technology

ADVANCED FABRIC ENERGY STORAGE (Termodeck)

a one day seminar at
EA Technology, Capenhurst, Chester

Thursday 30 October 1997

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PROGRAMME

10.00	Registration & Coffee
10.30	**Welcome & Introduction** *Russell Benstead, EA Technology*
10.35	**Principles of FES and Advanced FES** *Dr Rob Winwood, Consultant*
11.00	**History and Current Perspectives on Termodeck** *Derrick Braham, Marketing Director, Termodeck UK Ltd*
11.45	Coffee
12.00	**The Weidmuller Building - Design and Construction** *Simon Odam, Partner, Waterfield Odam & Associates*
13.00	Lunch
14.00	**The Weidmuller Building - Performance and Improved Control** *Dr Rob Winwood, Consultant*
15.00	Tea
15.15	**The Elizabeth Fry Building - Design and Performance** *Jason Happy, Buildings Research Establishment*
16.15	Open Discussion
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Speakers

Russell Benstead	EA Technology
Derrick Braham	Termodeck UK Limited
Jason Happy	Building Research Establishment
Simon Odam	Waterfield Odam & Associates
Dr Rob Winwood	Consultant

Delegates

Sheila Badger	Energy Design Advice Scheme
Eamonn Connolly	Energy Design Advice Scheme
Dave Covell	March Consulting Group
Mark Davies	British Steel Strip Products
Joanna Heggarty	Halcrow Gilbert Associates Limited
John Hemingbrough	East Midlands Electricity plc
Steve Howard	Norweb plc
Mark Limb	Air Infiltration & Ventilation Centre
Andrew Martin	Building Services Research Information Assoc.
Mike Moore	Greatorex Consulting Engineers
Martyn Newton	University of East Anglia
Neil Norwood	Notts County Council
Barry Redman	RMJM London Limited
Andrew Stephenson	British Steel Strip Products
Sharon Tetlow	Building Simulation Limited
Andrew Tinsdale	Oscar Faber Applied Research
Paul Vaughan	AMEC Construction Limited
Ian Ward	Energy Design Advice Scheme

Session 1:

Principles of FES and Advanced FES

Dr Rob Winwood
Consultant

The Principles of FES and Advanced FES

1. Introduction

The necessary conditions for human survival are often defined as food and shelter. Although shelter also implies some form of refuge, it may largely be taken to mean thermal comfort.

Historically, thermal comfort has been attained through the evolution of traditional building styles which suit the local environment. Thus the Eskimos' development of igloos was influenced by the availability of materials, the Native Americans' developed lightweight tent-like structures to suit their migratory lifestyles and regions such as Spain and North Africa developed buildings with thick walls to provide a stable, comfortable thermal environment. This final building type 'works' by using the thermal inertia of the walls to mediate the daily temperature swing - smoothing out the effects of hot days and cold nights to a comfortable average.

The examples of a desert building and a Wigwam define the extremes of construction - thermally heavy and thermally light. These building types have radically different behaviours, as shown below:

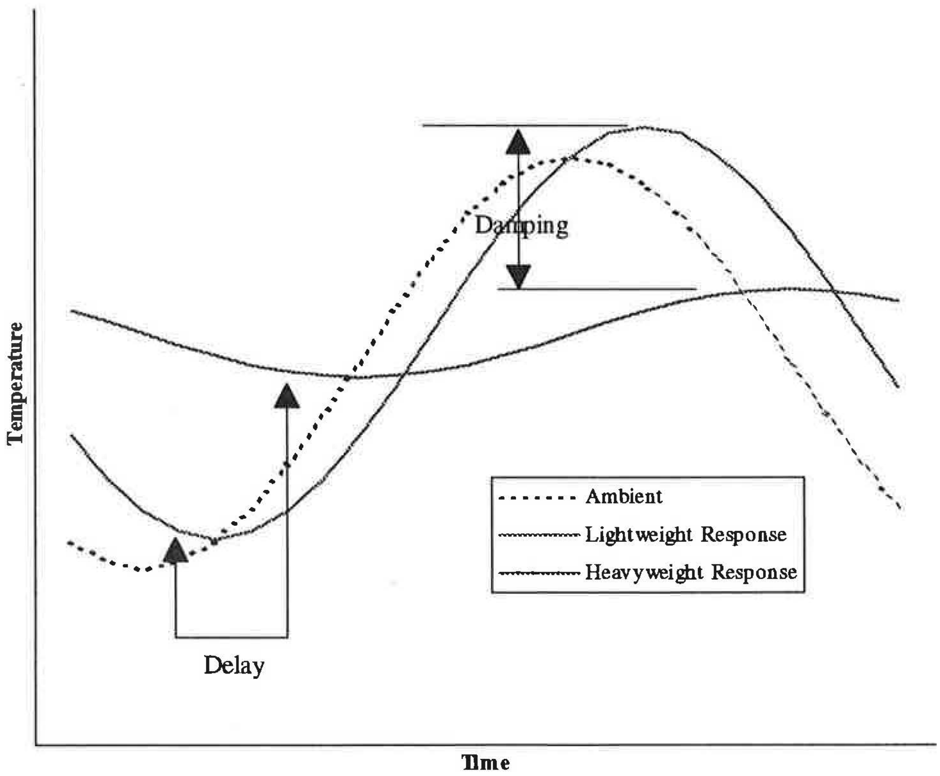


Figure 1

A thermally lightweight building is highly reactive, with internal temperature responding quickly to an injection of energy. Thermally heavy buildings, in contrast, have a high thermal inertia. They act as a 'thermal sponge' or a 'low pass thermal filter', absorbing heat energy for little change in temperature. As shown above, thermally heavy buildings respond to a periodic daily temperature cycle with a profile which is both damped and delayed in comparison to a lightweight building.

In the correct application, the attributes of either of these construction types can be beneficial. Thermally lightweight buildings are ideally suited to intermittent occupancy, where it may be necessary to raise the building's temperature at short notice. Thermally heavy buildings are best suited to applications with extended occupancy, such as hospitals and offices.

Any mismatch between a building's application and its thermal mass results in energy and cost penalties. The classic example is a traditional church, which has a very thermally heavy design but intermittent occupancy. In order to raise the church to a comfortable temperature it is often necessary to start heating several days in advance of the Sunday service.

Another mismatch between design and application can be found in some modern office buildings, which have high heat loads and a thermally lightweight construction (highly insulated with high levels of fenestration, suspended ceilings and fitted carpets). This leads to difficult temperature control problems which are too often solved by increasing the air conditioning and heating plant - using excessive energy to mask problems out rather than taking care to design them out. In an extreme case this behaviour may even lead to the use of energy for heating and then further energy for cooling in the same 24 hour period, as illustrated in Figure 2.

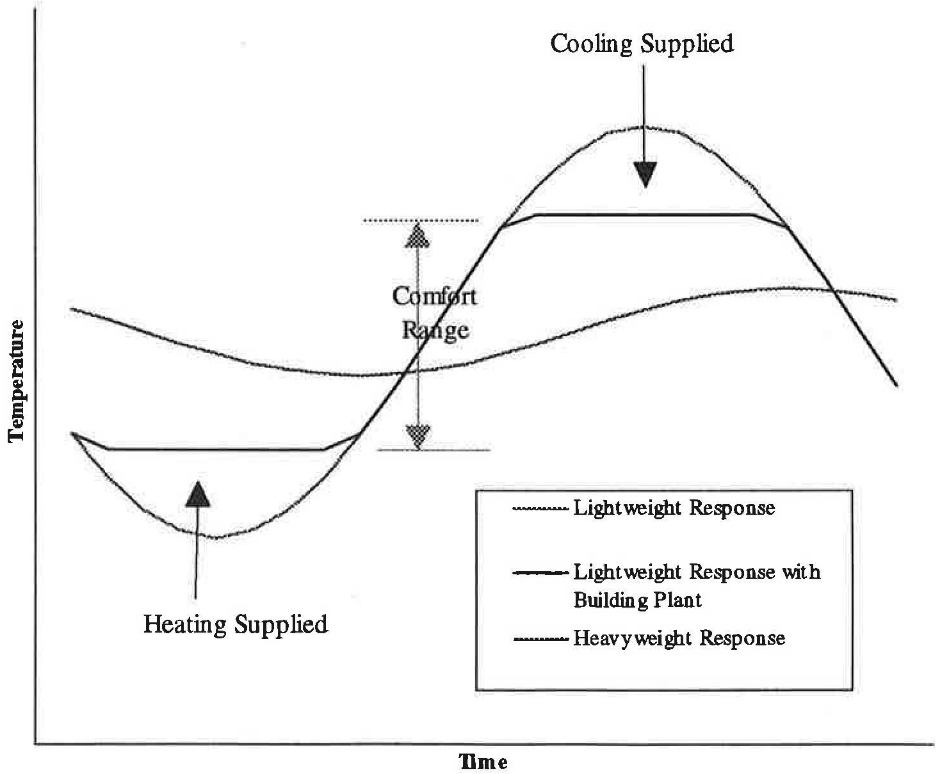


Figure 2

The result of this profligate use of energy is environmental degradation and financial cost.

It is the application of thermally heavy buildings for office use which is the subject of today's seminar. The considered use of a building's structural mass to store energy for temperature control purposes is known as 'Fabric Energy Storage' or FES.

2. Fabric Energy Storage (FES)

FES can be applied with free or mechanical ventilation. In its simplest form, it may involve simply leaving a window open at night as shown below:

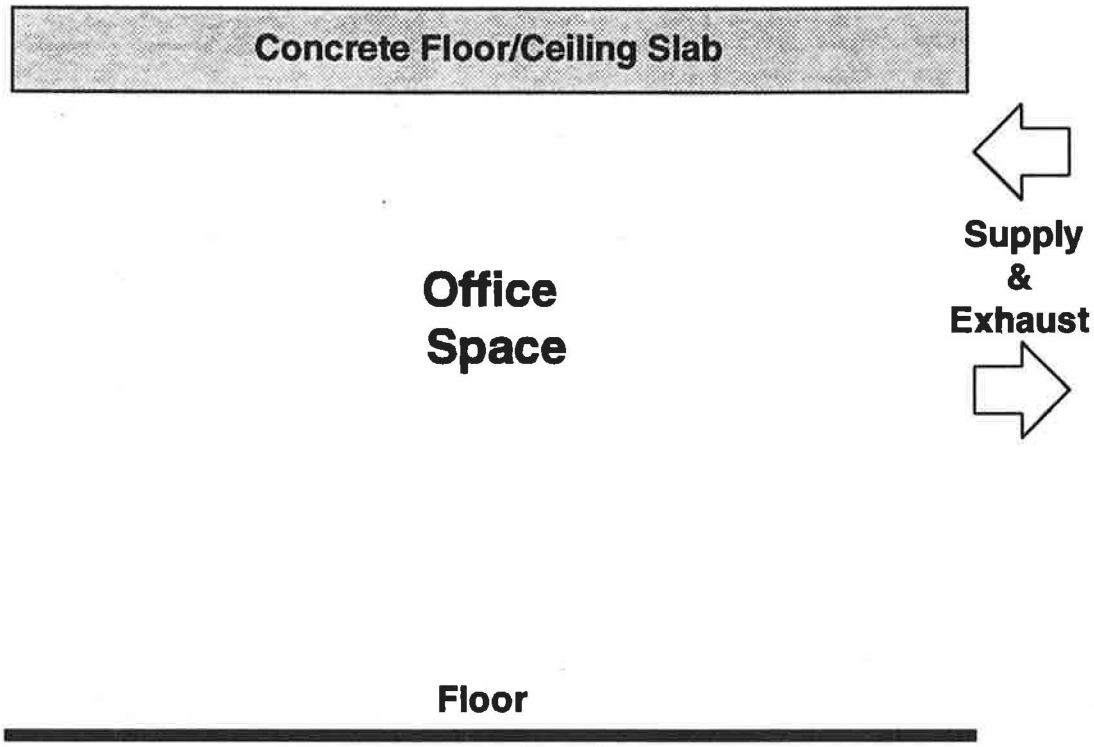


Figure 3

In more sophisticated installations it can involve under-floor mechanical ventilation with high level extract, as indicated in Figure 4. The under-floor ventilation yields forced convective heat transfer between the air and the slab whilst free convection and radiation occur at the top of the room.

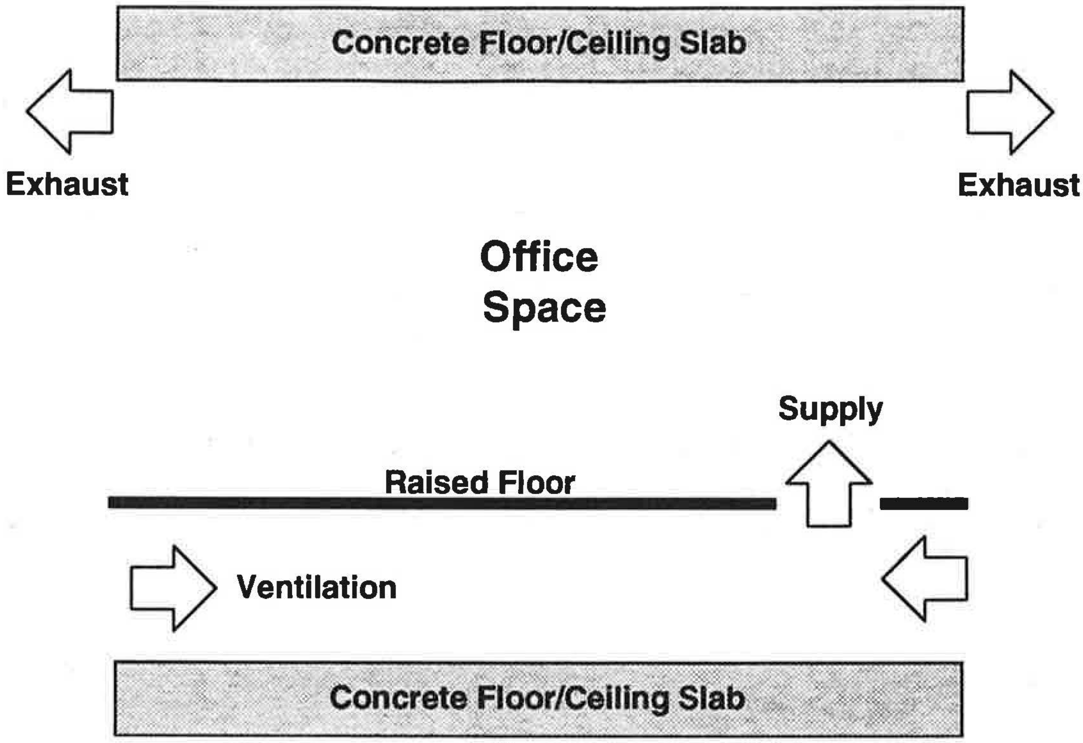


Figure 4

2.1 Benefits of FES

- FES provides the potential to store uncontrolled heat gains (solar or internal) without an excessive temperature rise and then either use it to avoid the need for heating later in the day or store it until it can be purged by night time free cooling.

- FES also allows the utilisation of off-peak electric heating which can be stored in the building's structure until the occupied part of the day. This will reduce running costs as well as limiting the building's maximum demand.

2.2 Difficulties with FES

- The control of an FES building must be pro-active rather than reactive. If the building becomes uncomfortable it will take a lot of time and energy to regain comfortable conditions. In naturally ventilated FES buildings it is particularly difficult to regulate the provision of night time free cooling.

- The heat transfer between the air and the structure is limited as FES relies on external heat transfer, the mechanisms for which are radiation and convection. Convection is dominated by the thermal resistance of the boundary layer of still air which adheres to a surface. Free convection does not produce large enough air velocities to significantly reduce this boundary layer and, whilst forced convection offers some improvement, air velocities are still low and it is difficult to keep the air stream in contact with the slab.

- In naturally ventilated FES buildings, where windows or ventilation pathways must be left open, the provision of night time free cooling can cause security concerns.

The correct application of FES will reduce energy consumption and so CO_2 emissions and cost. It will also reduce refrigerant usage. However, the uncertain and difficult-to-control nature of the heat transfer can lead to uncomfortable occupancy conditions.

One enhancement to FES is to force ventilation *through* the building's structure as well as passing it over an external surface. In this manner, additional forced convective heat transfer is achieved between the ventilation air and the thermal mass. Variation of the duration and flow rate of mechanical ventilation provides the opportunity for enhanced control of the heat exchange.

3. Advanced FES

Advanced FES has been applied in traditional architecture for thousands of years. Figure 5 shows a traditional desert dwelling from the area of modern-day Iraq. Ventilation is supplied via the roof-top wind scoop and passed through a cavity wall before entering the occupied space. Hot day time air is thus cooled by interaction with the walls and the heat transferred is later returned to warm the cold night air.

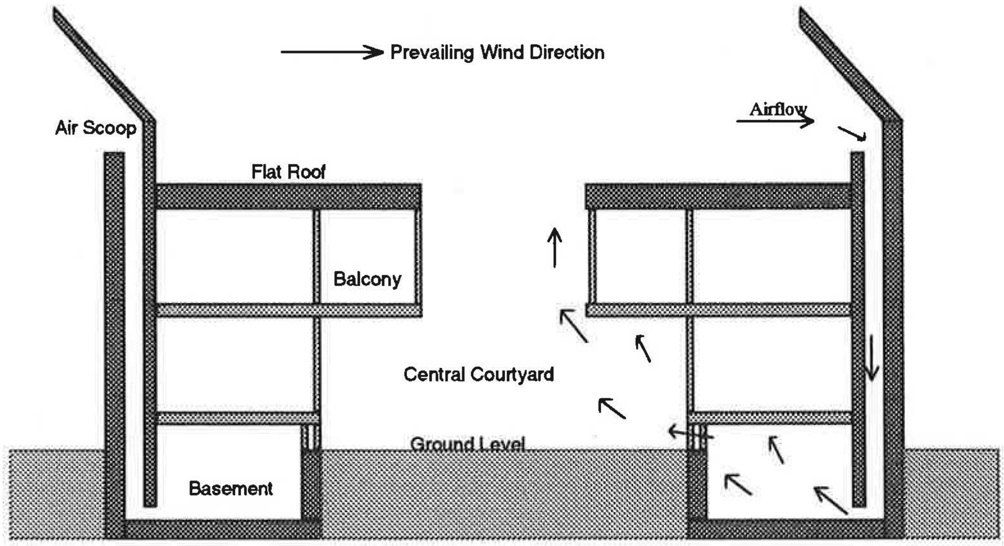


Figure 5

More recently, advanced FES has been applied to providing low cost cooling in modern, energy efficient offices. This provides all the benefits of 'simple' FES, but with enhanced comfort and control.

Several advanced FES systems have been applied in the UK, as shown below:

3.1 Plenum and Slab

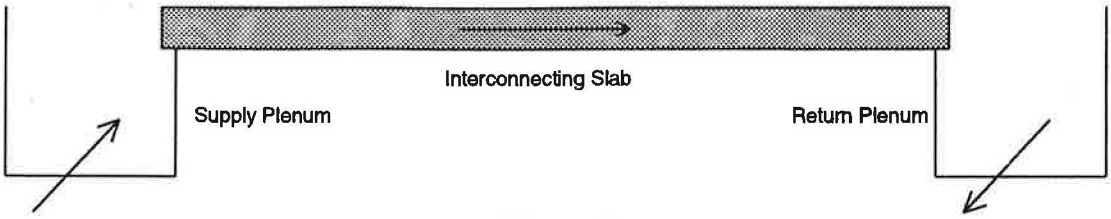


Figure 6

The 'Plenum and Slab' system was the first to be applied in the UK, in 1978. Air is supplied through a number of large plenums which are inter-connected by the hollow cores of the building's floor slabs. This system was used at the South West Regional Headquarters of the Central Electricity Generating Board, which is a prestige office building at Bedminster Down, Bristol. It was the first UK building to apply an advanced FES system and is, to September 1997, the only building to use Plenum and Slab technique.

The building has been fairly successful although it was necessary to retrospectively install some small mechanical cooling plant which is used on around 10 to 15 nights each year.

The Plenum and Slab design is not fully optimised for advanced FES. It seems to have focused upon the slabs as a method of providing an in-built under floor supply system, viewing the benefits of thermal storage as a secondary advantage.

3.2 The Generic Slab

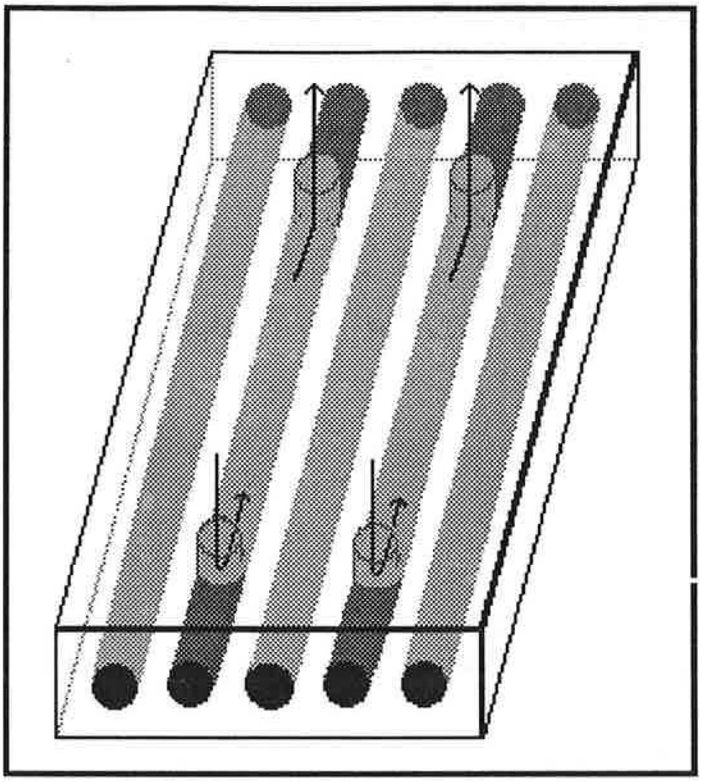


Figure 7

The generic slab, shown in Figure 7, was applied in 1994 in the Ionica building at Cambridge. The 4,000m^2, 3 storey office has been monitored by both the BSRIA and the BRE. It was designed to use a complicated mixture of passive stack, wind driven and mechanical ventilation along with openable windows, external shading and evaporative cooling.

An article written shortly after the building's construction predicted that the slabs would provide a cooling potential of between 10 and 15W/m^2, although the associated air flow rate and temperature differential were not stated.

3.3 The Hollow Core Screed

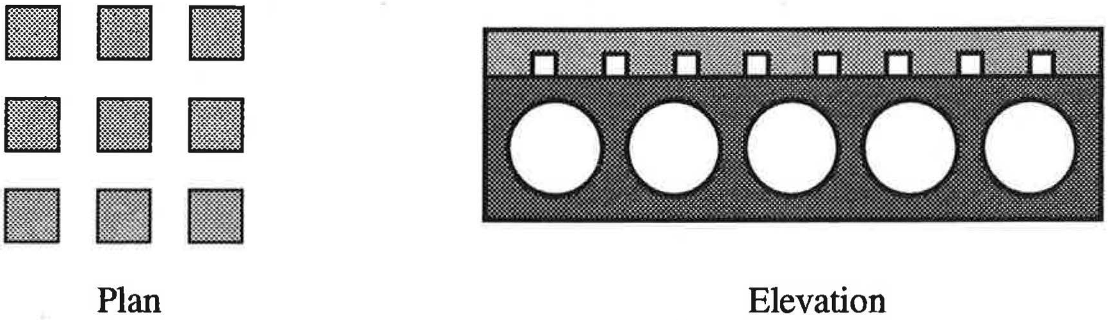


Figure 8

December 1993 brought the announcement of a patented advanced FES system which uses a hollow-core screed to distribute ventilation air. This technique is the only advanced FES system that may be retrofitted into an existing building, although it has yet to be put into practice. The complicated air path and small core height are designed to produce highly turbulent airflow and good heat transfer, however, there are unresolved concerns about inspecting and cleaning such a narrow air path.

