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Alternative Concepts in Cleanrooms

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1 The drive towards alternative approaches

This paper deals with approaches to cleanroom facilities which have developed in recent years as alternatives to what can be described as conventional solutions. It will emerge that, while these alternative approaches become technically imperative only at the high-performance end of the cleanroom spectrum, there are compelling financial reasons to employ them also for facilities where the performance requirements are less demanding.

The basic objective of a cleanroom has always been to achieve one or more of these three things: product protection, personnel protection, and control of cross-contamination from product to product. One of the main driving forces towards an alternative approach has been the trend to higher performance requirements, particularly in the pharmaceutical and mircroelectronics industries. One key element of cleanroom performance, though by no means the only one, is the particulate count. Here the trend has been inexorably towards lower counts, as technical requirements in the microelectronics industry become more demanding, and manufacturing regulations in the pharmaceutical industry more stringent.

Table 1: Particle Emission by Humans

Particles over 0.5 micron per minute	Type of movement
100,000	Standing or sitting still
500,000	Sitting with slight head, hand or lower arm movement
1,000,000	Sitting with medium body and arm movement, also slight foot movement
2,000,000	Standing with full body movement
5,000,000	Walking slowly (3.5 km/h).
7,500,000	Walking normally (6 km/h).
10,000,000	Walking briskly (9 km/h).
15-30,000,000	Free exercise and games

By far the most prolific emitters of particulate matter are human beings (see Table 1), and though the gowning of cleanroom personnel reduces this problem it does not by any means eliminate it. Table 2 shows the particle size requirements for the different classifications of the US Federal Standard 209b. At the low-performance end of the scale, a Class 100,000 cleanroom must have less than 100,000 particles at 0.5 micron size and over per cubic foot of air; it must have a descending quantity of larger particles — eg, at 10 micron size the permitted level is between only 100 and 200. At the high end of the scale, a Class 100 cleanroom must have less than 100 particles per cubic foot at 0.5 micron size and over, and the curve drops much more sharply: only about 20 particles of over 1 micron are permitted, and none at all over 4 microns. (Note: The Class 1,000 classification shown is not officially part of the Federal Standard, but has become a *de facto* standard and represents an increasingly common classification in actual use.)

Table 2: Maximum Particulate Counts permitted per cubic foot of air (US Federal Standard 209b)

Class	Size (microns)		
	0.5	1	5
100,000	100,000	20,000	700
10,000	10,000	2,000	60
1,000*	1,000	200	0
100	100	20	0

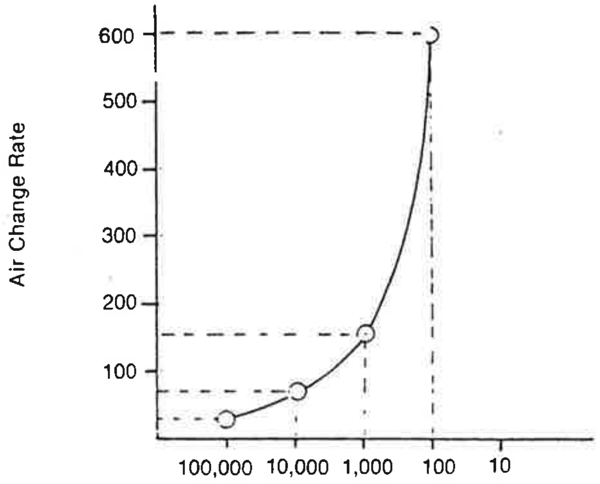
* indicates *de facto* standard

The design implications of moving up the classification scale (ie, of moving towards *lower* particulate counts) is dramatic. The chart in table 3 shows the volume of filtered air, expressed in air changes per hour, which is required to reduce particulate levels at different classifications. As is immediately obvious, the increase as we move towards higher performance is near-exponential. It is this fact that calls into question the viability of conventional approaches as performance requirements rise, because there is also a very substantial increase in both the capital and running costs of moving such large quantities of air by conventional means.

Further pressure is put on the conventional approach by the factors in cleanroom performance apart from particulate counts. Among these are:

- *airflow patterns,* which must be balanced not only from an airconditioning viewpoint, but also from a micro-contamination viewpoint;
- *temperature and humidity control,* which is required by process needs and for the comfort of personnel;
- *noise,* which is important because operatives work in cleanrooms for long periods with a high level of attention to detail;
- *vibration,* which is relevant where sensitive alignments and measurements are part of the process to be carried out in the cleanroom;

Table 3:
Air Volumes required at different Cleanroom classifications



Clean Room Classification (FED 209B)

- *static charges,* which can be transmitted by materials and personnel, and which can cause accumulations of particulate matter and affect product performance;
- *radio frequency interference,* which affects the sensitive equipment typically used in cleanrooms: systems that generate RFI cannot therefore be used.

