SECTION IV

RESULTS AND DISCUSSION

SECTION IV - TABLE OF CONTENTS

4. RESULTS AND DISCUSSION

This section presents the outcome of this research. It is divided into seven parts as follows:

Presenting the results
Single hood simulations - general analysis
Specific configuration recommendations
Experimental verification
Using the research data - ranking and comparison
Summary of recommendations
Future research

The results of this research are intended for use in one of four ways:

In conjunction with current design practice as additional recommendations. In this case, the designer should read sections 4.1, 4.2, 4.3, and 4.6 and follow the recommendations as given in sections 4.3 and 4.6.

To identify the likely performance of a proposed or existing configuration from the research data. In this case, sections 4.5.1 to 4.5.3 are critical with sections 4.1, 4.2, and 4.3 providing necessary background information. Sections 4.3 and 4.6 may be used to improve a proposed design.

To identify the performance of an existing laboratory configuration experimentally. In this case, the investigator should read section 4.4 with sections 4.1, 4.2, and 4.3, providing necessary background information.

The remainder of sections 4.5 and 4.7 are presented for those who wish to make a more fundamental comparison of their own design with those presented here, or as a database of information for any who wish to continue research into the effect of laboratory air flow on hood containment.

Volume II provides a summary of results from the different analysis methodologies for each simulation, however, only the leakage method is adopted for the assessments made here. Where appropriate in Volume I, a pictorial approach is used to show the specific differences for different configurations as an approach complimentary to the quantitative leakage assessment.

4.1 Presenting the Results

There are a number of ways of presenting the results of the simulations carried out. These can be either based upon visualization of the CFD results file, or, as described in section 2.5, based upon an automated analysis of the data in terms of containment performance. The former provides a qualitative approach and a number of methods are used in this research to demonstrate the different characteristics. The latter provides quantitative measurements of:

the leakage from the hood sash opening as a factor in proportion to the flow into the laboratory hood through the sash opening - defined to be the sash leakage factor;

the leakage from the working zone as a factor in proportion to the flow into the laboratory hood through the sash opening - defined to be the box leakage factor; and

the proportion of the leakage from the working zone as a percentage of that which leaked into the working zone from the laboratory hood through the sash opening - defined to be the box / sash leakage proportion.

Depending on the types of process being undertaken in the hood, the designer and hygienist may choose to optimize using any one of the parameters. For example, sash leakage factor would be used where the scientist at the hood is of highest priority. This might be the case where inhalation of the substance could be hazardous to health. If the issue were simply one of odor, then the designer may choose to optimize box / sash leakage proportion, which would minimize the leakage of any contaminant reaching the box (or working zone) into the lab. The latter could however allow high leakage into the imaginary box - if this is undesirable, then optimizing the box leakage factor will tend to minimize both sash and box leakage.

4.1.1 Visualizing the Flow - A Qualitative Approach

Three approaches are used to display the CFD results directly. Two of these show the data in selected planes (planar slices) while the third provides a view in a three dimensional visualization of the flow of selected air streams.

4.1.1.1 Using planar slices through model

The results of the analysis can be displayed in diagrammatic form, e.g. figure 4.01, showing concentration of tracer (kg species / kg air) as solid fills and air speed (m/s) as velocity vectors. The latter show the direction as well as the magnitude of airflow. Values for both can be obtained from the color bar in each diagram. The left of the key is the air speed in m/s (0.1 m/s is equivalent to 20 feet per minute) and the right of the key is the fraction of concentration in kg species / kg air. The vectors, or airflow arrows, are plotted so that the tail of the arrow is at the point where the value was calculated and show the direction of air movement. In 2-D views (plan or elevation) the length of the arrow indicates the 2-D velocity magnitude (i.e., the velocity projected onto the plane of viewing) when compared with a reference vector, while the color indicates the overall magnitude of air speed at the tail.

To aid analysis, the color scales are set the same on different diagrams. For example, the concentration scale is set to run from 0.0001 (0.1E-3) kg/kg to 0.00115 (1.15E-3) kg/kg. Values outside this range will appear as blank areas in the solid fill or a region with no vectors. If lower than the scale, this area is surrounded by colors at the bottom of the scale and above by colors at the top of the scale.

In the case of the hood in isolation (a hood operating in otherwise totally undisturbed air), figure 4.01, shows a very narrow band of contamination where the concentration falls from approximately 1000 times dilution from that in the hood (red) to 10,000 times dilution (mauve) in a short distance moving a way from the hood. This indicates a reasonable level of containment around the hood. The contamination shown in this diagram can be converted to a likely level of contamination in the real case. For example, in the simulations the sash opening is considered to be full of contamination (value 1 kg/kg). The contamination source required to achieve this would be the entire hood flow rate. Of course in reality the contamination source is much lower than this so the contamination predicted can be scaled according to the actual contamination source divided by the hood flow rate (the effective source in the simulation). If the source contamination rate is 4 l/min, and the air flow through the laboratory hood is 0.37 m^3/s, the mean contamination inside the laboratory hood would be $4x10^{-3}/60/0.37 = 1.8x10^{-4}$ kg/kg. Therefore the contamination, by volume, outside the hood will be approximately the predicted fractional concentration multiplied by 180ppm ($1.8 x10^{-4}$).

Considering the flow pattern and velocity magnitude, velocity vectors depict the high velocities through the sash opening and out through the slots. Since the flow here is dictated by the hood suction the velocity decays rapidly as the distance into the laboratory increases from the sash opening (approximately in proportion to the square of the distance). Thus the vectors diminish in size quickly outside the sash opening.

