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AN EVALUATION OF THE PERFORMANCE OF A SPORTS CENTRE WITH A LOW ENERGY DESIGN

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1. Introduction

The Dolphin Centre provides the town of Darlington in the North-East of England with swimming, dry sports and social facilities. Some of the funding came from the European Economic Community as part of an energy conservation demonstration project, including the cost of an audit. With several energy-saving features in one building, it is necessary to determine how well they work as an integrated system by becoming familiar with the system and taking many measurements over a long period. This has demonstrated inefficiencies and hence brought about changes with large savings in energy. The problems of control have been assessed both from numerical data and general obervations of staff behaviour.

2. The Building and its Systems

A major design consideration was the desire to reduce costs in use by producing an energy efficient solution and, because swimming facilities require far more energy to run than dry sports facilities, the design initially concentrated on these areas. This determined the basic design of the building envelope and the integrated heating and air conditioning system for the whole building.

The compact form reduces external surface area and combined with minimal glazing and a high standard of thermal insulation for the walls and roof ('U' values 0.3 to 0.4 W/m2.K) gives a total fabric heat loss of only 6.2 kW/K. As a result, ventilation accounts for most of the heat load.

The ozone disinfection system allows air recirculation with consequently large energy savings over a conventional system (1,2). To control humidity to acceptable levels, a heat pump (or chiller) system was chosen to dehumidify recirculated air under certain weather conditions. Alternatively, the proportion of fresh air can be increased when reclaimed heat is not wanted. The chilled water side of the chiller also provides heat reclaim from other areas, and space cooling; the hot water side provides general heating, topped up by conventional gas boilers. Runaround coils are used in most areas and fans are two-speed to save energy. No provision was made to reject heat from the building, but the swimming pools provide a short-term heat store for any excess energy.

There is little or no daylighting in the sports areas and these require lighting at all times during use. High pressure sodium (SON) lights are used for their high efficiency in the main sports and pool halls; tubular fluorescent lighting is used in the remaining areas.

A computerized Building Automation System, or BAS, provides monitoring and data logging, and automatic switching. A central computer is linked to 14 outstations with local electronic controls which modulate valves and dampers in accordance with parameters set from the computer; there is also the potential for complex control using software, but to date little use has been made of this facility. This is in contrast to DDC systems which use software for all control. The central computer was used for the audit, which ran over a 15 month period using hourly readings from 73 meters and sensors.

3. Results

In any building, if adequate environmental conditions are not achieved, then the services and buildings could be judged a failure, irrespective of how energy efficient they were. In the Dolphin Centre, generally good environmental conditions have been achieved and most users are well satisfied. The main problem has been excessively warm conditions in hot summer weather; however, with the changes to operation described below it is thought that this problem will be much reduced if not totally eliminated.

There have been some complaints about pool conditions, but these have often come from groups of users wanting mutually exclusive conditions. For example, old people and mothers with toddlers want warm temperatures which schoolchildren find too hot, and pool attendants want cooler air temperatures than swimmers. At other times, conditions were due to control problems, the main reason being unreliable humidity detectors in the pool hall.

3.1 Energy Breakdown

Over one year, the delivered electrical energy was 12 950GJ (1.03GJ/m2) and the delivered gas energy was 9890 GJ (0.771GJ/m2); the main breakdowns of energy by end use are shown in figure 1 for primary and delivered energy. The displaced segment shows the large reduction in consumption resulting from installing smaller water circulation pumps. Over 80% of the primary energy is for electricity, and of this only a small proportion (10.7%) is for the heat pump. This leaves almost 70% of the total primary energy for fans, lights and pumps, i.e. not directly generating heating or cooling.

As figure 2 shows, there are several interlinked energy distribution systems and heat recovery putting energy back into systems. An attempt to disaggregate energy flows within water systems in order to calculate heating and cooling demands in different areas and understand overall system dynamics was made using flow and return temperature measurements on water systems.

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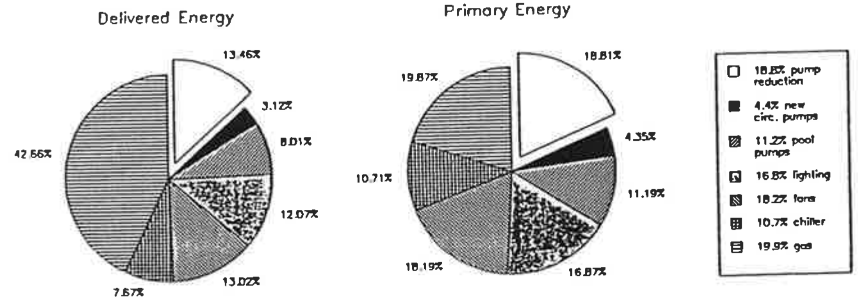

Fig. 1. Breakdown of total primary and delivered energy.

