#10955

## Session 4:

# The Weidmuller Building - Performance and Improved Control


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# 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.

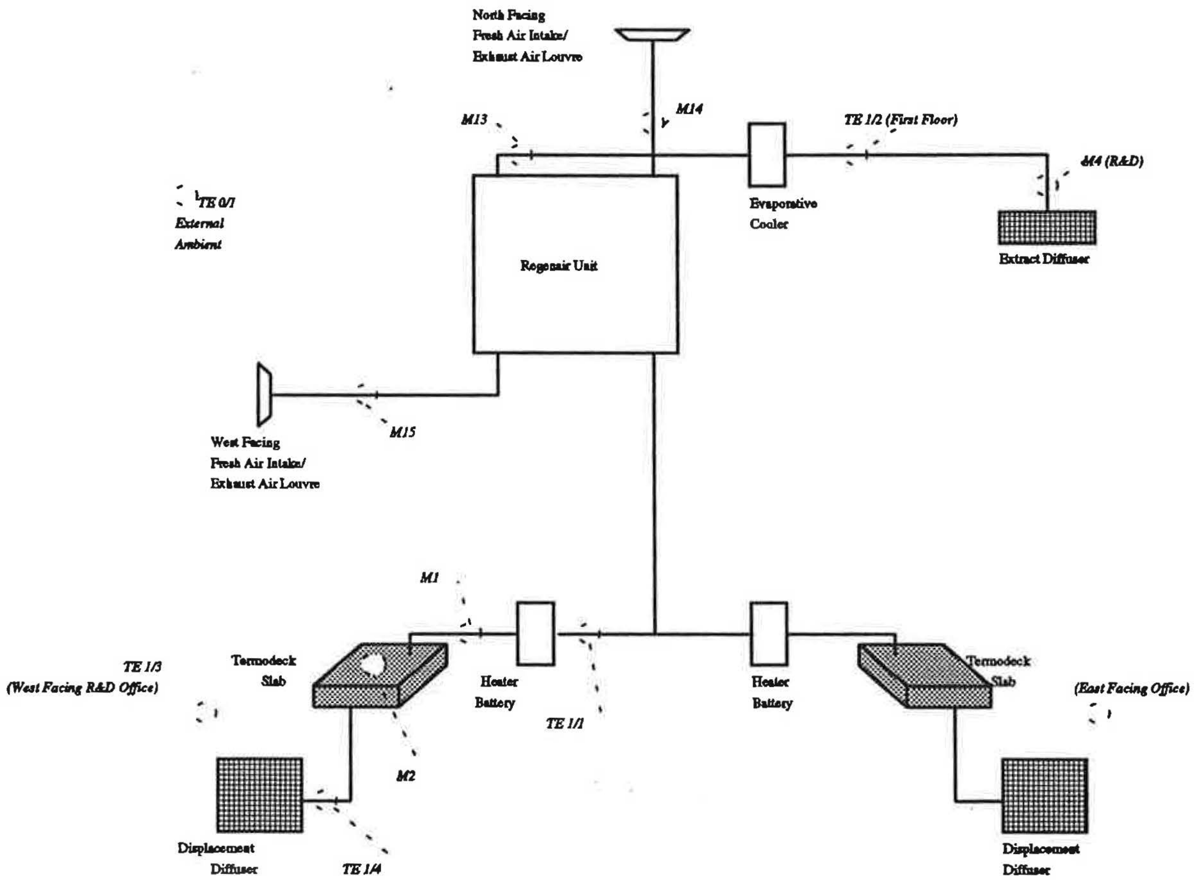


*Figure 1*

## 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.

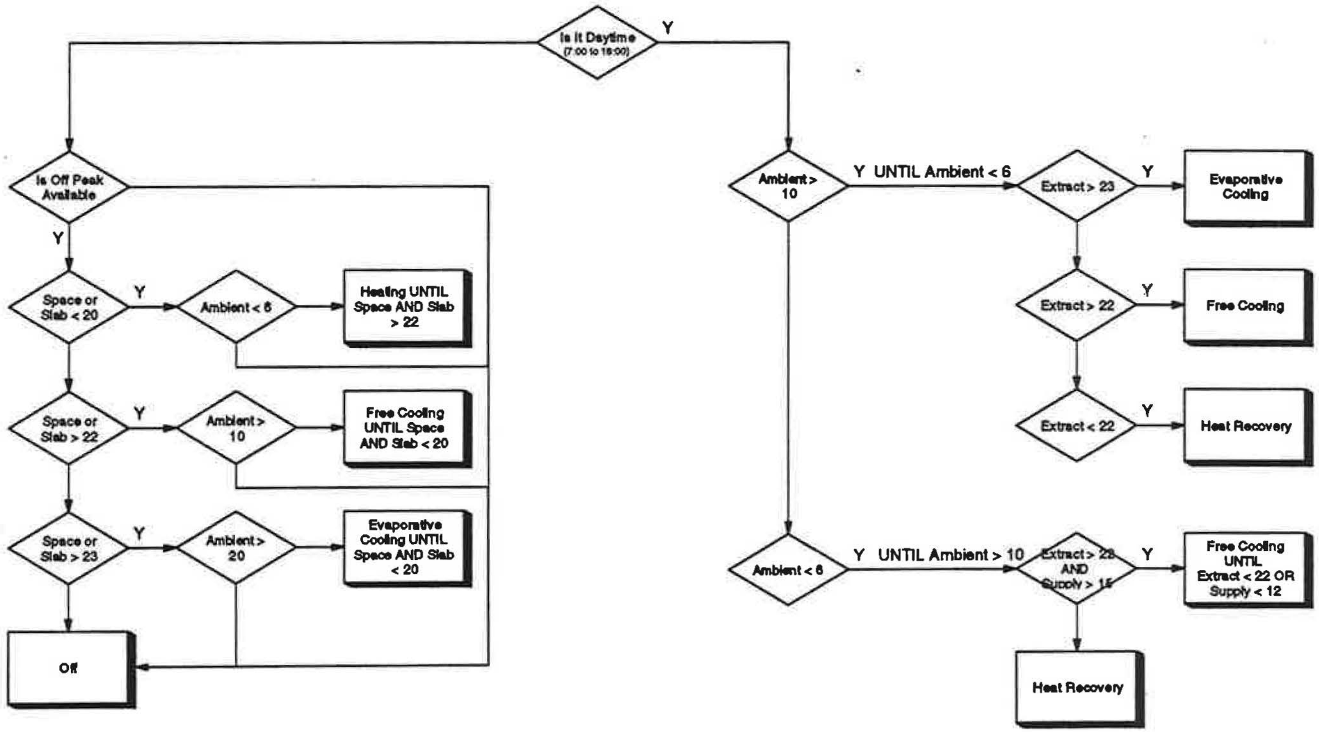


*Figure 2*

## 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

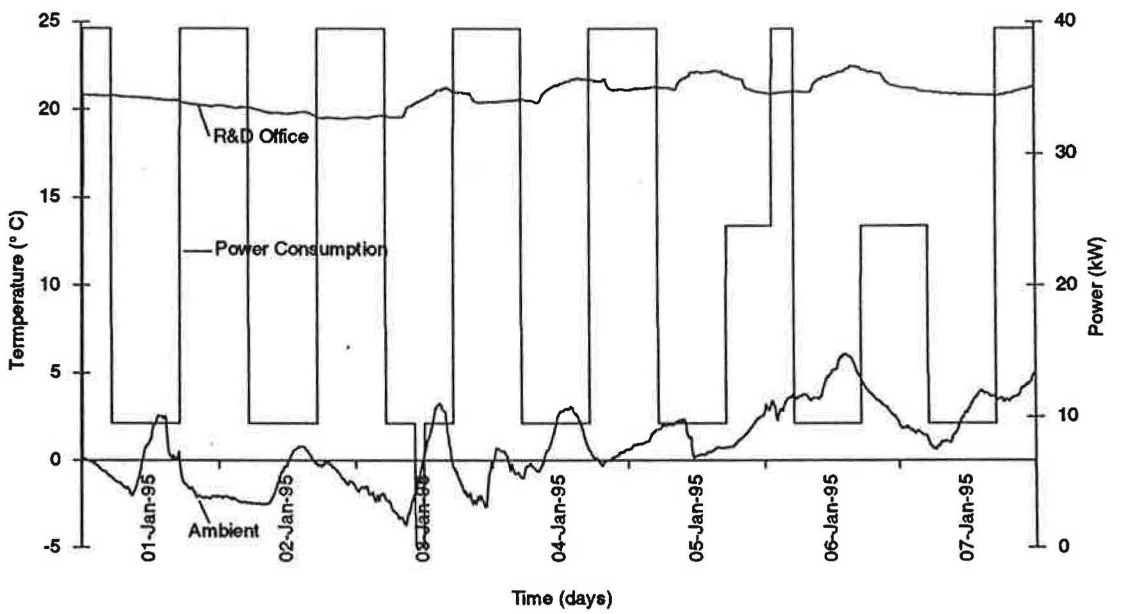


*Figure 3*

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

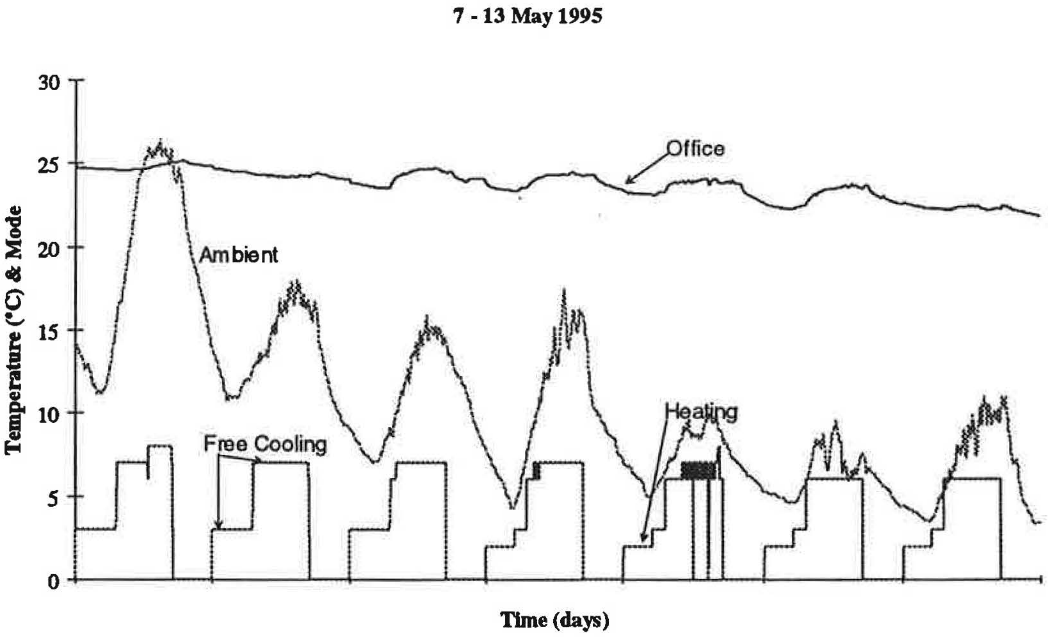


*Figure 4*

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

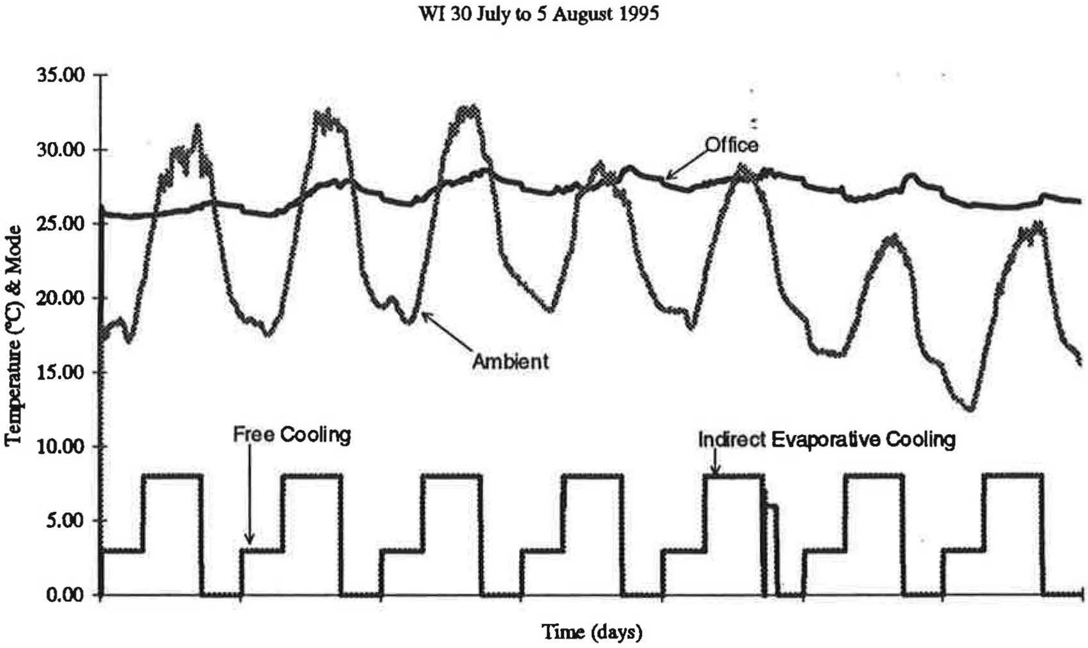


*Figure 5*

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.