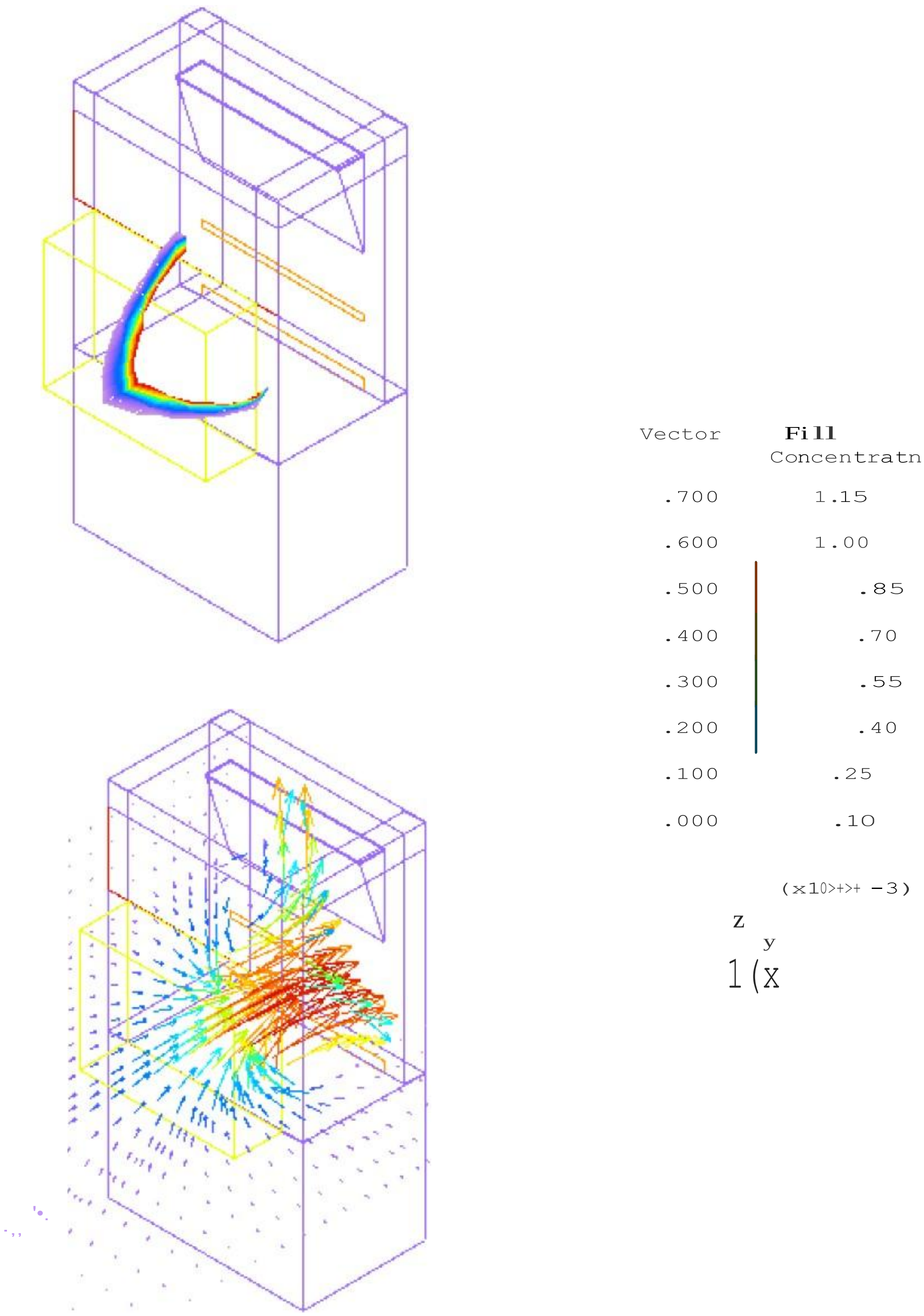


Figure 4.01 Flow into hood when isolated (RunOOO).

4.1.1.2 Using three dimensional flow visualization

Three dimensional flow visualization allows us to understand the interaction of complex flows. To determine the relative performance of different designs, we will compare the flow around a hood in isolation with the flow occurring in different configurations. Again, the hood in isolation is one that, except for the hood induced flow, experiences an undisturbed flow around it in the laboratory. First let us consider the hood configuration.

The hood in isolation is composed of the main cabinet, in this case a 4 foot hood, figure 4.02.

Inside, air exits through three adjustable slots in the rear baffle. For the purposes of these simulations the slot sizes and flows have been based on measured data.

The air entry is limited in height by the sash. For the simulations the sash is set fully open with an opening height of 30 in.

Air is drawn into the hood from the otherwise undisturbed room. To visualize this we will color air as it enters the undisturbed region around the hood, figure 4.03, and as it passes through the five faces of an imaginary box extending 12” outside the sash opening, figure 4.04. This region was chosen since it represents the zone in which the scientist will work and the air they may breathe. The performance will be analyzed on the faces of this box and a series of planes parallel to the hood sash opening within the box.

The air is colored in accordance with the air speed, white through blue, green, yellow, and red, representing low to high velocities respectively. Blue represents low velocities near zero, and red velocities of 100 fpm (0.5 m/s) or more. As we see, the air is drawn relatively uniformly through the sash opening into the hood. In fact the velocity distribution correlates well with that for a ‘perfect exhaust’

4.1.2 Calculating the Leakage Factors - A Quantitative Approach

As a more scientific and quantitative approach to enable comparison of the performance of one configuration with another, leakage from the hood into the laboratory through the sash opening into the ‘working zone’ and from there into the laboratory is calculated as described in section 2.56 and presented as numeric data in Volume II as leakage factors.

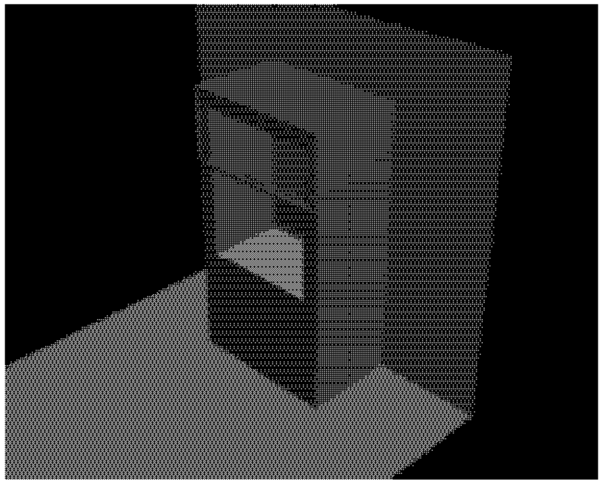


Figure 4.02 *Hood in isolation.*

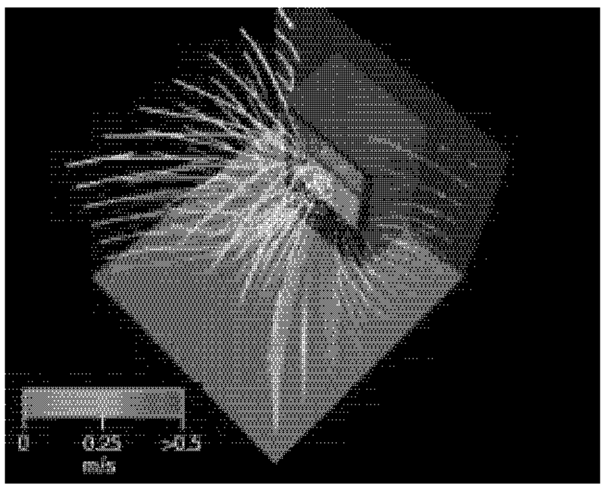


Figure 4.03 *Airflow through undisturbed region.*

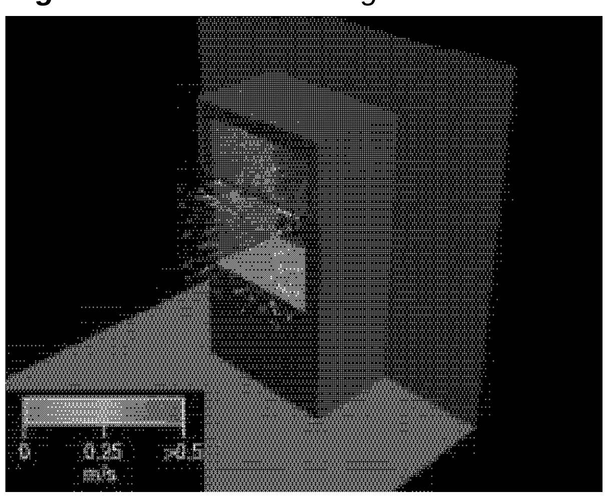


Figure 4.04 *Airflow around* sash *opening.*

> The sash opening is considered as this opening, where the air enters the hood, represents the boundary of the containment device, and beyond which the chemicals may be used.

> The working zone or box was considered to represent the boundary of the volume just outside the sash opening in which a scientist may work.

The leakage from the sash opening represents the contamination that may affect the scientist working at the hood, while the leakage from the box represents that which may affect scientists working elsewhere in the laboratory.

The leakage through the sash opening can be characterized by a leakage factor as follows:

> The sash leakage factor is the concentration, as a fraction of the hood flow, that leaks backwards against the flow and out of the hood through the sash opening into the laboratory, or more specifically the working zone or box. For example, in the large laboratory base case (run041) the leakage is 0.00369, which represents 0.369% of the design hood flow-rate.

