control blind, ventilated to the outside, with a perforated mirrored venetian blind between the inner and outer casements – manually adjustable to
- c) counter solar gains and glare
- d) Outer unit, single glazed unit in hinged aluminium exterior cladding
- e) Natural ventilation can be achieved by a separate and smaller side hung triple glazed unit, incorporated into the timber frame.

High performance windows are essential to minimise the internal window surface temperature and solar gains in summer, and maximise the passive cooling potential of the TermoDeck system. These windows also maintain high internal surface temperatures even in the severest winter weather, thereby avoiding both cold radiation from the window and associated downdraughts of cold air. Windows of heights below 1.6m do not require conventional LPHW perimeter heating to combat the downdraught, thereby achieving HVAC capital saving which more than offsets the higher capital costs of these windows. In very exposed rooms in severe climate locations, provision for some window heating may be advisable. This can be achieved by 100/150 watt thermistor controlled electric panel heaters.

To avoid cold bridging problems and air infiltration problems, special attention should be given to the window surrounds, and good quality insulated lintels, sills with insulated cavity closures, specified as standard.

Infiltration Standards

Preferred minimum standard:-

Air infiltration should not exceed 5m^3/h.m^2 @t 50 Pa over pressure [Note: Best Practice standards require 3m^3/h.m^2 @ 50 Pa].

These standards should be confirmed by independent pressure testing to the completed building. Achieving either of these standards, requires a commitment by both the design and construction teams. All main entrances, entrance lobby, all doors and windows need to be selected as specified to maintain very low infiltration throughout their operational life. Without such testing, HVAC engineers cannot risk designing for air filtration values of 0.05 air changes per hour (NB the operational value of 5m³/h.m² @ 50 Pa test pressure) in place of normal design margins of 1 air change per hour.

Ideally, all TermoDeck building projects should have infrared thermographic surveys on completion, to ensure the specified insulation has been correctly installed.

Highly Insulated, Thermally Heavy, Tight Building Envelope

Although the adoption of the above specifications for the design and construction of the building envelope will ensure very low specific boiler powers, typically 25w/m², it is salutary to note that steady state diurnal heating loads required for the infiltration air equals that of the external envelope.

Air infiltration - 50%)
Window - 33%) Proportion of installed boiler power
Opaque envelope - 17%)

Clearly improving the airtightness to the Best Practice specification (3m³/h.m² @ 50 Pa) has the highest priority for future development. Improving the window specification for both solar protection and overall thermal transmittance would be the next priority, but only provided the additional capital cost could be justified by further reductions in the HVAC plant (specifically by omitting any perimeter heating).

The energy efficient envelope using the above specification for the external construction elements is applicable to all commercial buildings, irrespective of natural ventilation, mechanical ventilation, air conditioning and mixed mode systems, or any combination of ventilation measures. The thermally heavy external walls in association with the exposed ceiling soffit usefully increases the structural thermal capacity which further enhances both the passive cooling storage using the cooler night air in summer, and internal heat storage in winter. Pre-cooling the exposed surfaces of the structural elements e.g. ceilings/floors etc., using natural ventilation can over cool these surfaces immediately prior to occupancy. This often requires the heating system to be energised in the spring and autumn periods, just to offset the over cooling. Operational experience thereby negates some of the already limited energy saving claimed for this form of passive cooling.

In contrast, the TermoDeck system passes the air through the centre of the hollow core concrete slab, internally cooling the concrete. In addition, the supply air temperature to these slabs is maintained above dew point temperature by the heat recovery unit. Generally the entry temperature to the cores may be 3 to 5 degrees lower or higher than be average slab surface temperature. The slab's thermal capacity provides very stable diurnal temperature profiles.

The typical TermoDeck slab entry temperatures have the following ranges:-

Mechanical cooling	14 to 15°C
Passive cooling	14 to 20°C
Heat recovery	20 to 24°C
Heating	24 to 35°C.