Among the many other interacting variables which affect the approach to cleanroom facilities, two call for special mention. *Reliability* is of prime importance because of the very high cost of downtime and process or product failure, in the expensive and lengthy production processes that typify cleanroom applications. *Flexibility* is equally important; because of the high investment involved in a cleanroom, increasing emphasis is being placed on the ability to make the fullest use of the facility throughout its projected life, a time-span that may see considerable changes in the process, equipment and product.

2 Conventional and alternative approaches

What is the conventional approach to cleanrooms that is being put under pressure by these developing trends? Familiar approaches to cleanroom design employ a *central plant system,* which conditions all air supplied to the cleanrooms and returns it for reconditioning and recirculation. However, as we have seen, the air volumes needed for a cleanroom of this type are substantial. This approach calls for large airhandling equipment, heating and chilling plant, extensive air duct distribution systems and large plantrooms and service voids. Because of the obvious impact on capital and installation costs, together with the performance difficulties they create, it is prudent to ask: can these problems inherent to the conventional approach be avoided?

Often, a cleanroom's thermal and ventilation needs form only a small part of the total air requirements for particulate control. *The provision of excessive plant can be avoided by locally recirculating most of the room air.* In this way the central airhandling plant is by-passed, and is left to condition only that air which is essential to the room's thermal and ventilation needs. To apply this approach, we must seek ways of *integrating* the design of the airconditioning system with that of the room.

A large number of design concepts can be applied to cleanrooms. These concepts are based largely on the performance requirements of the room and the types of application for which they are needed. The concepts fall basically into the categories of their particulate level classification mentioned in Section 1.

Air volumes required for Class 100,000 are relatively small and need not concern us here. However, alternative approaches are highly relevant to each of the three other classes, and merit being considered in turn. We shall do this in ascending order of cleanliness requirement.

(i) *Class 10,000*

Class 10,000 areas consist typically of a suite of cleanrooms where different processes or operations are carried out. The air-change rate ranges between 30 and 50 per hour — a modest figure compared to cleanrooms of higher classification, but high by comparison with the room's thermal requirements.

CLASS 10,000 — CONVENTIONAL

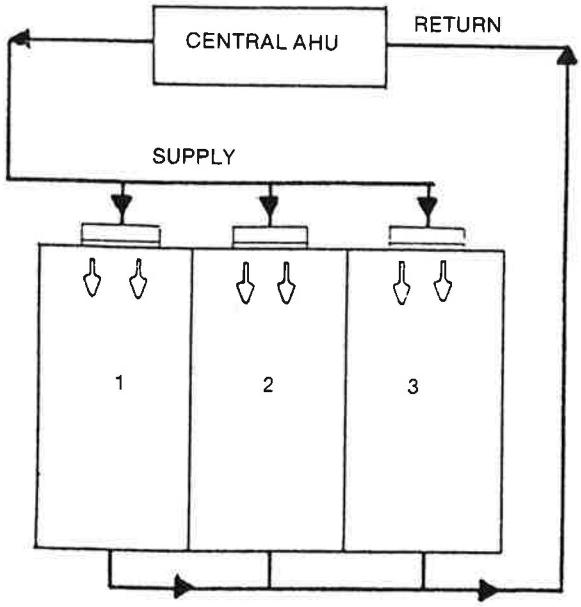


Fig 1

Conventional approach: Fig 1 shows a familiar way of dealing with this situation. A central plant conditions all air, which is supplied to individual rooms through distributed terminal filter units; temperature control is by individual room re-heat batteries. A disadvantage of this arrangement is that the quality of conditioned air from the central plant is governed entirely by particulate needs and not by the room's thermal and ventilation requirements.

Alternative approach: In the system shown in Fig 2, air is supplied to individual rooms through distributed laminar flow ceiling modules. A negative-pressure ceiling void makes possible the recirculation of some cleanroom air, thus by-passing the main plant; air returns to the plenum through airwalls within the cleanroom. This approach substantially reduces the need for large plant installations and distribution systems. At the same time, it provides individual room control by supplying conditioned air directly to laminar flow ceiling modules catering for the thermal needs of each room.