The box leakage can be characterized in a similar manner:

> The box leakage factor represents the concentration leakage, as a fraction of the hood flow out through the five faces of the box into the laboratory, away from the hood. For the large laboratory base case (run041), 0.000086 represents less than $^{1}/100^{th}$ of 1 percent leaking backwards against the flow. This is the amount of contamination leaking from the imaginary box (working zone) into the laboratory space if the hood is filled with contaminant.

The box leakage factor represents the overall leakage into the laboratory, which itself is dependent on the quantity of concentration that has already leaked through the sash opening. In addition to the sash leakage factor and box leakage factor, the box / sash leakage proportion is also used:

> The box / sash leakage proportion is defined as box leakage factor divided by sash leakage factor and is presented as a percentage. This proportion represents a measure of the hood's ability to scavenge the working zone, and is necessary to assess the ability of the hood to retrieve concentration spilled through the sash opening by other means (such as motion of the scientist working at the sash, or fluctuation in the ventilation system).

Of course this numeric presentation is difficult to assimilate for such a large number of simulations. To allow easier comparison the data are presented here as complete sets and as subsets in graphical form as X-Y scatter diagrams. While the hood containment is affected in a complex way, the leakage parameters have been found to correlate with measurable flow parameters. Although these measurable parameters include cross flow and turbulence intensity that are not undertaken as part of current practice during performance verification studies, they can be determined from measurements taken with currently available hot film / hot wire anemometers. Details of the measurement methodology can be found in 4.3.3. The remainder of this section defines the leakage parameters, and their comparative flow parameters. This includes an example of the use of the scatter diagrams in displaying the performance data for the different leakage criteria.

4.1.2.1 Sash leakage factor

Sash leakage factor demonstrates strong correlation with the turbulence intensity, figure 4.05, although as can clearly be seen there are several distinct lines. Turbulence is a type of flow that occurs when a fluid is moving quickly and / or within an unconfined space. It is characterized by a marked increase in mixing (often termed turbulent diffusion) where, superimposed on the principle motion, are countless irregular fluctuations. For empirical verification of an installation the strength of these velocity fluctuations can be measured (averaged from a measurement grid across the plane in question) using a hot film anemometer. Some commercially available anemometers automatically calculate a non-dimensional turbulence intensity as the root mean square (rms) of the fluctuating velocity divided by the mean velocity. This clearly relies upon a sufficient sampling frequency and duration. For this analysis the turbulence intensity is defined as:

$$\text{Turbulence intensity} = \sqrt{\overline{u_i^{2}}} = \sqrt{\tfrac{2}{3}k}$$

The measured value described above can therefore be converted to the definition used in this document by multiplying the measured value by the mean velocity.

It is of little consequence whether sash or average box turbulence intensity is used since there is strong correlation between the two, figure 4.06. This demonstrates that sash leakage is dependent on laboratory air flow, specifically the advected-in turbulence (advection is the process by which a quantity of fluid is transferred from one point to another due to the movement of the fluid). Thus the turbulent fluctuation in air velocity generated in the laboratory is carried in to the hood by the general flow of air.

