

A positive, individually ventilated caging system: a local barrier system to protect both animals and personnel

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Summary

Most local barrier systems are designed primarily either to protect animals from airborne contamination (exclusion) or to ensure the safety of personnel (hazard containment). Few, other than isolators, are able to cope with the often conflicting demands to do both. The Positive Individually Ventilated system (PIV), which provides pressure adjustable, individual supply and exhaust ventilation to each cage has been tested with this in mind as well as the need to ensure that environmental conditions comply with the requirements of the Home Office Code of Practice (CoP).

The results indicate that when compared with traditional open racking the system can reduce both the risk of animals becoming contaminated by airborne infection from the room and the risk of aeroallergens escaping from the cages into the room air. At the same time, environmental conditions within the cages are both less variable and less stressful to the occupants. Conditions of air temperature, relative humidity, ventilation rates, light intensity and (with appropriate air handling) sound levels, all comply with or are better than those required by the CoP.

Even with the room air change rate set at only 8/h (8 ac/h) the air distribution system results in draught-free cage ventilation rates of around 50–120 ac/h. This means that with at least the PIV exhaust(s) linked directly into the air conditioning system of the building, the size of the latter and its associated running costs can be reduced by around 50%; this energy saving concept has been approved in principle by the Home Office. Additional benefits include the fact that bedding is kept much drier allowing further cost savings in bedding and associated labour costs.

The system is thus beneficial to the animals in protecting them from airborne infection and other stresses. By providing a less variable environment it also helps to minimise the sort of interference with experiments which can arise from that source. Similarly, in accordance with the aims of 'The Control of Substances Hazardous to Health Regulations' (COSHH 1988) and the Health & Safety Executive (HSE 1990), by reducing dust levels in the room air, including allergens, it is also beneficial to the personnel working in the animal rooms.

Keywords Local barrier housing; environmental control; microenvironment; cage ventilation; containment system; COSHH

There are 2 major factors that have influenced the housing of laboratory animals over recent years. Firstly the increasing use of microbiologically defined

animals and secondly the need to protect personnel from the hazards of working with animals. The first demands the protection of animals from undesirable

organisms arising from outside their immediate environment, the second, protection of personnel from hazards arising from the animals, particularly airborne allergens. For many employers the significance of the latter was considerably increased when laboratory animal induced asthma became a prescribed industrial disease in 1981 and again in 1990 when 'The Control of Substances Hazardous to Health Regulations' (COSHH 1988) were implemented. Attempts to satisfy both these needs simultaneously can lead to conflicting requirements in terms of, for example, air distribution patterns within rooms (Clough 1987). Technological developments designed to cope with one or other of the above demands are constantly being refined (Keller *et al.* 1983, Torii *et al.* 1985, Yamauchi *et al.* 1989, Wathes & Johnson 1991, Lipman *et al.* 1992) though few devices other than those providing complete separation between animals and personnel, such as flexible film isolators, are able to cope with both.

Development of the PIV system of housing rodents began in 1963 at the Jackson Laboratories (Bar Harbour, ME 04609, USA). The prototype, built in 1966, underwent 4 stages of development and the current version, PIV Type III, has been in successful use there since 1981 (Personal communication, E. P. Les; Cunliffe-Beamer & Les, 1983, Schulhof 1990). Tests carried out on the system suggest it is able to meet both the demands described above as well as complying with the requirements of the Home Office Code of Practice for the Housing and Care of Animals used in Scientific Procedures (Home Office 1989) (CoP) associated with the Animals (Scientific Procedures) Act 1986.

Materials and methods

Animals and husbandry

When required, conventional mice of any strain, age and either sex, from stocks held by the institute concerned were used to provide maximum cage stocking levels

allowable under the CoP. Numbers per cage ranged from 3–5 mice of more than 30 g to 5–8 mice of less than 30 g according to cage size. The animals were provided with a pelleted diet and mains tap water *ad lib*, wood shavings were used as bedding and they were cared for in accordance with the normal practice of the institute.

Pressurized, individually ventilated cage system

The commercially available system used for the studies reported here (the Thoren Maxi-Miser, Thoren Caging Systems Inc., 815 West Seventh Street, Hazleton, PA 18201, USA) was a 112 polycarbonate cage, double-sided mouse rack of stainless steel construction provided by Lab Care Precision Ltd. (Calleywell Barn, Goldwell Lane, Aldington, Kent, TN25 7DX, UK). The system, illustrated in Figs 1 and 2, is such that air is supplied to and exhausted from each cage individually. Each cage is suspended from supporting rails attached to the hollow shelf above, which is divided internally lengthways to form 3 separate plenum chambers. The central plenum supplies air to cages on both sides of the rack and the 2 side plenums remove the exhaust air via optional disc filters which can be located in the exhaust holes. Each rack can be provided with an associated air handling unit which can be top, bottom or floor mounted. This has separate supply and exhaust fans each provided with a high efficiency (HEPA) filter. Adjustable dampers are available to control the relative pressure of the air in the supply and exhaust plenums in such a way that the air pressure within the cages can be either negative, equal or positive to that of the room. Manometers, provided on both supply and exhaust ducts, allow critical balancing. It is thus possible to use such racks as free-standing systems, needing only a power socket to supply the air handling unit. In this mode they are supplied with filtered air taken from the room which is then filtered again before being returned to the room. A very important aspect of the racks, however, is the facility to link their air supply and/or