3.4 The Termodeck Slab

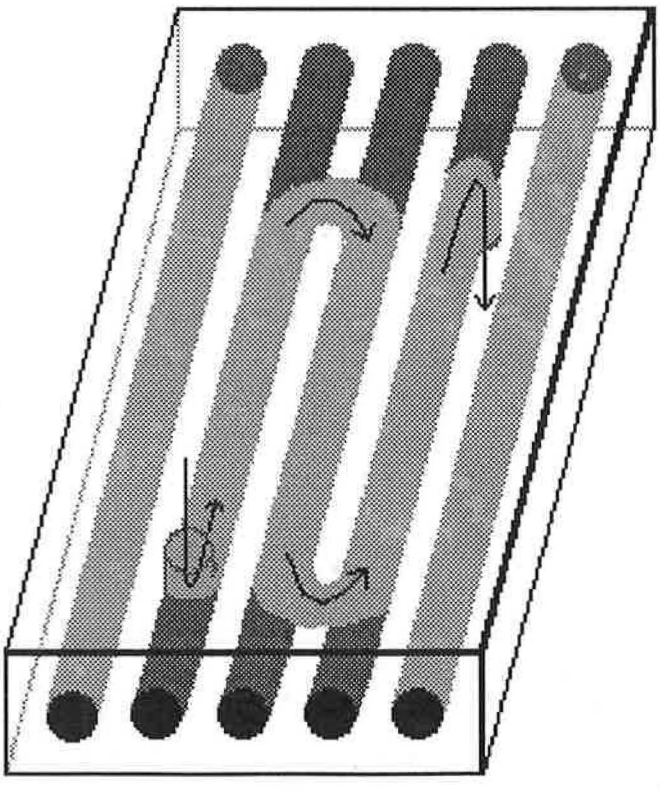


Figure 9

The most widely applied advanced FES system has been the patented Termodeck slab, which is shown above. The technique originated in Sweden in the late 1970's and has been applied in over 1,000,000m² of commercial buildings in Sweden, Belgium, Holland, Saudi Arabia and the UK.

The standard layout of a Termodeck building is very simple, as shown below. The exposed slabs are fed from a main supply duct which runs along a central corridor and is hidden behind a false ceiling. Air is supplied to the offices via ceiling diffusers and exits via high level grills back into the central corridor ceiling plenum, from where it is extracted.

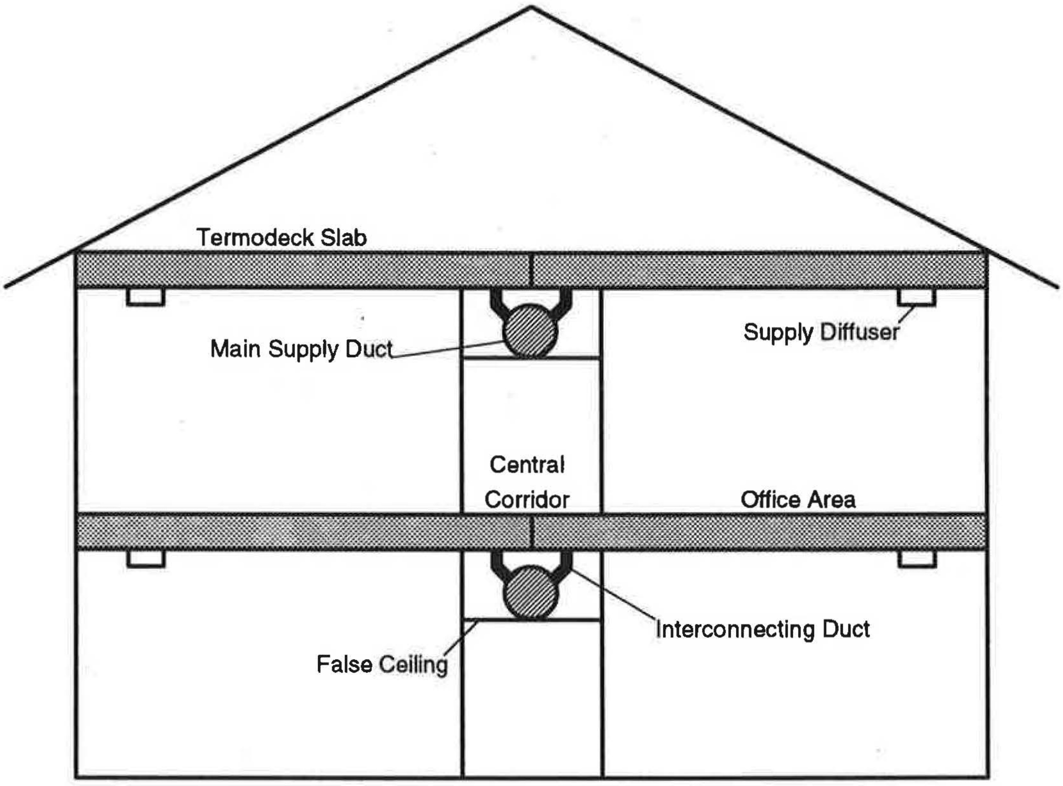


Figure 10

The Weidmuller Interface office at West Malling, Kent was the first UK application of Termodeck. It is a 2,400m², two storey office with supplementary heating and cooling from electric heater batteries, an indirect evaporative cooler and air supply via low level diffusers to provide displacement ventilation. Independent monitoring of the building has been undertaken by EA Technology, results from which will be described in later presentations.

The University of East Anglia's 'Elizabeth Fry Building' was the UK's second Termodeck project. The 3,250m², four storey building contains lecture halls, meeting rooms and a restaurant. In contrast to the Weidmuller building, it is laid out along traditional Termodeck lines with ventilation ducts hidden behind a false ceiling along the central corridor and air supply to the rooms via ceiling diffusers.

4. Summary

4.1 Benefits of Advanced FES

The benefits provided by advanced FES include:

- Stable, comfortable temperatures
- Low energy consumption leading to;
  - low running costs
  - low CO_2 emissions
- No refrigerant usage for air conditioning
- Reduced space required for heating and cooling plant
- Full fresh air ventilation

Session 2:

History and Current Perspectives on Termodeck

Derrick Braham
Termodeck UK Limited

HISTORY AND CURRENT PERSPECTIVES ON TERMODECK

G D Braham, C.Eng., F.C.I.B.S.E., M. Inst. E., M. Inst. R., M.A.S.H.R.A.E.

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 comfort 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.

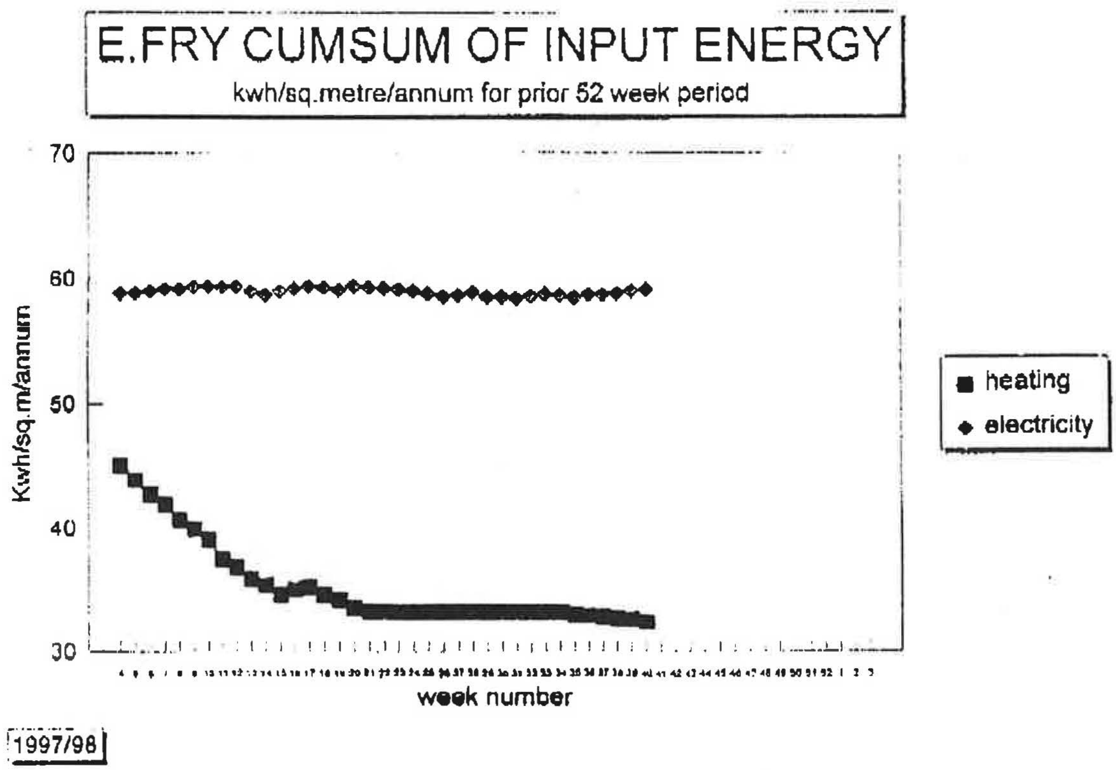
HVAC ENERGY CONSUMPTION IN TERMODECK BUILDINGS

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



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 $kWh/m^2.a$	0 $kWh/m^2.a$
Mechanical ventilation (using TermoDeck) Elizabeth Fry Building	32 $kWh/m^2.a$	16 $kWh/m^2.a$
Differences	115 $kWh/m^2.a$	16 $kWh/m^2.a$
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 $kWh/m^2.a$ in heating energy is achieved by approximately 16 $kWh/m^2.a$ 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. <u>Exposed slab (thermally active e.g. TermoDeck)</u>

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/m²degK; 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 5m³/h.m² @t 50 Pa over pressure [Note: Best Practice standards require 3m³/h.m² @ 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 times for normal (0800 to 1800 hours) occupancy:

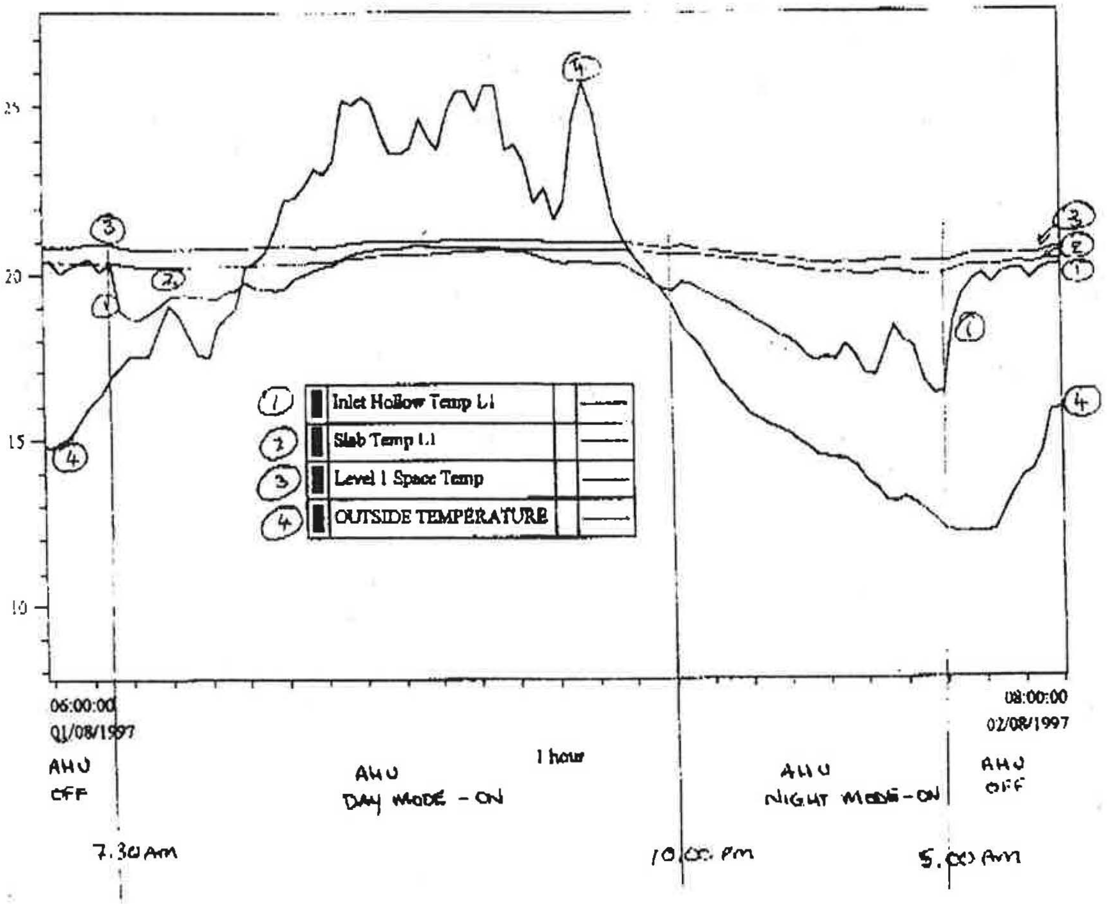
Summer	20 to 24 hours
Winter	12 to 18 hours.

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.

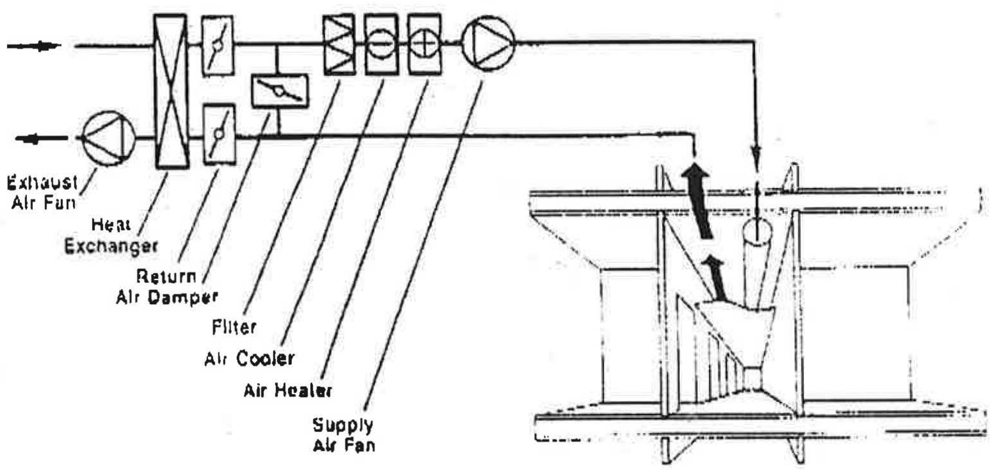
Thirdly TermoDeck buildings EDUCATE both their designers and operators. It is therefore essential for both HVAC design professionals and facility managers to collaborate for at least two years after handover to monitor the building's and system's performance in comfort, operational and energy terms, 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/(m³/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.

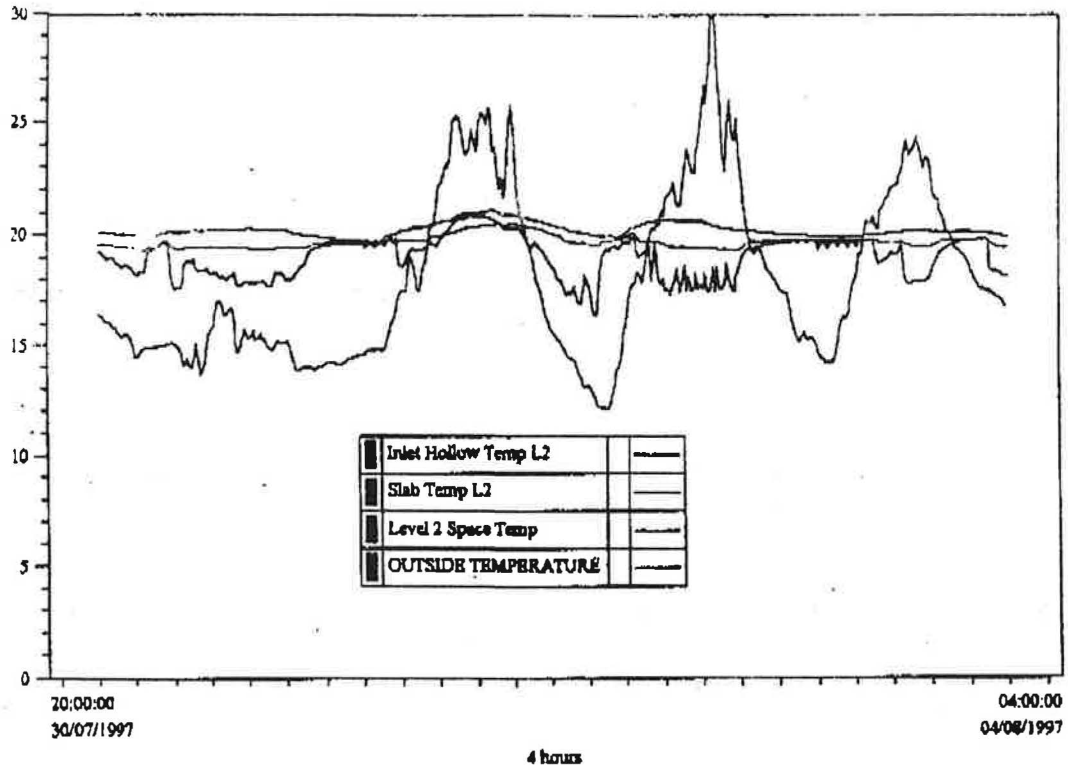
Room Air Distribution

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 !!!

Session 3:

The Weidmuller Building
- Design and Construction

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Waterfield Odam & Associates

THE WEIDMÜLLER INTERFACE BUILDING KINGS HILL WEST MALLING KENT.

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30th October 1997

CONTENTS

1. INTRODUCTION

In the 1980's and early 1990's Rouse Kent developed the West Malling Aerodrome site by providing the initial infrastructure for the business park that is now becoming an integrated business and residential community. The Weidmüller Interface building was the third building to be completed on the site and has a gross internal area of approximately ? m^2.

Waterfield Odam & Associates, having previously worked on projects for Weidmüller was engaged in September 1992 as the Building Services Consulting Engineers to prepare a design performance specification for the project.

Weidmüller decided in the early stages of the project to adopt a low energy approach and a building incorporating "Termodeck"® Thermal Storage Construction, coupled with High Efficiency Regenerative Air to Air Heat Recovery was developed from this point onwards.

Waterfield Odam & Associates developed the specification in discussion with the UK Structural Engineer for the project and the originator of the Termodeck system, Loa Anderson, in Stockholm.

This building was constructed in approximately 40 weeks and completed for occupation by Weidmüller in June 1994. It was the first Termodeck building to be occupied in the UK.

2. WHAT IS DIFFERENT ABOUT THIS BUILDING ?

The fundamental difference between this building and a conventional building are:-

- The structure has a high thermal insulation efficiency.
- There is a low leakage of air through the external building envelope.
- The building mass is used for thermal storage.
- The building structure consists of "Planks" with cast in ducts which are used to convey heated/cooled air.
- The main ventilation plant incorporates high efficiency thermal energy recovery and indirect evaporative cooling facilities.
- Several complementary energy conservation measures are incorporated into the design of the building.

3. STORAGE OF THERMAL ENERGY

Why the need to store thermal energy ?

This is necessary in this particular building because of the need to "Time Shift" the availability and utilisation of thermal energy. With the supply authorities tariff for this site "off peak" rate electricity used for heating is only available for a seven hour period between midnight and 08:00 AM each day and the cooler night air is generally only available during the hours of darkness in the summer months. It is also desirable to pre-cool the planks at night only when Off Peak electricity is available since this minimises the running cost of the fans.

A simple and common analogy for this building in heating terms is the conventional storage heater where Off Peak tariff electricity is used to heat the dense masonry blocks in the heater which then dissipate their stored thermal energy over the next day. The more advanced storage radiators are equipped with a fan to discharge the heat more quickly when required. This building does in effect function as a large fan assisted relatively low temperature (19° to 22°C) storage heater when operating in the heating mode when "tempered" air is discharged through the displacement ventilation diffusers. A significant proportion of the heating effect is however due to heat radiated from the underside of the plank into the occupied spaces.

A reversal of the analogy of the storage heater applies for the cooling cycle during the summer months when cooler night air is blown through the plank voids to cool the mass of the floor planks and so restore the plank temperature to the design intent of 19° to 22°C for the following day.

4. CONSTRUCTION

4.1 Structure

Whilst the use of pre-cast concrete planks, with or without longitudinal voids, is common practice in the construction of buildings their use as a means of storing and distributing thermal energy, and the passage of ventilation air, is not.

The planks used for the main open plan areas of this building are some of the longest ever made in the UK, being up to 16 m in length. Long pre-cast planks without intermediate support dictate a thicker section of plank with those used on this project being approximately 440 mm thick and 1200 mm wide. The weight of each of these 16 m planks is approximately 9 tonnes and each plank has four hollow bores along the long axis of the plank.

The planks are supported by a steel frame and pre-cast stair case units complete the structural elements of the interior of the building. The external walls of the building are of cavity construction with block work for the inner skin and bricks for the outer face.

The design of the structure and services installations for this building were integrated such that air handling plant passes air through the hollow voids of the planks where an exchange of thermal energy takes place between the air being blown through the voids and the concrete itself. If air hotter than the concrete is introduced the temperature of the concrete is raised and visa versa.

4.2 Internal Finishes

One of the main implications of the Termodeck system is the need for the underside of the floor planks to be exposed in the occupied spaces in which they are to maintain environmental conditions. This precludes the use of conventional false ceilings and so limits the designers choice of the means of providing artificial lighting in these areas. The obvious solutions to this problem in normal commercial premises is to provide wall mounted and free standing uplighters or to fix surface mounted low brightness luminaires to the underside of the planks.

Unless the exposed underside of the planks is considered acceptable some form of surface finish will be required to cover the Vee grove joint between adjoining planks. In the Weidmüller building the underside of all the planks were covered with an expanded metal mesh fixed to the planks with conventional masonry plugs and screws. This was then plastered over to give a smooth finish that can be decorated using conventional techniques.

Any form of plank finish having thermally insulating properties must obviously be avoided since it will attenuate the radiant heating or cooling effect of the planks. With the absence of the normal sound absorbing false ceiling the acoustic properties of occupied areas may require some thought to avoid an unacceptably reverberant environment.

If required, for aesthetic purposes, it is possible to use a false ceiling having an open grid construction but this will have little or no acoustic benefit and there is a limit to what you can hide with an open egg crate type ceiling.

4.3 Accommodation of Services

Subject to positional co-ordination it is possible to use the non active plank bores, the ones not used for the passage of air, for the installation of cables to serve lighting, fire alarm and small power installations.