In Class 10,000 cleanrooms, air requirements to overcome room loads occasionally exceed the particulate needs of the

CLASS 10,000 — ALTERNATVE

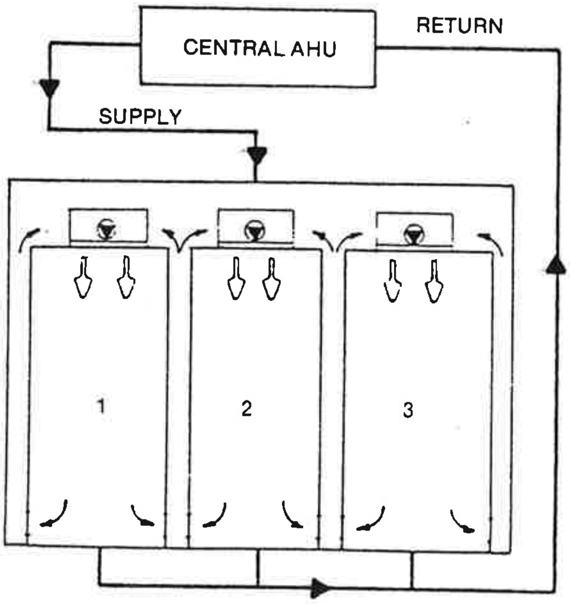


Fig 2

CLASS 1,000 — ALTERNATIVE

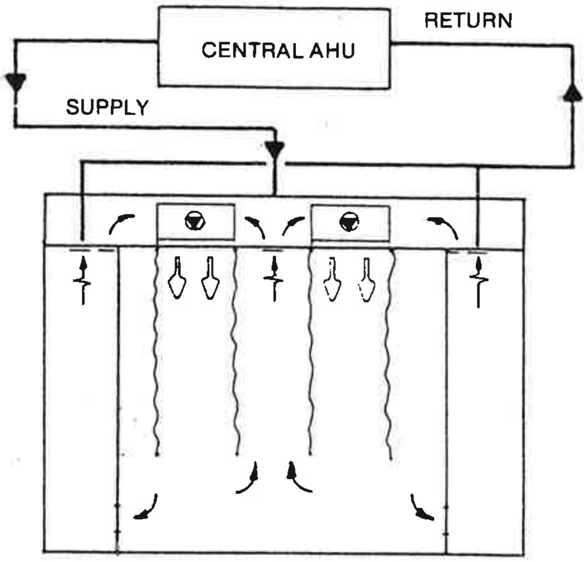


Fig 4

CLASS 1,000 — CONVENTIONAL

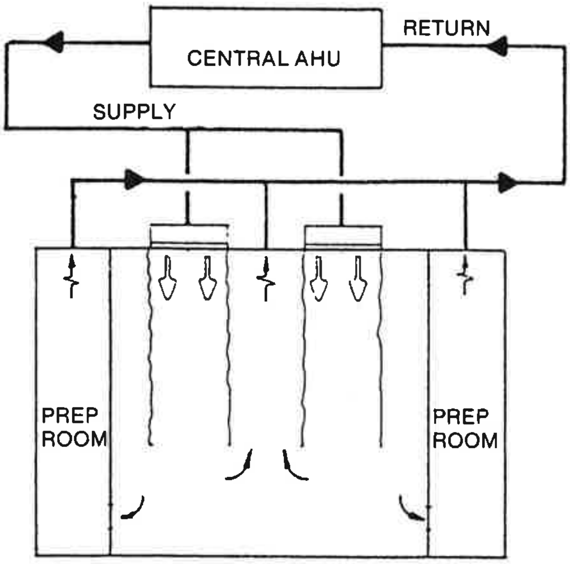


Fig 3

CLASS 1,000 — ALTERNATIVE

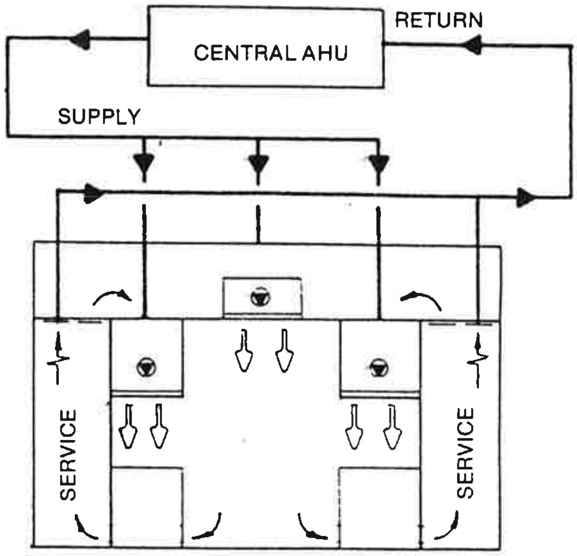


Fig 5

room. This can be dealt with by a cooling coil in any module serving a room with excessive room loads.