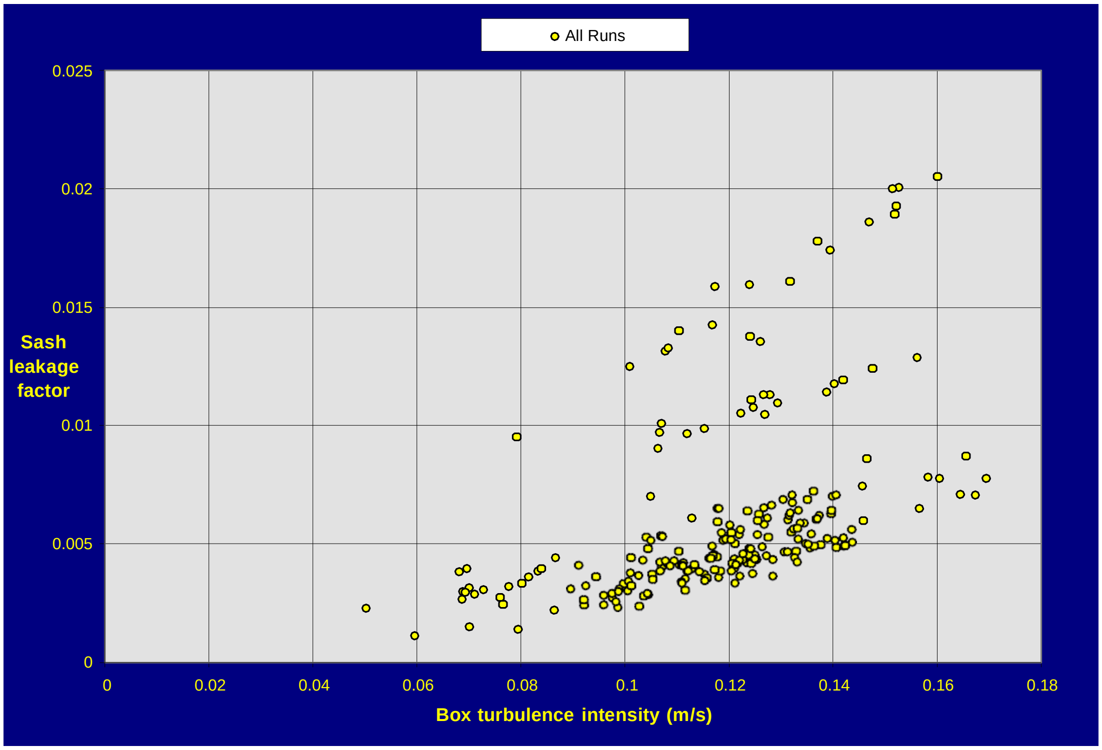


Figure 4.05 Sash leakage factor vs. Box turbulence intensity for all runs

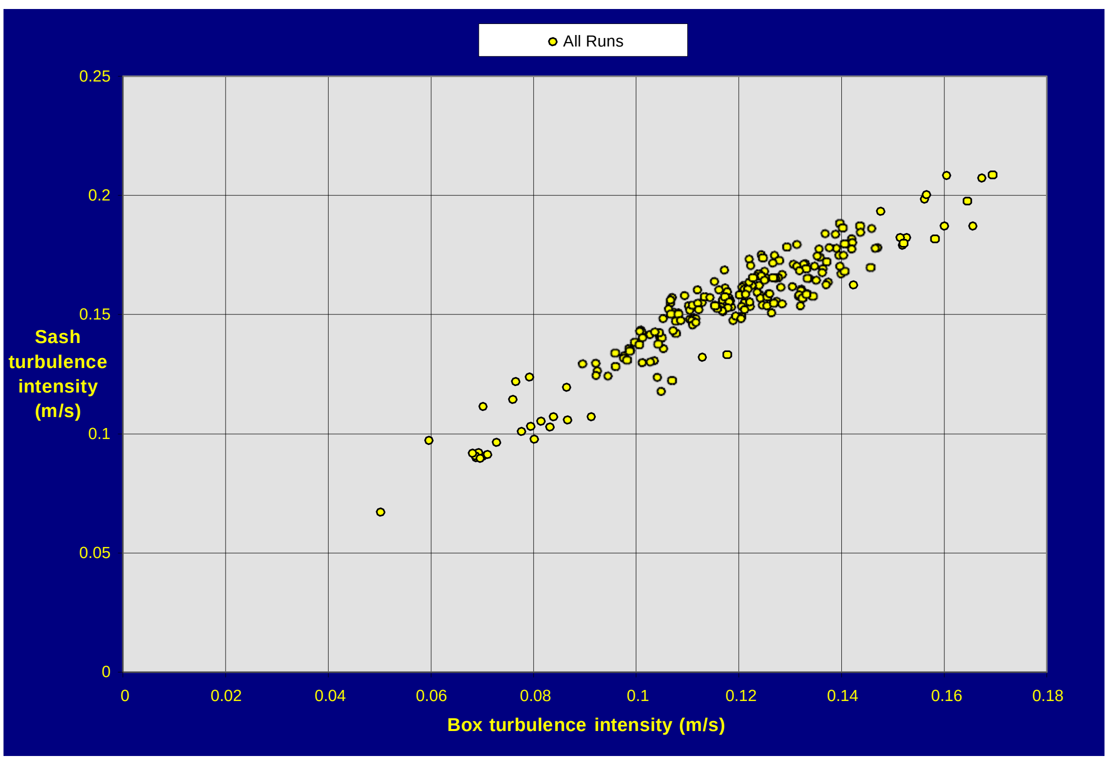


Figure 4.06 Sash turbulence intensity vs. Box turbulence intensity for all runs

4.1.2.2 Box / sash leakage proportion

Box / sash leakage proportion has a loose correlation with the cross flow, figure 4.07. To calculate this cross flow, the difference between the box inflow velocity perpendicular to the box face for the two opposite pairs (for horizontal inflow and vertical inflow) of box faces perpendicular to the sash plane is determined.

The magnitude of the resultant vector taken from both 'horizontal' and 'vertical' flows parallel to the sash opening is the cross flow magnitude. For empirical verification the cross flow can be calculated by measuring the velocities perpendicular to the four notional faces on a measurement grid.

4.1.2.3 Box leakage factor

Finally, the absolute box leakage factor depends both on turbulence and flow since it is a result of both sash leakage and box leakage. It has therefore been correlated with a parameter termed here as the 'disruption factor'. This disruption factor, similar in form to the Peclet number, is the ratio between a parameter characteristic of turbulent diffusion and a parameter characteristic of the advective flow into the hood, figure 4.08. In this case the former parameter is the average value of turbulence intensity at the five outer faces of the box. The latter parameter is taken to be the ratio of average inflow velocity at the sash opening to the cross flow velocity.

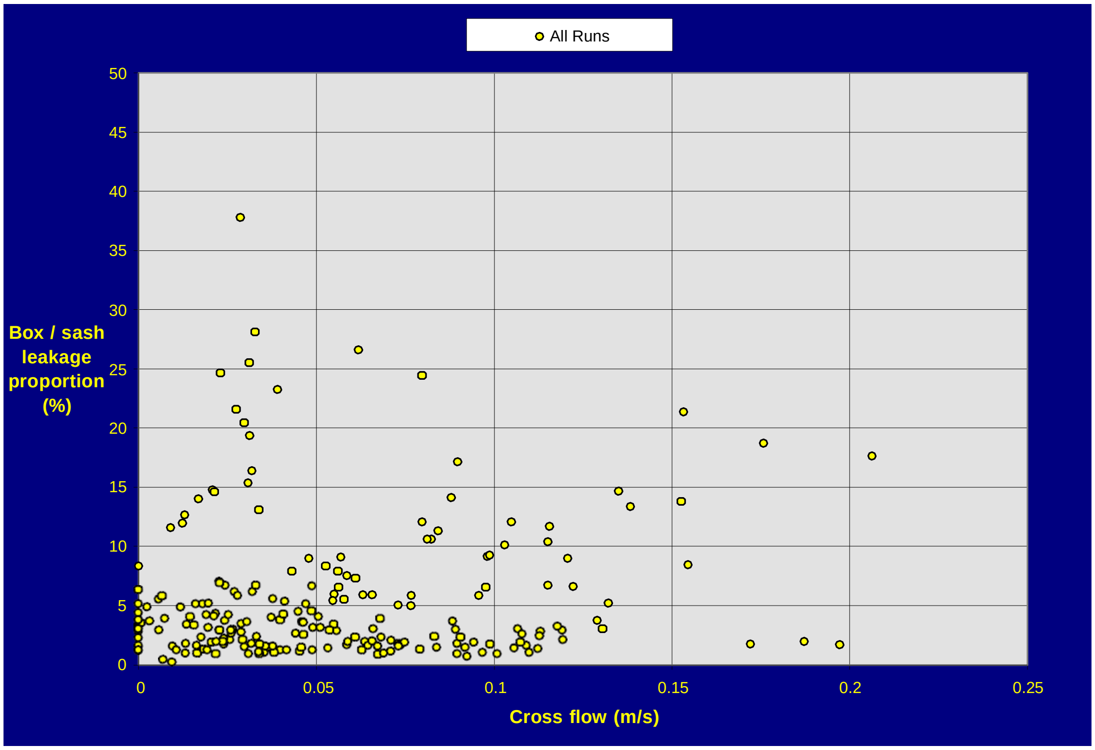


Figure 4.07 Box / sash leakage proportion vs. Cross flow for all runs

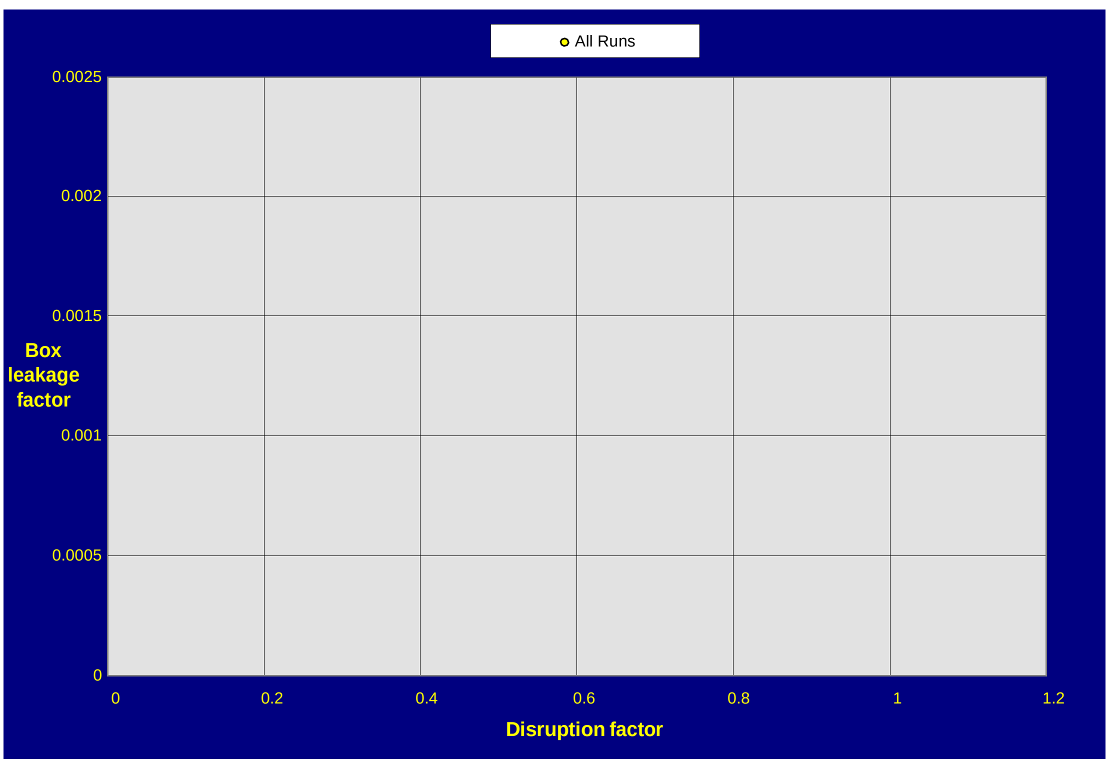


Figure 4.08 Box leakage factor vs. Disruption factor for all runs

4.2 Single Hood Simulations - General Analysis

This section presents the data for all the simulations with a view to identifying any configuration characteristics that affects sash, box, or overall leakage performance, or indeed any configuration parameters that have no effect on performance. This section uses the scatter diagrams presented in section 4.1 to identify where design parameters (such as diffuser type, ventilation rate, etc.) strongly influence containment performance.

