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Guidelines for the Most Effective Application Of Advanced Fabric Energy Storage

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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.

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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

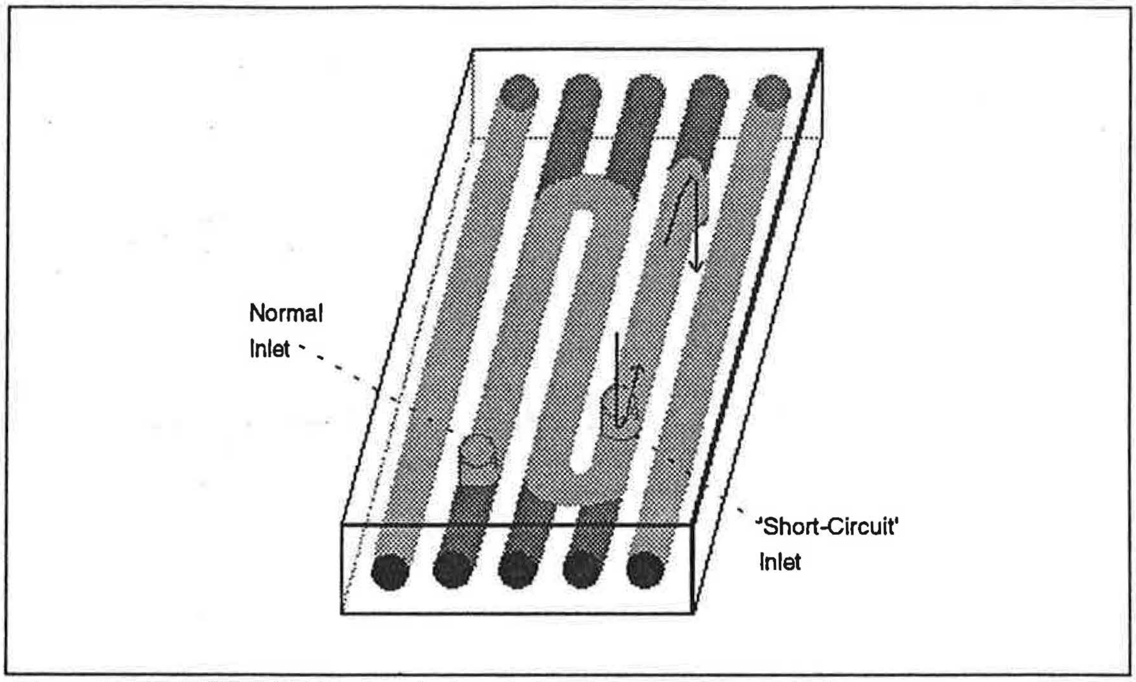


Figure 1: The 'FES-Slab' (showing air flow during short-circuit operation).

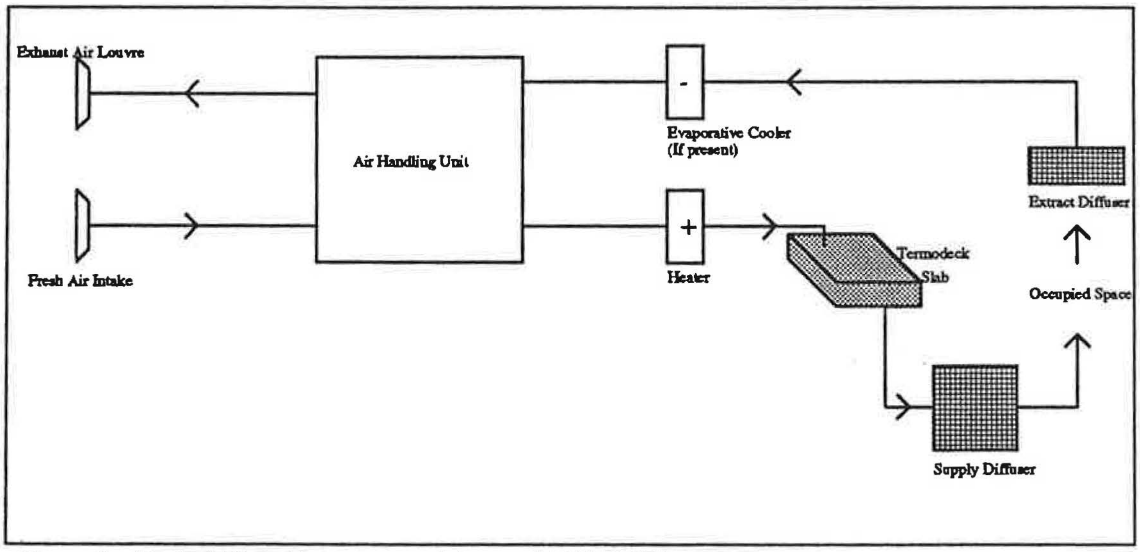
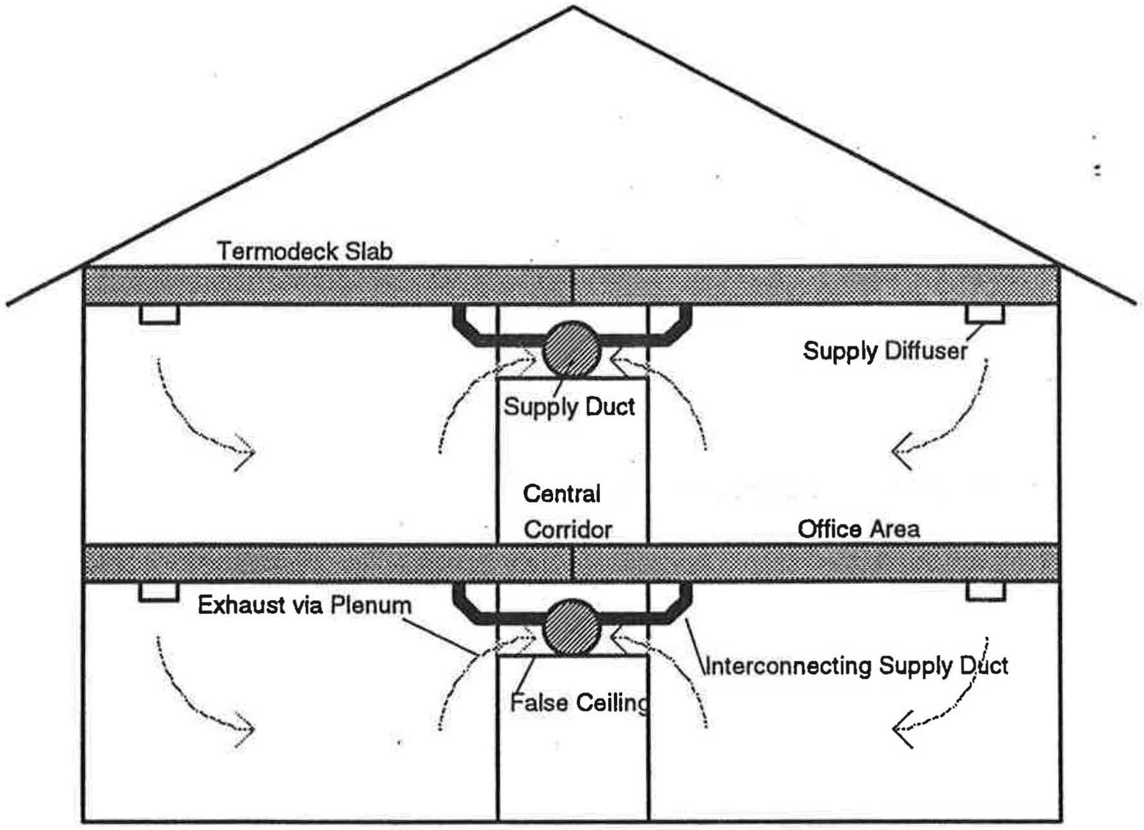