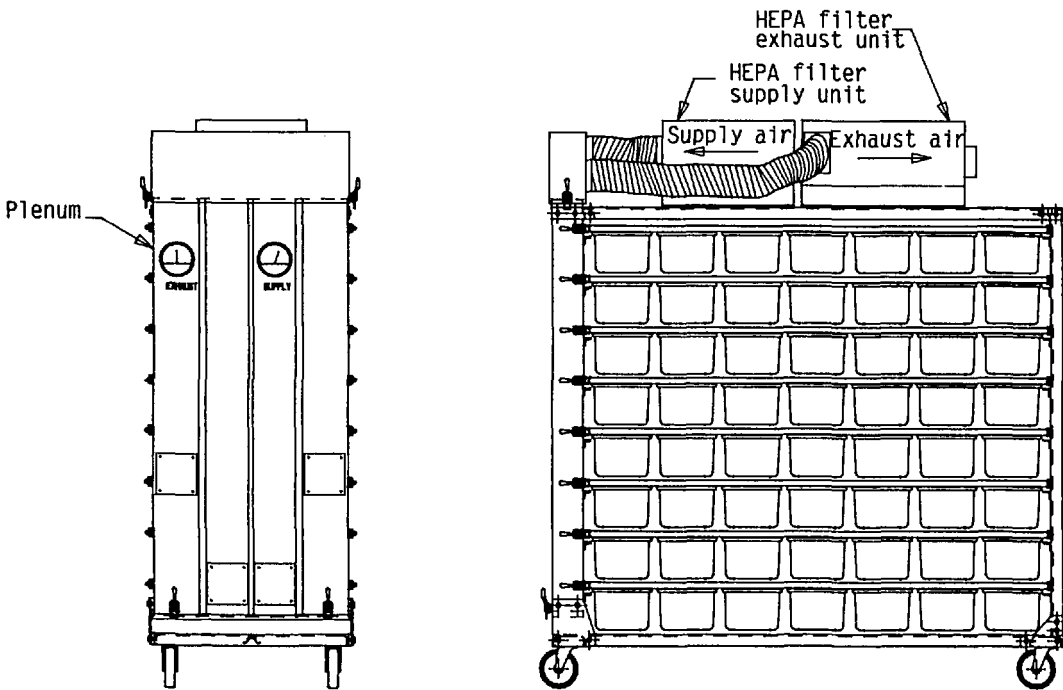


Fig 1 Diagram to show the structure of the 112 cage, double sided Thoren Maxi-Miser mouse rack

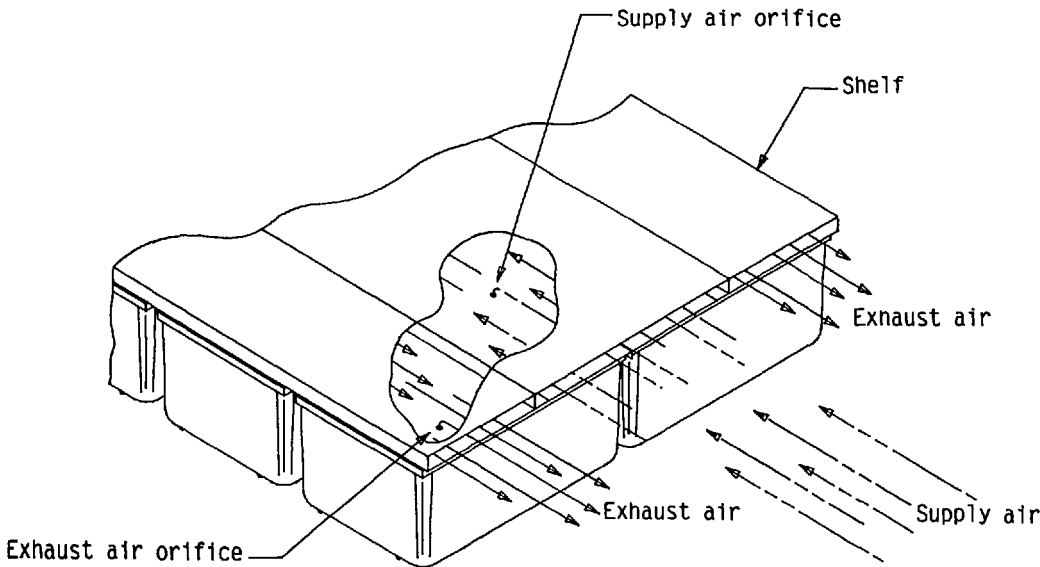


Fig 2 Diagram to show the air supply to and from each cage via the 3 plenum chambers formed inside the hollow shelves