4.2.1 Sash Leakage Factor

Figures 4.09 to 4.17 show sash leakage factor vs. box turbulence intensity. The sash leakage factor is the amount of contamination leaking out of the hood through the sash opening and backwards against the flow as a fraction of the hood flow. It assumes that the air inside the hood is totally contaminated and that the hood is unaffected by time varying conditions such as people movement, door openings, etc. The data are presented on the different figures with different groupings in order to identify any correlation between the chosen parameter and sash leakage. Of the simulations with a single hood, 20% have a sash leakage factor of less than 0.0036 (0.36%). This value is used for comparison of the performance of different layouts.

Figure 4.09 shows sash leakage factor vs. box turbulence intensity grouped by lab size and the presence of a scientist in front of the hood. It is immediately clear that much of the deviation from a single correlation is largely accounted for by two parameters, the laboratory size and the presence of a scientist. The large laboratory and the presence of a scientist act as an amplifier to the leakage through the sash opening, although at turbulence intensities below around 0.1, nearly all the performances collapse onto a single line resulting in a sash leakage factor of less than 0.5%. There are however some noticeable exceptions.

- In two instances, for the small laboratory with a scientist in front of the hood, the sash leakage factor is more than twice others, with performance similar to large laboratory simulations with a scientist present.
- For one small laboratory simulation without the scientist present, the sash leakage factor is similar to the poorer large laboratory designs.
- Although many of the sash leakage factors are higher for the large laboratory than the small lab, a significant number of large lab simulations perform more like the small lab, particularly at lower box turbulent intensities.

The best 20% of performances in terms of sash leakage factor are below 0.0036. These levels are achieved in both the small and large laboratory configurations without, and even with a scientist present. This suggests that laboratory size is not a key design parameter when minimizing sash leakage.

Figure 4.10 shows that sash leakage factor does not correlate well with diffuser type. In fact all diffuser types considered achieve sash leakage factors within the best 20%. Further, the spread of performance for any particular air terminal device is large; for example, many of the ‘good performances’ come from low velocity devices such as the radial TAD (TAD is a trade name by Krueger standing for total air diffuser. It is an air terminal designed to introduce at low velocity over a large area, spreading in a radial fan shape perpendicular to the center line of the diffuser) and the down-flow diffusers which also populate the high sash leakage rates.

While all hood positions can achieve low sash leakage, figure 4.11, position 2 appears consistently in the best 20% performances, even at higher turbulence intensities than 0.1. This suggests that a hood in the corner dominates the effect of many other design parameters reducing the risk of high leakage by poor design.

Figure 4.12 shows that many of the low turbulence intensities and low sash leakage factors are produced by low sash velocity (50 fpm). This is to be expected, but of course ignores the ease of disturbance by the scientist working in the hood. In the absence of other disturbance this suggests that lower sash velocities of 50 fpm can provide good containment at the sash opening. In fact almost half the 50 fpm simulations produced a sash leakage factor in the best 20%.

Figures 4.13 and 4.14 present the data for sash leakage factor vs. box turbulence intensity for the square diffuser simulations in the large and small laboratory simulations respectively. For the large laboratory, figure 4.13, the most consistent performance is achieved with the layout SQ C.2 (four 24” square diffusers laid out on quarters) all achieving performances in, or near, the 20% threshold of 0.0036. Although higher velocities do not guarantee failure (SQ A.1 - four 12” square diffusers laid out on quarters, SQ B.1 - two 24” square diffusers staggered either side of the hood, SQ B.2 - two 24” square diffusers along centerline of lab, SQ B.3 - two 24” square diffusers in line with the hood with quadrant towards the hood blanked), these layouts are sensitive to other conditions in the lab and so should be used with care. The staggered arrangement SQ B.1 produces the worst results and should be avoided. The small laboratory exhibits similar characteristics with the square diffuser in a staggered layout (SM SQ A.2a - two 12” square diffusers staggered either side of the hood) often producing high sash leakage similar to that from SQ B.1 in the large laboratory.

Figures 4.15 and 4.16 present the data for sash leakage factor vs. box turbulence intensity for the TAD radial diffuser in the large and small laboratory respectively. For the large lab, the worst performances are again associated with staggered diffuser arrangements, this is true whether 48” by 24” or 24” by 24” diffusers are used or

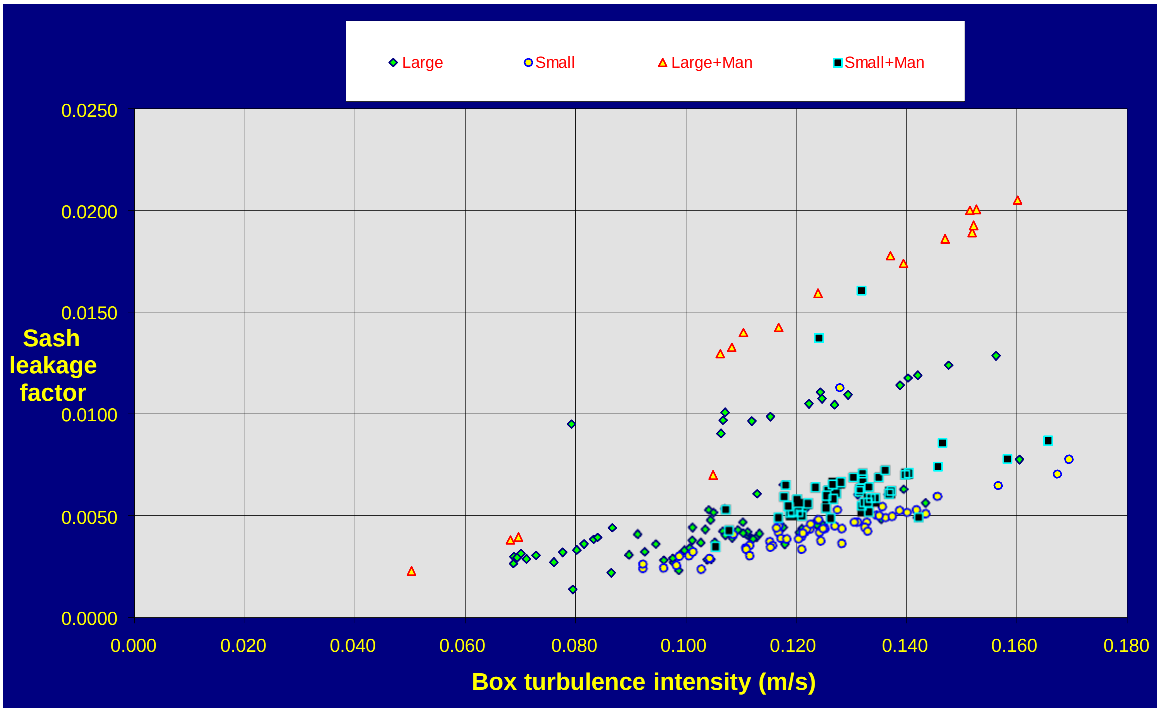


Figure 4.09 Sash leakage factor vs. Box turbulence intensity for laboratory size and presence of a scientist