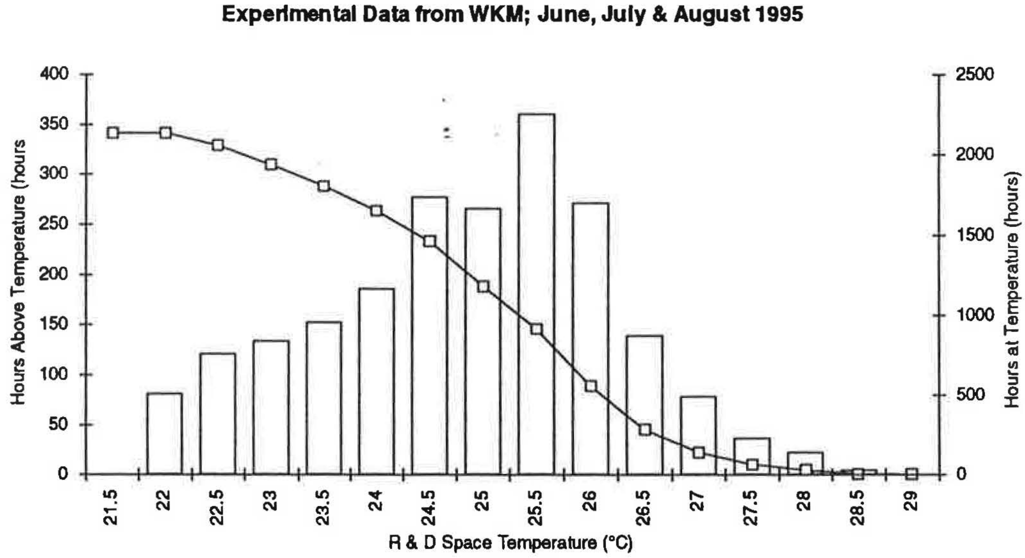


*Figure 6*

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

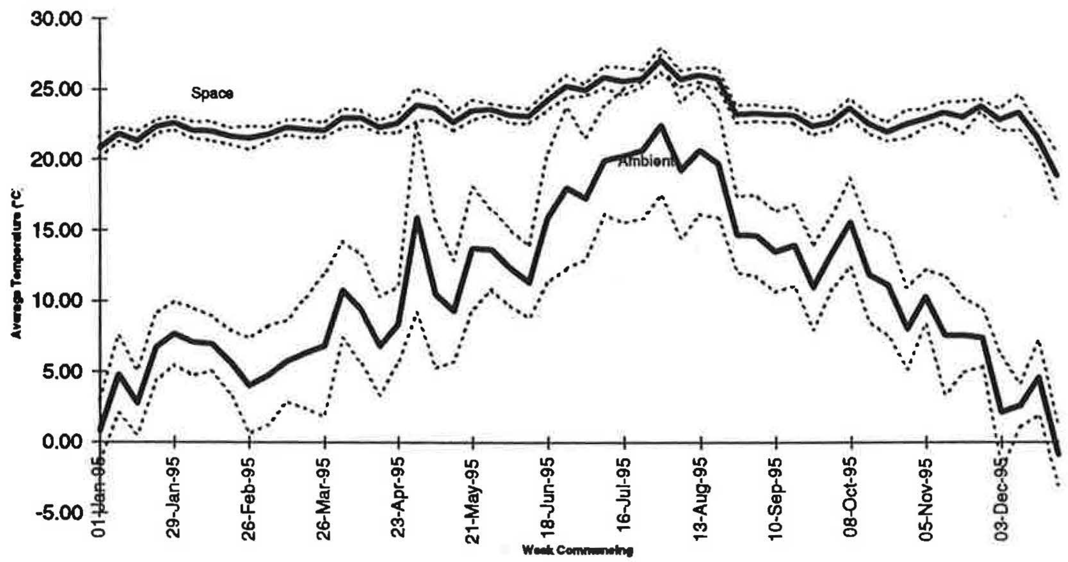


*Figure 7*

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

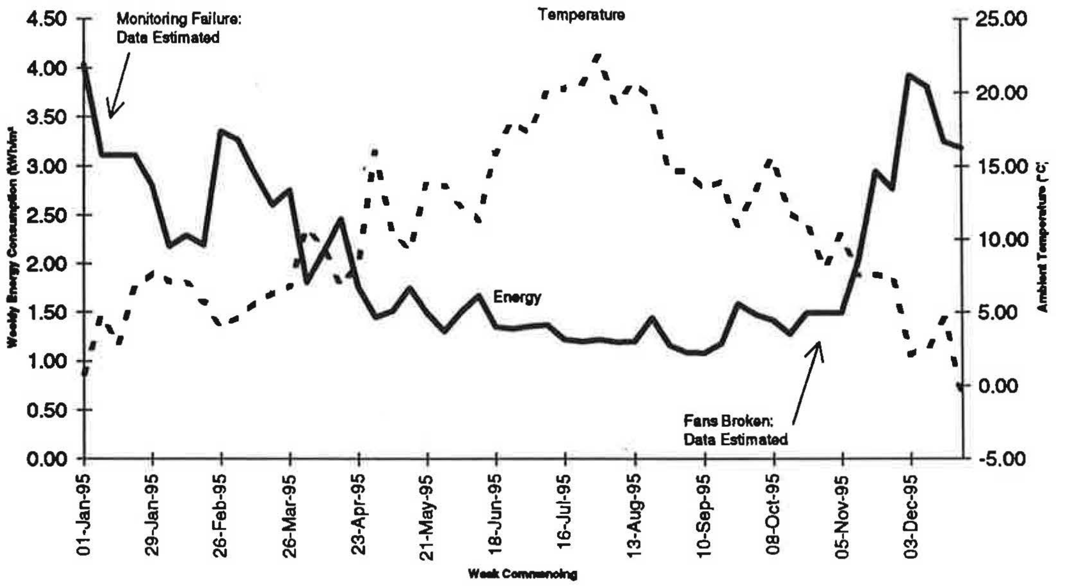


*Figure 8*

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.

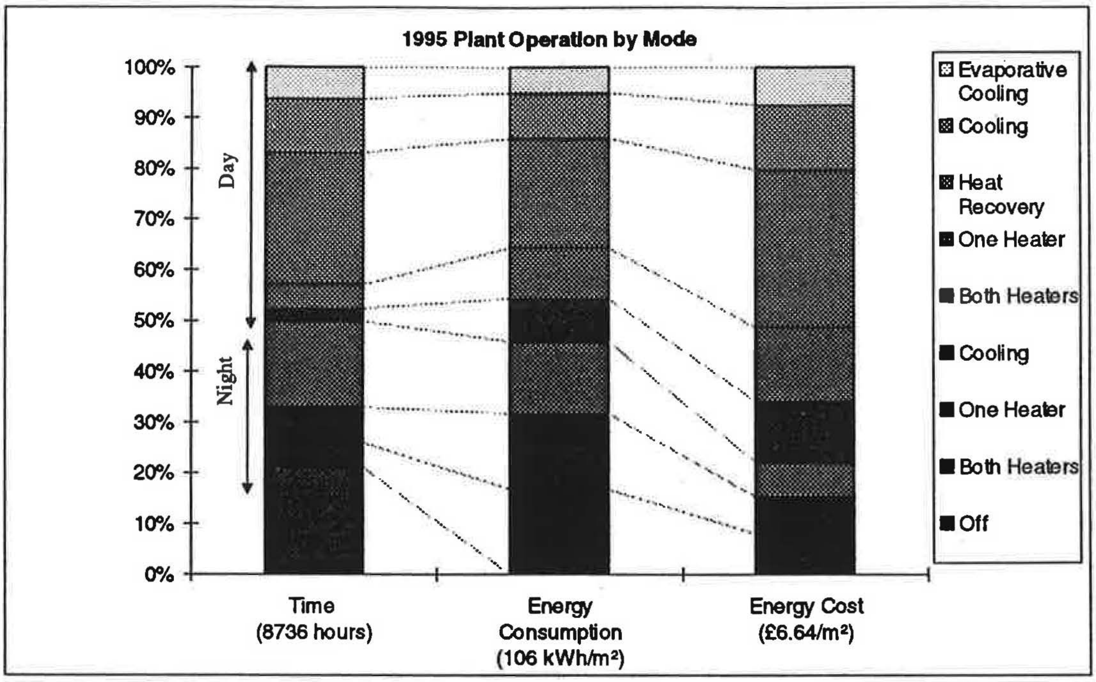


*Figure 9*

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

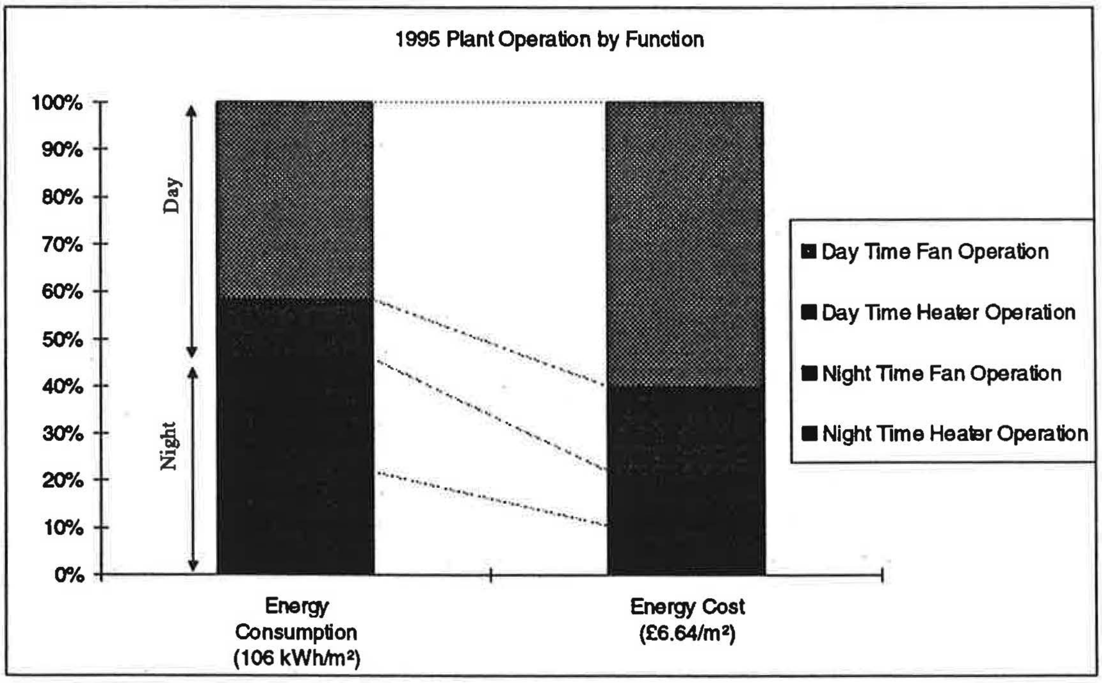


*Figure 10*

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.