exhaust spigots directly to the central ventilation system of the building thus avoiding mixing of the supply and exhaust air. Cages are provided with the commonly used type of stainless steel

wire cage top incorporating the food hopper and water bottle holder. This can additionally be provided with one of 3 different types of protective cover:

1. An autoclavable, plastic-framed filter top which fits snugly over the top edge of the cage
2. A similar filter top but provided with a single valve which opens under the air supply nozzle as the cage is inserted into its supporting rails
3. A close-fitting, solid, plastic top with 2 valves located in such a position that each opens under the supply and exhaust air nozzles as the cage is inserted into its supporting rails. The exhaust valve can be fitted with a disc filter in place of those that may be fitted to the exhaust holes of the outer plenums (see above)

For some tests, as indicated below, some cages on the rack were provided with cover type 1 but with 2 holes pierced in the filter material in positions corresponding with the air supply and exhaust nozzles above.

Control rack

Traditional, single sided, open mouse racks of painted steel or aluminium alloy construction, holding 56 M2 or M3 polypropylene cages (North Kent Plastics, Dartford, Kent, UK) were used as controls.

Tests for compliance with the Home Office CoP

For those tests where it was appropriate, each cage was stocked with the maximum number of mice allowable according to the CoP. Unless otherwise stated, tests were conducted with the racks housed in an animal room designated under the Animals (Scientific Procedures) Act 1986 and approved by the Home Office Inspectorate as complying with the requirements of the CoP.

Light intensity

This was measured using a GEC Minilux 2 illumination meter with a colour coated correction cell (GEC Measurements, General Electric Co. Ltd, St Leonard's Works, Stafford, ST17 4LX). Room light intensity was measured in the centre of the room, 1 m from the floor. Cage levels were measured centrally, at cage floor level in a

cage without animals but provided with food and an empty water bottle. All other cages on the rack were full of animals with food and water bottles in position.

Sound levels

These were measured using an IVIE IE-10A audio spectrum analyser (Sound Products, PO Box 91, Newport, Gwent, NP9 1YP) for both dB(A) and noise rating curve (NRC) determinations. Sound pressure level measurements were carried out 1 m from the floor in the centre of the room with the animal cages empty.

Ventilation rates

These were measured using an Analytical Instruments Model 505 detector chromatograph ventilation rate meter (VRM) (AI Ltd, London Road, Pampisford, Cambridge, CB2 4EF) employing sulphur hexafluoride (SF₆) as the tracer gas. The technique used was based on those developed to measure ventilation rates and check on air transfer between rooms in hospitals (Lidwell 1960, Foord & Lidwell 1973). Because the Thoren rack available had its own air handling unit and thus re-circulated room air, SF₆ being used to measure air change rates within the rack could also be re-circulated and produce false results. Thus, on those occasions when cage ventilation rates were being measured, procedures were adopted to ensure that the air from the rack was exhausted directly to the outside of the building so avoiding this problem.

Air temperature and relative humidity

Recordings of air temperature (T) and relative humidity (RH) were made using Lee-Integer DHL-48 data loggers provided with CH-12 T/RH probes (Ancom Signatrol (UK) Ltd, Unit C2 Northway Trading Estate, Tewksbury, Glos, GL20 8PA).

Room T and RH was recorded from probes located in the air approximately 20 cm in front of and just above an animal rack. Cage air T and RH was recorded from probes located either in the empty food hopper (food then being provided from an alternative source within the cage) or

introduced into the front of a cage through a pre-drilled, grommited hole, the probe being protected from the animals by a perforated plastic tube surrounding it.

Tests not directly associated with the CoP

Detection and characterization of ultrasound frequencies

This was carried out using a QMC Mini Bat Detector with a range of sensitivity from 10 kHz to 160 kHz. (QMC Instruments Ltd, Queen Mary College, Mile End Road, London E1). As for the assessment of audible sounds, measurements were carried out with the animal cages empty.