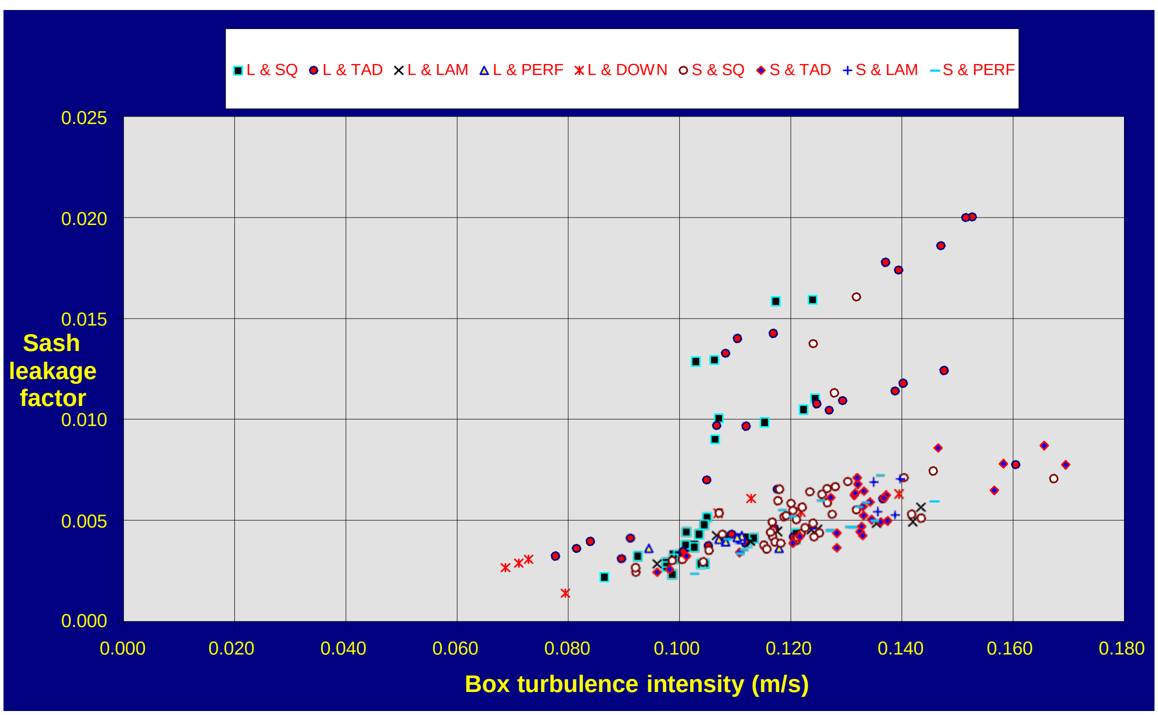


Figure 4.10 Sash leakage factor vs. Box turbulence intensity for laboratory size and supply diffuser type

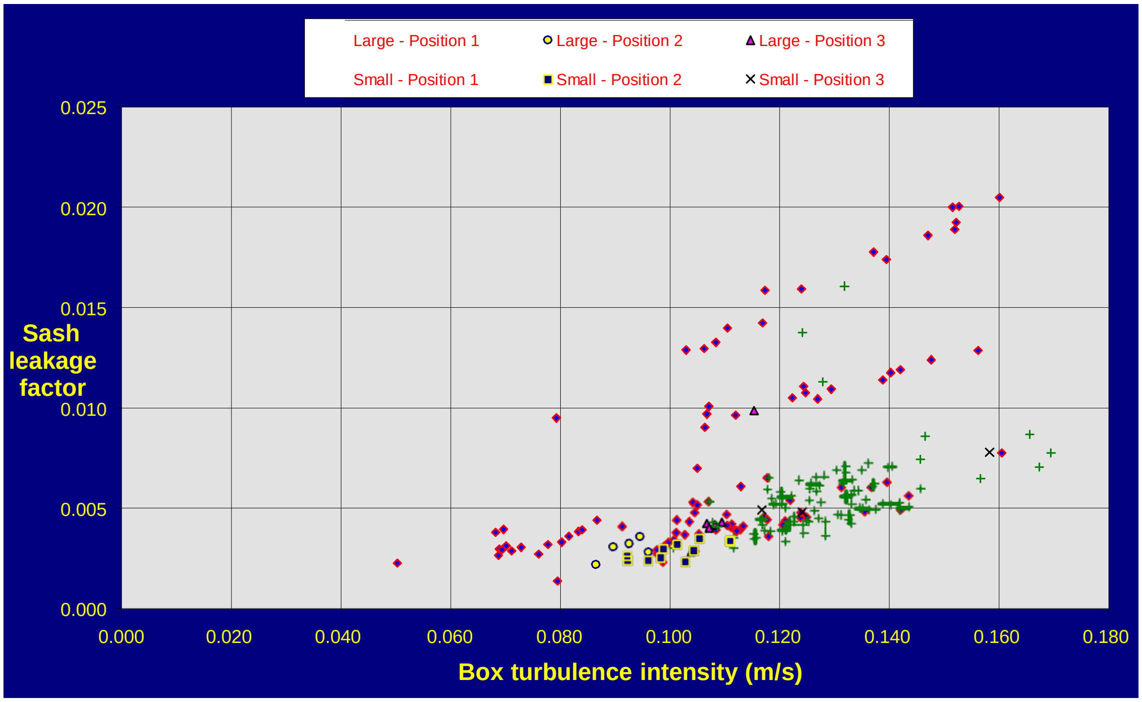


Figure 4.11 Sash leakage factor vs. Box turbulence intensity for laboratory size and hood position

