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Energy efficient factories: design and performance

D Hughes, BSc

This paper describes the results and assesses the investment economics resulting from the monitoring of occupied factory premises built with fabric insulation to higher standards than required by building regulations, and insulated loading doors.

This paper is addressed to developers, architects, builders, building services engineers, factory owners and tenants and others concerned in the specification, design and construction of modern 'advance' factories.

INTRODUCTION

The nature of UK industry has changed in recent years. There has been a move away from traditional heavy industries towards the smaller, service oriented, high-tech and light engineering industries.

This change is reflected in the types of building that industry now needs. Recent statistics show that since 1977 there has been a growth, from 25% to 60% in the proportion of factories built with a floor area less than 2500 m². A substantial proportion of this growth is the increase in number of small 'advance', or speculative, factories built by private developers, local authorities and Government development agencies. These factories tend to be of a lightweight design using two basic types of construction — diaphragm construction shown in Figure 2a, and cladding construction Figure 2b.

There is considerable scope for improving the energy efficiency of these buildings without significant cost penalty by increasing insulation thickness, by more careful detailing and by installation of insulated loading doors.

Figure 1 A typical low-energy factory

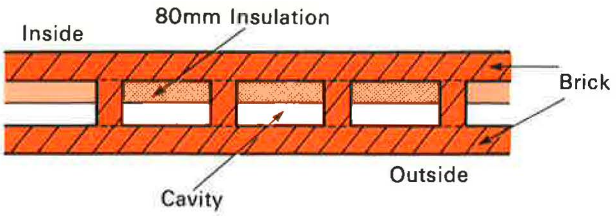

Figure 2a Diaphragm construction (U-value = 0.35W/m²K)

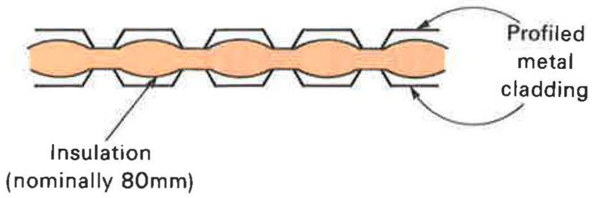

Figure 2b Metal cladding construction (U-value = 0.45W/m²K)

PERFORMANCE EVALUATION

A monitoring exercise was set up in order to evaluate the performance of low energy factories and the economics of their development. In this exercise the energy efficiency of advance factories designed to new energy efficient standards was compared with that of conventional ones. The project also examined the actual energy performance of the factories with reference to their designed energy performance. Six low energy factories were built at locations in South Wales and extensively monitored over two years. The scheme was managed by the Building Research Energy Conservation Support Unit (BRECSU); the project host and developer of the factories was the Welsh Development Agency.

The six low energy factories ranged in area from about 200 m² to about 2250 m². All factories had cladding roofs with U-values of 0.45W/m²/K, three had diaphragm walls with U-values of 0.35 W/m²/K, the remaining three having cladding walls with U-values similar to the roofs. These U-values compare with the 0.7W/m²/K in contemporary building regulations. The improved U-values were achieved by increasing the thickness of insulation from 60 to 80 mm.

All the low energy factories were fitted with insulated loading doors. These had a U-value of 0.45 W/m²/K compared with about 5-6 W/m²/K for conventional doors. The doors were also well sealed at the edges and joints in order to minimise air infiltration through cracks around the units.

Monitoring of the factories was comprehensive. Inside and ambient air temperatures were monitored continuously as was gas consumption for space heating. Air infiltration rates were measured by both constant concentration and pressurisation measurements. In addition thermographic techniques were used to measure the performance of the fabric.

Figure 3 shows the measured performance improvements of the low energy factories when compared with conventional counterparts. The annual energy savings achieved ranged from £929 in the 2250 m² factory to £244 in the 200 m² factories. This was equivalent to savings on the total annual energy bill of 28% to 45% respectively. Table 1 details the findings.

Table 1 Summary of results for all factory sizes

	Factory Size (m²)			
	200	840	1670	2257
Installation overcost (£) (K in NPV/K calculation)	808	1581	2662	3465
Energy savings				
Total — GJ/m²/year	0.27	0.19	0.11	0.08
(Total savings) %	45	45	32	28
— £/year	244	847	945	929
Ventilation component				
— GJ/m²/year	0.21	0.14	0.07	0.04
(proportion of total) %	78	74	64	50
Fabric component				
— GJ/m²/year	0.06	0.05	0.04	0.04
(proportion of total) %	22	26	36	50
Simple payback — years	3.3	1.9	2.8	3.7
IRR — %	31	52	34	25
NPV/K —	1.3	3.1	1.7	1.1