Typical TermoDeck slab operating time for normal (0800 to 1[illegible]00 hours) occupancy:

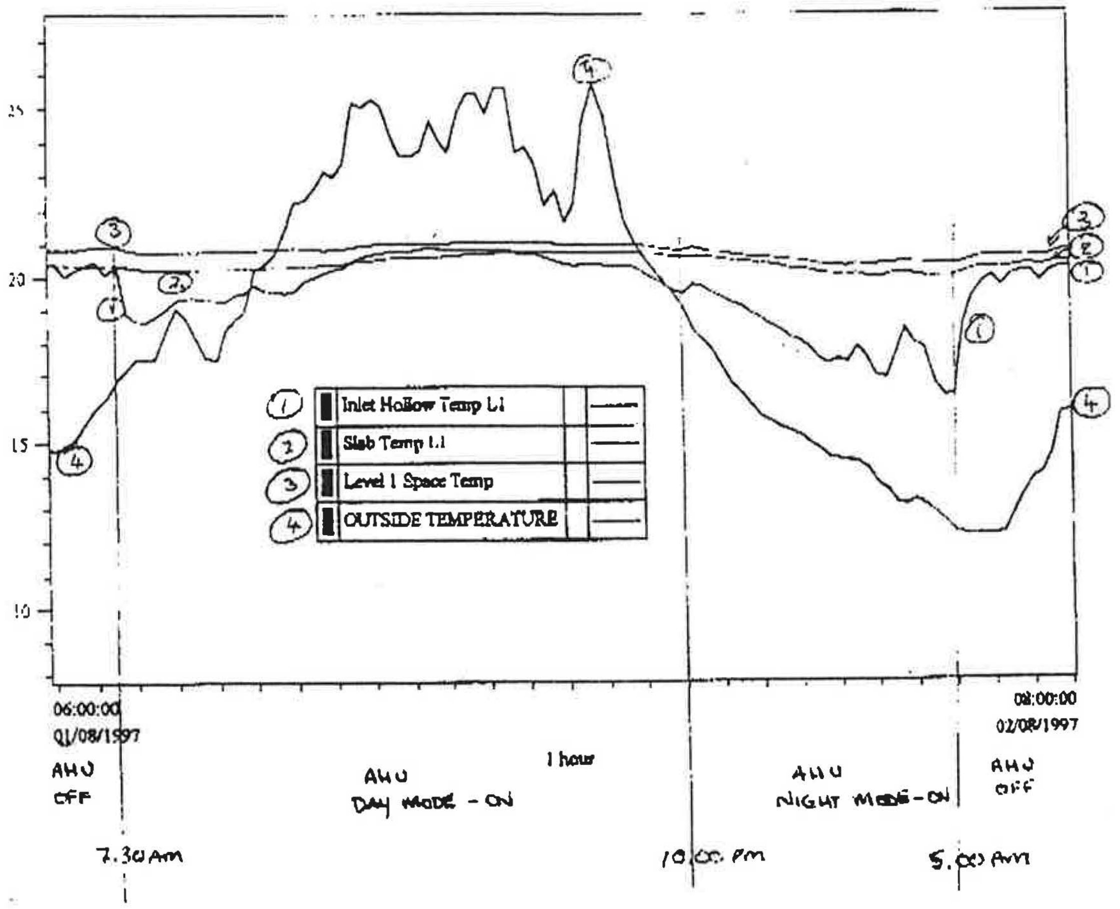
Summer	20 to 24 hours
Winter	12 to 18 hours.

Low Energy HVAC Plant

Incorporating HVAC systems into highly insulated, tight and thermally heavy building envelopes, to the standards quoted earlier would not seriously challenge designers of natural or mechanical ventilation, or indeed conventional air conditioning systems. Probably the principal differences would be the design margins used in calculating HVAC equipment sizes, due to the natural tendency to design with one's feedback experience and the prevailing company norms. However, when TermoDeck characteristics are added to an already unfamiliar design scenario, the designer's "uncertainty factor" increases by an order of magnitude! Until designers have witnessed the successful operation of "their" design through at least one calendar year the unspoken concerns remain. Therefore it important for designers to have the confidence to adopt the following design specifications for energy efficient HVAC plant, to ensure the successful integration of their system concepts into these highly insulated, thermally heavy TermoDeck buildings.