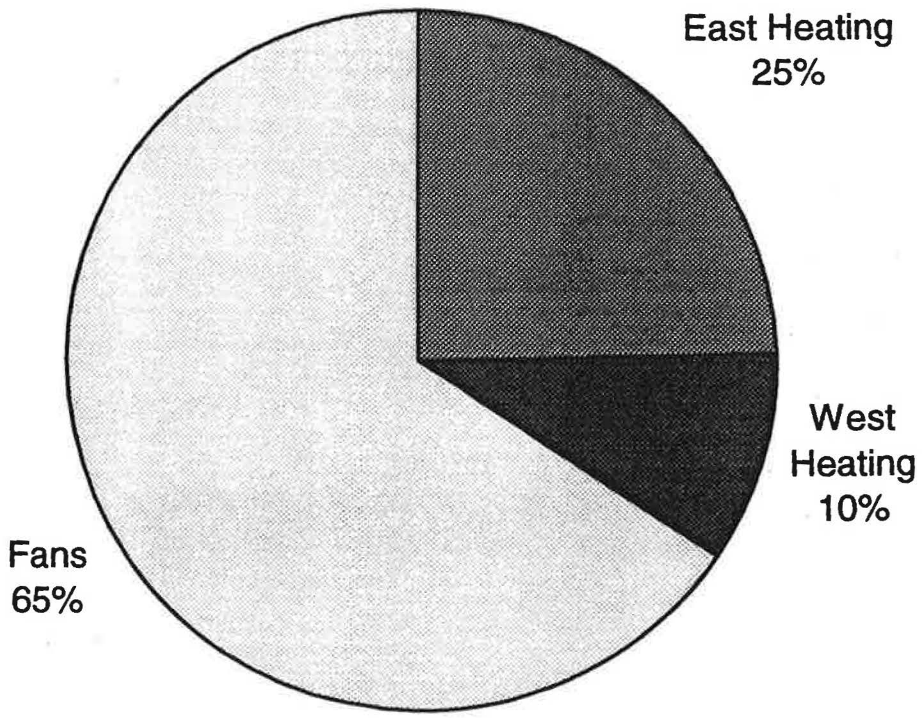


*Figure 11*

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

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.