The services to work stations in open plan areas at ground floor level in the building are distributed in a multi-compartment flush floor steel trunking fitted with three compartment floor boxes where required. The first floor level is also served by floor boxes with small power circuits being distributed from “Spider” boxes which can accept additional floor boxes as required. Telephone and data wiring is distributed via the semi-accessible floor void to each floor box.

5. MAIN VENTILATION, HEATING AND COOLING SYSTEMS

5.1 Main Air Handling Units

The central element of the main ventilation , heating and cooling installations are two air handling units, one for the ground floor and one for the first floor. Each of these air handling units consists of:-

1. A three phase belt driven centrifugal supply fan to provide air to the planks.
2. A three phase belt driven centrifugal extract fan to draw air from the occupied areas back to the air handling unit.
3. A panel filter to perform coarse filtering of the air being supplied to the occupied areas.
4. A bag filter, after the panel filter, to perform fine filtering of the air being supplied to the occupied areas.
5. Two short time cyclic high efficiency "air to air" plate heat recovery thermal storage modules.
6. A central Regenair damper system to control the mode of operation of the air handling plant.

The ratings of the main ventilation, heating and cooling plant are as follows:-:-

Ground Floor Supply Fan	7.5KW
Ground Floor Extract Fan	5.5KW
Ground Floor Heater Batteries	Two @ 36KW each
Ground Floor Indirect Evaporative Cooler	0.25KW Pump Motor
First Floor Supply Fan	5.5KW
First Floor Extract Fan	4.0KW
First Floor Heater Batteries	Two @ 36KW each
First Floor Indirect Evaporative Cooler	0.25KW Pump Motor

5.2 High Efficiency Energy Recovery

The plate heat stores incorporated in the air handling units consist of corrugated aluminium plates assembled in packs such that there are many convoluted paths through the corrugations for the air that either heats or cools the plates as it passes through the pack. These plate heat stores were developed by Eric Stenfors of Regenair in Stockholm and are now marketed in this country by ECE Ltd.

The time constant of these plate heat stores is typically one minute and in the heat recovery mode the flow through the stores is reversed at one minute intervals. The temperature of the supply air leaving the air handling unit when in the heat recovery mode is within 10% of the temperature of the extract air approaching the air handling unit.

The temperature of the air leaving both heat stores varies exponentially as a store is first "charged" and then "Discharged". In winter months the plates are heated by outgoing air and then give up this heat to the incoming air.

i.e. when the temperature is rising $\theta_t = \theta_\infty(1 - e^{\frac{-t}{k}})$,

and

when the temperature is falling $\theta_t = \theta_0 . e^{\frac{-t}{k}}$.

When the system goes into the heat recovery mode after the dampers have not moved for a period of time the plate stores take a finite number of cycles to reach a beneficial operating temperature. This initial charging process is again exponential with the cyclic charging variation imposed on the initial ramp envelope.

The Regenair damper system, which controls the air flow through each air handling unit, consists of a four blade damper arrangement such that the vertical and horizontal pairs of dampers are linked to function together. The damper blades can be used in the following modes:-

- **Shut down mode**: where the dampers form a cross to shut off all air flows through the air handling unit. This is used when the fans are not required to run to prevent heat loss due to convection or wind forces on the building.

- **Recirculation mode**: where the dampers form a "box", or rectangle to enable air to pass through the air handling unit back to the building with no air being drawn from outside the building, or expelled from the building. This is used during the heat charging process since no fresh air is required and would in fact be detrimental to the heating process due to the heat lost in exfiltrated air.

- **Heat recovery mode**: where the dampers alternate between the vertical and horizontal positions to alternately charge and discharge the short time cyclic plate heat stores. This is the normal operational mode of the damper system during the hours of occupancy in temperate weather. The heat recovery mode can also be used in conjunction with the indirect evaporative coolers to lower the temperature of the air entering the plate heat stores in the air handling plant.

- **Free cooling mode**: where both dampers remain in the horizontal or vertical position, apart from a change of position, at approximately three hourly intervals, to perform a cleaning function by reversing the air flow through the plate heat stores.

The Regenair system provides 100% fresh air, with no re-circulation during occupancy. This contributes to the avoidance of "Sick Building Syndrome" often attributed to air handling plant that re-circulates a large proportion of the air, typically 90%, that is extracted from occupied areas.

5.3 Electric Heater Batteries

Air from the air handling unit is distributed to the planks via a system of rectangular, and then circular, thermally insulated low pressure steel ductwork. After leaving the air handling unit the main rectangular duct divides into the A and B zones into which the two floor levels are subdivided. The air then passes through electric heater batteries which heat the air when required. These heater batteries consist of exposed mineral insulated heating elements suspended in the air flow. The heater batteries are protected by over temperature switches and are interlocked with the fan and damper control systems.

The provision of two separately controlled 36 KW three phase electric heater batteries, one for each main aspect of the building at each floor level, permits some selective control of the heat input to the building.

5.4 Ductwork and Connections to Concrete Planks

On leaving the heater batteries the air passes through header ducts to circular distribution ductwork which is in turn connected to circular holes in the planks to give access to the internal voids or "Plank Bores". These connections to the plank are via holes of typically 100 mm diameter and are effected by fitting ductwork spigots with circumferential neoprene rubber seals into diamond drilled holes which penetrate to the plank bores.

The air injected at any point on a plank then travels up one bore, along the axis of the plank, through a crossover chamber and then into the adjoining bore where it travels back in the reverse direction. The air is generally then reversed in direction at a second crossover chamber to make a third pass through the plank. The crossover chambers are formed by "Stitch Drilling" the plank at the required position to remove the solid portion between two bores. A former is then inserted and the drilled hole made good with concrete leaving a connection between the two adjoining bores.

The air leaves the plank via another circular duct. The exit ducts either individually feed a displacement diffuser or are connected to a common header duct to feed one or more displacement terminals.

Connections to the planks can be made to the upper or lower surface. In this building the planks serving the first floor, which form the first floor ceiling, are fed from above and air leaves from below. The planks serving the ground floor have both supply and delivery connections in the lower surface.

In most simpler Termodeck installations, such as in some ground floor parts of the Weidmüller building, air is diffused into the occupied areas via directional ceiling diffusers which are fitted directly into holes drilled into the underside of the plank to connect with an active bore.

5.5 Displacement Ventilation

Displacement ventilation, as its name implies, is based on the principal of the air supplied to occupied areas displacing the air in this space upwards such that heated and "Used" air in the occupancy zone is displaced toward the extract terminals which are sited at high level.

Each displacement ventilation terminal consists of a plenum box into which air is delivered by the ductwork system which is fed from the plank. The outlet from the duct in the plenum box is fitted with a distribution "Sock" in the shape of an inverted cone to equalise the pressure across the face of the displacement diffuser panel. Each displacement panel is individually balanced by regulating the air supplied to the panel from the feeder duct. This is achieved by measuring the static pressure inside the plenum box and adjusting the damper in the feeder ductwork.

Because of the physical dimensions of the ducts serving the displacement panels it is necessary to use surface ducts, or to form a false wall, as is the case with this building in which the vertical ducts can be installed.

Provided no person is situated within one metre of a displacement panel there should be no discernible discomfort due to this means of air supply into an occupied space. This is because the discharge velocity from a displacement ventilation panel should generally not exceed $1 ms^{-1}$.

One limitation that must be considered for displacement ventilation is that furniture must be designed or positioned such that it does not form an imporforate barrier at low level between the displacement panel and the area it is designed to serve.

The air supplied to the occupied areas is generally at a lower temperature than the air in that space. It therefore naturally distributes at low level by spreading across the area around furniture etc. Wherever people or machines are working in the occupied space they create a natural convection effect due to the heat emitted by the person or machine. This causes air in the vicinity to rise entraining air at low level which also rises. The convection process due to the relative densities of the warmed and cooler air results in the exhaled and warmed air rising above the occupancy zone where it is extracted as described above.

The occupancy zone is defined as an area between floor level and a height of say 2.5 m above floor level. When sizing an air supply and distribution system in terms of temperatures and air quality the region between 2.5 m above floor level and the underside of the ceiling need not be considered since it is not occupied.

5.6 Indirect Evaporative Cooling

This building is not provided with any form of mechanical or "Active Cooling" and so does not use refrigerant or refrigeration machinery of any sort.

The ground and first floor ventilation systems are however equipped with "Low Energy Cooling" in the form of indirect evaporative coolers in the extract ducts from the occupied area to the respective air handling unit. These two units are effectively humidifiers which reduce the temperature of the air passing through them by virtue of the latent heat of evaporation due to the water in the evaporation media being evaporated into the air stream without the addition of any other form of energy.

The indirect evaporative coolers are used in conjunction with the Regenair dampers and plate heat stores to reduce the temperature of the incoming air. This is achieved by cooling the outgoing air which reduces the temperature of the plate heat stores which in turn reduce the temperature of the incoming air.

The control of the Indirect Evaporative Coolers is such that the ponds are subject to a continuous mains water make up when they are in use. They are also drained down at least once in every 24 hour period and remain drained until required for cooling duty again. This control regime was instigated to avoid any problems with Legionella.

Discounting annual maintenance the only running costs for the evaporative coolers are the water consumed and the power to drive a small circulating pump and the fill and drain solenoid valves.

5.7 Down Draft Prevention Heaters

In other Termodeck buildings it was found that there was a need for down draft prevention heaters under windows in smaller rooms such as individual offices. These heaters have only to be rated at around 100 Watts each to overcome the glazing and frame losses in cold weather and so prevent the sensing of down drafts near windows.

A larger trench mounted electric heater was installed beneath the full height glazing to the front of the building to prevent cold down drafts from this expanse of glazing.

6. LOW ENERGY CONSTRUCTION TECHNIQUES

6.1 High Levels of Insulation

The standards of insulation employed in this building are higher than were required for compliance with the current Building Regulations and normal good practice. These enhanced levels of insulation that contribute to the low energy consumption for which this building was designed.

Insulation values used in the construction of this building are compared to normally accepted values as specified in the Building Regulations:-

Building Element	This Building	Building Regulations
Walls:	$0.2 Wm^{-2o}C^{-1}$	$0.45\ Wm^{-2o}C^{-1}$
Floor:	$0.3 Wm^{-2o}C^{-1}$	$0.45\ Wm^{-2o}C^{-1}$
Roof:	$0.2 Wm^{-2o}C^{-1}$	$0.25\ Wm^{-2o}C^{-1}$
Windows:	$1.9 Wm^{-2o}C^{-1}$	$3.3\ Wm^{-2o}C^{-1}$

To achieve these insulation levels the cavity walls were filled with 150mm Rockwool cavity batts and 50 mm Rockwool slabs were laid in the floor construction.. A layer of insulation slabs 300mm thick was laid over the second floor slab in the plant room and store area and 300 mm thick fibreglass insulation was used in the roof void at second floor level to reduce heat losses from the first floor area.

Windows are of the triple glazed type having a sealed outer double glazed module and a single inner pane. Venetian blinds are provided in the interstitial space between the outer double glazed module and the inner single pane. The size of the windows was also kept to a minimum to reduce heat loss and thermal gains.

Unlike a fully air-conditioned building it is quite acceptable for occupants of this building to open windows for additional ventilation should they wish to.

6.2 Building Envelope Integrity Testing

Whilst it is logical to specify high standards of insulation and air tight construction to prevent unwanted air infiltration or exfiltration it must be ensured that these requirements are achieved during the construction of the building.

Compliance with the specification in terms of insulation standards can be verified by inspecting the works as they progress. It is not such a simple matter to verify that air tightness has been achieved in all aspects of the construction since this is dependent on good detailing and high standards of workmanship throughout.

To prove the integrity of the building envelope in terms of air tightness it is necessary to perform a pressurisation or fan test. The test on this building was carried out by BSRIA, the Building Services Research and Information Association.

The fan test was performed by opening all internal doors, closing all external doors and windows and sealing ventilation openings such as the main ventilation intake and exhaust ducts. One external door opening was then used as a means of pressurising the building to a known pressure with respect to atmospheric pressure outside the building.

Pressurisation was achieved by a 1200mm diameter trailer mounted axial fan driven by the power take off on a V8 Land Rover. This test facility is available for hire from

BSRIA and can produce air flows of between 3 and 30 m^3s^{-1} which require a shaft power of up to 80 KW. The air flow rate used for the test on the building varied from 5.27 to 1.20 $m^3 s^{-1}$

The criteria for a successful test is if the rate of leakage of air from the building is less than 5 $m^3 hr^{-1} m^{-2}$ of external building envelope area when tested at a pressure of 25 Pa. 25 Pa is equivalent to a wind speed of 5 ms^{-1}, 11 mph or force 3 on the Beaufort scale.

As the leakage rate for the first test was 8.1 $m^3 hr^{-1} m^{-2}$ the building did not achieve the required degree of air tightness. The fan was stopped and smoke generators were used to fill the building with dense non staining "smoke". The fan was then started again and as the internal pressure increased the leakage paths were revealed where the smoke was ejected from the building.

Leakage was noted from below curtain walling, between window frames and the structure, through door seals and various other interfaces between elements of the building. These leakage paths were sealed and at a later date the building re-tested when it achieved a leakage rate of 1.2 $m^3 hr^{-1} m^{-2}$.

Before conducting smoke tests it is advisable to notify the Fire Brigade to avoid the embarrassing situation of some one calling them out unnecessarily !

7. COMPLEMENTARY ENERGY CONSERVATION MEASURES

7.1 Internal Lighting Controls

Control of the internal lighting is by means of the hybrid building management system such that the lighting is controlled by inputs from:-

- The intruder detection system to determine if the building is occupied or not.
- The Intruder detection system to determine if an intruder has been sensed in the building.

This control circuit has to operate in the fail safe mode in conjunction with the self contained emergency lighting luminaires. For this reason it is important to "drive" the lighting off so that normal sub circuit failure sensing as required by BS 5266 "Emergency Lighting" is maintained. The coil circuits for the normally closed contactors used to control the lighting are routed through the distributed I/O system Modulink outstation processor error contacts so that the lighting remains in the on state in the event of a loss of signal or fault condition.

7.2 External Lighting Controls

Control of the external lighting is by means of the hybrid building management system such that the lighting is controlled by inputs from:-

- A daylight level sensor
- Whether the building is occupied or not as determined by the intruder detection system
- External presence detectors
- A "hand/Off/Automatic" selector switch

Automatic lighting controls were provided for the toilet lighting such that they switch the lighting on for a predetermined time when a presence detector senses a person passing through the toilet entrance lobby.

7.3 Water Conservation Controls and Monitoring

Urinal flush controls are installed in the male toilets to only permit water to flow to the urinal cisterns when presence is detected in these toilet areas.

The building management system monitors water usage in the building at all times and so can be used to prove that there is no wastage when the building is unoccupied.

7.4 Reactive Maintenance Facility

Because the pressure drops across the ventilation plant are constantly monitored the cost of maintenance is reduced since filters are not changed at fixed time intervals but only when the media is contaminated to a predetermined level.

Alarms indicating various plant failure conditions are also initiated and indicated by the building management system.

8. HYBRID BUILDING MANAGEMENT SYSTEM

The original controls for all the mechanical services installations in this building were to have been of the conventional individual controller design with an option, at the clients preference, to adopt a Building Management System during the contractors design phase of the project.

The client in fact elected to delete the controls from the services contractors package and appoint a controls systems house to design, programme and commission a PLC based Hybrid Building Management System. This decision by the client in effect removed the controls for the mechanical services and lighting installation from the Main Contract since the systems house was appointed direct by the client and the control panel was in fact built in the clients own workshops by his staff.

On all Weidmüller projects there is a stated requirement to use either Weidmüller or group products such as those marketed by HT Electrical.

Two Toshiba T2 PLC's were originally used to provide all the control functions as well as the logging of temperatures, electrical loads, water consumption etc. Data is gathered instantaneously and continuously from temperature and pressure sensors and manual input switches around the building. The analogue and digital signals are collected from the more remote parts of the building via a distributed I/O system of Weidmüller manufacture. Outputs to remote devices are also transmitted via the distributed I/O system.

The original PLC's were replaced by a single GE Fanuc 90-30 PLC and the original Iplex SCADA package by a Cimplicity package in 1996.

The PLC is currently configured for a total I/O count of 171 made up of the following inputs and outputs:-

Digital Inputs:	64
Analogue Inputs:	57
Digital Outputs	47
Analogue Outputs	3

The PLC currently has a scan time of around 30 milliseconds.

The arithmetic functions of the PLC are used to control the ventilation, heating and passive cooling systems as well as the internal and external lighting. The decision process for the control of the main ventilation, heating and cooling systems is illustrated in the flow chart.

9. POSSIBLE IMPROVEMENTS TO THE INSTALLATION.

Probably the most likely means by which energy consumption can be further reduced in this building without major alterations to the ductwork or building structure are the introduction of:-

- Variable speed fan drives to match the fan speeds, and so energy consumption, to the required duty.
- Enclosure of the four main fan motors such the fan motor cooling air can be used to advantage in the air-stream during the winter and kept separate from the main air-stream in the summer.
- Air quality sensing such that a controlled level of re-circulation is introduced based on levels of carbon dioxide sensed in the air extracted from the occupied areas.

Before the above improvements are considered further operational data for the building with its new control regime should be gathered and analysed for a complete 12 month cycle.

Fine tuning of the set points used on the control logic should be undertaken after analysis of the systems operation for a period of time.

It may be possible to achieve further reductions in utility consumption by the fine tuning proposed but it is considered unlikely that consumption much less than 40 KWh m^{-2} per year for this building will be realised without more extensive works on the plant.

Even if only 40 KWh m^{-2} were to be achieved this is a commendable result since it is only 10% of the energy used in early poorly insulated building stock.

10. LESSONS THAT HAVE BEEN LEARNT ON THIS PROJECT

At least the following lessons have been learnt since the commencement of this project:-

1. An innovative project of this nature should not be let on a "Design Performance" basis unless the major contractors have had some experience of the technology involved or are prepared to invest in the same prior to commencing the design of the building and services.

   A conventional "Full Design" brief would have been of more benefit to the client since the main contractor and services contractor are under commercial pressures to design, install and commission what is, at the start of the project, an unknown quantity of which they have had no previous experience.

   Waterfield Odam & Associates invested in a trip to Stockholm for three engineers to meet the originators of the Termodeck and Regenair systems as well as to view several projects utilising these systems, both under construction and completed and occupied buildings. The services contractor did not.

2. Where two or more air handling units are to be installed the intakes/outlets must be positioned such that the discharge from one system does not adversely affect the second or subsequent units. It was for this reason that the operation of the two Regenair damper systems have now been co-ordinated such that the ducts terminated on each face of the building both either intake or discharge at the same time when ever possible.
3. Because of the long thermal time constant of the building it is necessary to obtain early warning of any system failure. A winter weekend without charging of the planks will result in depressed temperatures at the start of the following week with no means of raising the internal temperatures. Even using full "Emergency Heating" will take several hours, at normal electricity tariff rates, to start to raise the internal ambient temperature of the building.
4. To tune the control of the main heating and ventilation systems it is necessary to have a historic record of past operation of the systems and the building's response to the system operation.

5. The ducts connecting the air handling units to the exterior of the building are subject to rapidly varying pressures as they change from a positive pressure "Discharge" duct to a negative pressure "Intake" duct. They must therefore be correctly designed and constructed to prevent excessive flexing which leads to splitting of the joints and the generation of excessive noise when the pressure changes from positive to negative and back again when in the heat recovery mode.

6. The electric heater batteries must be of sufficient rating to cope with the heat loss of a typical 24 hour period at winter design conditions. To achieve compliance with this requirement the heater batteries must be able to charge the slab to the required temperature, during the 7 Hour period when Off Peak electricity is available, under winter design conditions.

7. Because the internal environment is dependent on the design output of the slab in terms of heat emissions, for both heating and cooling, it is of necessity relatively finely balanced and is not tolerant of major and sustained disturbances in terms of heat gain or loss.

8. A consistent heat gain in one particular area such as a computer equipment room can lead to problems in a Termodeck building. In the case of the Weidmüller Building a need has now arisen for the computer and communications equipment in a small internal room to run 24 hours every day of the year.

   When the main ventilation system is in its shut down state awaiting Off Peak electricity there is no air movement in the building and so cooling in this room is limited to the radiant effect of the concrete plank ceiling. This one problem room, with it's concentrated and continuous heat gain, will now have to be dealt with as a single area and the installation of two small split cooling units to provide at least 50% standby capability should one unit fail is under consideration.

9. In the event of failure of the automatic controls it is necessary to have a means of "driving" the main fans, dampers and heater batteries by using manual control switches. This at least enables the building to remain in an occupiable state even if the ventilation, heating and cooling system is not operating at its most efficient.

S J Odam

Waterfield Odam & Associates 30th October 1997

WHAT IS DIFFERENT ABOUT THIS BUILDING ?

- The structure has a high thermal insulation efficiency.

- There is a low leakage of air through the external building envelope.

- The building mass is used for thermal storage.

- The building structure consists of "Planks" with cast in ducts which are used to convey heated/cooled air.

- The main ventilation plant incorporates high efficiency thermal energy recovery and indirect evaporative cooling facilities.

- Several complementary energy conservation measures are incorporated into the design of the building.

MAIN PLANT RATINGS

GROUND FLOOR

Supply Fan	7.5KW Motor
Extract Fan	5.5KW Motor
Heater Batteries	Two @ 36KW each
Indirect Evaporative Cooler	0.25KW Pump Motor

FIRST FLOOR

Supply Fan	5.5KW Motor
Extract Fan	4.0KW Motor
Heater Batteries	Two @ 36KW each
Indirect Evaporative Cooler	0.25KW Pump Motor

REGENAIR DAMPER MODES

- **SHUT DOWN MODE**: where the dampers form a **"Cross"** to shut off all air flows through the air handling unit. This is used when the fans are not required to run to prevent heat loss due to convection or wind forces on the building.

- **RECIRCULATION MODE**: where the dampers form a **"Box"**, to enable air to pass through the air handling unit back to the building with no air being drawn from outside the building, or expelled from the building. This is used during the heat charging process.

- **HEAT RECOVERY MODE**: where the dampers **Alternate** between the vertical and horizontal positions to alternately charge and discharge the short time cyclic plate heat stores.

- **FREE COOLING MODE**: where both dampers remain in the **Horizontal or Vertical** position, apart from a change of position, at approximately three hourly intervals, to perform a cleaning function by reversing the air flow through the plate heat stores.

The Regenair system provides 100% fresh air, with no re-circulation during occupancy

COMPARATIVE THERMAL INSULATION VALUES

Building Element	Weidmüller Building	Building Regulations
Walls:	$0.2 Wm^{-2}°C^{-1}$	$0.45\ Wm^{-2}°C^{-1}$
Floor:	$0.3 Wm^{-2}°C^{-1}$	$0.45\ Wm^{-2}°C^{-1}$
Roof:	$0.2 Wm^{-2}°C^{-1}$	$0.25\ Wm^{-2}°C^{-1}$
Windows:	$1.9 Wm^{-2}°C^{-1}$	$3.3\ Wm^{-2}°C^{-1}$

GENERAL PRINCIPLES

- The "ducts" formed in the planks carry warm or cool air to try to maintain the plank temperature between 19° and 22° C.

- When the outside temperature falls below 19°C the planks act as a mainly radiant heat source.

- When the outside temperature rises above 22°C the planks act as a mainly radiant cooling source.