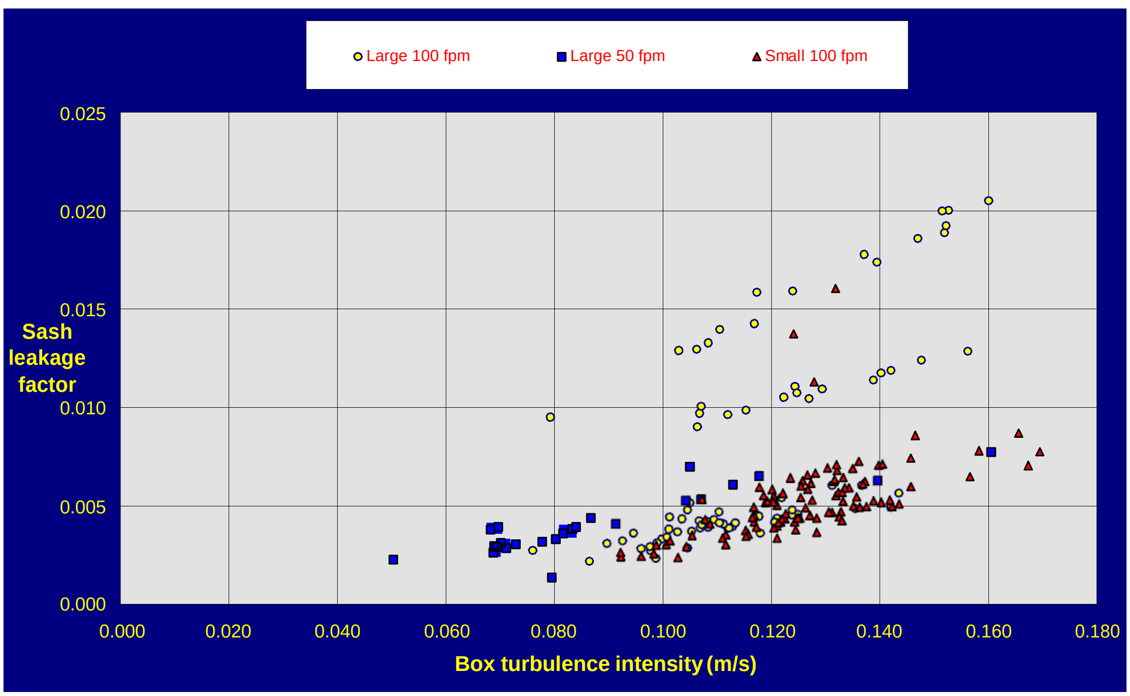
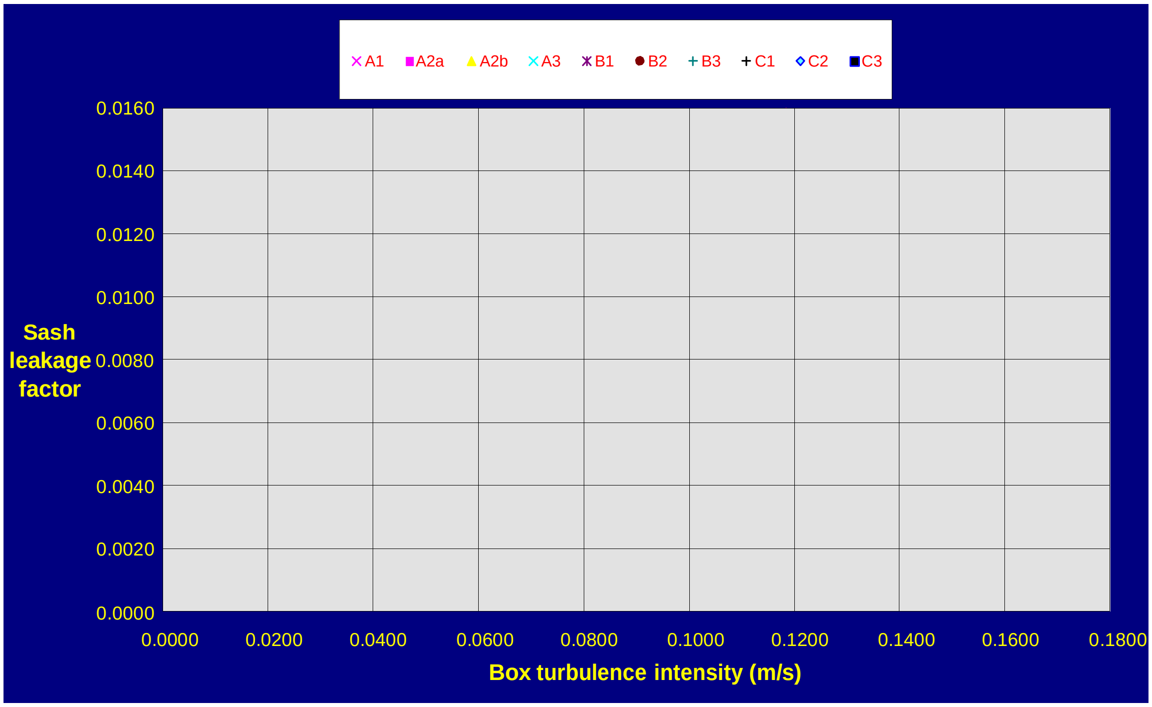
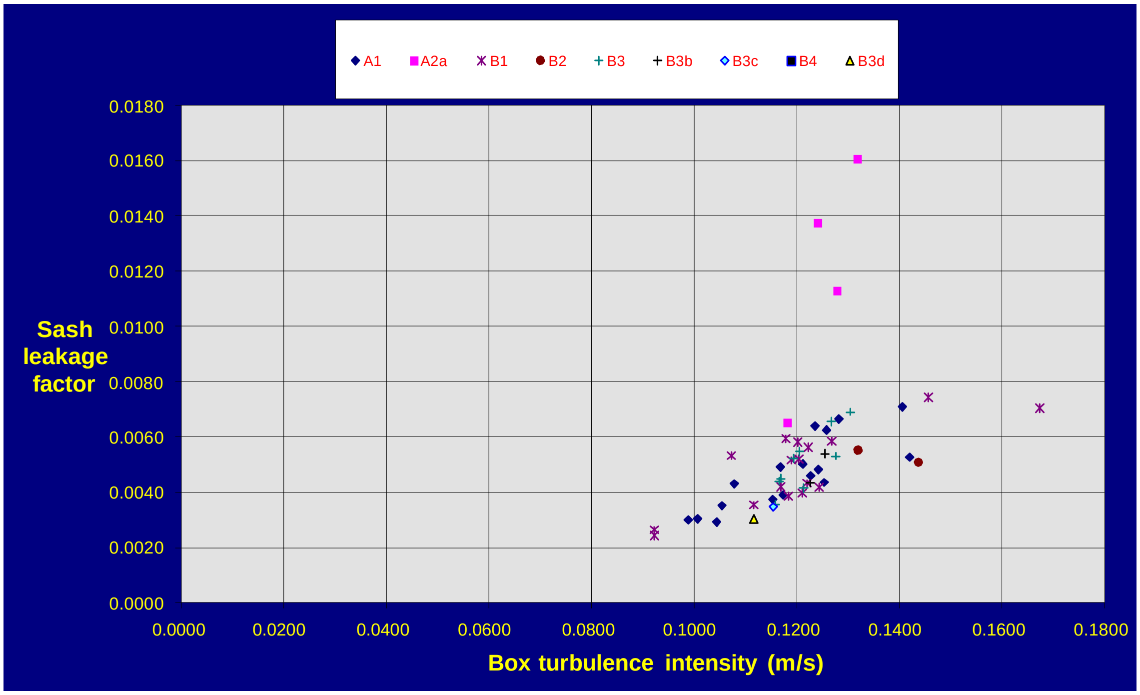


Figure 4.12 Sash leakage factor vs. Box turbulence intensity for laboratory size and hood exhaust speed