Figure 2

Typical BEMS graph for TermoDeck systems in highly insulated heavy buildings



Aide-mémoire for Designers of TermoDeck HVAC Systems

Firstly HVAC systems for TermoDeck buildings are essentially SIMPLE. Over complex systems are usually first generation designs, and are generally more expensive in capital and operating costs, and quickly redundant.

Secondly whenever TermoDeck buildings exhibit a disappointing performance initially, it is predominantly a CONTROL issue, usually caused by specifying design philosophies based on past experience, which had proved very successful in conventional buildings.

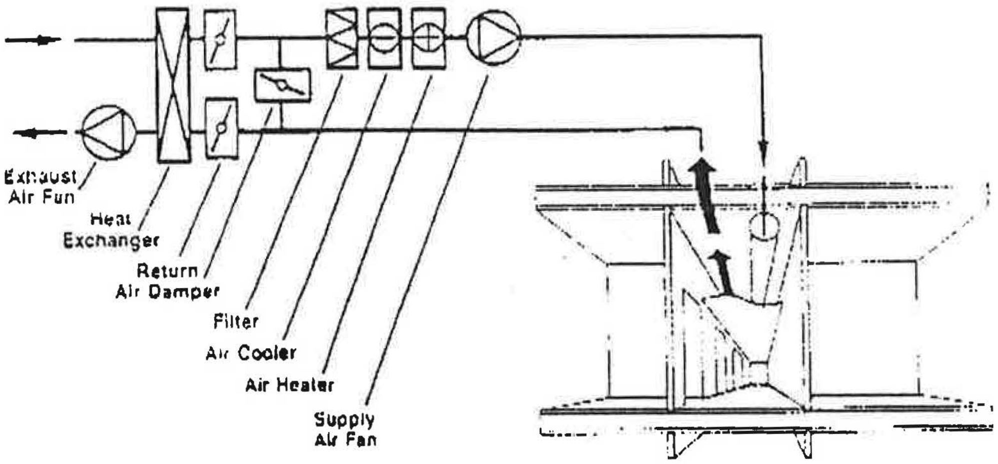
Thirdly TermoDeck buildings EDUCATE both their designers and operators. It is therefore essential for both HVAC design professionals and facility managers to collaborate for at least two years after handover to monitor the building's and system's performance in comfort, operational and energy terms, preferably in association with the controls specifier and the national TermoDeck agent.

Design Brief for Energy Efficient HVAC in TermoDeck Buildings:-

Air Handling Unit

Figure 3

Schematic diagram of HVAC system in a TermoDeck building



Location

Ideally central within the building to minimise index runs of ductwork and at high level (generally roof) with fresh air intakes on the north elevation remote from ingested contaminants (e.g. chimney fumes, cooling tower discharge and all exhaust air discharges), to ensure best possible air quality.

Heat Recovery

The sensible heat recovery efficiency should be in excess of 80% (ideally greater than 90%) with latent heat recovery, if practical. It should be capable of modulating in winter. The heat recovery function is the primary heating mechanism recovering the occupation heat gains for storage in the TermoDeck slab, and minimising the installed boiler loads. In summer heat recovery affords protection from peak summer day temperatures during the occupation period, thereby conserving "free" cooling obtained during the previous night. In these conditions it also allows the use of indirect evaporative cooling.

Recirculation

Recirculation and fresh air/exhaust damper facility for use during extended winter holidays (with zero occupancy), also overnight and after initial start up in winter under normal occupation operation.

Filters

Both pre-filters and secondary filters should be to normal commercial filtration efficiency, however consideration should be given to:-
minimising pressure drop under normal operating conditions
avoiding generation of odours from decomposing organic/vegetable matter (i.e. limit filter operative life and therefore capacity).
Ideally electrostatic filters with automatic daily washdown of collector plates should be used.

Cooling coils

Whilst free cooling using lower ambient night air temperatures is the primary cooling function for the TermoDeck system, supplementary cooling is essential for buildings requiring dehumidification and/or with high internal heat gains.