- The air is tempered to a temperature between 19° and 22° C during its passage through the plank bores.

- The air is then discharged at low velocity at low level via displacement ventilation terminals.

- During occupancy times the system normally operates in either Heat Recovery or Free Cooling Mode.

- During winter off peak charging the system operates in Full Recirculation Mode.

- During summer off peak charging the system operates in the Free Cooling Mode.

- During summer when the internal air temperature is less than external air temperatures the system can operate in the Heat Recovery Mode alone or Heat Recovery Mode with Indirect Evaporative Cooling

- When the planks are between 19° and 22° C no off peakor "Emergency Heating or cooling takes place.

- The above is intended to produce occupied areas with air and surface temperatures normally between 19° and 22° C and a 100% fresh air input to the building.

CONTROL OF THE MAIN PLANT

THE NON OCCUPANCY "CHARGING" PROCESS

Considering the plank temperature from its coldest to its hottest the "charging" functions are:-

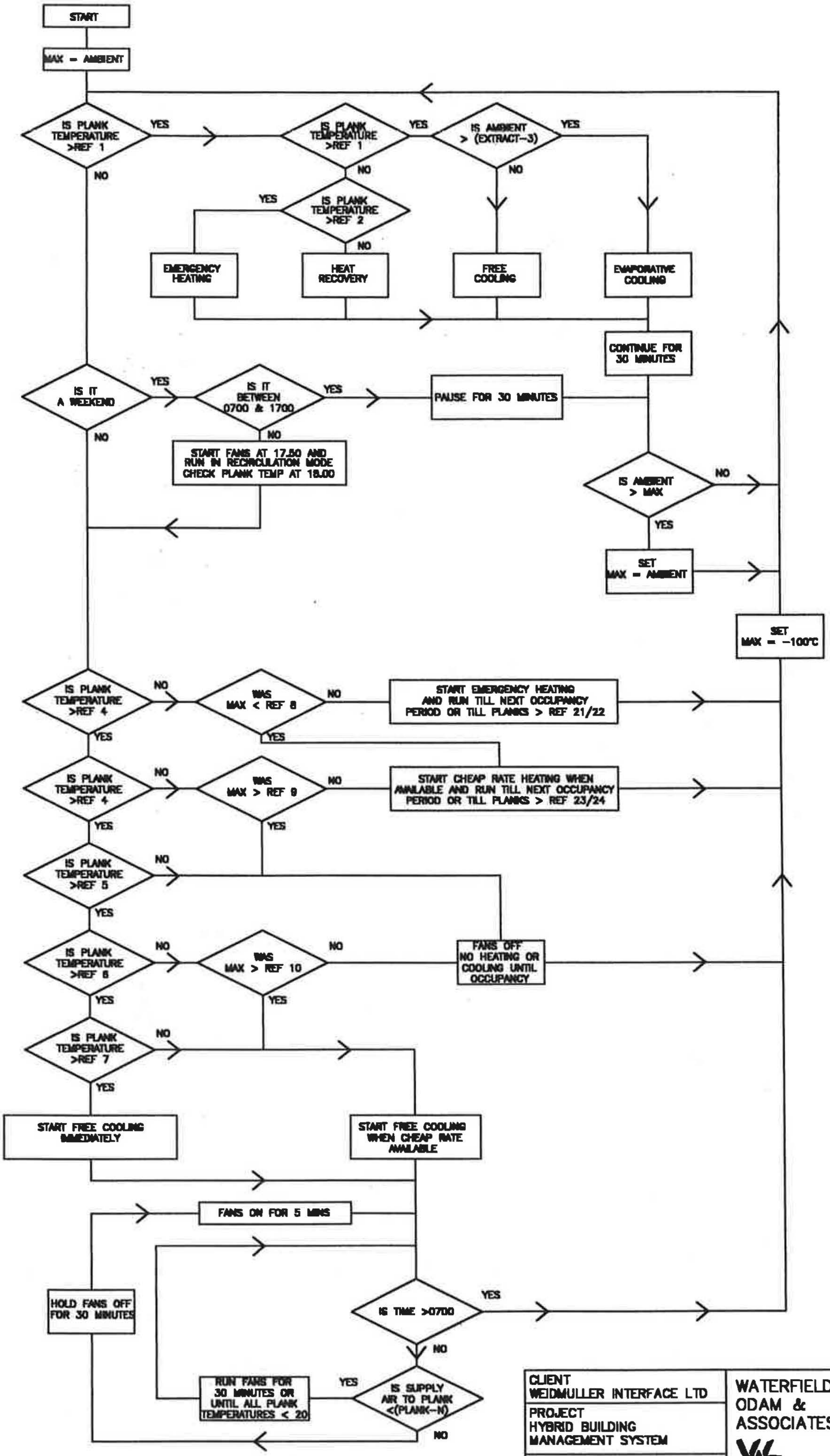
- Emergency heating
- Off peak heating
- Dead band. i.e. no heating or cooling
- Off peak free cooling
- Emergency free cooling.

These functions are regulated by sensors that measure external air temperature, internal air temperature and plank temperatures. There is also an element of prediction in this routine since the decision process updates the external ambient temperature at the end of occupancy each day.

CONTROL DURING OCCUPANCY

During occupancy the range of control functions, from lowest to highest internal temperature, attempt to control the air supplied to the occupied areas to between 19° to 22°C by selecting one of the following:-

- Emergency heating with heat recovery
- Heat recovery from extract air
- Ventilation only, also referred to as Free cooling
- Cooling recovery from extract air
- Evaporative cooling with cooling recovery

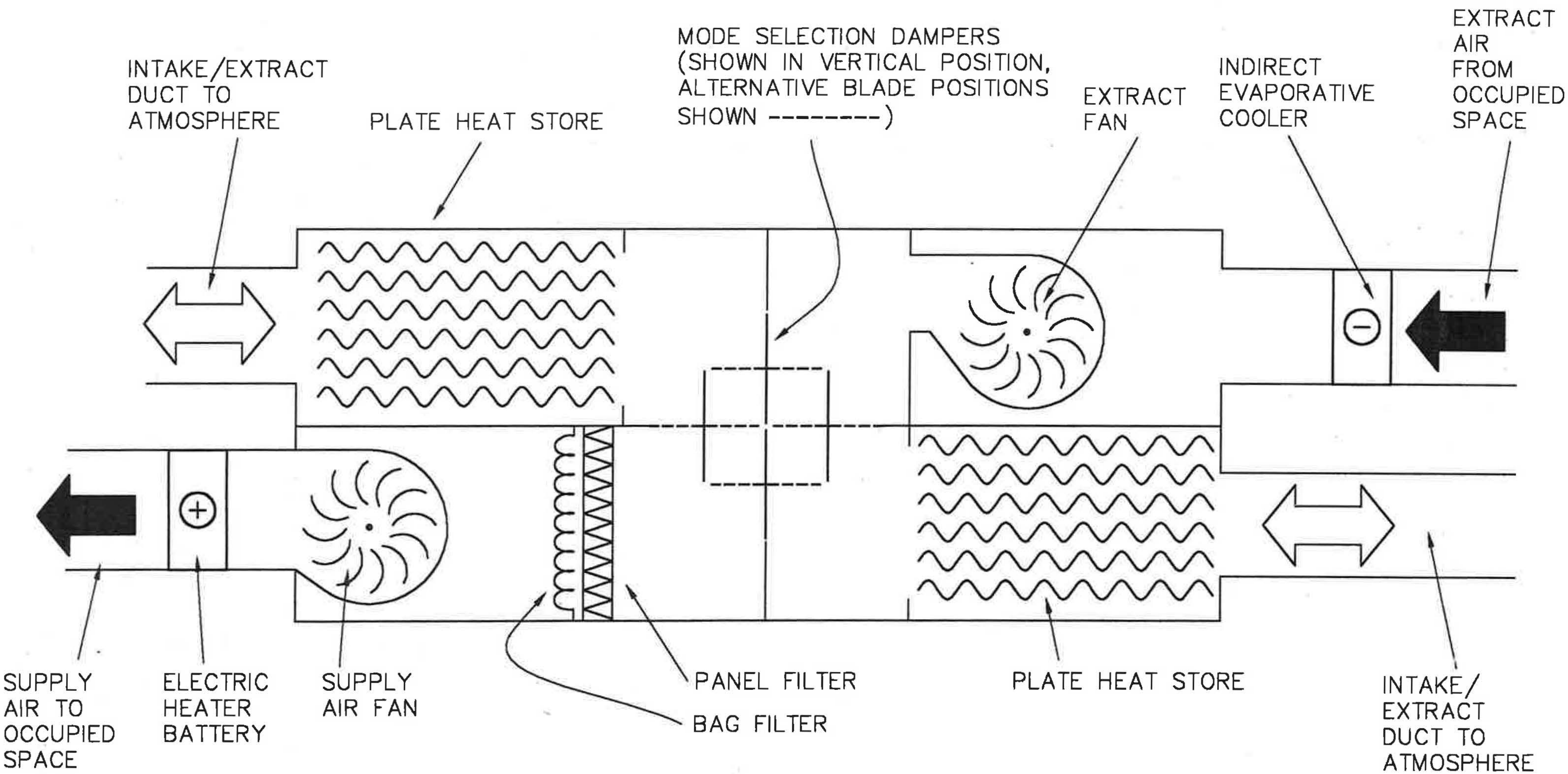


CLIENT
WEIDMULLER INTERFACE LTD

PROJECT
HYBRID BUILDING MANAGEMENT SYSTEM

TITLE
FLOW DIAGRAM

WATERFIELD ODAM & ASSOCIATES
AMHERST HOUSE
22 LONDON ROAD
RIVERHEAD
SEVENOAKS
KENT TN13 2BW
TEL 01732 465444
FAX 01732 452550



AIR HANDLING UNIT

Session 4:

The Weidmuller Building
- Performance and Improved Control

Dr Rob Winwood
Consultant

The Weidmuller Building - Performance and Improved Control

Contents

1. Monitoring

EA Technology has undertaken independent monitoring of the Weidmuller building since shortly after its initial occupation in 1994.

The building is divided into two zones (the first and second floor) for air supply purposes. Each of these air supply zones is sub-divided into two heating zones, which correspond to the East and West facing offices on each floor.

Monitoring concentrated upon the West-Facing, first floor R & D office as it was considered that its combination of heat loads and orientation would create the greatest risk of overheating. Temperatures and energy consumptions have been recorded using a combination of the building's own BEMS sensors and dedicated thermocouples. Temperature sensors were positioned throughout the ventilation system, as illustrated below and data was collected at five minute intervals.

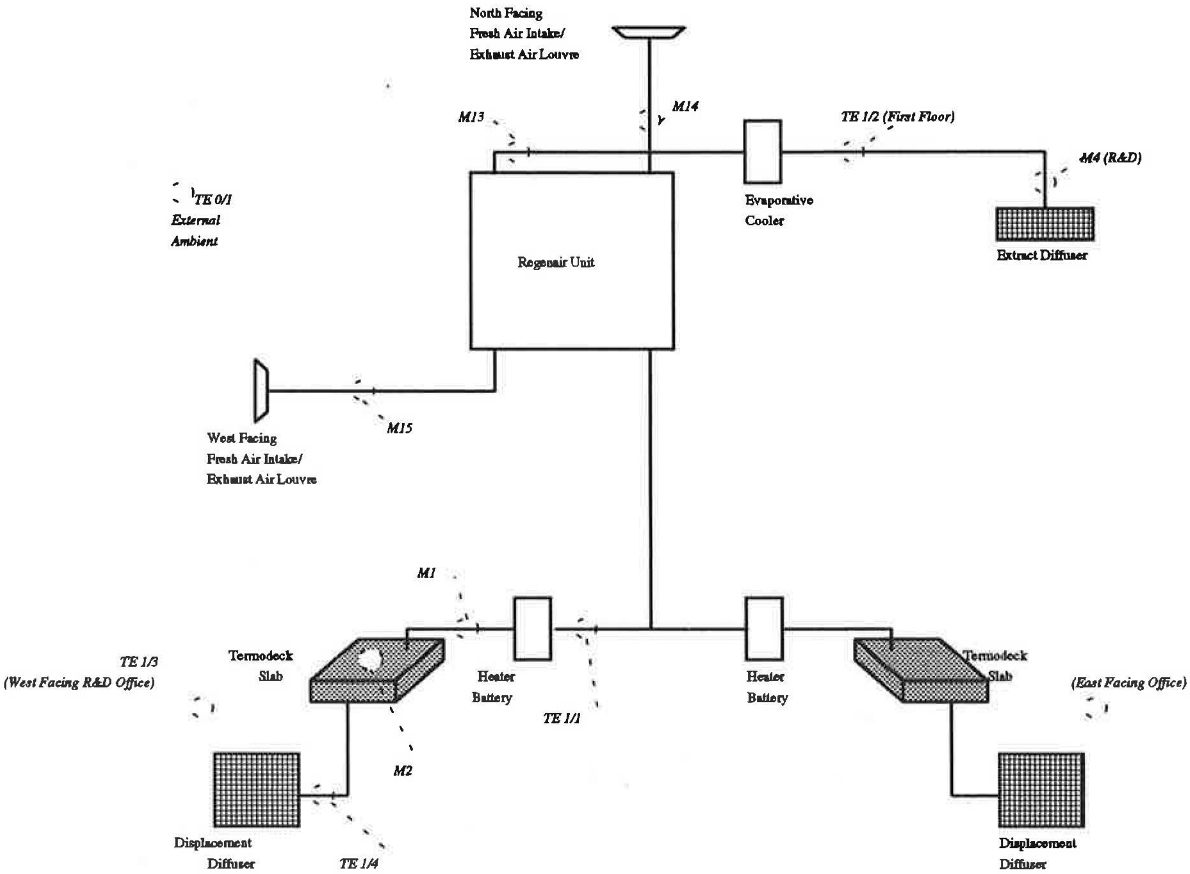


Figure 1

2. 1995: Original Control Schedule

2.1 Control Schedule

In 1995 the building was operated according to the control schedule below, which was designed to keep temperatures in the range 20 - 23°C for most of the year.

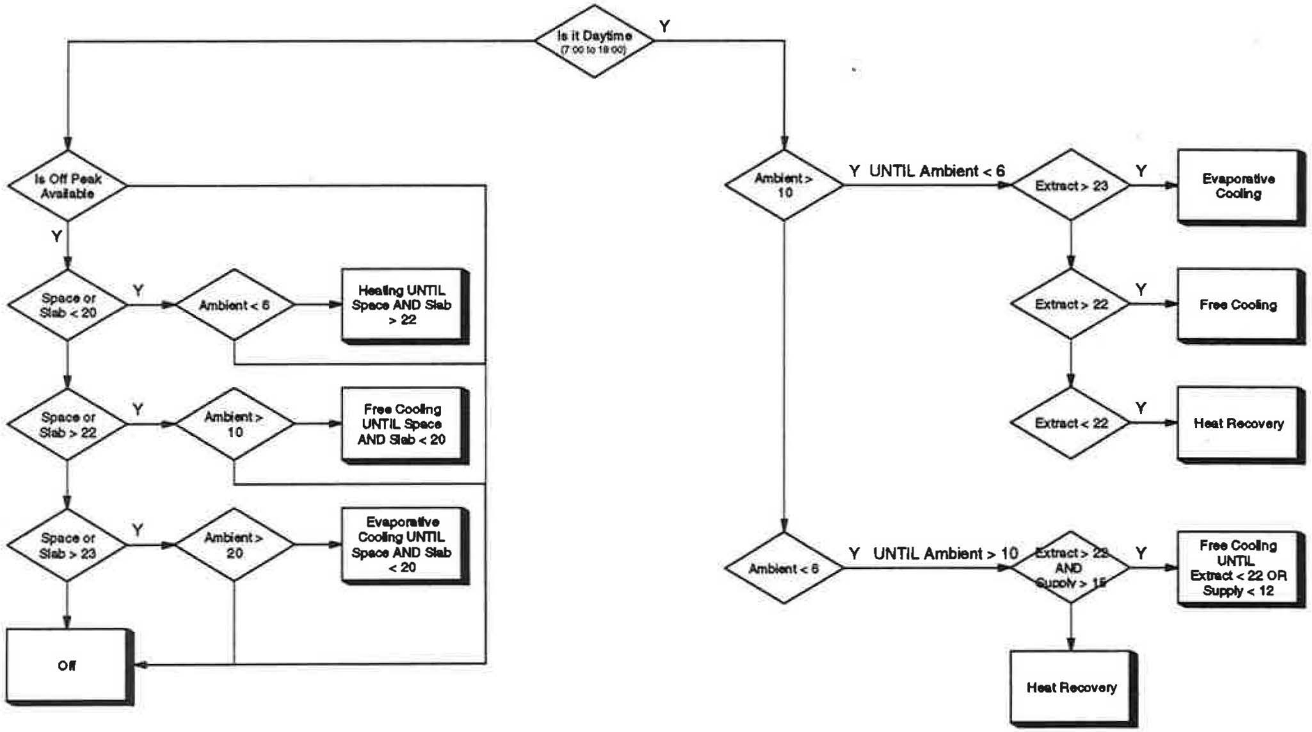


Figure 2

2.2 Thermal Performance

The control schedule's success at maintaining comfortable conditions is shown in the following section, which gives detailed data from each season and an annual summary of the temperatures achieved.

2.2.1 Winter

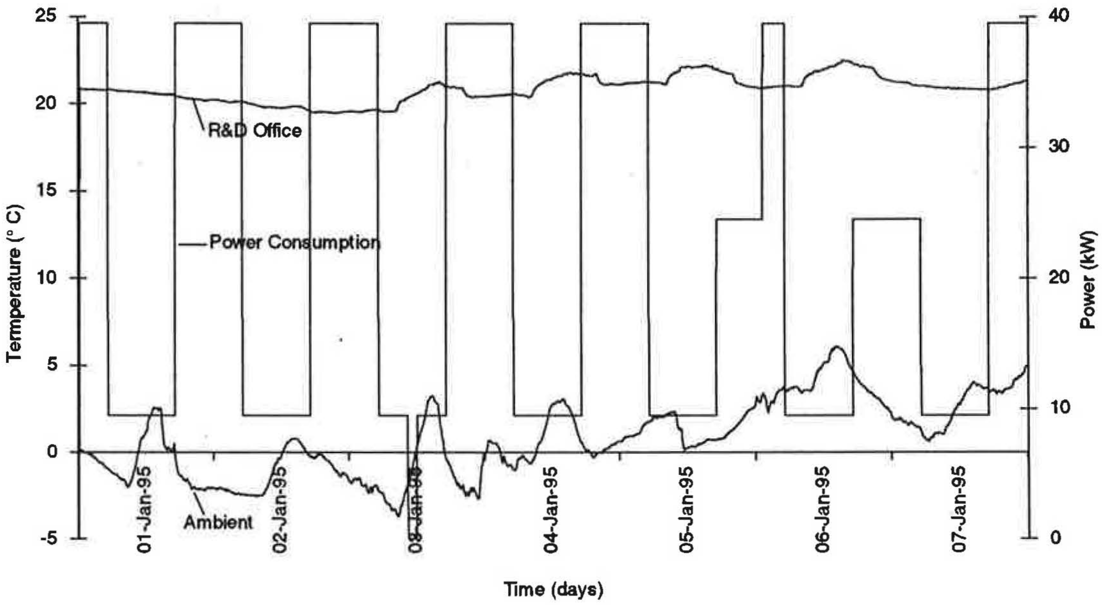


Figure 3

Figure 3 shows the building's performance during the coldest week of 1995. It shows that comfortable temperatures were maintained, albeit at the expense of considerable heating. At this time the signal indicating the availability of off-peak electricity was not functioning, resulting in heating throughout the entire unoccupied period.

The drop in power consumption from 39.5kW to 24.5kW on the 5 January occurs as only the heater battery supplying the eastern half of the first floor was required to operate. More evidence of this imbalance between the heating requirements of the east and west facing offices is presented later in this document.

Figure 3 also indicates that the 1995 control schedule did not discriminate between weekdays and weekends, resulting in fan operation throughout the 1st and 7th January.

2.2.2 Spring

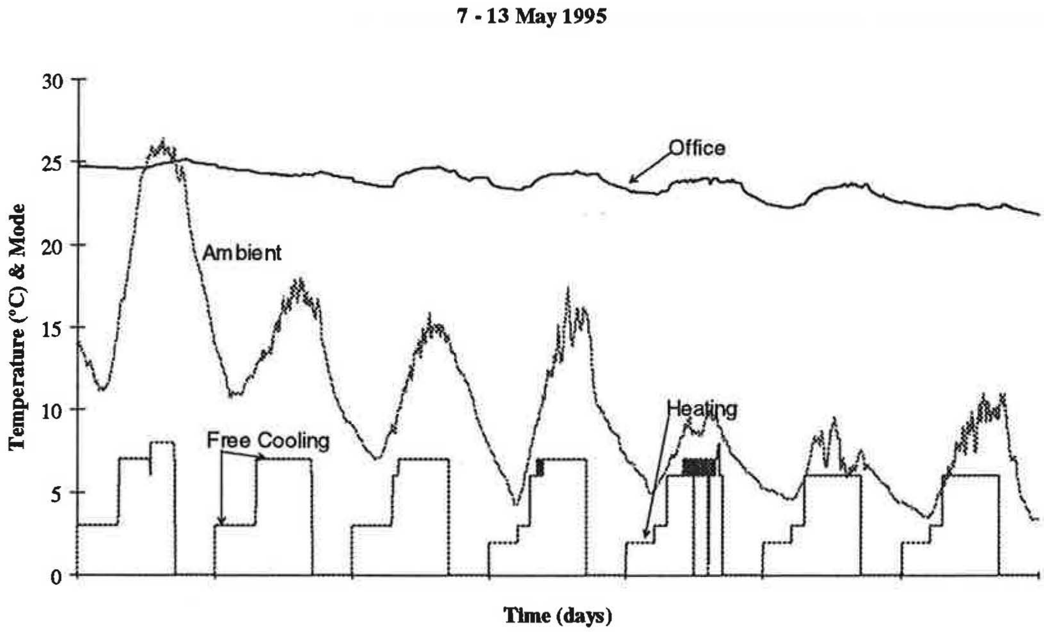


Figure 4

Figure 4 shows the temperatures experienced during early May 1995. The off peak availability signal was now working correctly, although a software bug caused the control schedule to default to heat recovery rather than off.

The imbalance between the heating demands of the east and west facing offices is clearly evident in this figure. The 10th and 11th May both exhibit heating and cooling within the same day because, in the morning, the East facing office was cool enough to require heating whilst, in the afternoon, the West facing office was warm enough to warrant cooling.

