Session 3:

The Weidmuller Building
- Design and Construction

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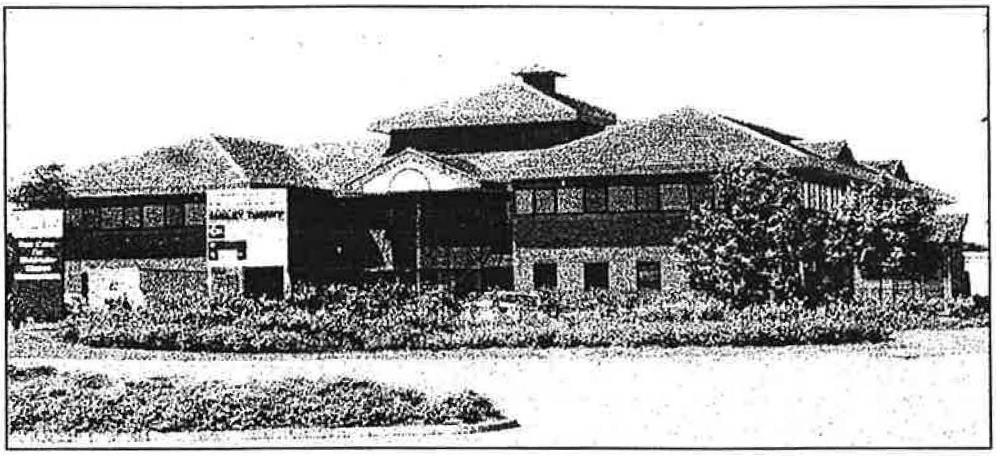
THE WEIDMÜLLER INTERFACE BUILDING
KINGS HILL WEST MALLING KENT.



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

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

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.

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Waterfield Odam & Associates 30th October 1997