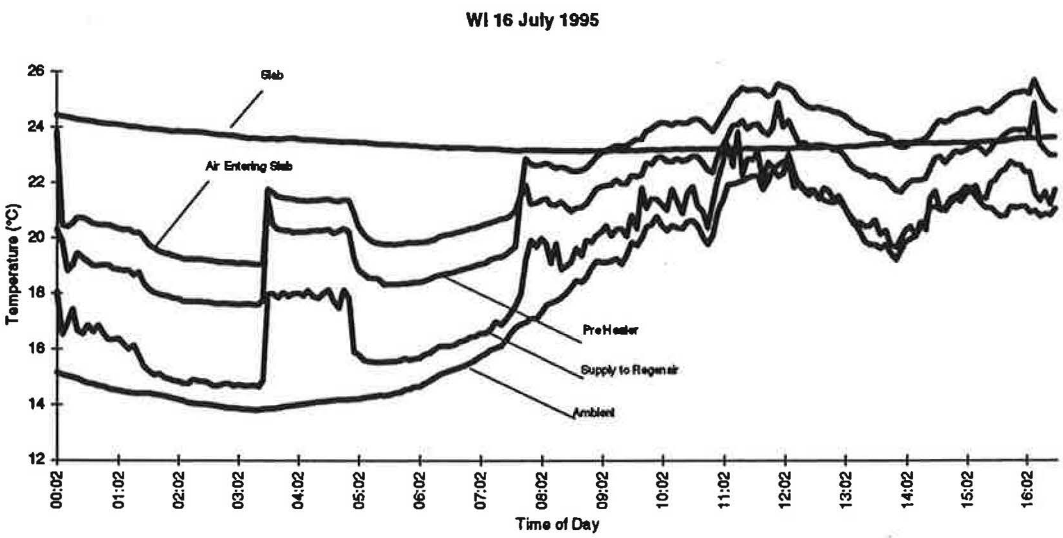


*Figure 15*

## 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*

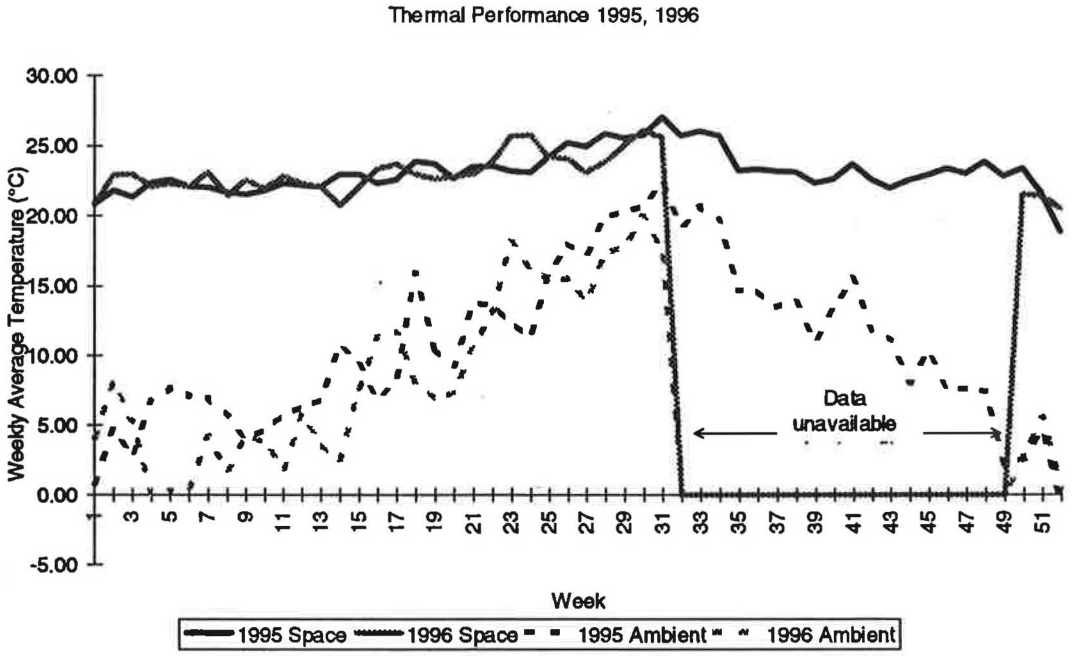


*Figure 16*

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*

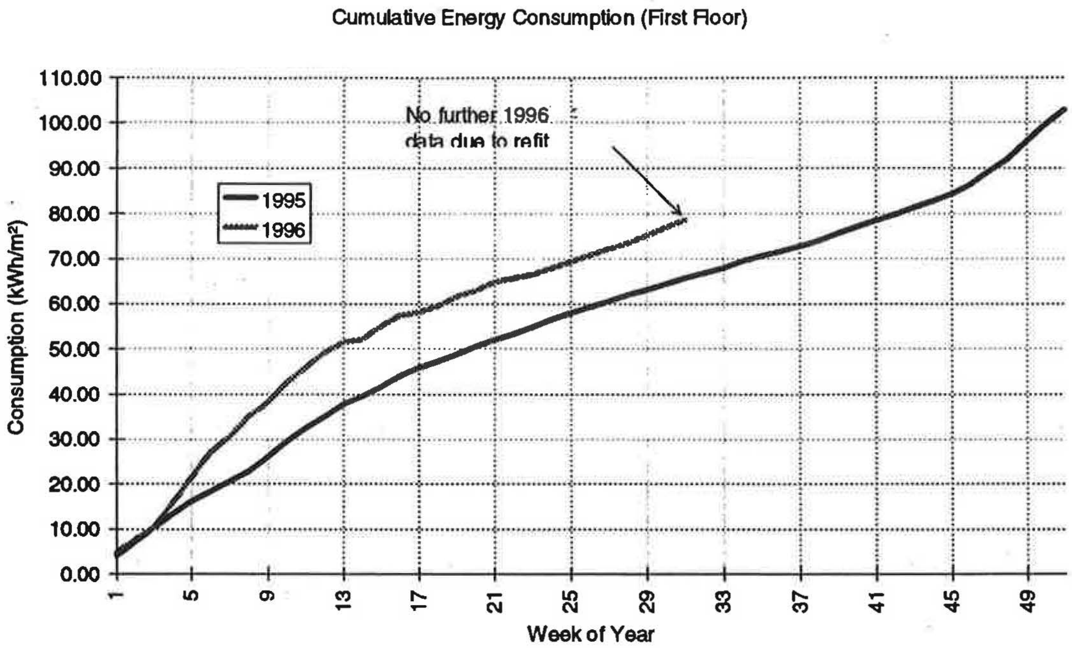


*Figure 17*

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

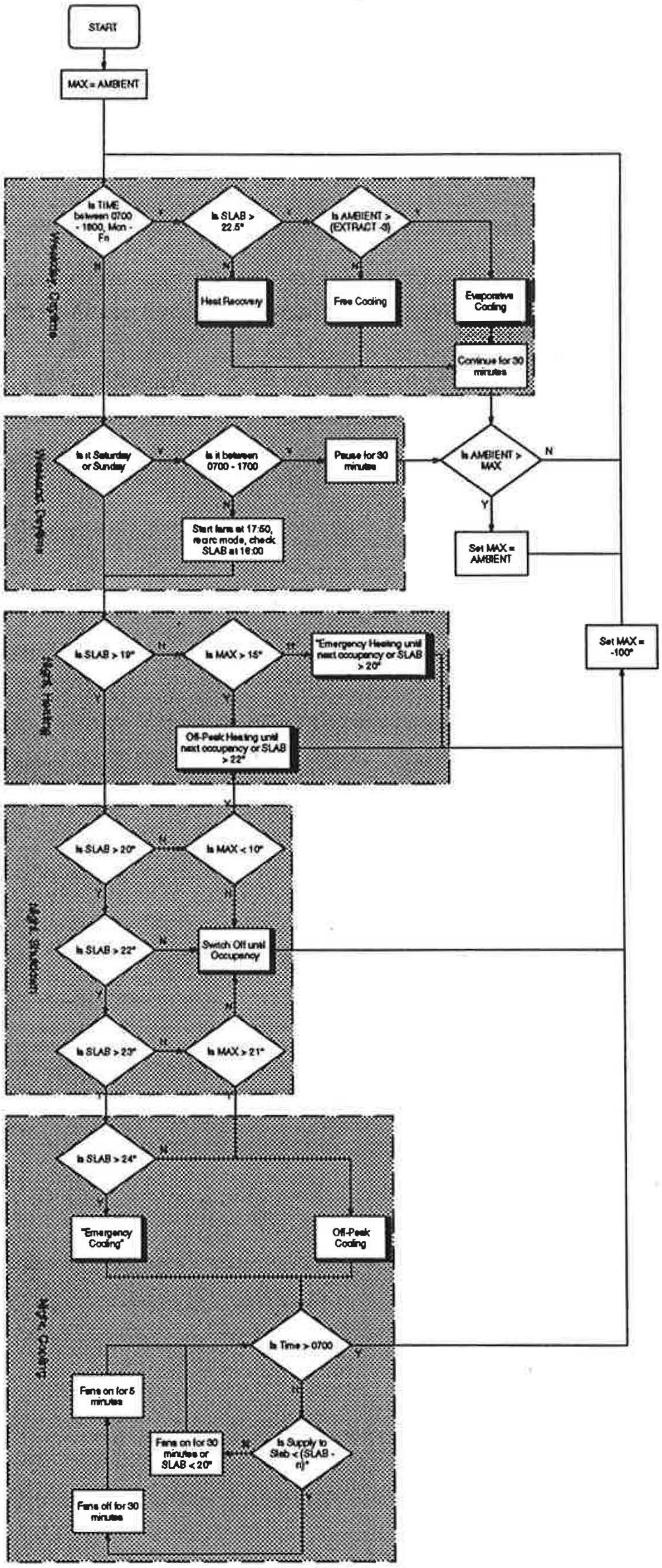


*Figure 18*