2.2.3 Summer

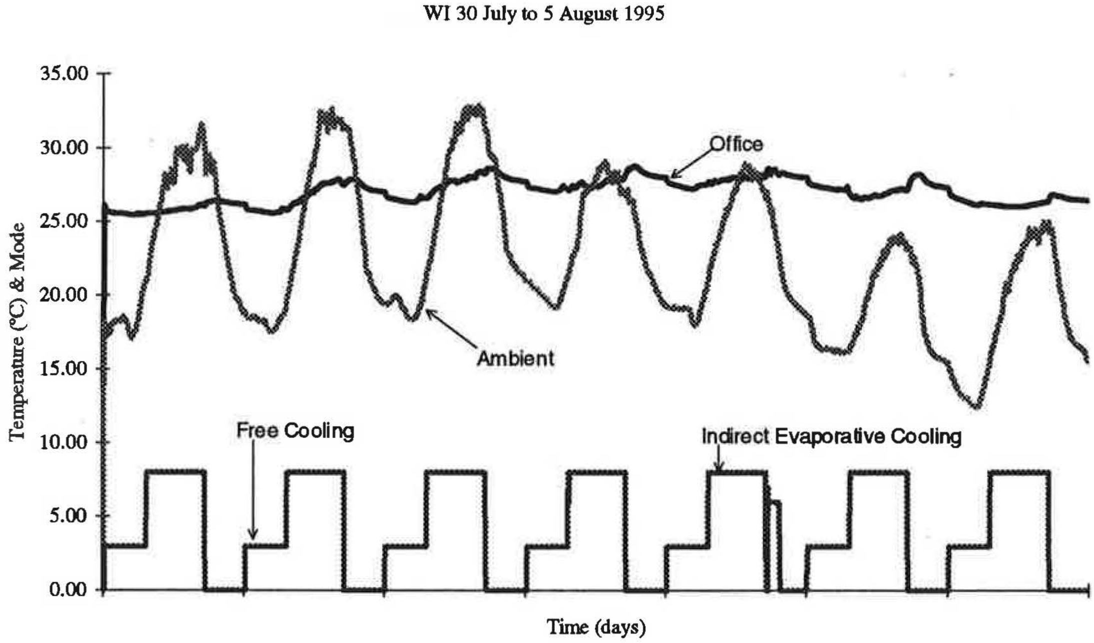


Figure 5

The figure above shows the building's disappointing performance during the hottest week of 1995.

This period highlighted several problems with the building's summertime operation;

- The control schedule prohibited free cooling in the period after occupation and before midnight.
- There were considerable uncontrolled heat gains to the ventilation air before it reached the slabs, as discussed below later in this document.

Figure 6 shows an investigation of the temperatures attained throughout the whole of the summer period.

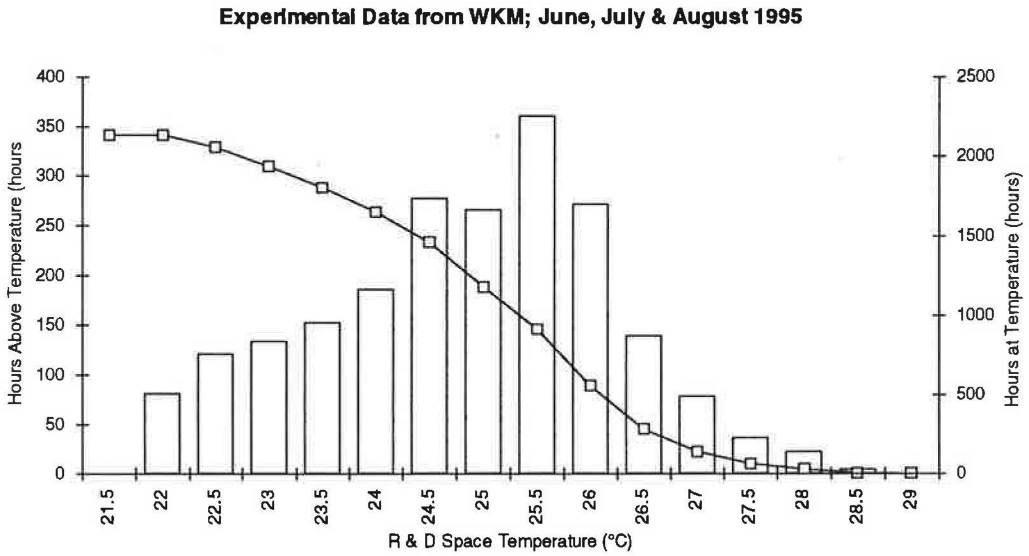


Figure 6

It shows that the office temperature was above 25° for approximately 190 hours (including unoccupied periods) and above 28° for approximately 10 hours, corresponding to approximately 2% and 0.1% of the year. The BRECSU recommendation for naturally ventilated buildings is that they should spend no more than 5% of the *occupied* hours above 25° and no more than 1% of occupied hours above 28°C.

2.2.4 Annual Performance

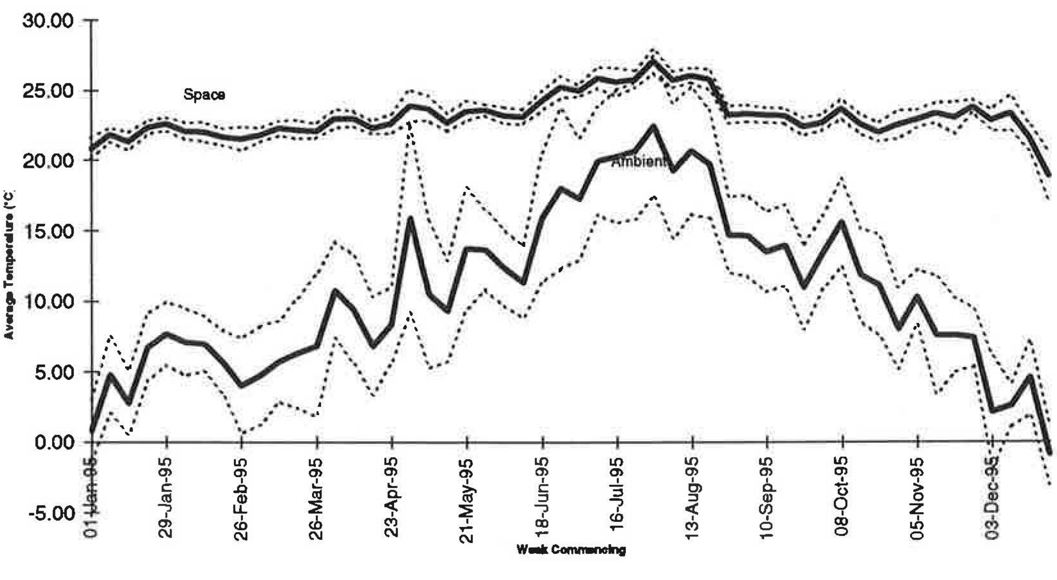


Figure 7

Figure 7 shows the building's performance over the whole of 1995. It indicates that, except for a few summer weeks, the building achieved comfortable temperatures throughout 1995.

Dotted lines on the figure indicate the standard deviation of each reading. They show that the maintained temperatures were exceptionally stable, both on a diurnal and a seasonal basis.

2.3 Operational Performance

2.3.1 Energy Consumption

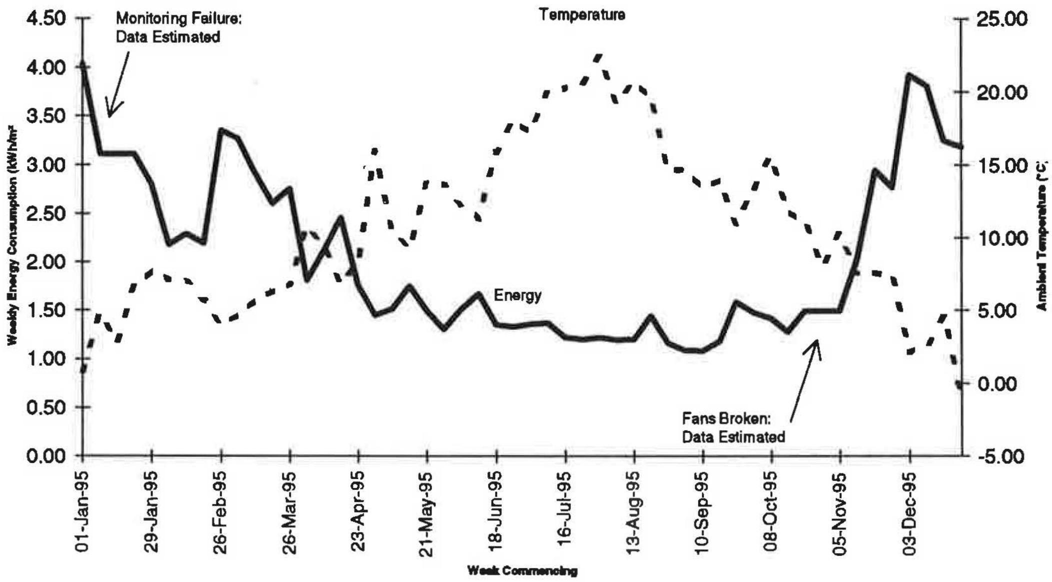


Figure 8

Figure 8 shows the annual energy consumption, which totalled 106 kWh/m^2.

2.3.2 Operational Modes and Cost

The graphs below give a detailed breakdown of the building's energy consumption. They also show an estimate of the building's running costs. These were calculated on the basis of a tariff with a standard rate of 9p/kWh and a seven hour off peak period with a rate of 3p/kWh. It should be noted that this is an assumed tariff and that the costs calculated in this way are for indicative purposes only.

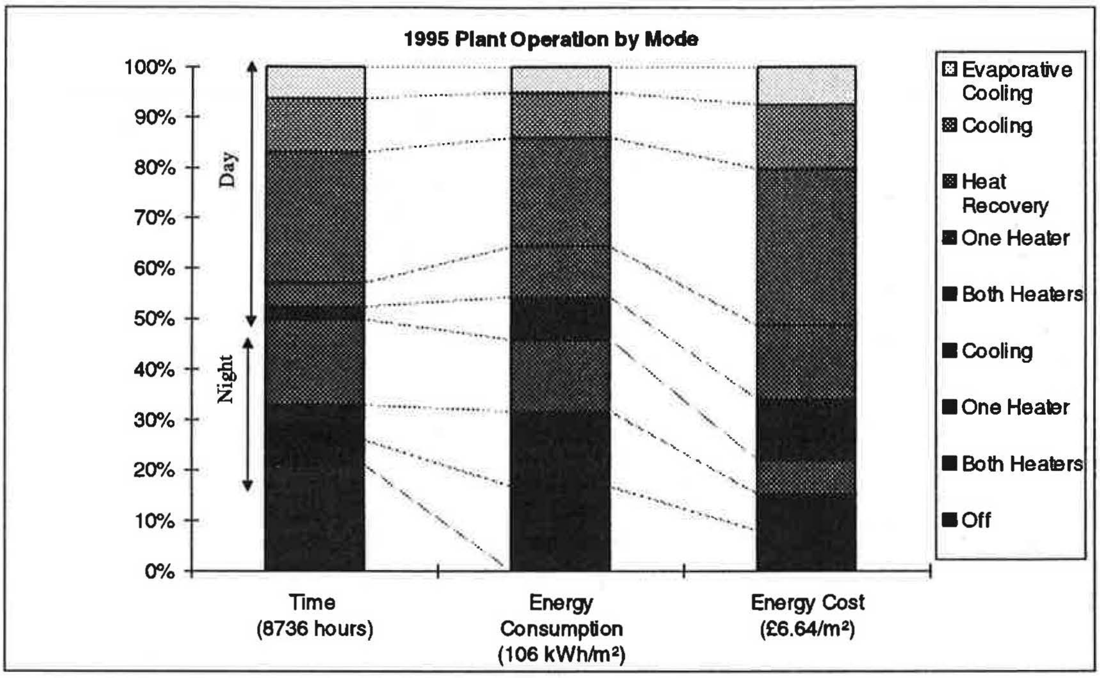


Figure 9

Notice the effect of the tariff, which causes the disproportionate impact of daytime operation upon the building's running costs.

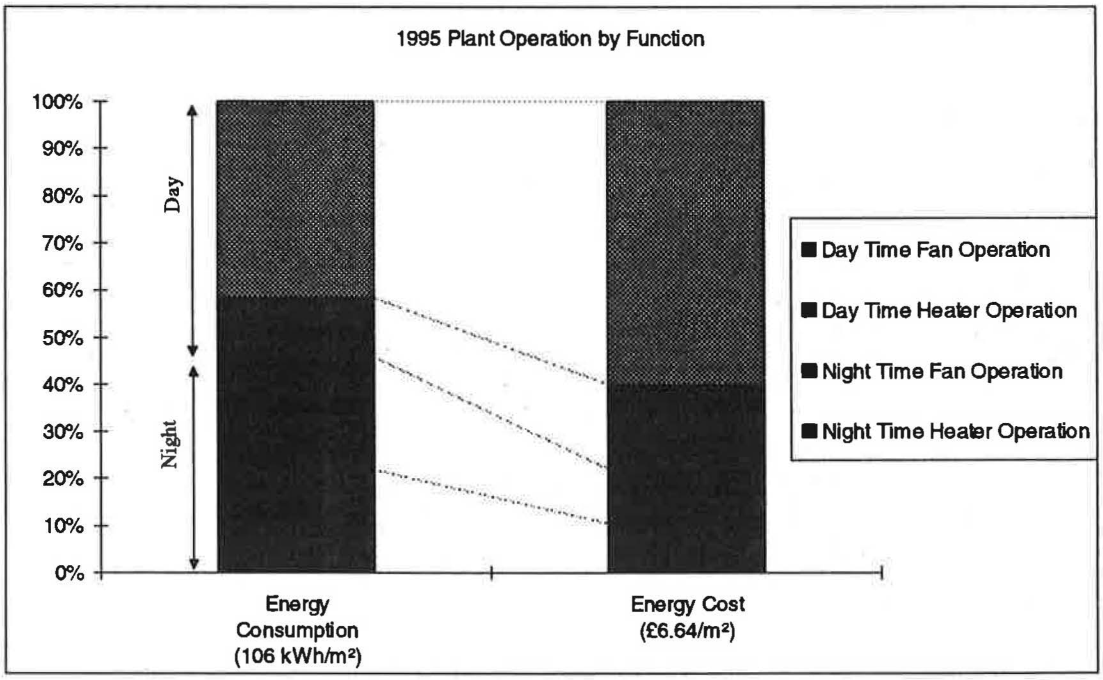


Figure 10

Figure 10 shows the building's consumption by function and highlights the overwhelming proportion of the building's running costs which are due to day time energy consumption (about 75%). It also shows the significance of maximising the efficiency of the fans, which accounted for approximately 65% of energy consumed and around 75% of the energy cost.

2.4 Weaknesses of the First Year's Operation

1995's operation should be seen as an example of what can happen if a Termodeck building is incorrectly operated. However, it is a tribute to the system that, despite all the problems, comfortable conditions were generally maintained throughout the year.

The following section describes some of the weaknesses in the 1995 operation of the building.

2.4.1 Control Temperature

The 1995 control schedule operated according to various conditions of the space, slab, extract and supply temperatures. A better alternative may have been to concentrate upon controlling the slab temperature, which is the predominant influence upon thermal conditions in the building. Air temperatures, particularly the extract temperature, were much more volatile than the slab temperature causing unnecessary and energy consuming swings from heating to cooling.

2.4.2 Unbalanced Heat Loads.

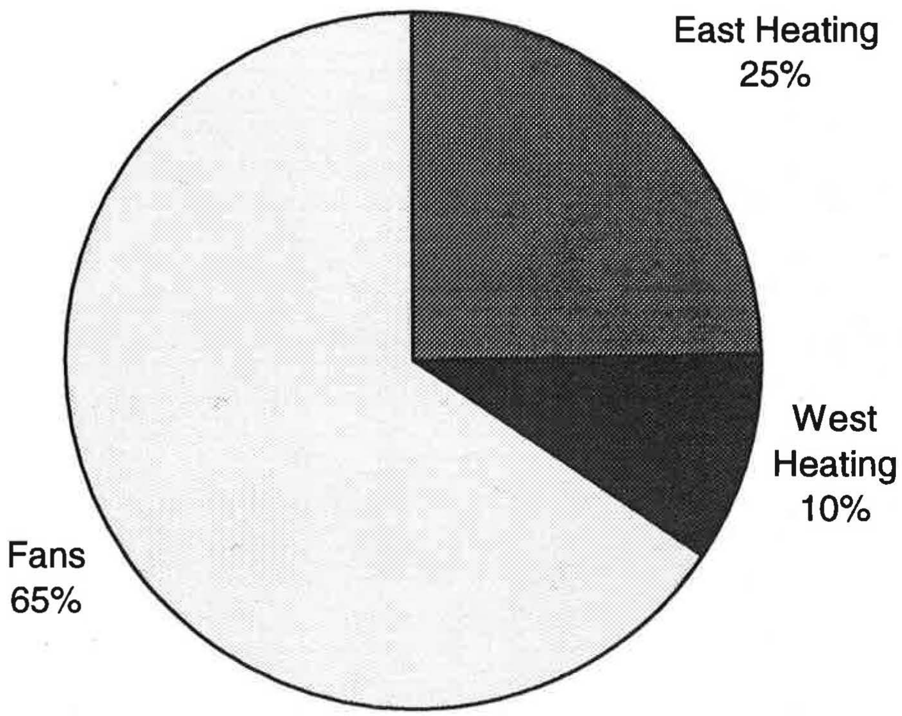


Figure 11

Figure 11 shows the energy usage split between the fans and heaters of each zone. It indicates the effect of the imbalance in heat loads between the zones which resulted in the East facing office having more than twice the heating requirement of the West facing office. It also made control more problematic, occasionally leading to heating and cooling within the same daily period, as illustrated in Figure 4.

Computer simulation has predicted that an east facing office can support an extra $5W/m^2$ of heat loads before it has the same risk of overheating as an equivalent west facing office

2.4.3 Indirect Evaporative Cooler Usage

Detailed investigation, shown in the figure below, indicated that the original control schedule resulted in premature operation of the Indirect Evaporative Cooler (IEC). The figure shows that, on Saturday 22nd June, IEC operation began at around 5:15 am and resulted in an increase in the incoming air temperature (the reverse of the desired effect). In fact, IEC operation did not become beneficial until around 12am.

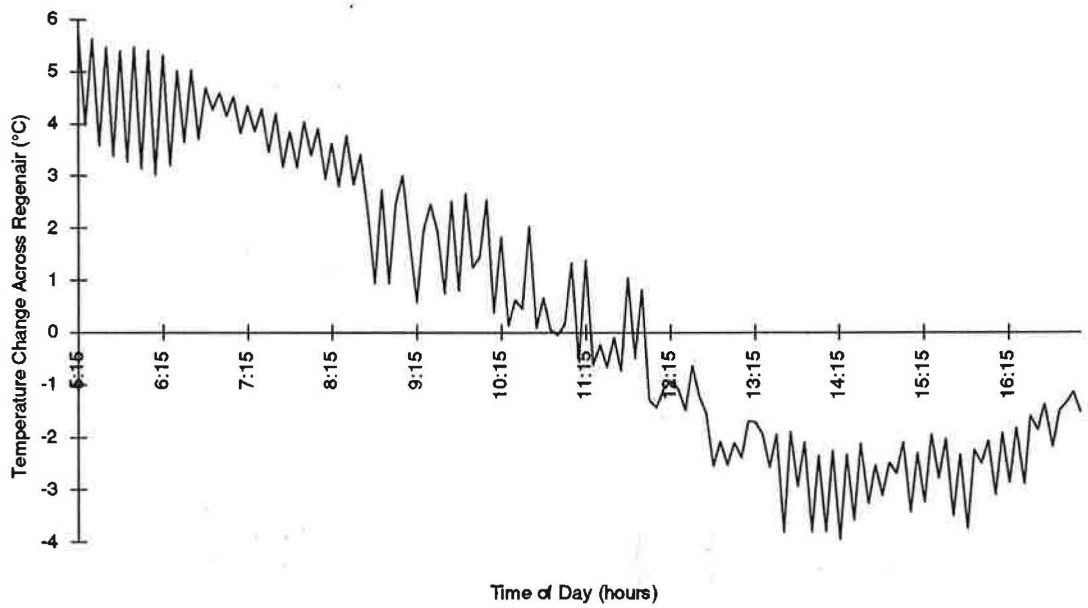


Figure 12

2.4.4 Efficiency of Heating

The figure below shows that, on average, only 41% of the energy expended in providing heating (including fan power) reached the slabs as useful heat. The remainder was lost as the air passed around the re-circulating ventilation circuit, with the most significant heat loss occurring as air passed through the Regenair unit.

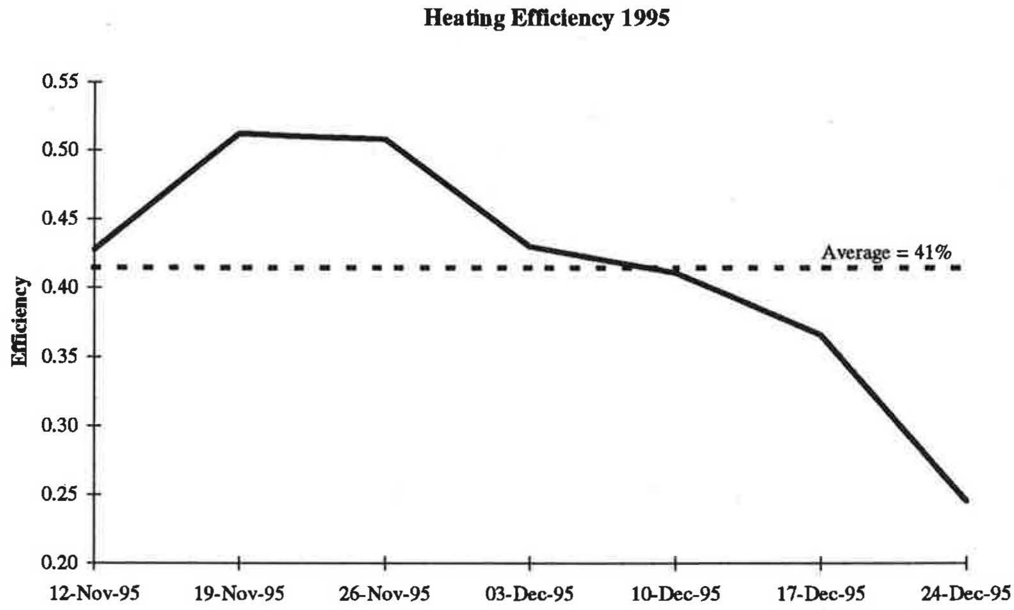


Figure 13

2.4.5 Efficiency of Cooling

Figure 14 shows the coefficient of performance (COP) attained during night time cooling in June, July and August 1995.