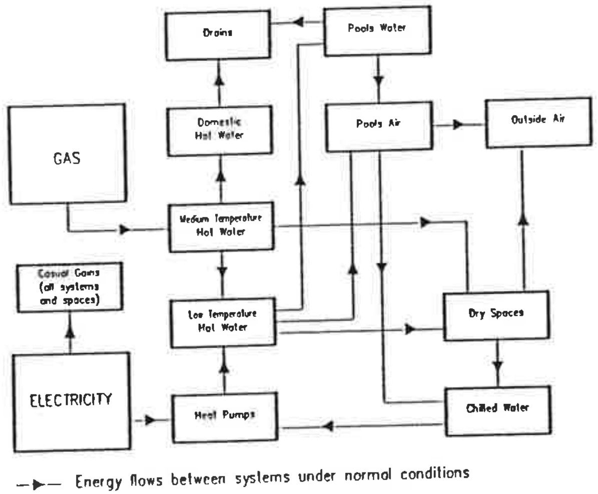

Fig. 2. System interactions

However, because the flow rates were very high on the water distribution systems (prior to installing smaller pumps), the temperature differences between flow and return were of the same order as the measurement errors, i.e. about 1oC. This made the intended analysis impossible.

3.2 Plant Sizing

The hourly variations in boiler load with external air temperature are shown in figures 3 and 4 for six days, for the North-East of England, of very warm weather and six days of cold weather respectively. The percentage load on the left hand axes is for one of the three installed boilers. For the cold weather, the maximum load in one hour was 127%, and the average was 85%.

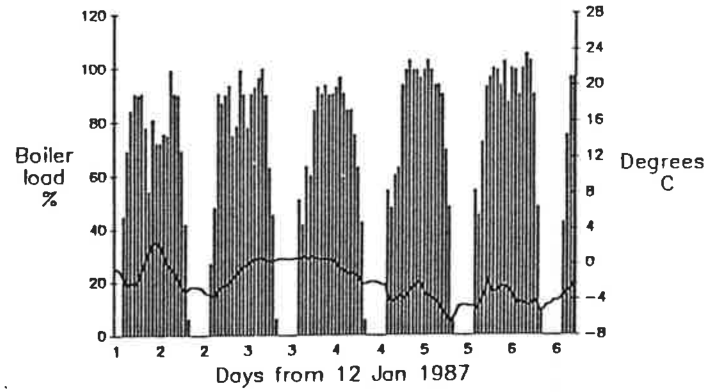

Fig. 3. Boiler load and external air temperature for cold weather.

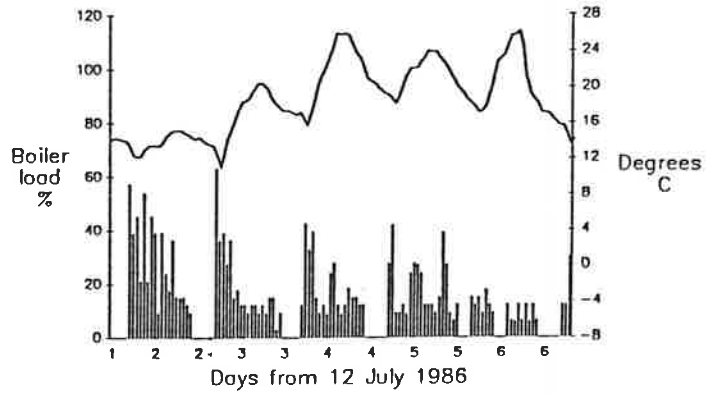

Fig. 4. Boiler load and external air temperature for hot weather.

In warm weather (figure 4) the maximum load was 63%, with an average load of 19%, of one boiler. Most of the load was for domestic hot water, which had to be at a high temperature for catering, but most of the demand was for showers which required a much lower temperature, much of which could be met by the preheat from the heat pump system. An independent system for catering hot water would be more efficient.

Over a year, the average boiler load was 41% of one boiler or 14% of the total capacity. Figure 5 shows the cumulative boiler load distribution with time. It can be seen that the weekly average total boiler load was less than 20% for 90% of the time and the load was less than 12% for 50% of the time.