### *4.2 Thermal Performance*

#### 4.2.1 Winter

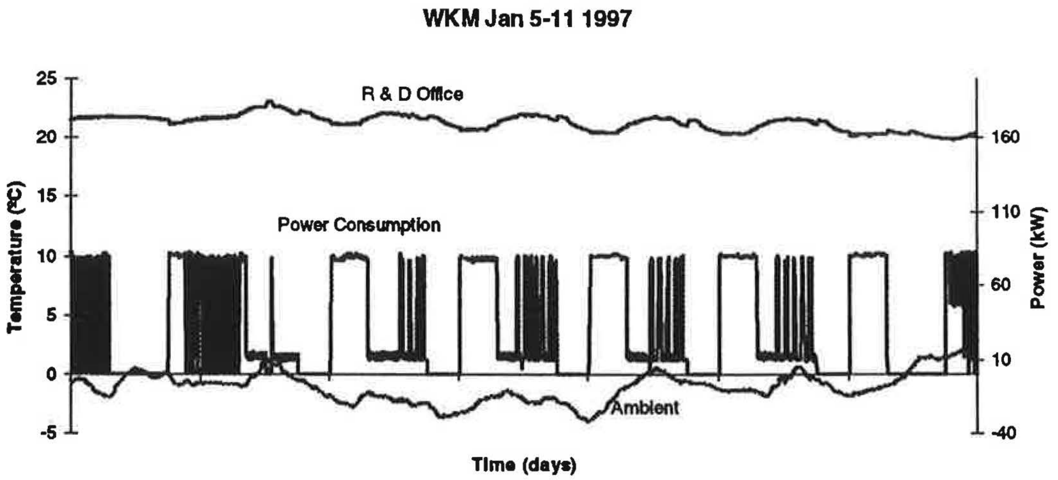


*Figure 19*

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

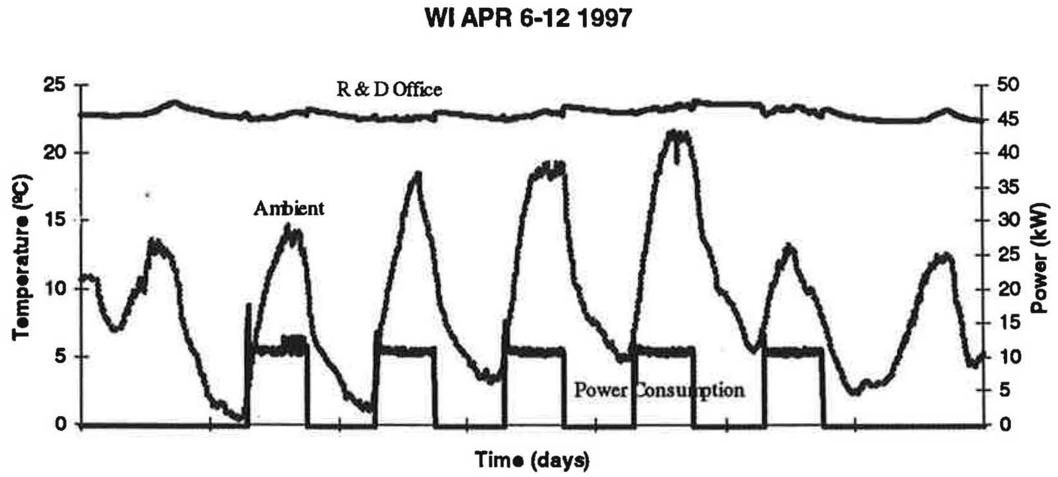


*Figure 20*

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.

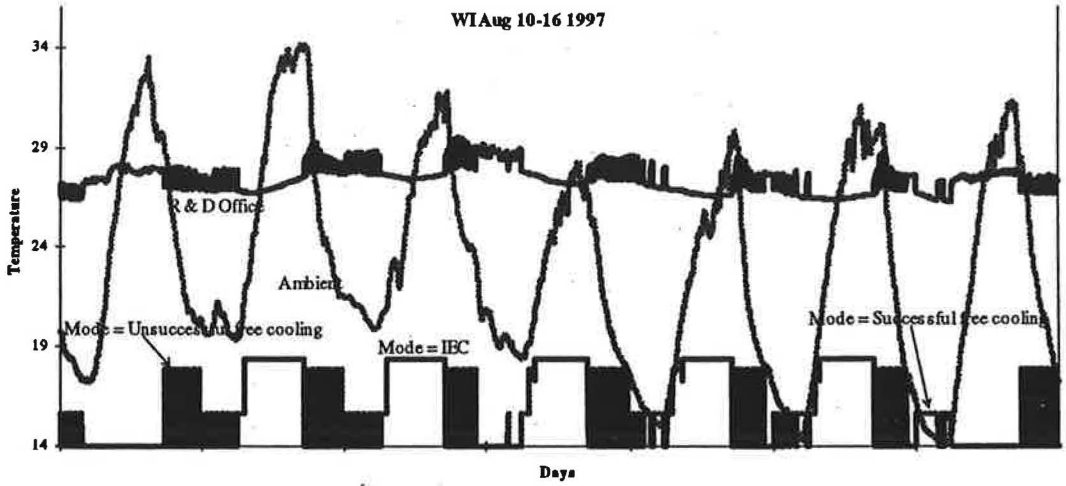


*Figure 21*

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.