Air pressure differentials

These were measured with the rack full of empty cages using an Airdata Multimeter micromanometer (Shortridge Instruments Inc, 7855 E. Redfield Road, Scottsdale, Arizona 85260, USA). The front of the cage used for checking within-cage air pressure was fitted with a brass nipple of the appropriate size to accept the sampling tube from the micromanometer. So that air pressure could be checked in cages in various positions on the rack this 'measuring cage' was interchanged with cages in the positions shown in Table 3.

Containment tests

In order to assess the ability of the system to reduce or prevent the transfer of airborne particles between room and cage air, the PIV caging and control (NKP) racks were set up in an animal room housing conventional mice. These were held in 3 NKP racks arranged in the shape of a U; the 2 test racks were placed parallel to each other within the arms of the U with its closed end up-wind. Settle plates (sterile Petri dishes containing nutrient agar) were exposed in the pre-sterilized cages of the PIV caging and control rack overnight for 16–20 h. The plates were then removed from the cages and cultured at 30°C for 24–48 h. The number of colony-forming units (CFUs) growing on each plate was

assessed by direct counting. The test was carried out twice, firstly with the PIV rack balanced so that the cage air pressure was positive and secondly negative compared with that of the room. During the positive test there were 1239 mice in the room, the PIV rack supply plenum air pressure reading was +107 Pa and that of the exhaust, +13 Pa. For the negative test there were 1177 mice present, the supply plenum reading was +13 Pa and the exhaust +107 Pa. In both tests all cages on the control racks had wire tops. Of the 112 cages on the PIV rack, 33 had wire tops only, 33 were additionally provided with cover type 1, 33 with cover type 1 with 2 holes, 4 with cover type 1 with a single valve over the supply nozzle and 9 with cover type 3.

Taking the mean number of CFUs per plate on the control rack as 100% and comparing this with the mean number of CFUs per plate on the test rack the percentage protection provided by the test rack was calculated.

Results

Tests for compliance with the Home Office CoP

Light intensity

The light intensity measured 1 m from the floor at the centre of the room was 580 lux. The levels measured inside the animal cages are shown in Table 1 and ranged from 20–62 lux in the transparent, polycarbonate cages on the PIV rack and from 28–530 lux in the translucent, polypropylene cages on the control rack. Along row variation on the PIV rack ranged from 1.4 to 1.9 times brighter in the brightest cage compared to the dimmest (20 v. 28 and 24 v. 42 lx), whilst on the control rack it ranged from 1.7 to 12.5 times brighter (320 v. 530 and 36 v. 450 lx). The brightest cage on the top row of the PIV rack was 3 times brighter than the dimmest on the bottom row (62 v. 20 lx), whilst that on the control rack was 19 times brighter (530 v. 28 lx).

Table 1 Light intensity measurements (lux) in animal cages

Rack row	Traditional rack						PIV rack							
	(54 Polypropylene cages)						(56 Polycarbonate cages)							
1	320	320	340	360	360	530*	62	36	38	42	48	52	52*	
4	—	—	—	—	—	—	38	32	28	24	26	42	46	
5	84	36	42	47	84	450	—	—	—	—	—	—	—	
8	—	—	—	—	—	—	28	20	22	26	20	22	23	
9	79	28	32	44	58	300	—	—	—	—	—	—	—	

*Window end of room

Sound levels

The results (see Table 2) show that the background sound level in the room increased from 46 dB(A)/NRC42 to 53 dB(A)/NRC48 with the air handling unit (AHU) mounted on the top of the rack and 58 dB(A)/NRC56 with a separate, floor mounted AHU. The bracketed figures in the Table show that the sound levels exceeding those recommended in the CoP are in the frequency range 125 Hz to 4 kHz.

Ventilation rates

With a room ventilation rate of 17 ac/h, the ventilation rate of one cage on the top shelf, one on the middle and one on the bottom shelf of the control rack ranged from 13–19 ac/h whilst that of 3 similarly situated cages on the PIV rack ranged from 60–81 ac/h.

More intensive studies of cage number 25 on the PIV rack demonstrated that the air change rate varied depending upon pressure differentials and whether or not a disc filter was in position on the exhaust outlet. The lowest ventilation rate of 48 ac/h occurred when the within-cage air pressure was negative to that of the room and a disc filter was fitted in the exhaust

valve; with the disc filter removed, the ventilation rate went up to 129 ac/h. When the within-cage air pressure was set positive to that of the room, the ventilation rate was 122 ac/h with the filter in position and 142 ac/h without.

These results compare well with the manufacturer's own findings that in an open top cage, or one fitted with a solid lid with 2 valves, the ventilation rate varies from 68–139 ac/h. Their results were obtained by calculation using anemometric methods to determine the volume of air entering a cage and comparing this with its volume.