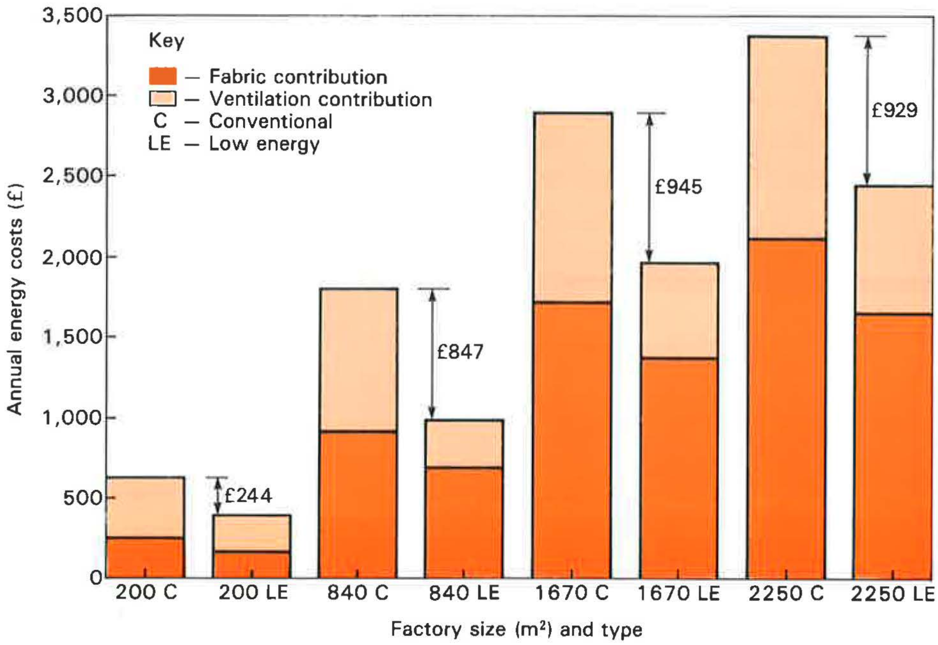

Figure 3 Energy savings in factories

When the separate fabric and ventilation loss components are considered it can be seen that improvements in ventilation performance had a most significant effect. This can be seen in some detail in Table 1 which shows that improvements in ventilation contributed to between 78% and 50% of the total reduction in energy savings.

Figure 4 compares in some detail the air infiltration performance of a small low energy factory with a similar conventional factory and shows that there was a marked reduction (59%) in the infiltration rate in the low energy factory. The installation of insulated loading doors, with good sealing characteristics, had the most significant impact resulting in a reduction of 45% in the infiltration rate.

The actual U-values of the completed factory fabric were compared with design values. To measure this correlation an extensive thermographic survey of the low-energy factories was undertaken. The results are presented in Figure 5 in four forms: *design elemental, measured elemental, structural* (taking into account cold bridging eg brickwork returns in diaphragm construction, spacer battens in cladding) and finally *as-built* (taking into account building errors, eg missing or compressed insulation).

The results from this part of the study bear an important message. It was measured that the cladding roofs had missing or faulty insulation over about 5% of their total area, due mainly to adjacent strips of insulation not being butted together properly. These building errors were shown to increase the *as-built* U-values by 26%, a significant diminution of the average total potential savings through a better insulated roof. The wall sections — both of diaphragm and cladding construction — had considerably fewer building errors, in the order of about 1% of total area resulting in subsequent increases in *structural* U-value to the order of only 2-3%.

Analysis of the performance of the heating systems in the factories also yielded important information. The heating systems installed in the factories represented best current practice. A variety of systems were installed:

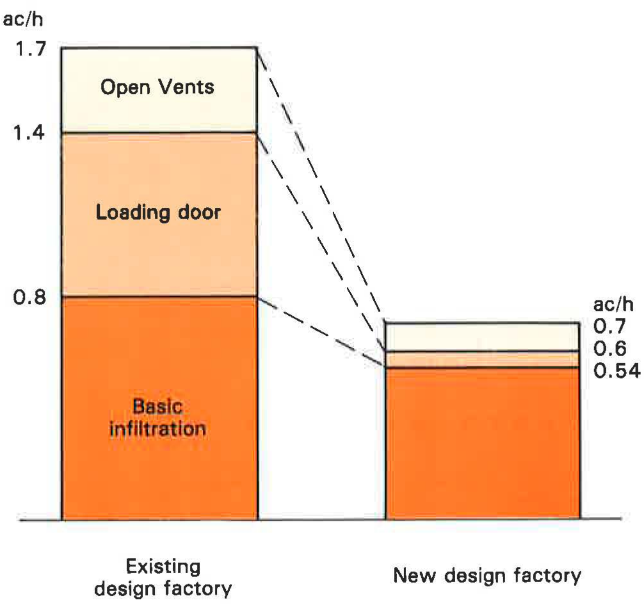

Figure 4 Air infiltration in the two factory types

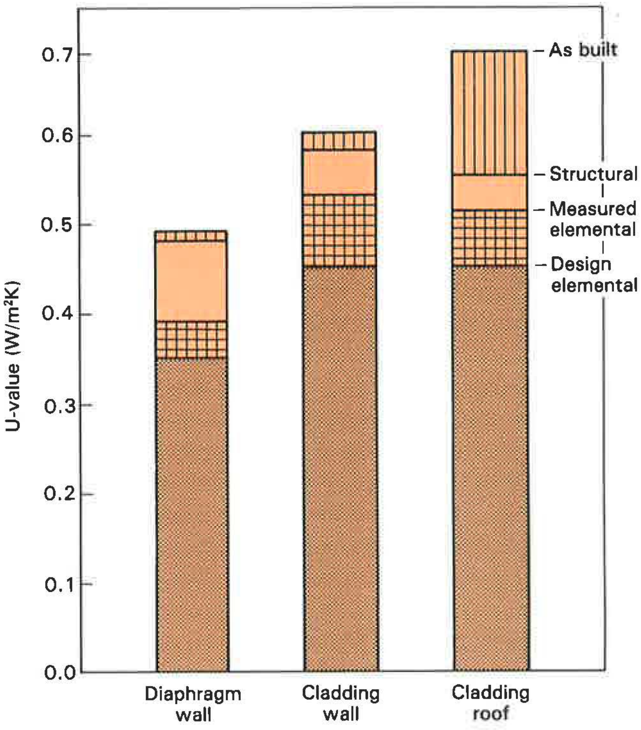

Figure 5 U-values of structure types

a Unit warm air heaters

b Direct fired wall mounted gas fired radiant plaques

c Gas fired radiant tubes

d Medium pressure hot water radiant panels

The low energy factories require very small amounts of heat input, and only system **a** (Unit warm air heaters) allowed modulation, matching system heat output to building demand. The other heating systems resulted in lack of adequate control over heat input to the space, causing overheating and consequent increased temperature gradients (and increasing energy losses through the roof) as well as thermal discomfort. These results show the importance of matching heating systems to building size. Cost savings in the capital expenditure for heating systems will consequently accrue as the correctly sized systems will be smaller and cheaper.

ECONOMIC ASSESSMENT

As shown in Table 1, three methods for assessing the potential of investing in low energy factory design have been considered in this paper, these are: simple payback, internal rate of return (IRR) and net present value per unit cost (NPV/K). The selection of criteria will depend on the individual organisation considering the investment.

The simple payback method relates the overcost of the low energy design to the annual savings achieved. The payback period ranged from 1.9 years to 3.7 years depending on the factory size. The longest payback was obtained for the largest factory (2257 m^2) as the insulation measures relate to the building fabric and the ratio of fabric area to floor area is smallest in the larger building. The impact of the loading door is common to all factory sizes.

If the Internal Rate of Return (IRR) or yield is calculated for these investments (and a lifetime of 10 years considered) then values ranging from 25% to 52% are obtained for these investments.

Another method which may be considered appropriate for assessing energy efficiency investment is net present value. This relates the net present value of the annual savings to the capital cost of the measure discounted at a fixed rate (5% in this case) over the likely (unrefurbished) lifetime of the system (again 10 years). The quotient of net present value over discounted overcost (NPV/K) is the assessment factor, the larger the figure the better value for money it represents.

In this work NPV/K ranged from 1.1 to 3.1 all of which represent very worthwhile investments. Again the lowest value was for the largest factory.

CONCLUSIONS

1 Implementation of the low-energy design measures and principles in this work will result in savings in the order of 28-45% depending on factory size.

2 To achieve these savings care must be taken to ensure correct installation of insulation. 5% missing insulation in the roof can result in an increase in the overall effective U-value of the order of 26%.

3 The savings were achieved within an average payback period of about 2-3 years (on capital overcosts). The NPV/K quotient was between 1.1 and 3.1. These results all imply that the investment was particularly worthwhile.

4 The reduction of air infiltration via the loading door was a major element in increasing the energy efficiency of this type of building.

5 The installation of smaller, better controlled heating systems in this type of factory is beneficial as they will result in increased energy efficiency and lower capital costs.

This work has been undertaken as part of the research, development and demonstration programme of the

Energy Efficiency Office

DEPARTMENT OF ENERGY

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