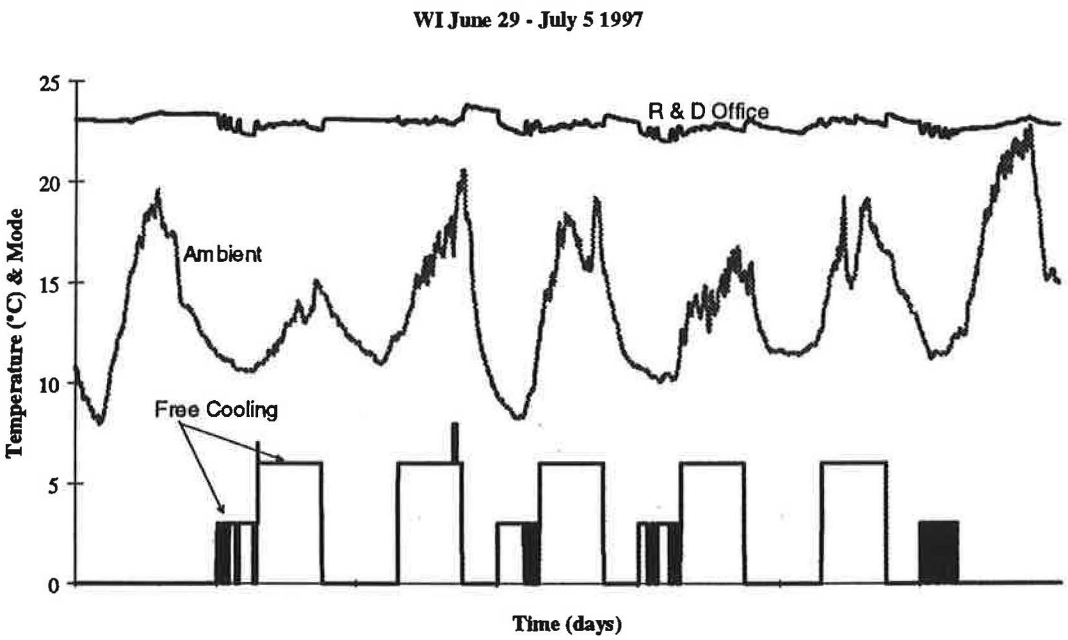


*Figure 22*

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

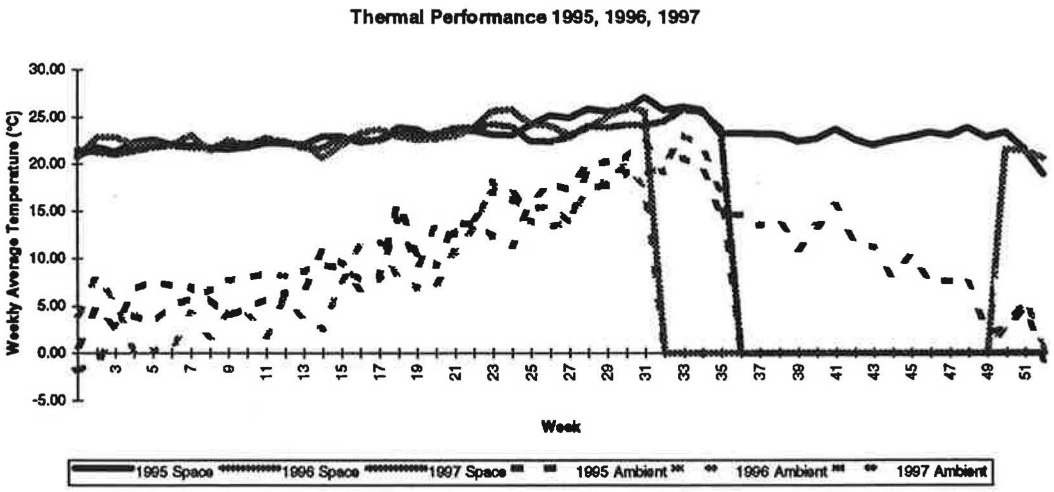


*Figure 23*

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).