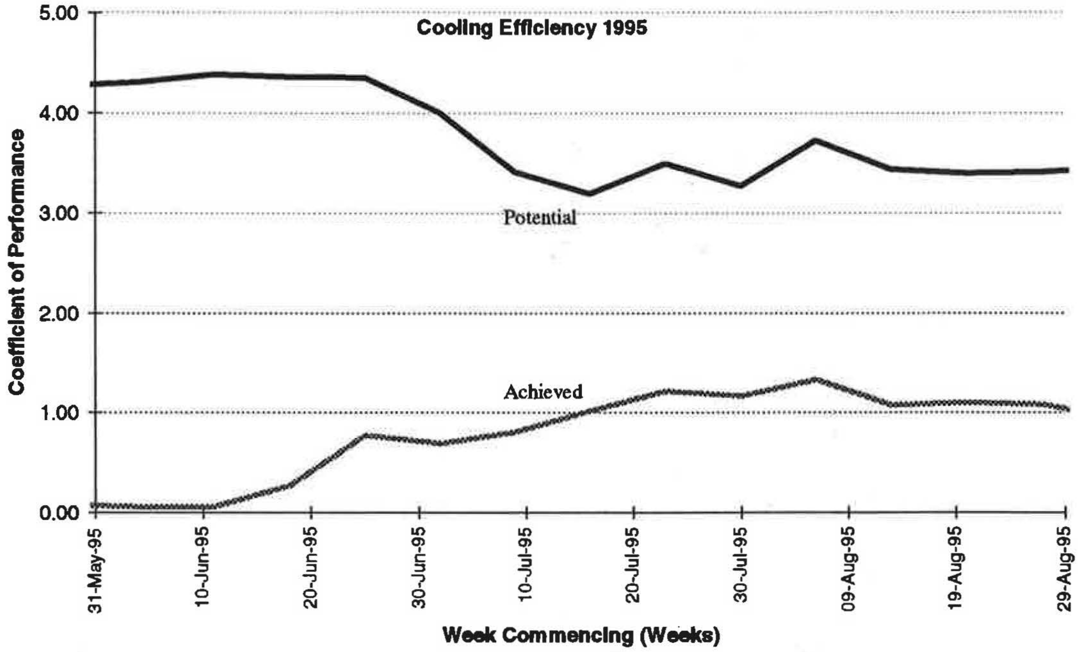


Figure 14

The 'Achieved' COP evaluates the ratio of delivered cooling compared to the fan energy expended in achieving that cooling. It was calculated from;

$$COP = Average\left(\frac{Mass\ Flow\ Rate \times Specific\ Heat\ Capacity \times (T_{Pre\ Slab} - T_{Slab})}{Fan\ Power}\right)$$

The 'Potential' COP was evaluated cooling with respect to the ambient temperature, rather than the pre-slab temperature (ie it removed the effect of heat gains within the air supply ductwork).

The very low achieved COPs for the first few weeks of the summer were found to be due to a software bug which actuated heat recovery, even when calling for free cooling.

2.4.6 Uncontrolled Heat Gains

The increase in the achieved COP throughout July 1995 was due to identification and reduction of uncontrolled heat gains during the ventilation air's passage to the slab. These gains are indicated in the Figure below, which shows that they significantly reduced the impact of free cooling. It also shows that there was occasional mixing between the ground and first floor AHUs, as shown by the increase in heat gain between around 3:30 and 5:00am.

As shown, from around 9am the heat gains overwhelmed the available free cooling and resulted in air being supplied to the slab at greater than slab temperature, effectively heating the slab. It would have been more effective if, at this point, the control had simply shut the fans off rather than supplying heat to the slabs.

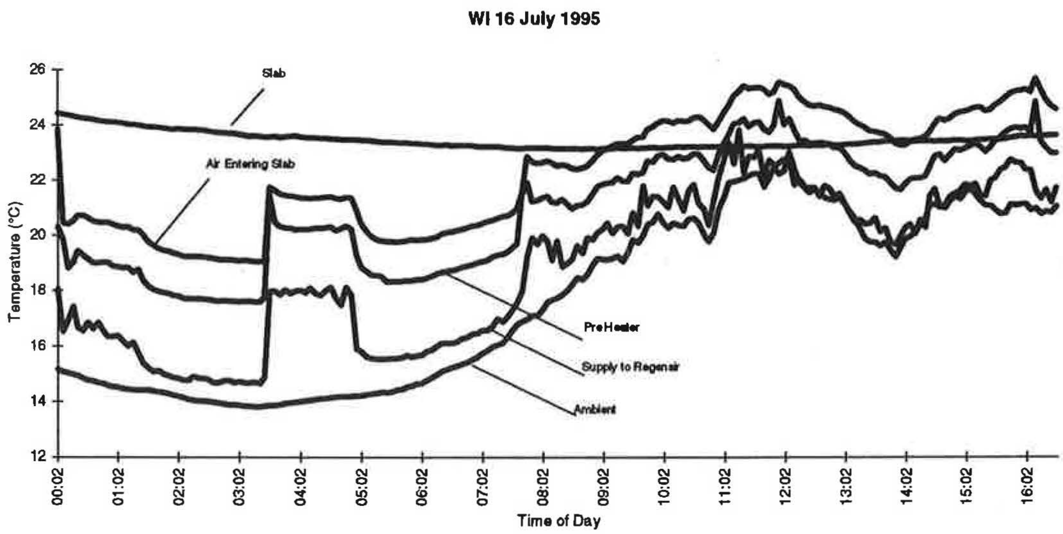


Figure 15

3. 1996: Operation with Manual Control

Following analysis of 1995's performance it was agreed that the Weidmuller building's control system should be upgraded and a new schedule applied. However, whilst preparatory work was underway, the building was operated for the first 31 weeks of 1996 under manual control. This consisted of several push buttons which offered free cooling, heat recovery or heating in either continuous or off-peak modes.

3.1 Temperatures

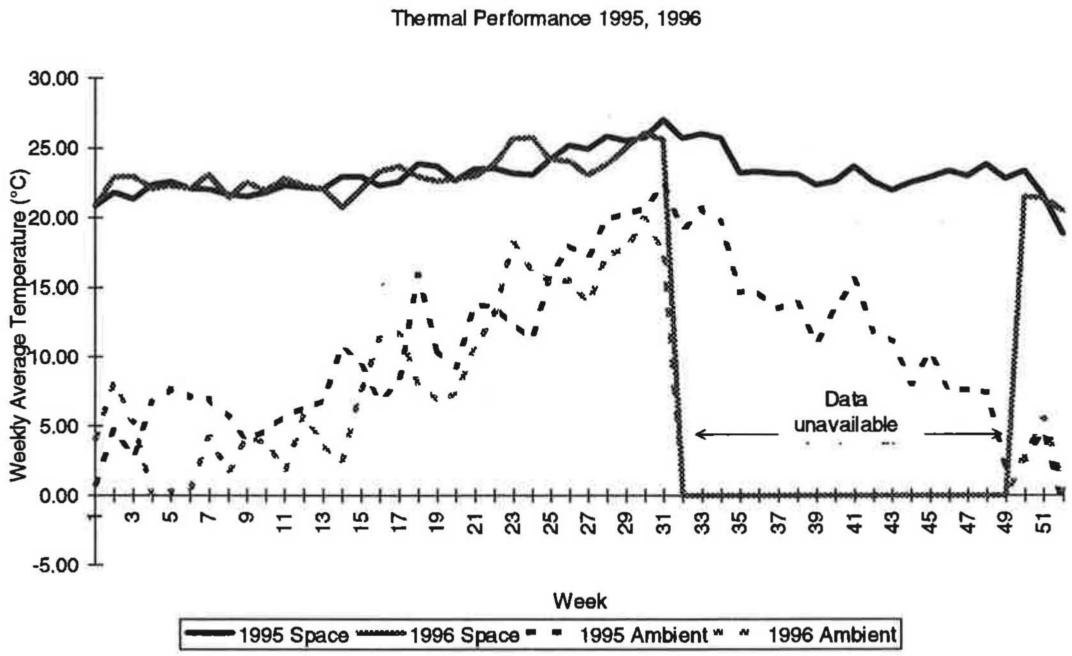


Figure 16

Figure 16 shows that the temperatures achieved by manual control were not significantly different from those provided by the original, automatic control algorithm. However, as shown below, manual control used more electricity to achieve these temperatures.

3.2 Energy Consumption

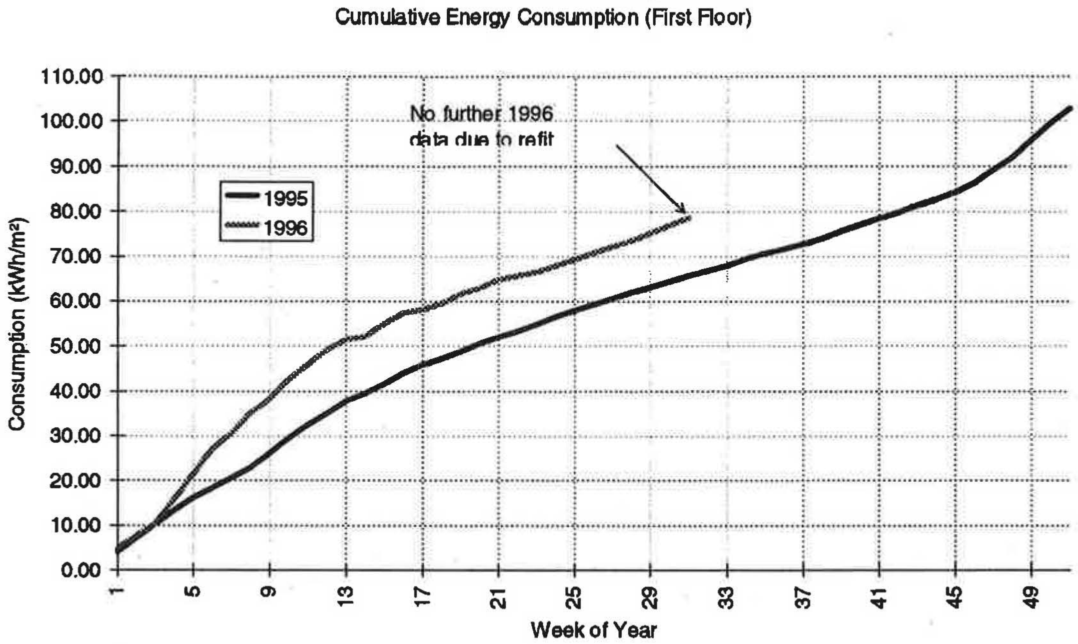


Figure 17

It is interesting that, although the office temperatures achieved in 1996 were broadly similar to those attained in 1997, the power to manually control the building made the occupants', anecdotally, much happier with its performance.

4. 1997: Implementation of Improved Control

Throughout the second half of 1996 much of the Weidmuller building's control apparatus was replaced and the algorithm within the BEMS was updated to that shown in Figure 18.

The major changes implemented during the refit were;

- The size of the electric heater batteries was increased from 15kW to 36kW. This was intended to improve the heating efficiency and to increase the amount of heat which could be supplied during the off peak hours. Increased use of off-peak heating should result in reduced daytime heating which Figure 10 showed to account for around 20% of the building's 1995 running costs.
- The control schedule was defined to operate with regard to slab mass temperature rather than the more volatile extract or supply air temperatures. This was intended to stabilise the building's control and limit unnecessary cycling of the heating and cooling plant.
- Intelligent sensing was used to determine when to free cool the building. Thus the new control schedule will turn the system off if, during night time free cooling, the heat gains overwhelm the available cooling. This should both improve internal conditions and reduce unnecessary energy consumption.
- Intelligent sensing was also used to determine when to initiate the indirect evaporative cooler. Before evaporative cooling is started a comparison is made between the exhaust air temperature and the ambient temperature to ensure that continued free cooling would not be a better option.
- Free cooling was defined to occur only via the shorter, North-facing supply to the Regenair. This will have the dual benefits of reducing the residence time in the roof space and of allowing the Regenair's dampers to be horizontal, creating the least turbulence. Both of these effects will reduce the uncontrolled heat gains during night time free cooling and improve the building's summer performance.
- The control schedule was programmed to allow 'emergency' heating and cooling outside of the off-peak period, should the conditions warrant it.

4.1 Control Schedule

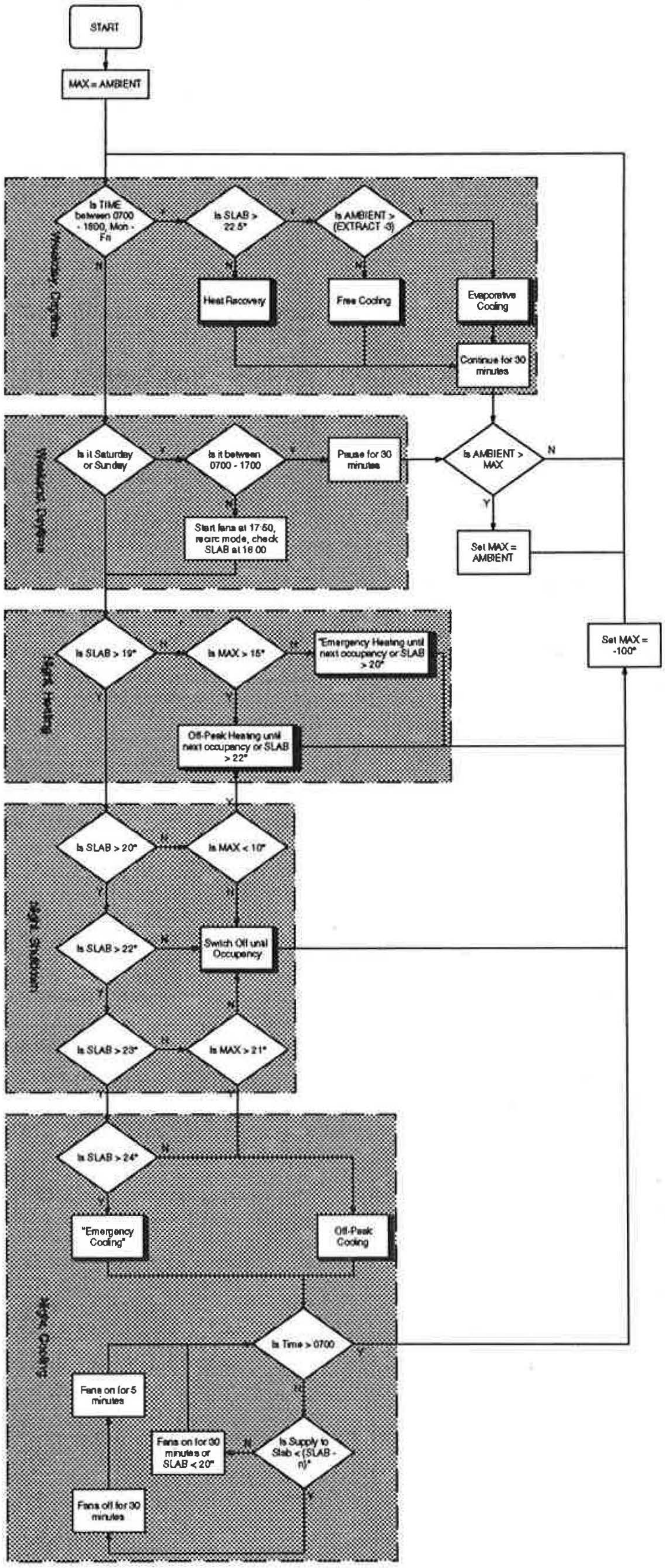


Figure 18

4.2 Thermal Performance

4.2.1 Winter

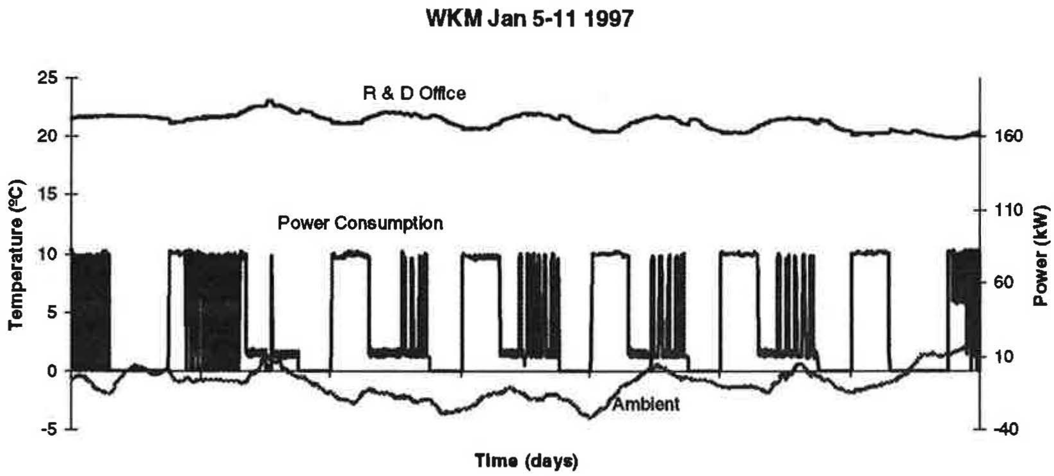


Figure 19

Figure 19 shows the building's performance during a particularly cold week, when the ambient temperature rarely rose above freezing. As shown, the building maintained comfortable temperatures throughout and still managed to shift the majority of heating load to the off-peak tariff.

4.2.2 Spring

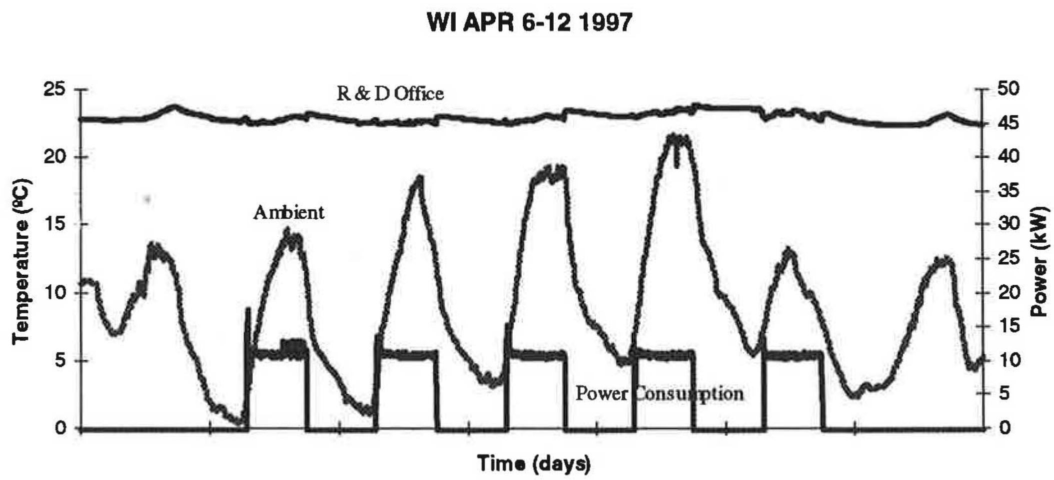


Figure 20

During mid-season weeks, Figure 20 shows that the new control was much more efficient than the previous algorithm. Energy was only consumed during office hours and outside of these periods the building was self-regulating.

4.2.3 Summer

In general, the Weidmuller building achieved a greater level of comfort during summer 1997 than during summer 1995. However, the temperatures experienced during the high summer weeks were still disappointing, as shown below.

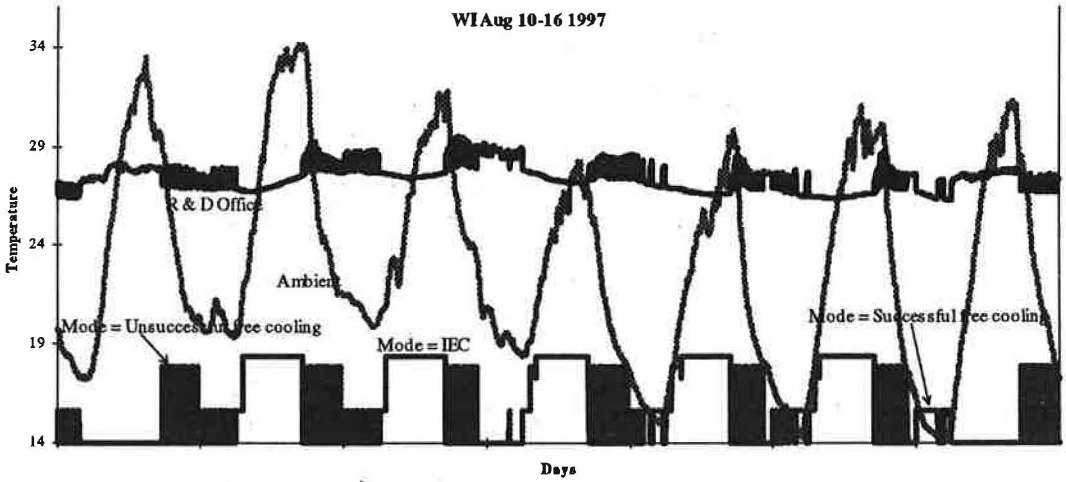


Figure 21

Figure 21 shows the building's performance during the hottest week of 1997. The continuous cycling of the control schedule outside of the occupied period was caused by the "Is Supply to Slab < SLAB - N" decision box. Once again uncontrolled heat gains to the ventilation system overwhelmed the available free cooling, however, this time the control schedule prevented the fans from running and unnecessarily raising the building's energy consumption.

The figure below shows the building's operation in a cooler part of the summer, when free cooling was not overwhelmed by heat gains. The figure shows night cooling being correctly shifted to the off peak period and, during periods when heat gains overwhelmed the available cooling, being prevented.

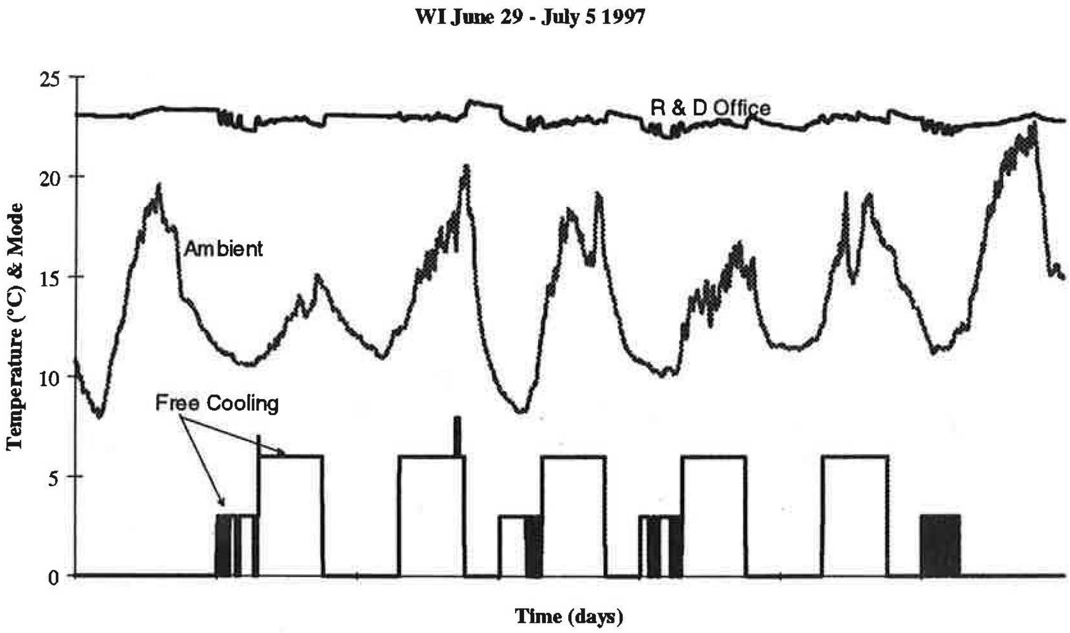


Figure 22

Detailed analysis of the heat gains eventually showed that the control schedule had been incorrectly implemented. Night time cooling was occurring via the West facing supply duct, which resulted in additional heat gains of around 2°C.