Air temperature and relative humidity

Figures 3a and 3b show records of air temperature (T) and relative humidity (RH) collected over a period of one week in an animal room with a ventilation rate of 18 ac/h. The figures also compare the room conditions with those from 2 cages on the PIV rack and 2 in similar positions on the control rack (cage 11 and 35 on the PIV rack and 10 and 36 on the control rack). All cages were filled with mice to the maximum stocking density allowed under the CoP.

Table 2 Sound levels measured at the centre of the room, 1 m from the floor under the conditions shown (Numbers in brackets exceed the CoP requirements)

State of PIV rack	Octave band mid frequency (Hz)									
	dB(A)	63	125	250	500	1k	2k	4k	8k	NRC
OFF	46	46	40	42	42	42	40	33	33	42
ON, top mounted AHU*	(53)	62	(62)	53	(49)	(48)	(44)	40	36	(48)
ON, floor mounted AHU	(58)	60	(69)	(61)	(59)	(53)	(48)	(42)	36	(56)
(CoP requires NRC 45		71	61	54	48	45	42	40	38	45)

*AHU=Air handling unit

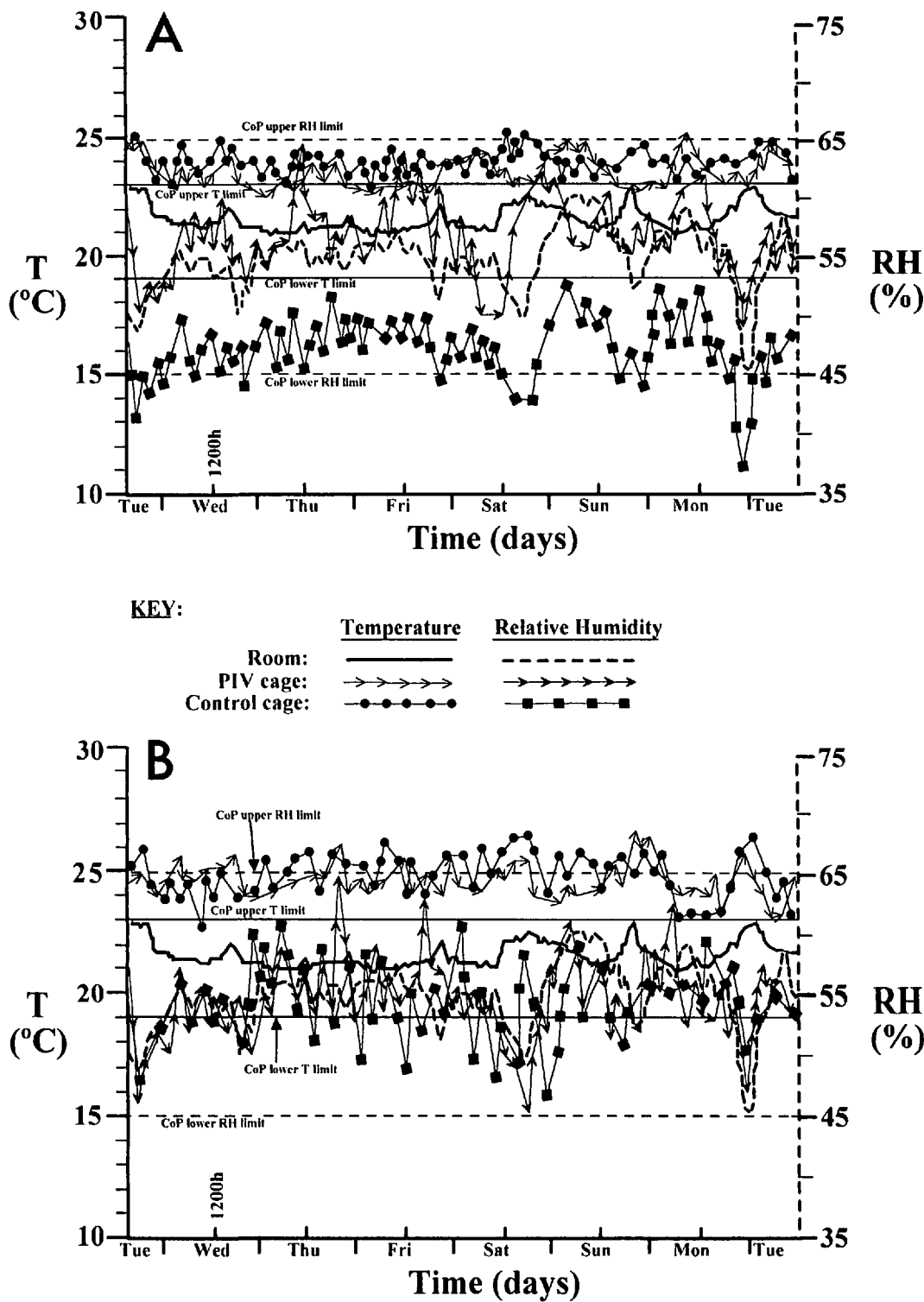


Fig 3 Temperature (T) and relative humidity (RH) records for one week from air in the room: A, in cage 11 of the PIV rack and cage 10 of the control rack; and B, in cage 35 of the PIV rack and cage 36 of the control rack

The records show that on both racks, in common with previous reports (Allander & Abel 1973, Clough 1984), cage T remains at around 1–4°C higher than that recorded from the room. In the case of RH, it can be seen that except for a few hours in cage 10 on the control rack, this parameter remained within the upper and lower limits recommended by the CoP in both the room and the cages.