(ii) *Class 1,000*

As we move upwards in the classification table, the volumes of air involved increase dramatically and thermal room loads have less impact on the total volumes of air required.

The normal requirement in a Class 1,000 cleanroom calls for the protection of a particular product or process within the room by the creation of a Class 100 area directly above the product. This area is protected from contamination by suspending drapes around it. The rest of the room is kept at a lower level of control, giving a combined effect of Class 1,000 throughout the room in general.

Typical applications are in the pharmaceutical industry, where the cleanliness of containers after washing must be maintained and microcontamination of preparations avoided during bottling and capping. The entire process is protected from contamination by creating a screened Class 100 area along the length of the process line.

Conventional approach: Fig 3 shows a common approach for this type of application. Air is supplied from the central plant to filter banks directly over the product, and also to terminal filters distributed throughout the room. Air is extracted at low level around the room perimeter, and at high level outside the drapes of the Class 100 area. As with the Class 10,000 example dealt with above, there is total return of air to the central plant — only in this case the plant requirements are much greater.

Alternative approach: Fig 4 shows how local recirculation can be used in this type of application. Again we make use of the negative-pressure ceiling concept for recirculation, returning air through the airwalls enclosing the cleanroom

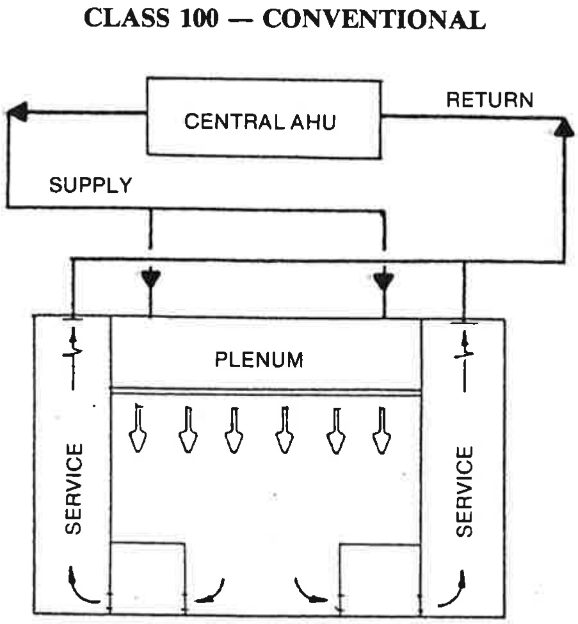


Fig 6

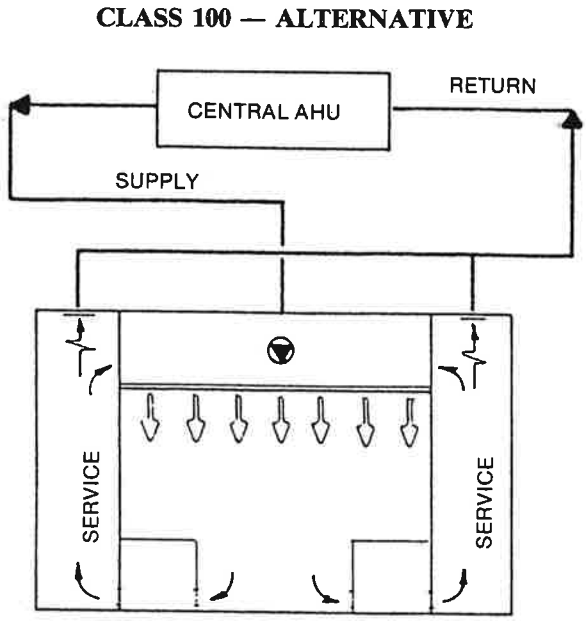


Fig 7

and the ceiling grilles outside the drapes of the process line. Laminar flow modules supply air to the process line. How the rest of the room is treated depends largely on its size and needs. For large installations, modules can be positioned strategically to optimise the efficient distribution of air within the room. In all cases, however, the important factor is that most air supplied to the room by-passes the central plant. This produces large savings in capital and running costs, and in the space requirements of the installation.