4.2.4 Annual Performance

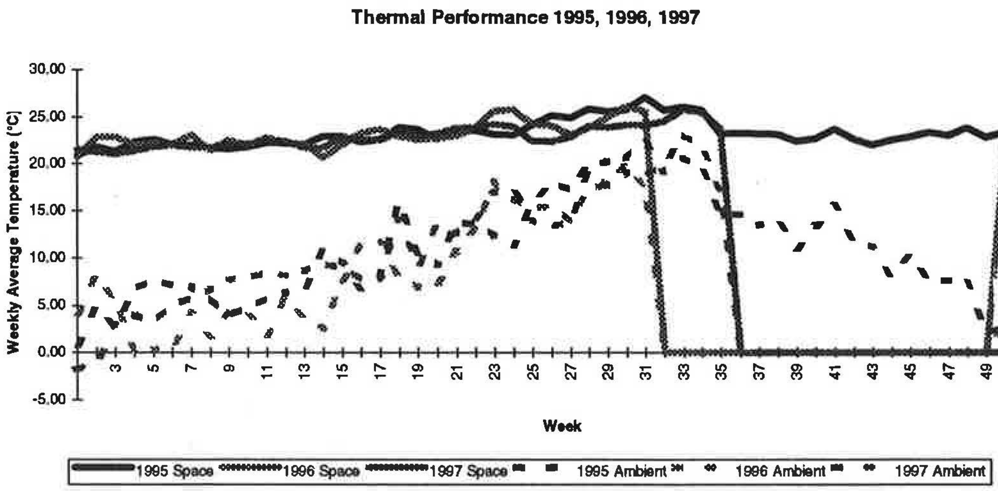


Figure 23

Figure 23 shows that the 1997 control schedule achieved much the same temperatures as in the previous years, although the summertime performance was improved.

4.3 Operational Performance

4.3.1 Energy Consumption

Figure 24 shows that, although the new schedule maintained similar temperatures to previous years, it did so for the expenditure of less energy. Visual extrapolation of this data to the end of the year suggests an annual energy consumption of around 80kWh/m² (around 20% lower than the 1995 value).

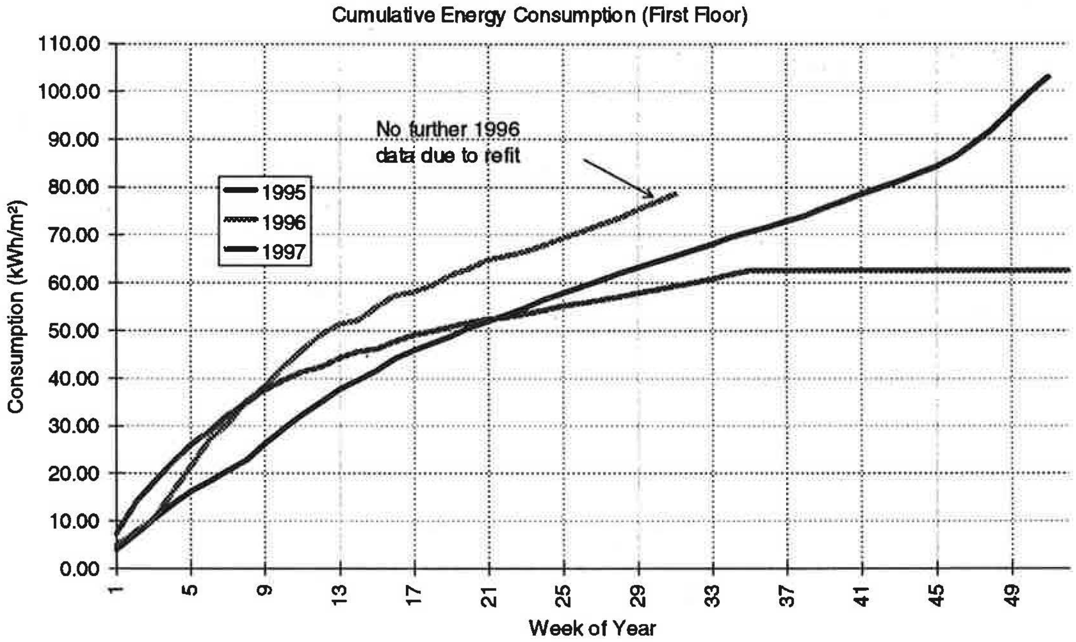


Figure 24

4.3.2 Operational Modes and Cost

Evaluating the building's 1997 operation, as far as data was available, with the same assumed tariff as above resulted in the graph below. It is not possible to perform an accurate comparison until a full year's data has been collected, however, the figure currently indicates that the building spent a much greater proportion of time switched off than in 1995 and that off-peak heating accounted for a greater proportion of total energy consumption.

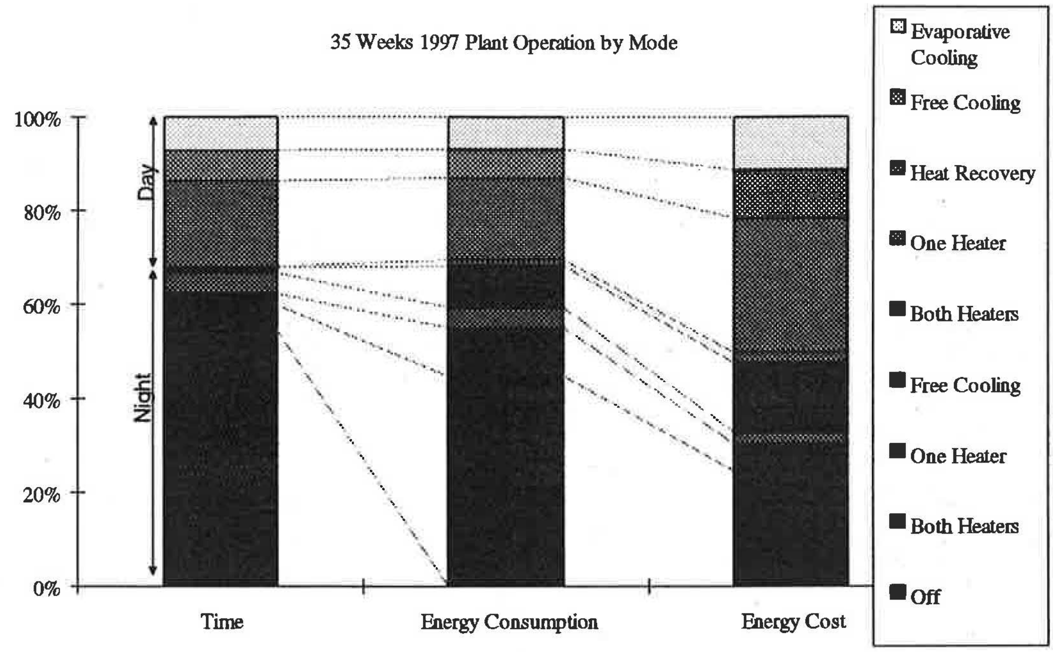


Figure 25

Evaluating the data with respect to the operational function confirms that a greater proportion of the building's energy requirement has been shifted to the night time off-peak period, as shown in Figure 26

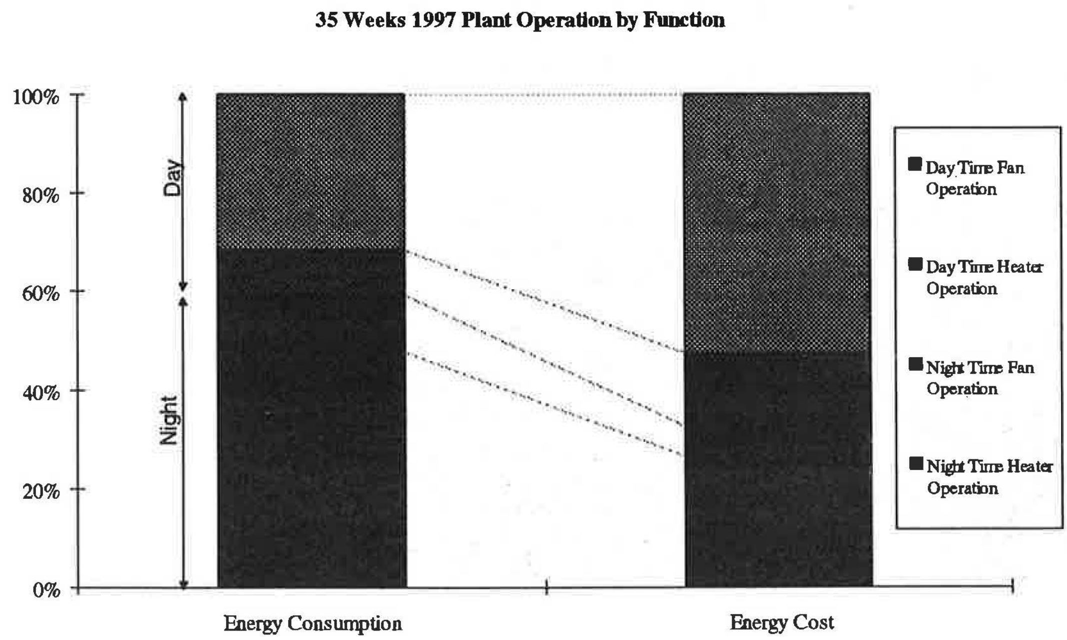


Figure 26

4.4 Improvements Due To The Refit

4.4.1 Efficiency of Heating

Figure 27, below, shows that the refit has improved the Weidmuller building's heating efficiency to 50%.

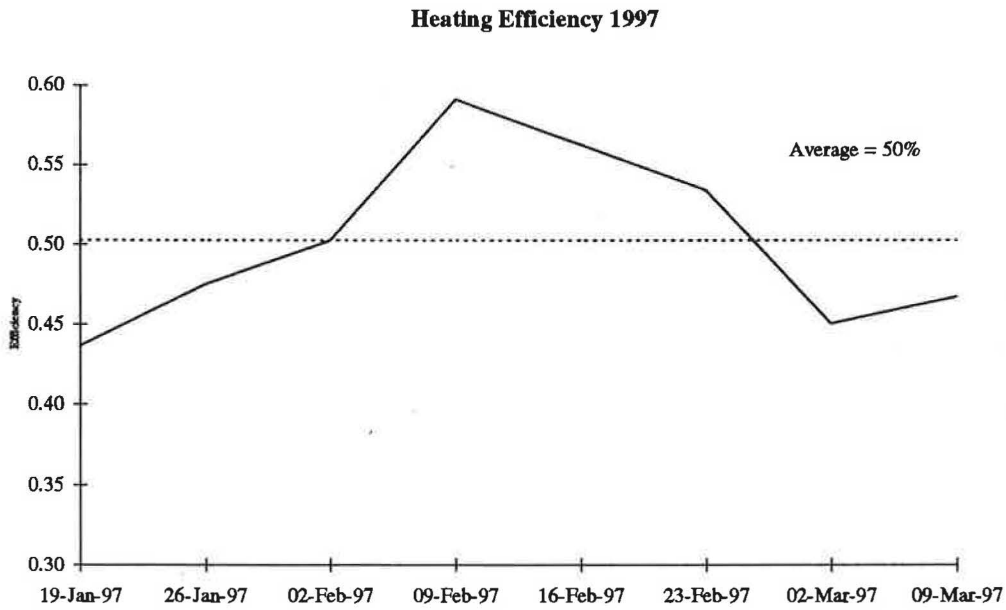


Figure 27

4.4.2 Efficiency of Cooling

The building's cooling efficiency was also increased, as shown below. The refit and improved control schedule has resulted in the average cooling COP to 1.5, which is nearly double its 1995 value of 0.8.

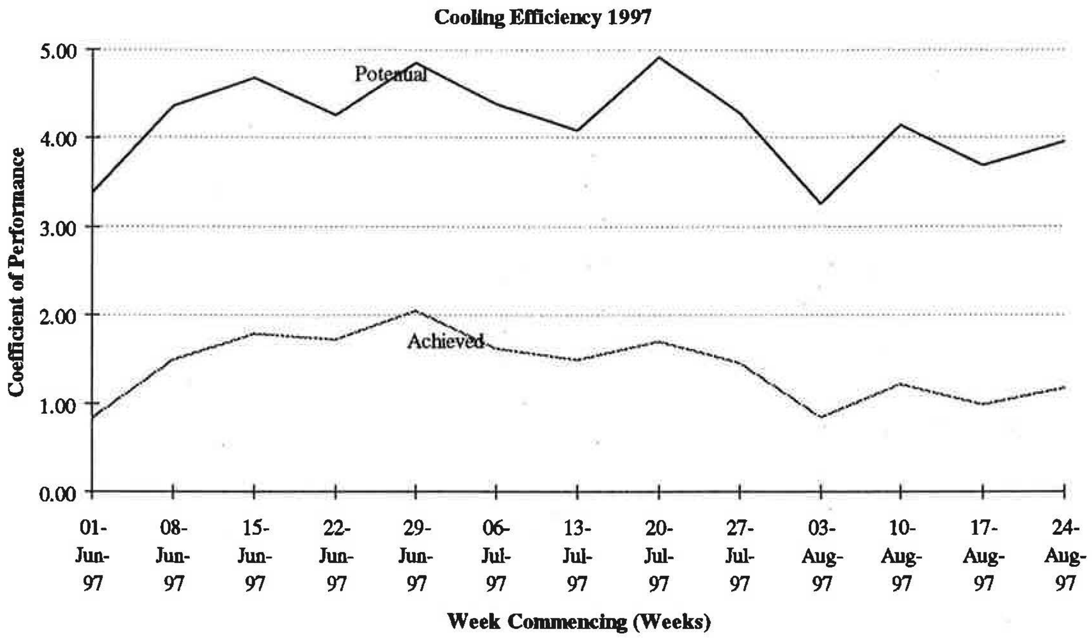


Figure 28

4.4.3 Regressions

Detailed analysis of all three years' data allowed the following regression curves to be drawn. The first, shown below, indicates the variation of the building's weekly energy consumption with temperature. It clearly indicates that the new control schedule is more efficient than the scheme and also that, while in heating mode, the new schedule is more responsive to changes in temperature than the previous algorithm.

For the purpose of this analysis the 'break-even' point at which the building switches from heating to cooling is taken to be an ambient temperature of 14°C. The figure shows that this is the case for 1995 and 1996 operation, however, inspection of the 1997 data indicates that the new schedule may have reduced this value to around 12°C.

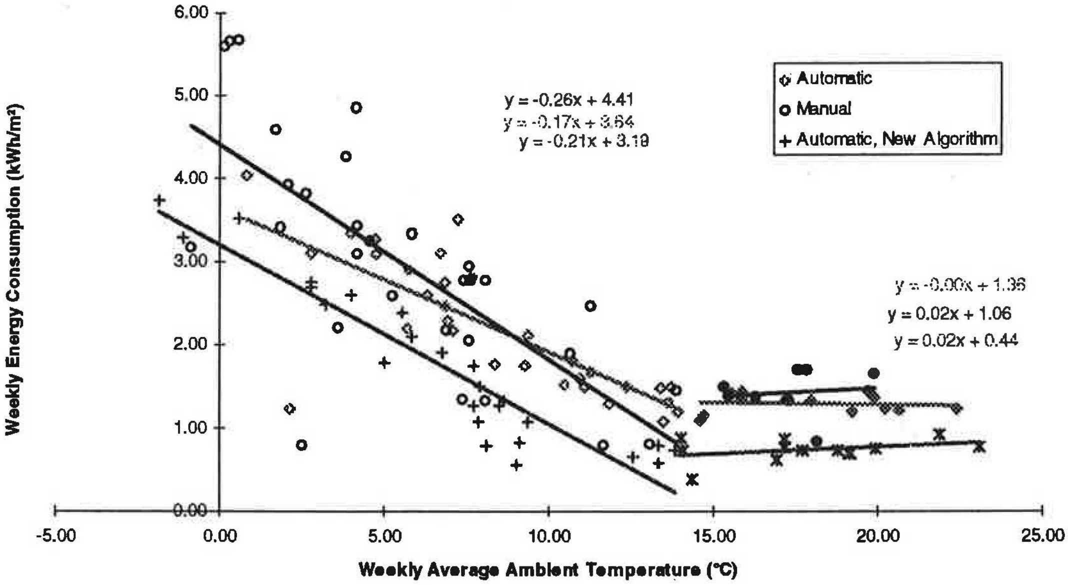


Figure 29

Figure 29 shows a regression analysis of the Weidmuller building's internal temperatures plotted against the corresponding ambient temperatures. It shows that, during the heating season, the 1995 and 1997 control schedules maintained very similar temperatures, however, during the cooling season the 1997 schedule produced a much better performance.

It is interesting that, during the manually controlled heating season, the temperatures selected were always around 0.5°C warmer than with the automatic schedules. However, the summer temperatures achieved with manual control were generally inferior to those attained via either of the automatic schedules.

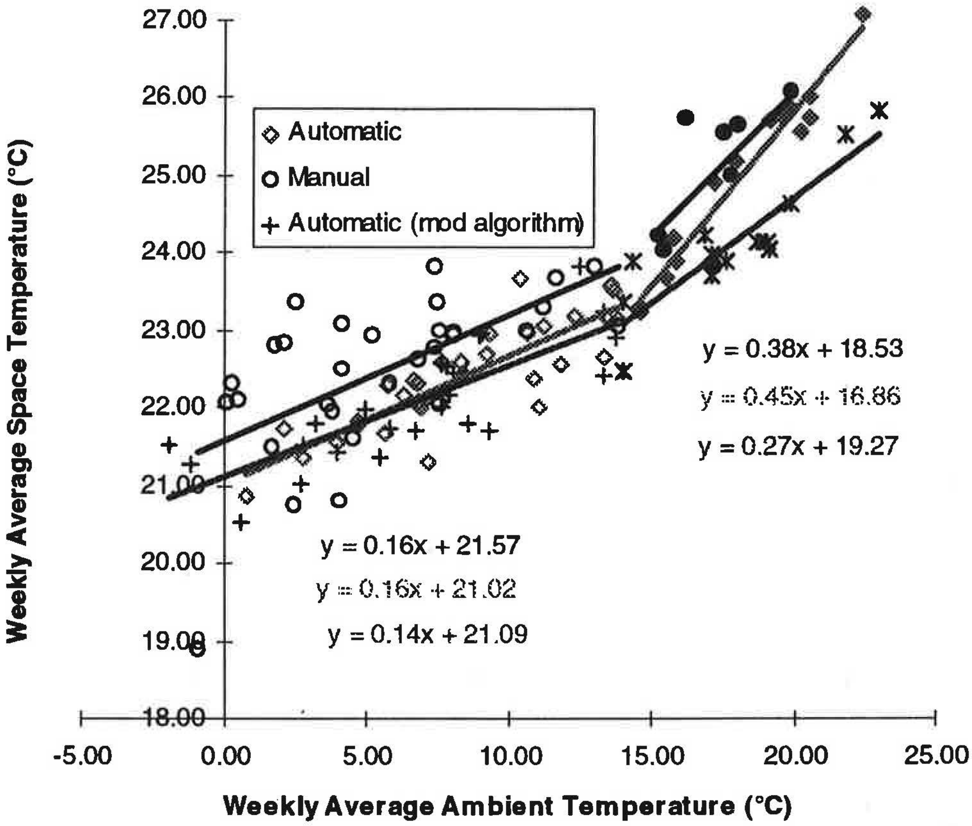


Figure 30

4.4.4 Reduced Running Costs

Evaluation of the energy consumption data shown in Figure 24 in conjunction with the assumed tariff yields the graph below. This shows that, although the 1997 schedule has made only a relatively modest improvement upon the Weidmuller building's energy consumption (around 10% by the end of August), it has been responsible for a considerable cost saving (around 25% by the end of August). This has been achieved through improved use of the off peak period, which was demonstrated in Figures 25 and 26 and is summarised in Figure 32.

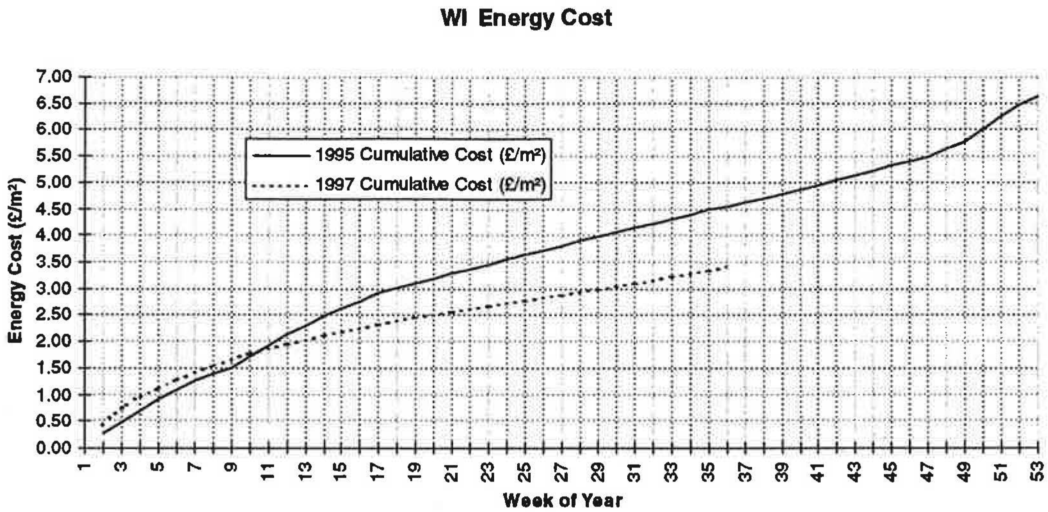


Figure 31

4.4.5 Improved Use of Off-Peak

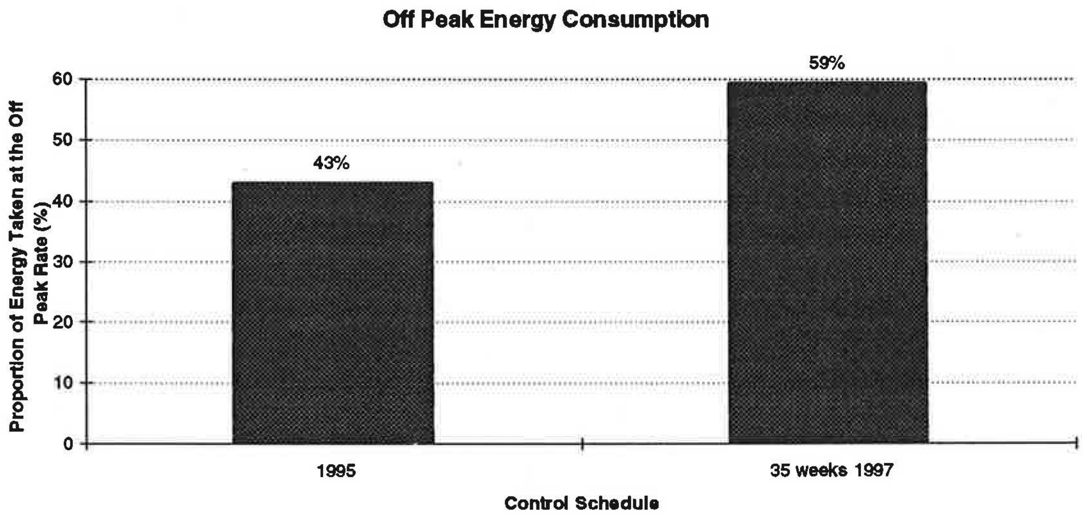


Figure 32

4.4.6 Summary

The new control schedule has resulted in the Weidmuller building providing improved comfort levels at the same time as reducing its energy consumption. It has also made improved use of the building's thermal storage to shift a greater proportion of this reduced energy consumption to the off peak tariff, resulting in a significant reduction in running costs.

5. Further Improvements

The following adjustments should improve the performance of the Weidmuller building still further;

- Winter performance could be improved by ensuring that the ventilation circuit is tightly sealed during recirculation mode. There is some suspicion that ambient air is currently leaking into the circuit during night time heating, causing an uncontrolled heat loss.