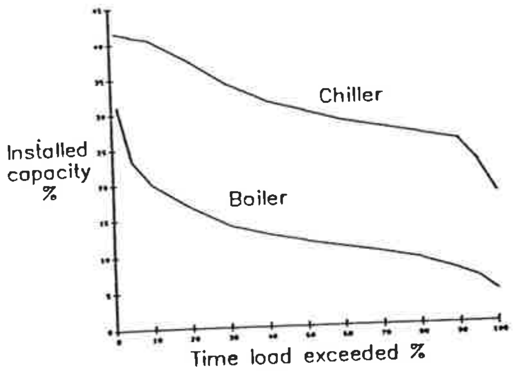

Fig. 5. Cumulative chiller and boiler loads from weekly mean values over one year.

A similar result can be seen for the chiller (Fig. 5). Two chillers, each with a maximum electrical capacity of 148kW, were installed with the original intention that they should run together, but they have subsequently only been controlled to run separately. In hot summer weather when there was a high cooling demand, the lack of a means to reject heat from the building meant that the internal heat dump of the pools became uncomfortably hot. Doubling the chiller capacity with two machines would have simply hastened the process and added even more heat to the building from the compressor motor. This result demonstrates the importance of correctly sizing the whole system.

3.3 Circulation Pumps

Early analysis showed that electricity for heating and cooling circulation pumps formed an unusually high proportion of the total, as shown in figure 1. The pumps were clearly oversized, and so they were replaced with smaller pumps in November 1986, reducing the total pumping power for these systems from 141kW to 33kW. Table 1 shows the changes in capacity which this brought about; the power for pumping is approximately proportional to the cube of the flow rate.

	OLD		NEW	
	Power kW	Flow kg/s	Power kW	Flow kg/s
Chilled	55	83	15	25
Low Temperature	75	104	15	55
Medium Temperature	11	36	3	20

Table 1: Comparison of sizing for old and new circulation pumps.

3.4 Controls

In terms of achieving good internal conditions, the control system has worked well as explained in section 1. However, the audit has uncovered many shortcomings in the controls (which has led to several of these being rectified). Over a year, the correlation between boiler gas (excluding gas for cooking) and external air temperature is poor, and between electricity for the chiller and external air temperature there is no significant correlation.

Part of this is due to several major improvements to operation of plant and controls during the monitoring period. For example, during the winter of 1986, a combination of seized air dampers and faulty humidity centres prevented any recirculation of the cool air with maximum (but unnecessary) dehumidification on the extract air from the chiller system which ran close to full load. In the winter of 1987, the air was being recirculated and there was no call for dehumidification, resulting in a minimal chiller load. Similarly, until May 1986, the boilers ran continuously, but subsequently they were turned off overnight without adverse effects. At the same time, the hours run each day of many items of plant and lighting were substantially reduced by matching them to occupancy level.

Despite these improvements, there remained the lack of an overall optimising control strategy, reflecting the difficulty in forming such a strategy for a large building with complex systems. At a fundamental level, fixed return temperatures were given for the three main HVAC water systems, unmodified by external conditions, and this lead to control conflicts between the chiller and boilers. The problems of summer overheating, and the observation that under typical winter conditions dehumidification of recirculated pool air is unnecessary, strongly suggests that the balance between heating and cooling/reclaim demands on the heat pump system had been poorly predicted.

General observations indicated that the control system was not well understood, and the split between local and computer controls caused great confusion. Most of the management and building services staff who used the BAS were not familiar with computers, many being unfamiliar even with keyboards. They viewed 'the computer' with some awe, perceiving it as an intelligent machine for which human intervention was more likely to do serious harm than good, rather than a data processing machine. When attempting to use it, they found the rather primitive and software difficult to use: the problem was exacerbated by a lack of good documentation. Maintenance staff were rotated monthly, so never had the chance to become sufficiently familiar with the BAS.

It was found completely impractical to control lights and plant to match usage by switching from a computer terminal keyboard. Various forms of automatic control were considered, but none was found to be feasible, and so a manual switch panel with display board was installed in February 1987, after the monitored period. This was not just to save energy, but also to give staff more direct control.