Table 3 Air pressure in Pascals measured inside an empty cage with a solid top and 2 valves or (bracketed figures) a filter top with 2 holes in cage positions 1, 7, 25, 50, 56, 57, 63, 81, 106 and 112 in the PIV rack and with or without the exhaust disc filter fitted as indicated

Plenum pressure Range of mean air pressures in cages setting (n=6)			
Exhaust	Supply	Without filter	With filter
+127	+13	–8.56 to –4.70	–2.98 to –0.75
+13	+127	+10.04 to +16.25 (+1.20 to +1.60)	+13.97 to +23.18
+102	+51	–2.21 to +1.08 (–0.70 to –0.50)	+5.15 to +5.19

Tests not directly associated with the CoP

Detection and characterization of ultrasound frequencies

No ultrasounds were detectable arising from the PIV system.

Air pressure differentials

The bracketed figures in Table 3 show that in cages fitted with filter tops with two holes and no disc filter present, air pressure within the cage was just over +1 Pa with the supply plenum pressure set about 10× higher than that of the exhaust (+127 v. +13 Pa); with the supply pressure set at half that of the exhaust (51 v. 102 Pa), air pressure within the cages was around –0.6 Pa.

The greatest cage v. room pressure differentials (up to +23 Pa within the cage) were found when cages were fitted with a double-valved, solid top with an exhaust disc filter fitted and with the maximum pressure difference in the supply and exhaust plenums (+127 v. +13 Pa respectively).

Table 4 Contamination rate from room to cages on control rack and on PIV rack with cages under A, POSITIVE and B, NEGATIVE pressure compared with that of the room

Type of cage top	No. of cages	Cages with CFUs		No. of CFUs/plate	
		No.	%	Mean	Range
A					
PIV rack					
Wire grid	33	2	6.1	0.09	0–2
Filter top +2 holes	33	3	9.1	0.09	0–1
Filter top (entire)	33	4	12.1	0.14	0–1
Solid top +2 valves	9	0	0.0	0.00	0
Totals:	108	9	8.3	0.08	0–2
Control rack					
Wire grid	56	56	100.00	87.98	24–179*
B					
PIV rack					
Wire grid	33	32	96.96	7.15	0–21
Filter top +2 holes	32	30	93.75	4.84	0–18
Filter top (entire)	28	26	92.85	11.75	0–44
Solid top +2 valves	9	3	33.00	0.33	0–1
Totals:	102	91	89.20	6.02	0–44
Control rack					
Wire grid	56	56	100.00	94.76	0–182*

*The results from one plate, too heavily contaminated to count, are not included in this table

Containment tests

The results of these tests are summarized in Tables 4A and B. In both tests 100% of plates on the control rack were contaminated and in each case one of those plates was so heavily contaminated that it was impossible to count the number of CFUs. Excluding the heavily contaminated plate in each case, the mean number of CFUs per plate was calculated to be 88 and 95. From Table 4A it can be seen that with the PIV cages at positive pressure compared with that of the room, 9 of the 108 settle plates became contaminated, giving a mean number of 0.08 CFUs per plate with none of the plates having more than 2 CFUs. Table 4B, with the PIV cages under negative pressure, shows that although 91 of the 102 settle plates became contaminated the mean number of CFUs per plate was only 6.02 compared to the 95 of the controls.

From these results it will be seen that using the PIV system with the cages under negative pressure reduced the contamination rate by 94.3%. With the cages under positive pressure, contamination was reduced by 99. Hence the system apparently provides a similar degree of protection whether a filter top is fitted or not although, as might be expected, providing cages with a twin-valved, solid top apparently does give even better protection.

Discussion

Tests for compliance with the Home Office CoP

Light intensity

The CoP states that a light intensity of 350–400 lux at bench level is adequate for routine activities. It also points out, however, that care may be required to avoid undesirably high levels inside cages. This is especially so for albino animals which can suffer from light-induced retinal damage when exposed to intensities as low as 32 lux (Weisse *et al.* 1974) or 60 lux (Stotzer *et al.* 1970) and it is known that there is a real danger of light-induced blindness in albino animals in most laboratories (Weihe 1976; Bellhorn 1980).