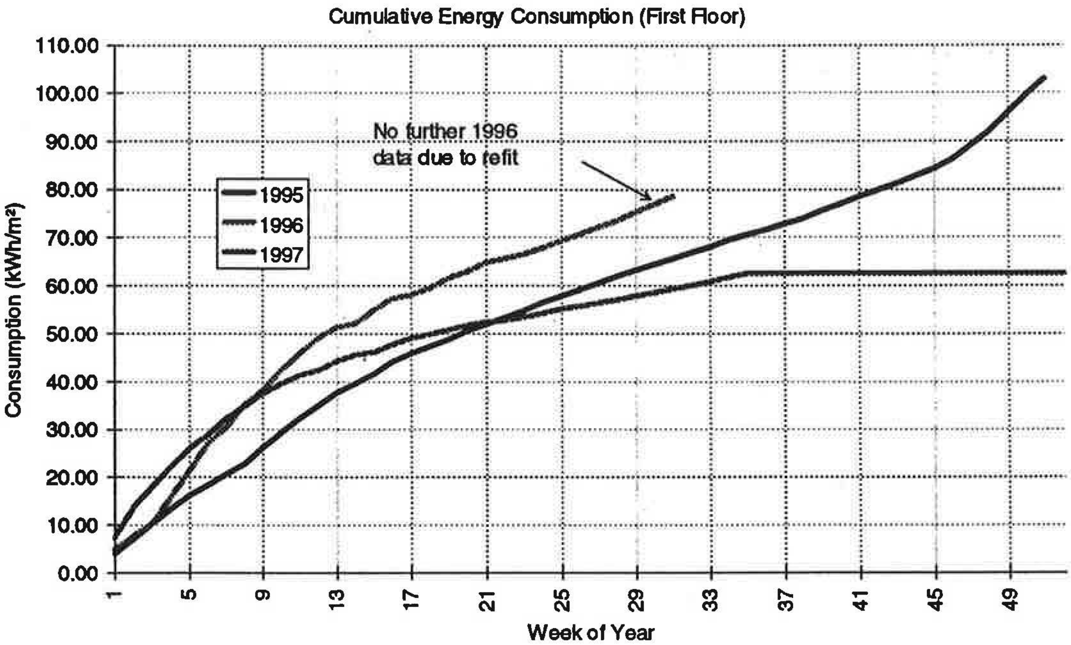


*Figure 24*

### 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.

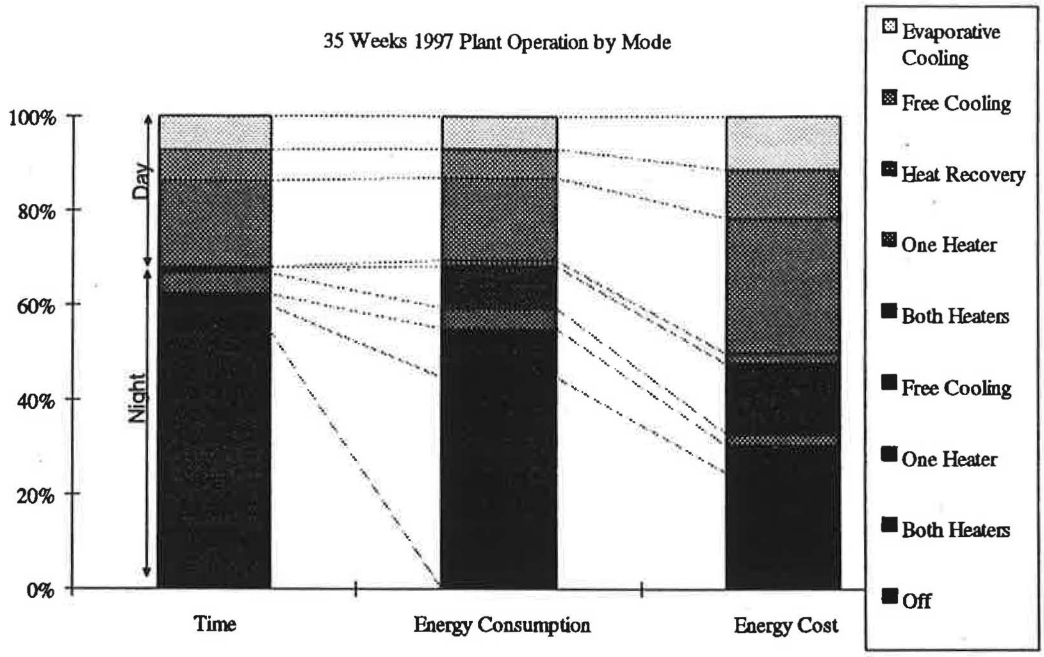


*Figure 25*

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

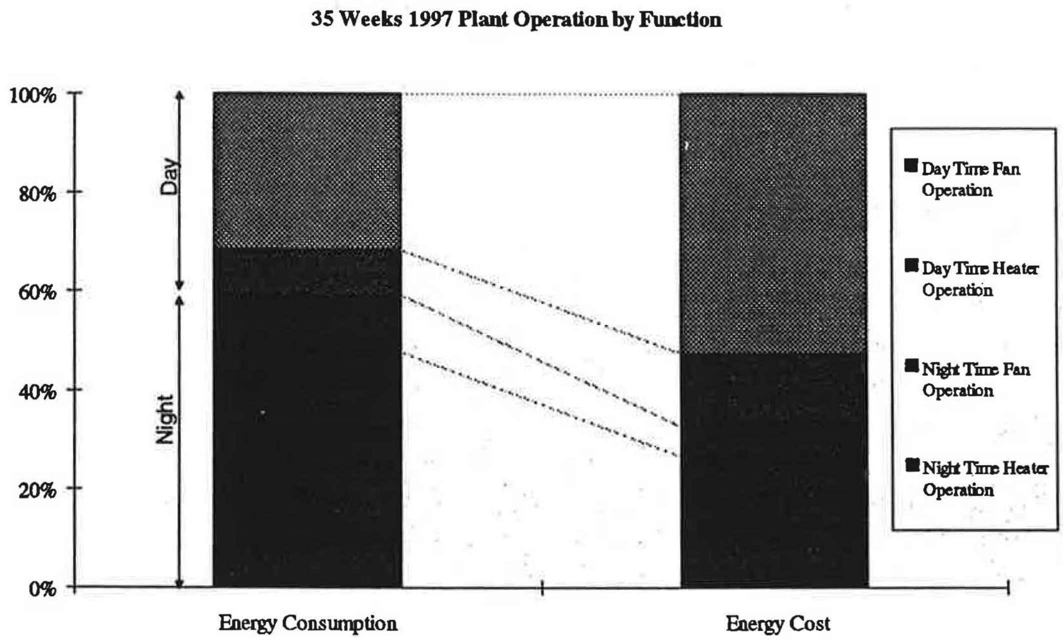


*Figure 26*

### *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%.

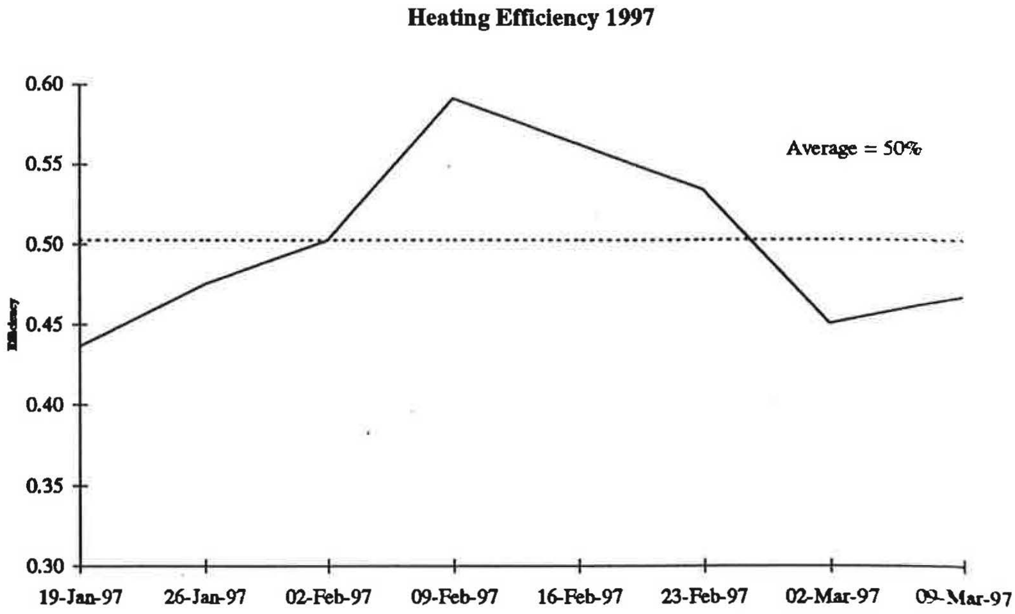


*Figure 27*

#### 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.

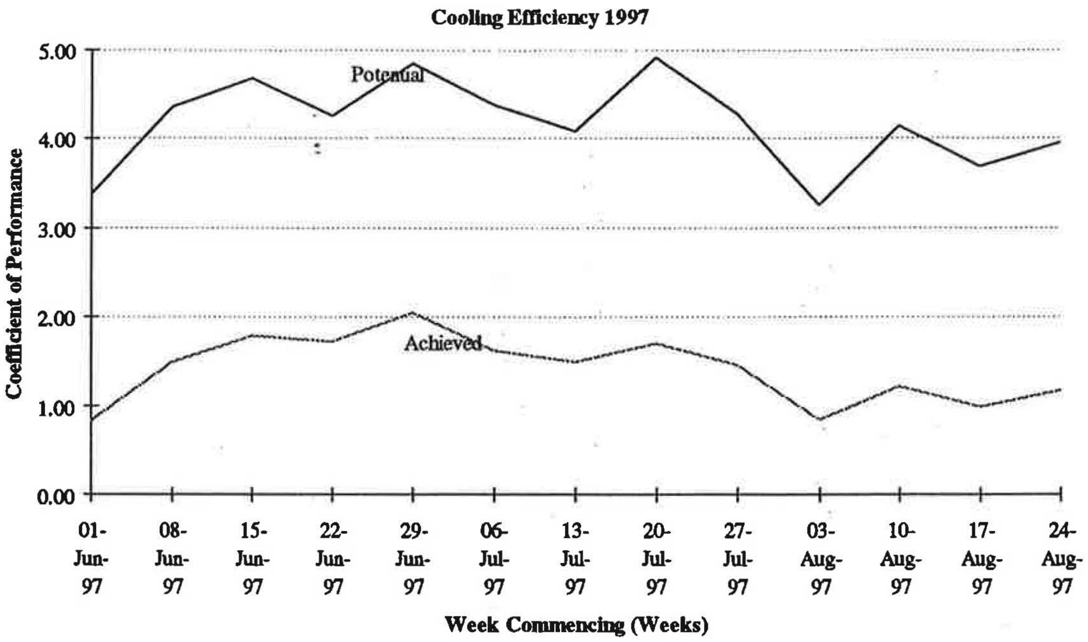


*Figure 28*

### 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.

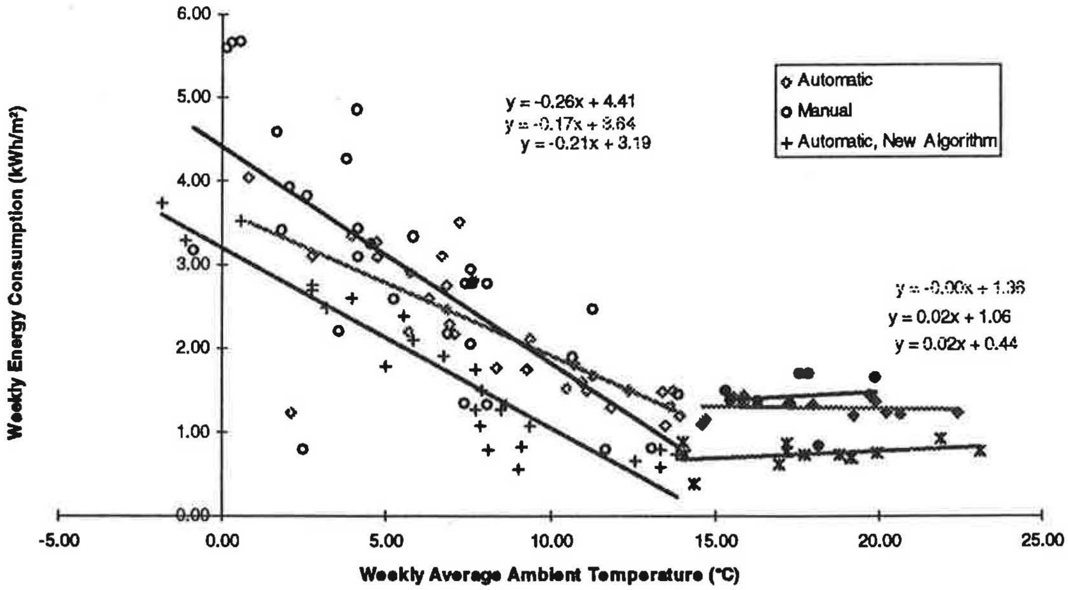


*Figure 29*

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.