Another typical application of a Class 1,000 cleanroom is in wafer fabrication in the semiconductor industry. This also requires Class 100 over the production line and Class 1,000 in work aisles. Fig 5 shows how recirculation can be used in the service aisle to reduce plant requirements. Conditioned air feeds directly from the central plant to individual laminar flow ceiling modules, to counteract the various heat loads along the process line. Excessive heat loads in a particular area are offset by a cooling coil in the module above. Air returns to the central plant from the service aisles, minus any process exhausts dumped to outside.

It is worth noting that the total air requirements of the room may be many times greater than its thermal needs. As the overall values for this type of installation are extremely large, the savings which can be made through the use of local recirculation are equally large.

(iii) *Class 100*

Many cleanroom installations demand total laminar air flow throughout, to remove all particles and prevent microcontamination.

Conventional approach: Fig 6 shows a conventional approach to such an application (semiconductor wafer fabrication). All air is supplied from the central plant across terminal filter banks and returned through the service aisles for mixing, reconditioning and recirculation to the cleanroom.

Alternative approaches: Fig 7 shows one way of tackling the problem through local recirculation. Here each work aisle is served by a series of laminar flow ceiling modules. Air is returned at low level to the service aisles at either side of the work aisle, where most of it is recirculated through prefilters on top of the ceiling modules. The rest, minus any process exhaust, is returned to the central plant. The recirculation air is mixed with conditioned air from the central plant being supplied to the room.

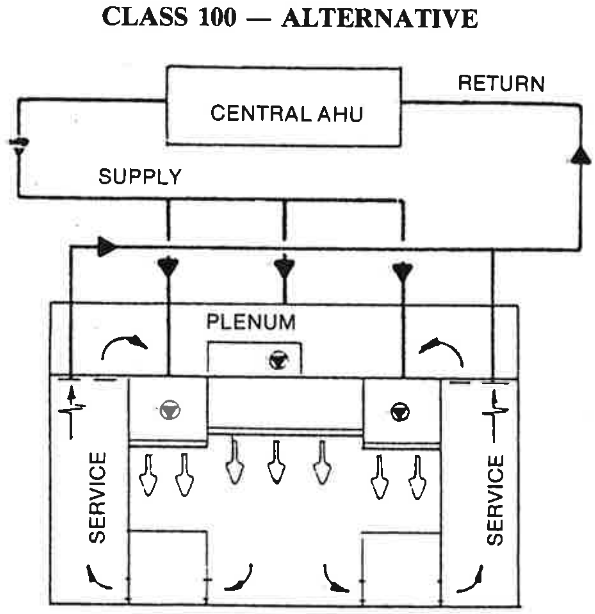


Fig 8

Fig 8 shows another recirculation approach. Here laminar flow ceiling modules cover the entire length of each process line, while a separate localised air conditioning unit serves a filtered ceiling covering the work aisle. Conditioned air from the central plant is fed to the local recirculating system to look after thermal needs. The main advantage of this system over Fig 7 is that it offers separate control of the work aisle to look after the needs of the occupants, isolating it from the process line where thermal loads are much greater. Cooling coils in individual modules can treat areas of particularly high heat loads along the process line.

Approaches 7 and 8 suit applications where the process is carried out within a relatively narrow aisle (up to approximately 4.0 m). However, many processes demand much wider cleanrooms, and the transport of products from

CLASS 100 — ALTERNATIVE

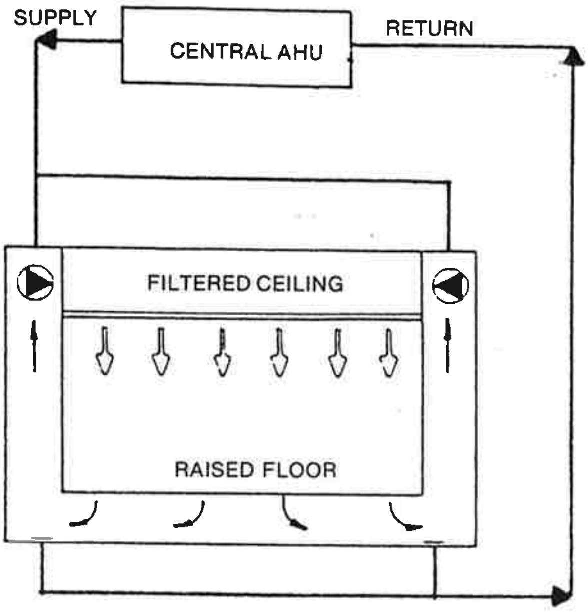


Fig 9

one stage of the process to another creates the need for a total laminar flow ceiling. For such applications a different approach is called for.