In addition to the conventional chilled water cooling, the thermal capacity of the TermoDeck system allows direct expansion heat pumps or mechanical refrigeration to be used with ON/OFF regulation, without room comfort penalties. Outlet air temperatures from the TermoDeck slab are normally within ½°C of the average ceiling surface temperature and always within 1°C.

Supplementary cooling using passive techniques include:-

Indirect Evaporative Systems

UK experience of which is still limited to two installations. Operational experience gained over two summers indicates this can be a useful low cost technique, however, its performance is constrained by the prevailing relative humidity.

Ground Source

Direct cooling using ethylene glycol/water circuits connected to multiple plastic tubes sunk into the earth using vertical cores 10 to 30 metres deep. This is a very promising technique for sustained supplementary cooling during summer heat waves. For dehumidification cooling it can be used in conjunction with reverse cycle water/water heat pumps for additional cooling performance in summer, and for bivalent heating during severe winter weather (i.e. heat pump/boiler combination).

Heating coils

Whilst heat recovery is the primary heating mechanism, supplementary heating is essential for severe winter weather. Although all types of air heating techniques can be used, the low supply air temperatures required by TermoDeck favour high efficiency systems, typically condensing gas boilers with low pressure hot water systems, operating either monovalently or bivalently with ground/air source heat pumps.

Supply/Exhaust Air Fans

Low annual energy targets require energy efficient fan motor combinations. Given that the building's occupancy and thermal loads determine the volume air flows, then the fan power requirements are dictated by the total pressure rise needed to move the required air flows. Low energy targets therefore require low air velocities and smooth air flows within both the air handling unit and the air distribution system. These factors increase the initial capital costs and are easy targets in competitive tendering. Therefore, low energy fan systems need to be carefully specified and agreed with clients as fundamental to low energy designs.

The most convenient mechanism is to specify the required installed SFP specific fan power, (and define SFP as total installed supply and exhaust fan motor power divided by the supply air flow), the units being either kW/(m^3/s) or W/(l/s).

The first generation of UK TermoDeck buildings had SFP of between 2 and 4 W/(l/s). All the current designs specify a maximum SFP of 1 W/(l/s). Generally this means increased air handling unit size whilst selecting the most efficient fan/motor combination and using low velocity ductwork.

Air Distributions System

Low energy systems require minimum possible index run for the ductwork design layout and the use of low air velocity throughout the distribution (maximum velocity 5m/s). Although the TermoDeck slab is integral, it is interesting to note that the normal pressure drop within each slab is only 50 Pa (with air velocities around 1 m/s).

In order to avoid excessive heat gain/loss to the supply and exhaust airflows it is essential for the supply air ductwork system to be efficiently insulated. In addition UK experience has demonstrated the wisdom of ensuring both the supply and exhaust air distribution systems are within the insulated building envelope, ideally immediately after leaving/entering the air-handling unit.