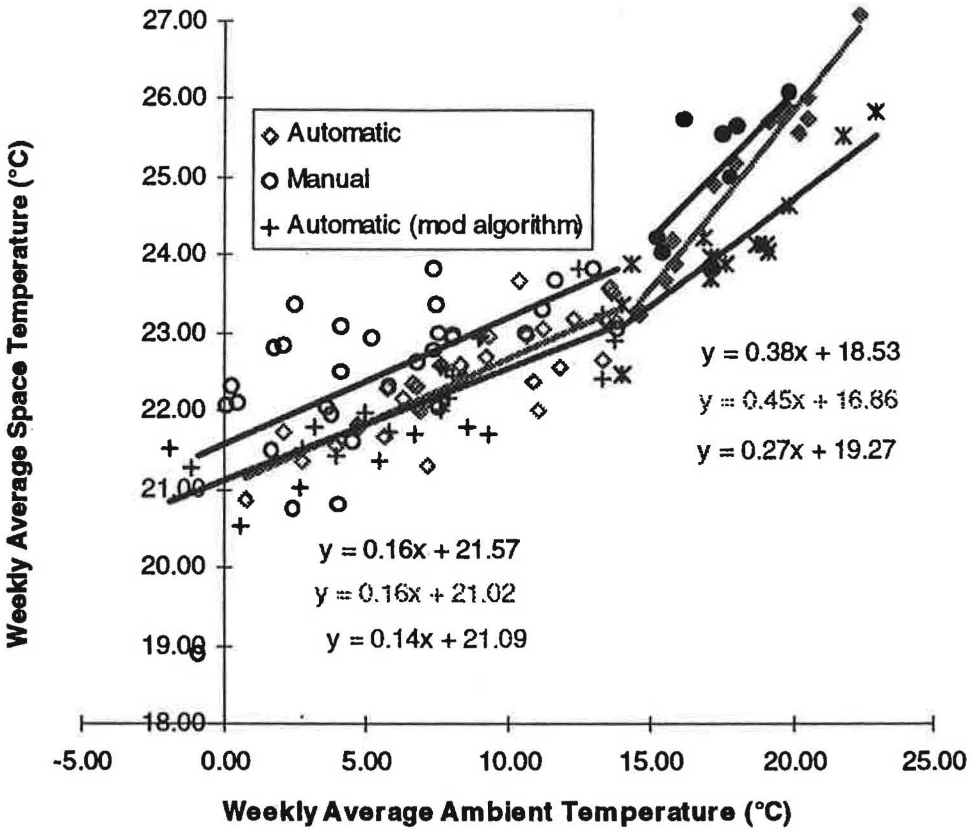


*Figure 30*

### 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.

WI Energy Cost

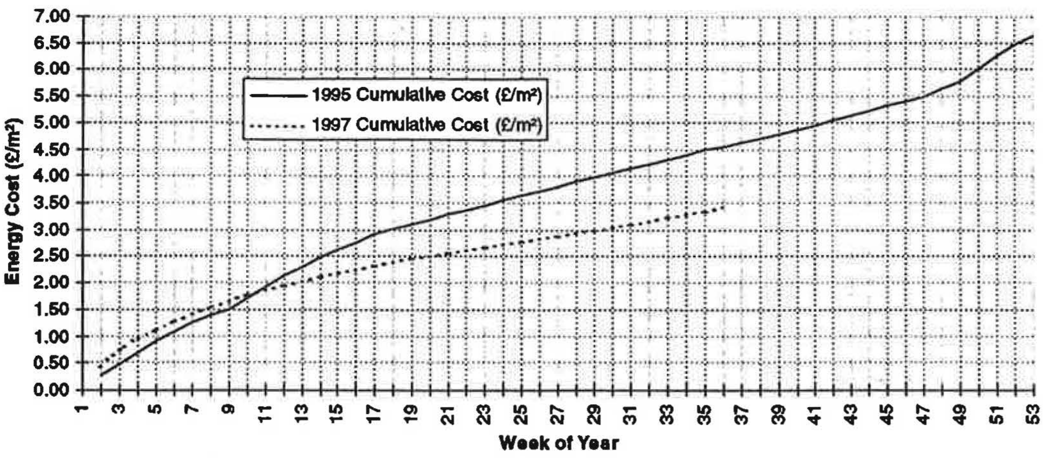


*Figure 31*

### 4.4.5 Improved Use of Off-Peak

Off Peak Energy Consumption

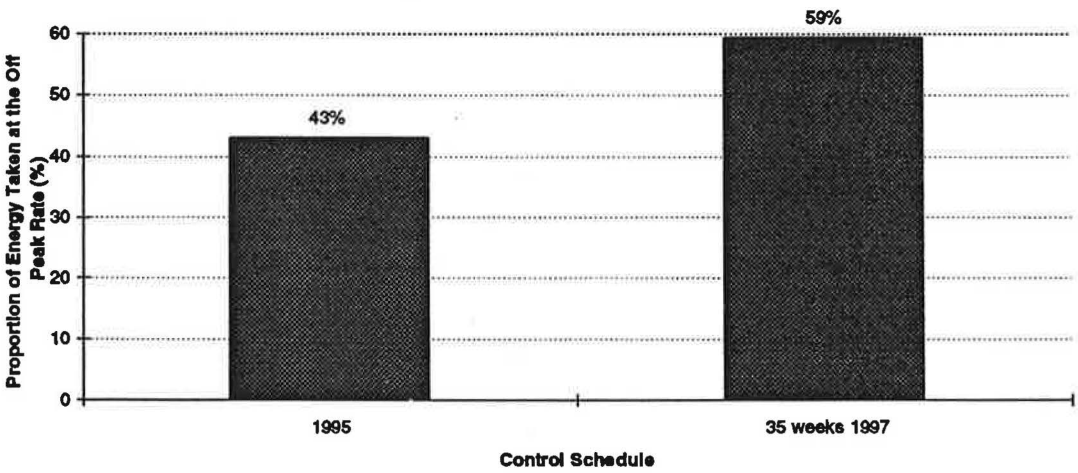


*Figure 32*

### 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.

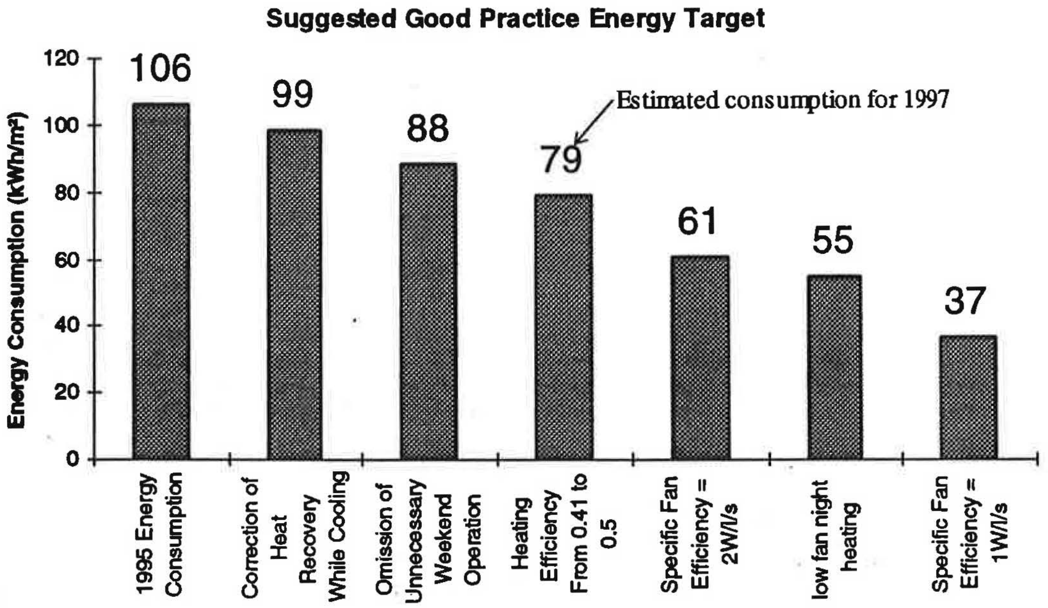


*Figure 33*

## 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.