Fig 9 shows a solution to this problem by creating a positive-pressure plenum above the filtered ceiling. Recirculating fans in the void give an even distribution of air across the filtered ceiling. Air is extracted through grilles in the raised floor, and returned through airwalls to the recirculating fans. Conditioned air from the central plant is mixed with the recirculated air to overcome the room's thermal and ventilation needs. Alternatively, coils within the recirculation system can be used to overcome particularly high room loads.

Fig 10 shows how a laminar flow wall module can be used effectively in hospital operating theatres. Here the need is to prevent contamination of open wounds by removing all particles and micro-organisms from the operating area. Horizontal air flow patterns carry contaminants away from the area of the wound. A glass screen at either side of the operating area facilitaties air return to the recirculation fans. Conditioned air is fed from the central plant to mix with the recirculated air, to remove thermal loads and provide ventilation for occupants. Some of the clean air can be extracted through the preparation rooms beside the operating theatre, giving a high level of cleanliness to these rooms. This air can then be returned to the central plant.

3 The impact of alternative approaches on cost

It will be obvious from the foregoing that at the Class 100 level, the difference in cost between the conventional approach and the alternative approaches will be very substantial. At that level, also, cost is far from being the only consideration militating against a conventional approach: the difficulty of delivering to all the parameters of the performance specification may rule out the use of a conventional approach from the start.

In the case of cleanrooms of other classifications, the performance specification can usually be met by either the conventional or the alternative approaches. In this situation the decision on which approach to adopt will depend on

CLASS 100 — ALTERNATIVE

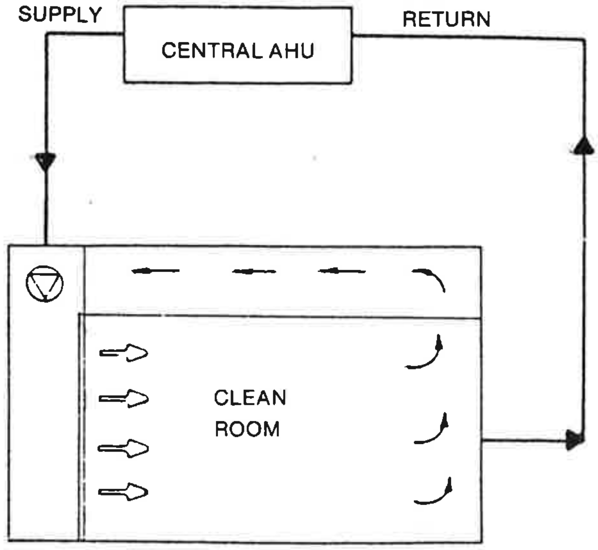


Fig 10

other factors, of which by far the most important is cost. For this reason we will concentrate in this section on comparing directly the capital and running costs of both approaches in two actual Class 10,000 and Class 1,000 cleanrooms.

Table 4 illustrates the capital cost comparison for the Class 10,000 installation. The conventional system assumes a central airhandling unit feeding to distributed terminal filter units, with total recirculation of air to the central plant. The alternative approach comprises a central airhandling unit feeding to distributed laminar flow ceiling modules, operating on a high level of local recirculation.

TABLE 4:
CAPITAL COSTS ON A CLASS 10,000 CLEANROOM

	Elements	Conventional	Alternative
Savings	Ductwork	100	45
	Air handling unit	100	58
	Plantroom	100	64
Equal Costs	Boiler plant	100	100
	Chiller plant	100	100
	Heating pipework	100	100
	Controls	100	100
Additional Costs	Building structure	100	110
	Terminal filters/LAFs	100	115
	Chiller pipework	100	135
	Structural steel	100	200
TOTAL PROJECT COST:		100	92

The table is presented so that the cost of each element and the total cost for the conventional approach is indexed at 100, and the costs for the alternative approach are shown in each case relative to that index. As may be seen, major savings are offered by the alternative approach in the ductwork, airhandling equipment, and plantroom floor areas. Some items will not change in terms of capital cost (though some of these will offer sizeable reductions in running costs). A number of items will cost more, though as is clear from the overall cost figure, the savings far outweigh the increased costs.

In this case of a Class 10,000 cleanroom, the overall capital cost advantage of an alternative approach is calculated at 8 per cent. (This is a worst case situation, as some of the room loads in the actual example were relatively high. Larger