Room Air Distribution

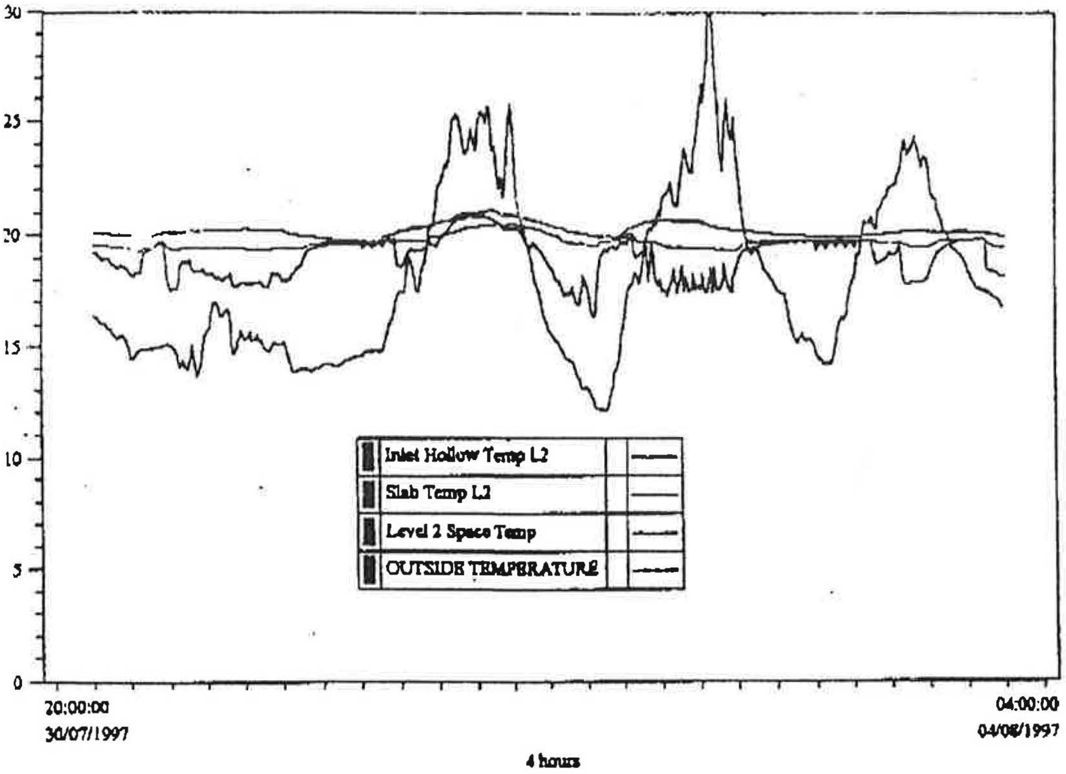
Scandinavian and UK TermoDeck systems are successfully operating with mixed room air distribution using ceiling and side wall air supply diffusers, and also with displacement ventilation systems using floor outlets and low well outlets. Both mixed flow and displacement flow operates very satisfactory with the radiant heat/coolth transfer from the exposed TermoDeck slab. The close temperature differences between the mean slab temperature, and the outlet air supplied from the slab, minimise the risk of draughts within the occupied room volume for both types of room air distributions.

Controls

The close temperature differences that favour comfortable room air distribution also provide significant self regulation of the room dry bulb temperatures whilst the exposed TermoDeck slab soffit and the thermally heavy envelope provide stable mean radiant temperatures throughout the occupation period. Consequently the dry resultant temperatures (and operative temperatures) remain relatively constant, day and night. Even if the supply air temperature to the TermoDeck slabs oscillates wildly, the radiant and air outlet temperatures remain very stable (usually within ½°C). Although slab temperatures swing very slowly it is important to monitor even small temperature changes (±0.1°C) to check for long term (1 day, 4 day and 7 day) trends to establish the stable operating patterns, particularly in severe/hot weather. Figure 4 is a typical 6-day output graph showing small diurnal temperature swings with overall trend stability

Figure 4

Typical profiles of temperature trends in a passive cooled TermoDeck building with modest internal heat gains



The UK experience to date can therefore be summarised as:-

Specify the recommended TermoDeck control logic in its entirety (and if that doesn't work - follow it implicitly!). Twenty years Scandinavian experience in over 300 TermoDeck installations does have relevance in the UK, given these Scandinavian thermal characteristics (i.e. highly insulated, thermally heavy and airtight buildings).
Specify Hand/OFF/Auto switches on all main AHU plant functions (e.g. heat recovery operation, damper operation, fan motor operation and speed and if practical supplementary heating (cooling plant). Even the best controls malfunction in time (some, sooner than later) but the TermoDeck system allows for effective manual operation, until the repairs are undertaken, (tomorrow, next week, next month, the time is not crucial!!), without penalising the internal comfort conditions.

Specify a good Building Energy Management System (BEMS) which can monitor and record the 24 hour, 4 day and 7 day temperature trends, recording the ambient air temperature, supply air temperatures to the slab, slab temperature and the room (exhaust) temperature for each zone. Record the operating modes of each AHU component. Finally record and review the AHU fan energy demands and consumption, the delivered heating energy to the (gas) boilers or (electric) heat pumps, the HWS water usage and heating energy.

CONCLUSION

Without this data neither the client nor the designer will know how good the TermoDeck climate comfort control concept is !!!