- High summer temperatures will be reduced by correcting the control software to provide free cooling only via the North-facing supply duct. This should reduce the uncontrolled temperature rise by around 2°C and greatly improve the summer cooling.

In addition, there are improvements which it is not possible to retrospectively undertake at the Weidmuller building, but which should be incorporated into any new projects.

- Fan power has been shown to be account for the majority of the Weidmuller building's running costs. Improved fan efficiency would reduce energy consumption and reduce heat 'pick up', improving summer performance.
- Uncontrolled heat gains and losses have a significant impact upon the building's comfort levels in summer and its heating efficiency in winter. Bringing the ducting within the thermally controlled spaces (as in the traditional Termodeck design) would reduce heat gains during summer and heat losses during winter. This would increase both the cooling and heating efficiency, improving the building's comfort levels and energy efficiency.

6. Energy Consumption Predictions.

Using the data from 1995, it was possible to estimate the Weidmuller building's likely annual energy consumption following a series of improvements. This data is given in the figure below, which shows a good agreement with the 80kWh/m² visually extrapolated from Figure 24. The data suggests that using efficient, multi speed fans would cut the building's energy consumption even further, concurring with experience gained from later projects.

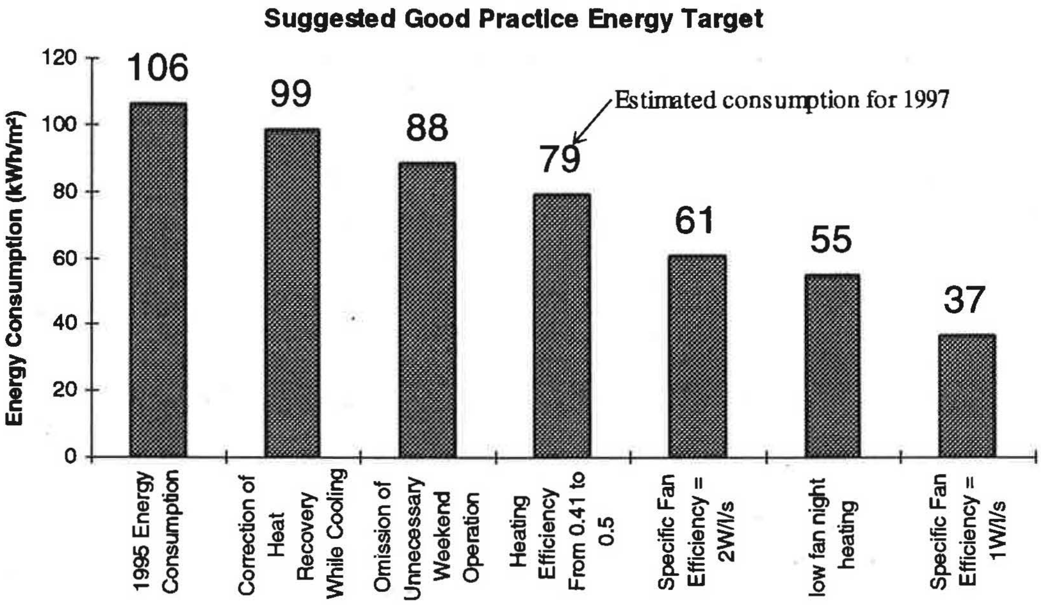


Figure 33

7. Conclusions

The performance of the Weidmuller Termodeck building has been improved by its 1996 refit. It now produces better temperature control, uses less energy and has lower running costs than was originally the case. These improvements were made possible by the lessons learnt from the building's first year of operation. The application of these lessons to new projects should enable the construction of buildings with good temperature control, low heating and ventilation energy consumption (around 40kWh/m²) and minimal running costs.

The lessons are summarised in a document entitled "Guidelines for the Most Effective Application of Advanced Fabric Energy Storage". Their wide spread application would produce very significant environmental and economic benefits for the UK population.

Session 5:

The Elizabeth Fry Building - Design and Performance

Jason Happy
Buildings Research Establishment

(Paper to be provided separately)

Appendix:

Guidelines for the Most Effective Application of Advanced Fabric Energy Storage

Dr Rob Winwood
Consultant

Guidelines for the Most Effective Application Of Advanced Fabric Energy Storage

R. B. Winwood BSc MSc PhD

Synopsis

Advanced Fabric Energy Storage allows buildings to maintain a comfortable internal environment whilst incurring a significantly reduced energy consumption and financial cost.

This paper provides a concise reference of the key design features of advanced Fabric Energy Storage, sharing experience gained from several years of involvement with the first UK projects.

1. Introduction

1.1. Advanced Fabric Energy Storage

Advanced fabric energy storage (FES) systems are defined as those which pass ventilation air through a building's structure for the purpose of exchanging heat ('Termodeck-type' systems). When properly controlled, this has advantages for the provision of thermal comfort and the energy-efficient operation of the building.

Experience has shown that, if properly designed, UK advanced FES office buildings can expect to achieve HVAC energy consumptions of around 50kWh/m² or less. This document is intended to allow Building Services Engineers to learn from early experience and ensure that advanced FES buildings *are* properly designed.

1.2. Background

UK research in to, and application of, advanced FES has focused upon four systems[1 to 6]. The clear market leader and the major focus of this paper is the "FES-Slab" (known in the UK by the trade-name Termodeck), which is illustrated in Figure 1. The guidelines presented here are, however, equally valid for any form of advanced FES.

Advanced FES has been used for thousands of years. The architecture of several desert regions utilised wind-scoops to force air through wall cavities before entering the occupied spaces. The development of modern advanced FES was spurred by the energy crises of the 1970s. The basic technique is unchanged from that of the desert architecture, however, we now use mechanical ventilation rather than wind power and pre-fabricated concrete floor slabs rather than cavity walls.

The most successful system, the FES-Slab, was first used in 1979 and has subsequently found application in more than 1,000,000m² of buildings in the UK, Holland, Belgium, Saudi Arabia and, principally, Sweden. The first UK FES-Slab buildings were constructed during 1993 and the system is gaining a high profile with several further projects constructed during 1996 and 1997. In addition to the FES-Slab, two alternative advanced FES systems have been used in the UK; one in an ex-CEGB building near Bristol and one in the Ionica building, Cambridge.

1.3. Potential Impact

The HVAC energy consumption of an advanced FES building should be around 50 kWh/m², compared with about 120 kWh/m² for a well controlled conventional building. Assuming that 800,000m² of advanced FES buildings are constructed in the ten years following the system's introduction to the UK (as occurred in Sweden) our annual energy requirement would be reduced by around 56GWh. Assuming an average electricity cost of 5p/kWh, this equates to a direct financial saving of about £3M per annum, with further savings resulting from demand shifting a proportion of the remaining energy consumption to the night time cheap tariff.

2. Design Guidelines

The following guidelines are intended to aid practising building services engineers in the design and application of advanced FES buildings. They describe the design of a building in terms of three key areas; its structure and layout, its plant and its control strategy.

2.1. Structure and Layout

2.1.1. General

The first requirement for any advanced FES building is that its rate of heat loss must be minimised; the entire principle of thermal storage is compromised by a 'leaky' storage medium. High levels of insulation and good air tightness are therefore essential

Buildings with extended occupancy periods gain the most benefit from the very stable temperatures of advanced FES systems. The technique is increasingly unsuitable for buildings with short periods of intermittent occupancy (< 8 hours per day), which would be better served by a more reactive lightweight construction.

2.1.2. Slabs

The following section gives advice upon the selection of a particular advanced FES system.

The thermal performance of an advanced FES system may be characterised in terms of the efficiency of the heat exchange between the ventilation air and the slab and the slab's thermal inertia; (how much of the available heat is transferred from the ventilation air to the slab, and what effect does this have upon the slab's temperature).

It has been shown that, at slab lengths of 12m or more, all advanced FES systems provide a heat transfer efficiency of around 100%[(1)] (i.e. the ventilation air will exit the slab at virtually slab temperature). The parameter which therefore has most effect upon the slab's performance is its thermal inertia, which should be maximised in order to make the slab's temperature as stable as possible. This can be simply achieved by ensuring that the internal air path encompasses as much of the slab's mass as possible.

Having maximised the thermal inertia of each individual slab, the same principle should be applied to maximise that of the whole building. This is achieved by ensuring that as many slabs as possible are connected to the air supply. For example, it is better to supply 80l/s of air through four slabs each supplying 20l/s rather than 2 slabs each supplying 40l/s.

2.1.3. Layout

The orientation of an advanced FES building, in conjunction with the distribution of its internal gains, has a significant effect upon its thermal performance. Differences in solar gain means that, for the same overheating risk, a north-facing office can sustain about 10W/m^2 greater heat loads than that in an equivalent south-facing office.

The inappropriate distribution of heat loads can lead to a significant temperature differential between the slabs in adjacent zones, which results in control difficulties if both zones are served by the same air handling unit.

2.2. Plant

Figure 2 shows a typical plant layout for an advanced FES building. The following sections give advice upon its' design.

2.2.1. Air Handling Units

The air handling units in an advanced FES building should be able to provide the following modes of operation:

- High efficiency heat recovery (at least 60%).
- Direct ventilation with minimum heat pick-up.
- 100% recirculation.

The air handling units should also be well insulated as they form the most turbulent portion of the air path and therefore offer a significant opportunity for uncontrolled heat transfer. Situating the units within the building's thermally controlled spaces will minimise uncontrolled heat transfer, both in the units and in the ductwork supplying the units.

2.2.2. Fans

Fan efficiency is a very significant factor in the energy consumption of an advanced FES building. Monitoring has shown the fans can be expected to account for around two thirds of its HVAC energy consumption and three quarters of the cost. Specific fan powers of less than $2W/ls^{-1}$ (i.e. 2W of fan power for every 1 ls^{-1} of air supply) have been shown to be practical[19] and should be achieved or, ideally, bettered.

Fans should be dual speed.

- The low speed should be used during periods of night time heating to reduce the fan energy consumption.
- The standard fan speed should be used for the normal, day time operation and night cooling. It will be determined by the occupants' fresh air requirements.

Detailed analysis has shown that maximum and minimum efficient fan speeds for any length of slab can be calculated theoretically[1]. Although it is not appropriate to present the detail here, the key point is that the flow rate through a FES-Slab should not be increased such that the residence time of air within the slab is less than 10s. At this flow rate the reduced residence time significantly limits the heat exchange between the air and the slab.

2.2.3. Ductwork

The ductwork of an advanced FES building should be designed to minimise uncontrolled heat exchange. Failure to achieve this can result in year-round inefficiencies which have a major impact upon both the building's comfort and its energy consumption. Uncontrolled summer heat gains can reduce the available free cooling whereas, in the winter, uncontrolled heat losses can result in a significant proportion of the heating energy simply going to compensate for the losses incurred whilst transporting the air through the ductwork.

Uncontrolled heat exchange can be minimised by:

- Keeping as much of the ductwork as possible within the thermally controlled spaces (for example effective free cooling is very difficult if the ventilation is first passed through an unventilated loft space where summer temperatures may exceed 40°C).

- Insulating the ductwork to minimise heat *gains* as well as heat losses (i.e. *before* the heater batteries as well as after them).

The ductwork should also be arranged to avoid short-circuiting between air handling units, which has been found to have a significant effect upon the availability of free cooling.

2.2.4. Heaters

Advanced FES buildings may be heated with gas or off-peak electricity. Electric heaters would be expected to provide the benefits of reduced capital and maintenance costs whilst gas heaters would remove the necessity for night time fan operation (although with efficient, low speed fans using cheap rate electricity this is not expected to provide a major advantage).

Assuming that electric heaters are selected, they should be generously sized to ensure that the full heating requirement can be supplied during the off-peak period. Over-sizing will also provide the additional benefit of reducing the period of night time fan operation.

If gas heaters are selected they should be sized for operation throughout the entire occupied period, resulting in 'trickle heating'. The heaters should always be used at full capacity, as this is where they are most efficient. The high heat transfer efficiency will ensure that the supply air temperature has been reduced to that of the slabs before it enters the occupied space.

2.2.5. Chillers

Mechanical Cooling

Free cooling with night ventilation should be sufficient to avoid summer time overheating in virtually all UK advanced FES buildings, providing that they are properly designed and controlled.

If, however, the pressure to install 'backup' mechanical cooling is irresistible, it should be used during the night time cheap tariff, relying upon the building's thermal inertia to avoid afternoon peaks (in the same manner as electric heating). The suggestion to use mechanical cooling as 'quick response' mechanism during the daytime (and therefore at the standard tariff) should be firmly rejected. Even in conjunction with the 'short-circuit' airpath shown in Figure 2, the high ventilation-slab heat transfer efficiency means that most cooling will go into storage. Its effect will therefore not be felt in the occupied spaces for several hours, by which time the occupants will probably have left the building.

At September 1997 it has only been necessary to install mechanical cooling for occasional use in one very early UK advanced FES building, where a non-standard design limited the system's free cooling performance. The use of mechanical cooling with advanced FES is only common in Saudi Arabia, where the combination of high thermal inertia and the absence of a split electricity tariff encourages 24-hour operation of the chillers, enabling significant reduction in their capacity and capital cost[21,22].

Evaporative Cooling

Experience has shown that an evaporative cooler cannot be expected to produce much more than a 3°C temperature drop, which may well be overwhelmed by uncontrolled heat gains to the ductwork. It is unclear whether this limited performance makes evaporative cooling a cost-effective improvement to an advanced FES building.

2.3. Control

The control of an advanced FES building is vital to its comfortable and efficient operation. The philosophy is not complicated, although it does require a new approach. Standard, direct-response control strategies will produce very poor environmental conditions and high energy consumption. A brief outline of the control principles appropriate for an advanced FES building are presented here.

2.3.1. Philosophy

Experience has shown that the slab temperature has an overwhelming influence upon the temperature of the occupied spaces (space temperature rarely deviates from slab temperature by more than 1°C). Control of an advanced FES building should therefore focus upon controlling the slab temperature on the assumption that space temperature will follow.

2.3.2. Day Time Operation

The requirement of daytime control is to provide adequate ventilation whilst having the minimum unnecessary impact upon the stored thermal energy. This can be summarised as simply to maintain the AHU in the most appropriate mode, determined by the ambient and slab temperatures.

It is expected that the AHU will provide heat recovery throughout most of the winter and mid-seasons, whilst it will move to direct ventilation or 'coolth recovery' during the summer.

2.3.3. Night Time Operation

The purpose of night time operation is to replenish or remove thermal energy which the slab has exchanged with the ventilation air during the day. The mode of night time operation should be either heating or cooling, dependant upon the slab temperature.

When free cooling, it is important to ensure that the ambient-slab temperature differential is large enough to overcome the heat gains incurred in passing ventilation air through the ducting. Failure to do this can lead to effective heating during periods of nominal free cooling and exacerbate the building's overheating.

2.3.4. Example Control Schedules

Figure shows an example of a control schedule which has been successfully applied in a UK advanced FES buildings.

3. Conclusions

Advanced FES can provide a cost and energy efficient method of maintaining comfortable temperatures within buildings, however, for optimum performance the building's structure, layout, plantwork and control strategy must form an integrated solution to the problem of providing comfortable internal conditions. This paper has addressed the key issues in the specification of such a building.

4. Sources of Further Information

The paper distils the lessons learned from UK research programs of the last five years, which have included experimental analysis, theoretical modelling and monitoring of advanced FES buildings. In order to keep this document concise, discussion of the underlying work has often been brief. If required, further detail may be gained from the published literature, which is widely available[e.g. 7 to 20].

Figures

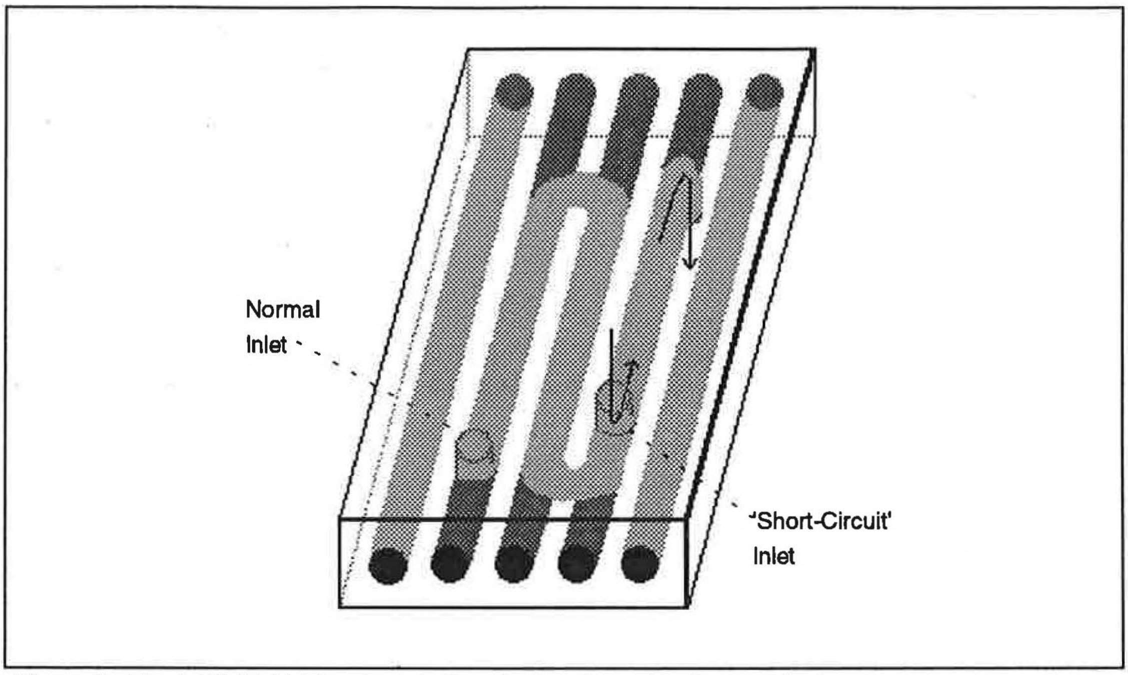


Figure 1: The 'FES-Slab' (showing air flow during short-circuit operation).

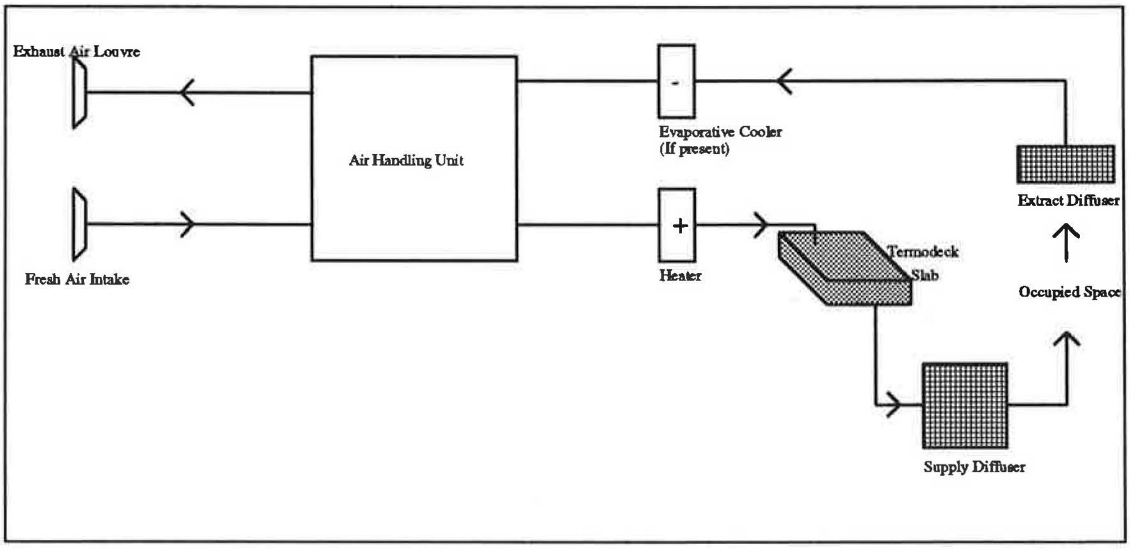
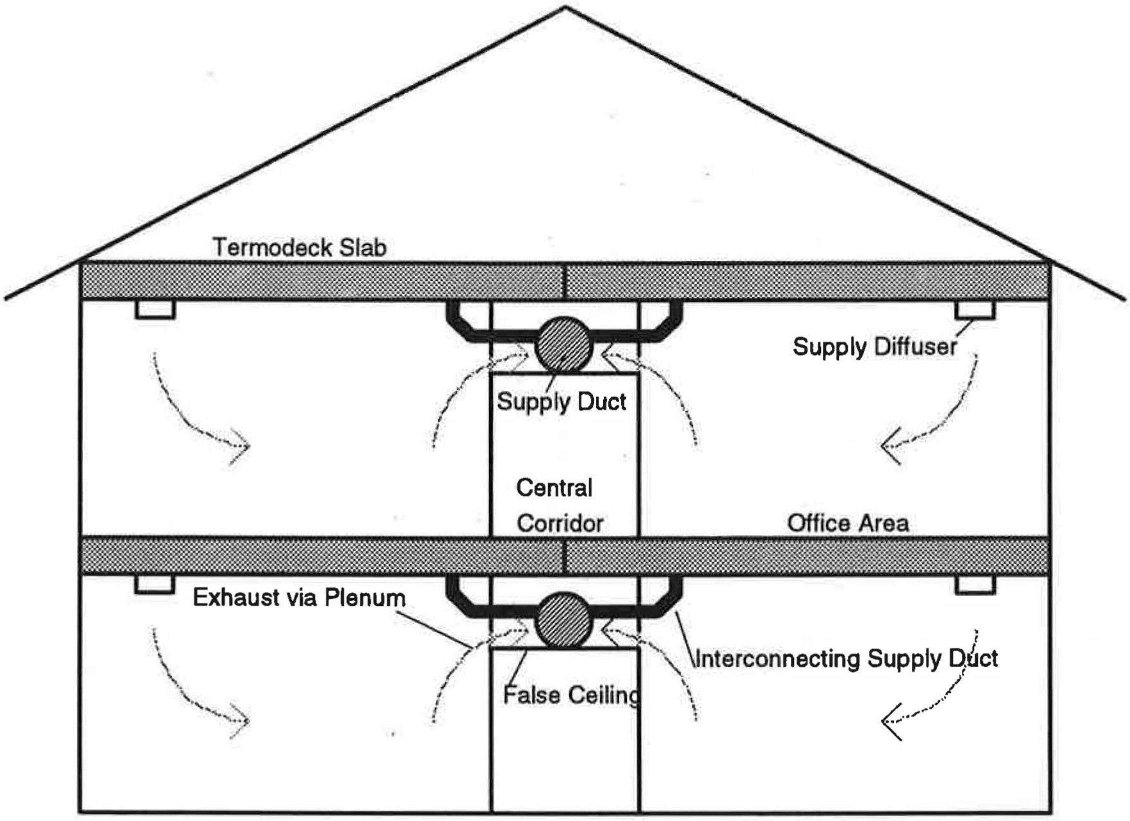


Figure 2: Typical Plant Layout at an Advanced FES Building.


Termodeck Slab
Supply Diffuser
Supply Duct
Central
Corridor
Office Area
Exhaust via Plenum
Interconnecting Supply Duct
False Ceiling

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