The light intensity at animal eye level in cages on the PIV rack is generally much lower (20–62 lux) and more evenly distributed both horizontally and vertically than in cages on the control rack (28–530 lux). From the evidence available (Stotzer *et al.* 1970, Weiss *et al.* 1974, Weihe 1976, Bellhorn 1980) it is clear that albino animals housed in cages on the PIV rack would be less likely to suffer from light-induced retinopathy than those on the control rack. Also, because cage light intensities on the control rack vary over a much larger range than those on the PIV rack (19-fold versus 3-fold difference), any physiological effects that this factor might have (Clough, 1982) would be less likely to be expressed amongst groups of animals housed on the PIV rack thus helping to minimise any experimental variation arising from this cause.

Sound levels

The PIV rack with a top- or floor-mounted air handling unit increased the sound level in the empty room to a level above the recommendations of the CoP (Home Office 1989). It must be pointed out, however, that the racks tested were fitted with fans suitable for use with the American electrical supply (120 V, 60 Hz) plus transformers/convertors to allow their use in the UK and this could be contributing to the 'high' sound levels reported above. The rack manufacturers have provided a report (Report-9105) of June 1991 (S. Thomas, personal communication) from an Acoustical & Vibration consultant who has made measurements in an existing American pharmaceutical facility with 3 PIV racks operating in one animal room. Their results show that with the room air conditioning system turned off, the 3 racks produced a sound level of 48 dB(A) and an average NRC of 39.

It is anticipated that there would be no noise problem if (as indicated above under 'Materials & Methods') the rack(s) in a room were connected directly into the centralized air supply and exhaust system of the room itself. It is also possible that replacement of the American fans with

others designed specifically for the UK electrical supply would reduce the sound levels to within those recommended in the CoP. Yet another solution would be to mount the AHUs provided in such a way that they were outside the animal room.

Ventilation rates

The cage ventilation rate in the PIV system is affected by various factors including pressurization and the type of cage top and filter configuration used. The highest ventilation rates of well over 100 ac/h were obtained in cages fitted with a twin-valved, solid top. The valve configuration is such, however, that this does not result in linear air speeds within the cage which might be interpreted as 'draughty' for the animals. Even the lowest rate measured on the rack (48 ac/h) is 3-4 times higher than that of the cages on the control rack and it is clear that air distribution to cages using the PIV system is very much more efficient than when traditional 'open' racking is employed. The conditions produced comply with the recommendations of the CoP (Home Office 1989).

Air temperature and relative humidity

Room conditions for both these factors complied with the recommendations of the CoP (Home Office 1989). RH in the cages on both racks also complied with the CoP requirement for rooms; the fact that for some hours the RH in cage 10 of the control rack fell below the 'CoP lower limit for RH' is covered by the statement in the CoP that 'Prolonged periods below 40% or above 70% should be avoided'. Air temperature was very similar in cages on both racks which may appear surprising because, as mentioned above, the ventilation rate is so much higher in the PIV cages. It should be remembered, however, that during the time the recordings were made the PIV rack was powered by its own AHU and room air was thus being re-circulated. Hence, although the PIV rack provides a high cage-air-change rate, the actual fresh air change rate cannot be higher than that of the room, in this case, 18 ac/h. It is anticipated that in

a room with PIV racks in exclusive use with their exhausts connected directly into that of the building system, a large proportion of the animal heat gain would be excluded so that cage T conditions would be much closer to those of the room.

Tests not directly related to the CoP

Detection and characterization of ultrasound frequencies

No ultrasounds were detected arising from the PIV system

Air pressure differentials

Any pressure differential existing between cage air and that of the surroundings is dependent upon the relative pressures set in the supply and exhaust plenums as well as by the presence or absence of exhaust disc filters. Also, whilst the results do show some variation between cages, depending upon their position in the rack, it must be remembered that the pressure differentials being measured are very small.

It is clear, however, that judicious balancing and use of filters can ensure that air pressure within cages will remain either negative, equal or positive to that of the room.

Containment tests

The tests carried out demonstrate that use of the PIV system greatly reduces the transmission of airborne particles from the room into the cage air when compared with cages housed on traditional 'open' racking. Under the conditions of the test with the cages under positive pressure, contamination was reduced by 99.9% and even with cages under negative pressure, by 94.3%. The level of protection was very similar with or without a filter top although, as might be expected, providing cages with a solid top (with valves) apparently does give even better protection.