3.5 Comparison with other Buildings

A number of problem areas have been identified, but the question still remains of how good the performance of the Dolphin Centre is. Unfortunately, there is no absolute standard for comparison; it can only be compared against buildings of a similar type. Such information is sparse and the best that is available in the UK is the data obtained by the Audit Commission in their study of Local Authority Buildings (3). In this study some 3200 buildings were surveyed in 20 different categories in terms of delivered energy.

Of particular interest are the three categories associated with leisure buildings: these are sports centres, leisure centres with pools, and swimming pools. The annual average total consumptions per square metre of floor area for the same use profiles are 1.36, 5.0 and 6.5 GJ/m2 compared to the 1.8GJ/m2 of the Dolphin Centre. The low percentage pool area of the Dolphin Centre (6.6%) suggests that its category lies somewhere between a sports and a leisure centre. If the Audit Commission figures are factored to obtain the pro rata average performance for a pool area of 6.6 % the expected consumption is 2.8 GJ/m2. (This was done by hypothesizing a building consisting of a combination of leisure centre with typical pool area, and sports centre without pool, with total floor and pool areas equal to those of the Dolphin Centre.) On this basis the Centre still compares very favourably, with a consumption per unit area some 35 % lower than the average and some 17 % below the upper quartile, as shown in figure 6.

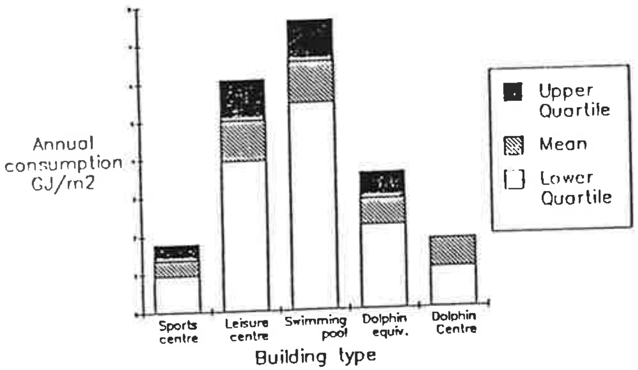

Fig. 6. Comparison of Dolphin Centre annual delivered energy use compared with other buildings of similar type.

Some data are available from the Audit Commission which suggests that a comparison based on primary energy, which relates more closely to cost, would be much less favourable. A reasonable assessment would put the primary energy requirement of the Dolphin Centre at 4.6 GJ/m2 compared to the consumption of the equivalent building (as defined above) of 4.3 GJ/m2. The consumption of the Dolphin Centre can however be expected to fall considerably over the next year as the improvements in control take effect.

4. Conclusions

Compared to most leisure buildings, the Dolphin Centre has proved to be reasonably efficient, and high standards of internal conditions throughout the year have been maintained. However, the study has highlighted several issues of design and control. Low energy buildings do not (by definition) require a large amount of heat input, but may require a substantial input of non-heating electrical energy for lights, fans and pumps, constituting a large primary energy requirement. Heat pumps create strong interactions and feedback between systems and require careful overall control for efficient operation.

The conventional design methods used in the UK have developed for traditional building types. It is implicitly assumed that there is a high rate of heat loss through fabric and ventilation, so that the main problem is supplying adequate heating. Each system is considered separately; there is scarcely any modelling of system interactions, and the treatment of control is at a very simple level.

The resulting conflict between building type and design principles have been illustrated in this paper for a particular case. Using current sizing algorithms and adding a safety margin has resulted in oversizing of plant; overall control and interactions have not been dealt with adequately by traditional methods. Some potential savings from low energy design have been negated by inadequacies in controlling them. Pool halls create a large demand for heating and reclaim, and accurate humidity measurement is crucial, but notoriously unreliable.

The early involvement of a controls consultant in the design process, followed by teamwork between the architect, services consultant and control consultant throughout, would seem important for this type of building. Another requirement is better prediction of behaviour during design. This could mean using a computer model of the building, its services and controls, although this requires the development of better modelling tools and methodology (4).

The audit has also shown that a BAS will not by itself give good control and low energy use. It may also require a change in the use of staff resources; a report on the monitoring of the effectiveness of BAS systems in the UK concluded that "...the ideal of having a member of staff allocated to making full management use of the central station may not be met from the outset ... the full energy saving potential may ... only be achieved after a lengthy period of familiarisation and adjustment." For some purposes, a manual system may always be better.

References

(1) Energy Efficiency Office, Energy Management Systems, ETSU, Harwell, Oxfordshire, UK, 1984.

(2) Audit Commission, Saving Energy in Local Authority Buildings, HMSO, London, 1985.