Figure 2: Typical Plant Layout at an Advanced FES Building.


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

References

1. Winwood R, The Application Of Advanced Fabric Energy Storage Within UK Commercial Buildings, PhD Thesis, University Of Manchester Institute Of Science And Technology, October 1995.
2. Beggs C. B, Warwicker B, & Howarth A. T, A New And Retrofit Method For The Elimination Of Air Conditioning In Existing Buildings Through The Utilisation Of Fabric Thermal Storage Technology, Proc. I. Mech. E. Seminar S260; "The Development Of Passive Buildings - Future Or Folly ?", London, 15 December 1994.
3. Termodeck - Passive Climate Control, Strangbetong, Sweden, 1989.
4. Bunn R, Termodeck: The Thermal Flywheel, Building Services, May 1991, P.41-44.
5. Evans B, Low Energy Design For A High Tech Office, Architects Journal, 17 November 1993, P.29-32.
6. Cambridge Calling, Architects Journal, 1 December 1994, P29-38
7. Willis S. & Wilkins J, Mass Appeal, Building Services, January 1993, P.25-27.
8. Wiech C. & Smith J. T, A Concrete Solution, Building Services Journal, March 1993, P.47.
9. Bunn R, Slab And Trickle, Building Services, February 1994, P.30-32.
10. Winwood R, Benstead R, Edwards R, & Letherman K M, Building Fabric Thermal Storage: Use of Computational Fluid Dynamics for Modelling, Building Services Engineering Research and Technology 15(3), Autumn 1994, P. 171-178.
11. Winwood R, Benstead R, & Edwards R, Modelling the Thermal Flywheel, Building Services Journal, October 1994, P.47.
12. Husslage J, Efficient Cooling Of Buildings Using Night Ventilation In Hollow Core Floors, Proc. European Conference on Energy Performance and Indoor Climate In Buildings, Lyon, 24-26 Nov. 1994.
13. Winwood R, Benstead R, & Edwards R, Computer Modelling of the Termodeck Thermal Storage System, Proc. European Conference on Energy Performance and Indoor Climate in Buildings, Lyon, November 1994.
14. Barnard N, Dynamic Energy Storage In The Building Fabric, BSRIA Technical Report TR 9/94.
15. Winwood R, Feedback From Termodeck In Use, Building Services Journal, April 1995, P.21.
16. Bunn R, Teaching Low Energy, Building Services Journal, April 1995, P.19-23.
17. Olivier D, Setting The Record Straight, Building Services Journal, June 1995, P.13.
18. Beggs C, Warwicker B, Winwood R, & Edwards R, A New And Retrofit Method For The Utilisation Of Fabric Thermal Storage In Existing Buildings, Proc. CIBSE National Conference, Eastbourne, 1995.
19. Kendrick C, The Use of Structural Components to Provide Thermal Storage and Night Cooling in a Building at the University of East Anglia, MSc Thesis, Cranfield University, September 1995.
20. Winwood R, Benstead R & Edwards R, Advanced Fabric Energy Storage 1, 2, 3 & 4 Building Services Engineering Research and Technology 18(1), Spring 1997, P. 1-30.
21. Testing Time, Gulf Construction, May 1993.
22. Press Release from Hollow Core Systems (Mid East) Ltd, January 1995.