Allergen containment

Preliminary results from recent studies (Personal communication, J. Wallace)

indicate that use of the PIV system in animal rooms results in a significant reduction of circulating aeroallergens as compared to rooms housing animals in traditional open cages under the same conditions. This is the case even when cage air pressure is set to be positive to that of the room. As might be expected, however, the indications are that a greater reduction is obtained with the cage air pressure equal to that of the room and the greatest reduction, to below the level of detection of the sampling equipment, was obtained with the system operating in negative mode.

There are reports that aeroallergens arising from guineapigs and rats are mainly associated with dust particles of 5–8 μm or larger (Swanson *et al.* 1984, Platts-Mills *et al.* 1986, Gordon *et al.* 1992) and it is known that many aeroallergens, including animal dander, are normally carried on particles constituting part of the total dust load (Clough 1992). This being the case, it is clear that in rooms utilizing the PIV system, total room dust levels will also be reduced.

In common with other local barrier systems, the 'barrier' is only effective whilst the cages are housed within the protection of the rack. This is particularly relevant to the containment of particles (including allergens) which often escape into the room air in large numbers when cages are removed from such racks for servicing (Yamauchi *et al.* 1989). To help alleviate this problem the manufacturers recommend that protective tops (see Materials & Methods) are fitted to each cage and that their servicing is carried out inside a mobile clean bench which can be provided by them as part of 'the system'. From this point of view also, safe change procedures may have to be applied when the HEPA filters are changed in order to minimize the release of allergens from them into the general environment.

General

Riley (1975), studying mouse mammary tumours and their latent period, suggested

that factors contributing significantly to the decreased stress experienced by his animals housed within protected ventilated shelves included protection from 'dust, odour, noise, pheromones, potentially infected aerosols and chronic anxiety'. The results from the current tests show that the PIV system can provide similar protection.

Conclusions

It has been demonstrated that the PIV barrier housing system can provide benefits both for the animals housed within it and personnel working in the rooms. These include:

1. Cage level light intensities are lower and more evenly distributed both horizontally and vertically than in cages on the control rack. Animals housed within the system are less likely to suffer from light-induced retinopathy and are better protected from physiological changes induced by variations in light intensity.
2. With appropriate configuration sound levels will comply with the recommendations of the CoP (Home Office 1989).
3. Air distribution to individual cages is at worst nearly 4 times and at best nearly 11 times better than on the control rack. This means that bedding in the cages stays drier longer and thus needs changing less frequently; this can confer savings in both bedding and associated labour costs. Dry bedding is also desirable in terms of delaying the build up of odours (Wallace 1984) and inhibiting the development of ammonia (Clough 1976). It has been recorded that replacing sawdust bedding regenerates fighting in established social groups of male albino mice (Brain & Evans 1975), hence less frequent bedding changes would reduce this source of 'stress'.
4. It has been demonstrated that in this (EP Les, Personal communication) and similar systems with equally efficient

air distribution (Yamauchi *et al.* 1989) it is possible to reduce the room air change rate to levels as low as 8 ac/h whilst still maintaining more than 50 ac/h in the cages. This can confer considerable savings in both capital and running costs of the central air conditioning plant (Clough 1991) as, in simplistic terms, this needs to be only half the size and capacity of a plant to provide the CoP recommendation of 15–20 ac/h per room. In relation to this factor it is worth noting that the Home Office Inspectorate has expressed approval of this energy-saving concept in principle, provided that the following conditions are satisfied:

- a. it can be demonstrated that the air change rates in the animal cages meet or exceed those set out in the CoP for animal rooms
 - b. all of the exhaust air from each such device is ducted directly into the room exhaust system to prevent re-circulation
 - c. animal welfare is not compromised in any way
 - d. all other standards set out in the CoP are met in full
5. In a room with 18 ac/h, T and RH is very similar in both control and PIV cages. It is anticipated, however, that even in rooms with ventilation rates as low as 8 ac/h (provided they are furnished exclusively with PIV racks exhausting directly into the central exhaust system) both cage T and RH would be closer to that of the room than in cages on open racks.
 6. It is possible to adjust cage air pressure to be negative, equal or positive to that of the room. Depending on the pressure differential created this can:
 - a. reduce viable, particulate, airborne contamination from room to cage air by 94.3–99.9%
 - b. bring about a reduction in the level of particulate, airborne, animal aeroallergens in the room air to such an extent that they are undetectable by current methods
 - c. reduce the particle count of the room air itself
 7. The provision of less variable environmental conditions that comply with and are often 'better' than those stipulated in the CoP and are less stressful to some animals.
 8. Protect the animals from airborne contamination arising from the room
 9. Protect personnel from airborne contamination arising from the animals as well as reducing the level of airborne particles in the room air generally both factors being beneficial in relation to the COSHH Regulations and the recommendations of the Health & Safety Executive relating specifically to laboratory animal induced allergies (HSE 1990)

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