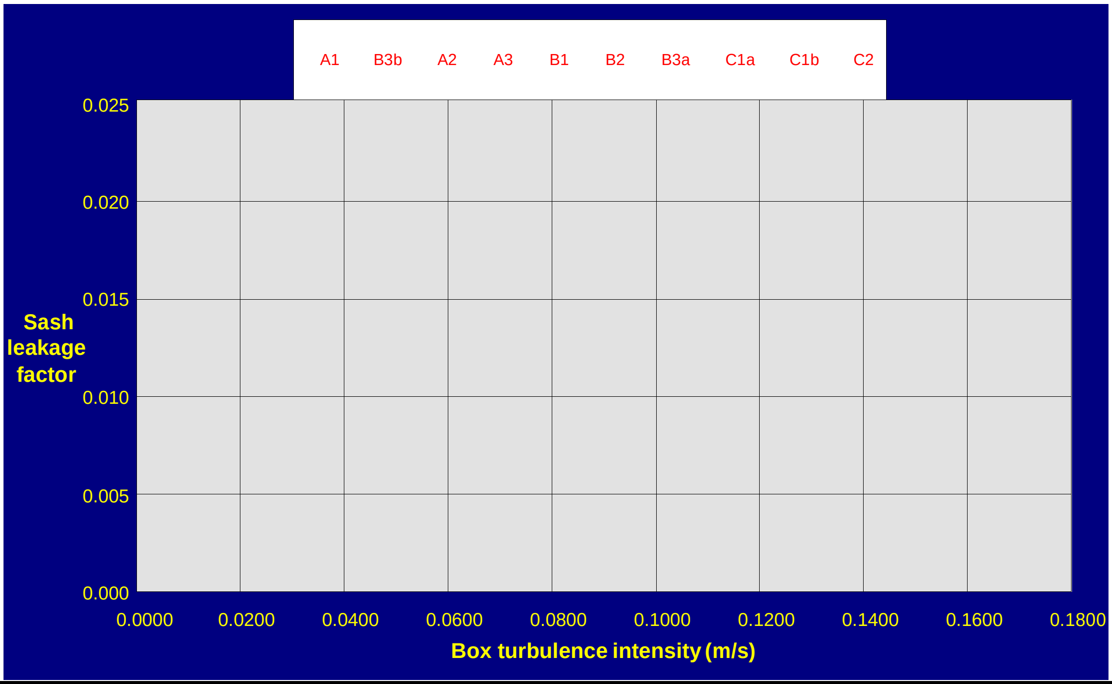
Layout Name	No. / Type / Size	Description	Simulation Nos.
SQ A.1	4 / Square / 12”	Laid out on quarters	41,43,44,52-58, 76-9,122,142
SQ A.2a	4 / Square / 12”	Spaced close to end walls	61
SQ A.2b	4 / Square / 12”	Spaced close to end walls, quadrants towards walls blanked	62
SQ A.3	4 / Square / 12”	Diffusers staggered	63
SQ B.1	2 / Square / 24”	Staggered spacing	42,45,46,106, 107,123,143
SQ B.2	2 / Square / 24”	Along centerline	64,86-88
SQ B.3	2 / Square / 24”	In line in front if hood, quadrant towards hood blanked	65
SQ C.1	4 / Square / 24”	Spaced close to end walls	2,10,18
SQ C.2	4 / Square / 24”	Laid out on quarters	3,15,19,25,28,31,33
SQ C.3	4 / Square / 24”	Diffusers staggered	4,11

Figure 4.13 Sash leakage factor vs. Box turbulence intensity for large laboratory square supply diffuser arrangement



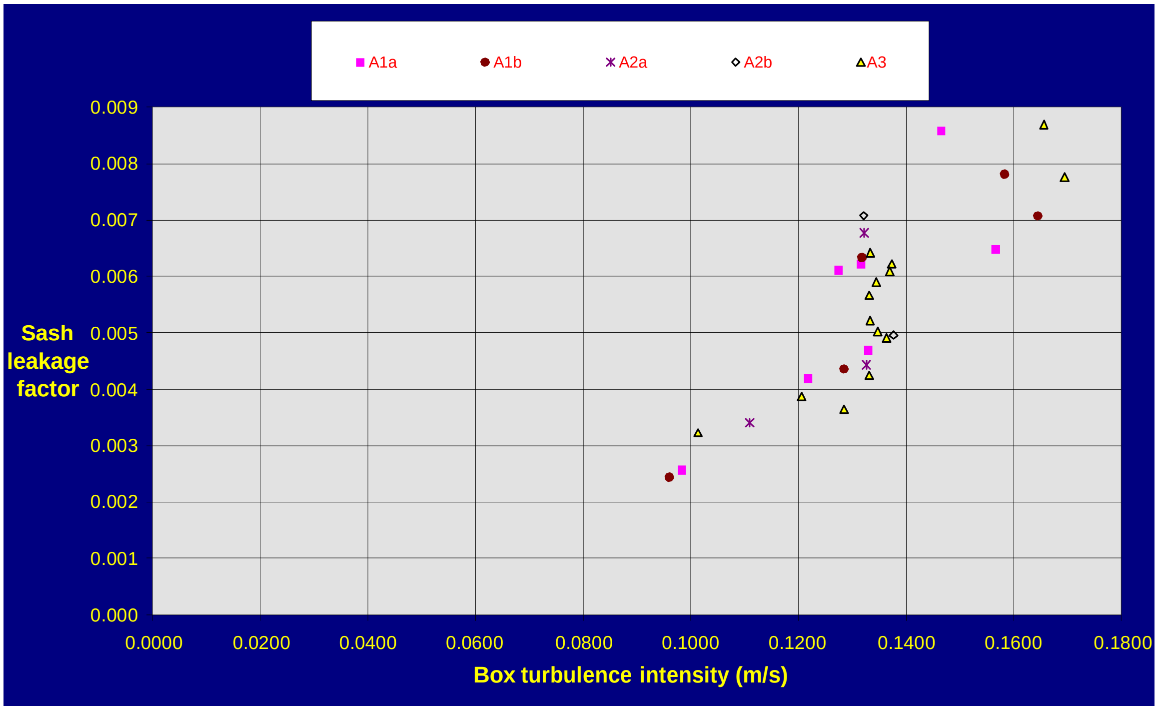
Layout Name	No. / Type / Size	Description	Simulation Nos.
SM SQ A.1	2 / Square / 12"	Even jet throw along centerline	82,82c,110,110c,118,118c, 126,126c,130,130c,134,138, 139,139c,148,153,155,183, 184,193
SM SQ A.2a	2 / Square / 12"	Staggered	102,102c,103, 148,149
SM SQ B.1	1 / Square / 24	On center line, away from main door	83,83c,119,119c,127,127c, 131,131c,135,135c,139,140, 140c,150,179,185
SM SQ B.2	1 / Square / 24	On centerline, close to main door	104,104c
SM SQ B.3	1 / Square / 24	On centerline, in front of hood	112,113,113c,189,190
SM SQ B.3b	1 / Square / 24	On centerline, in front of hood, quadrant towards hood blanked	105,105c,111,111c,151
SM SQ B3c	1 / Square / 24	1 foot further away from hood than SM SQ B3	191
SM SQ B3d	1 / Square / 24	1 foot nearer to hood than SM SQ B3	192
SM SQ B4	2 / Square / 24	Between SM SQ B.1 and SM SQ B.3	188

Figure 4.14 Sash leakage factor vs. Box turbulence intensity for small laboratory square supply diffuser arrangement



Layout Name	No. / Type / Size	Description	Simulation Nos.
TAD A.1	2 / Radial / 48"x24"	Along centerline, radial spread across laboratory	16,17,20,26,29,32,34,49,49c, 92-94
TAD A.2	2 / Radial / 48"x24"	Staggered array, radial spread across laboratory	5,12, 69,69c
TAD A.3	2 / Radial / 48"x24"	Staggered array, diffusers close to hood, radial spread across laboratory	6,13, 70,70c
TAD B.1	2 / Radial / 24"x24"	Along centerline, radial spread across laboratory	50,50c,81,124, 144,147
TAD B.2	2 / Radial / 24"x24"	Staggered array, radial spread across laboratory	71,71c
TAD B.3a	2 / Radial / 24"x24"	Staggered array, diffusers close to hood, radial spread across laboratory	72,146
TAD B.3b	2 / Radial / 24"x24"	Staggered array, diffusers close to hood, radial spread along laboratory	73
TAD C.1a	4 / Radial / 24"x24"	Laid out on quarters, radial spread across laboratory	51
TAD C.1b	4 / Radial / 24"x24"	Laid out on quarters, radial spread along laboratory	74
TAD C.2	4 / Radial / 24"x24"	Staggered array, radial spread across laboratory	75,75c

Figure 4.15 Sash leakage factor vs. Box turbulence intensity for large laboratory TAD supply diffuser arrangement



Layout Name	No. / Type / Size	Description	Simulation Nos.
SM TAD A.1a	1 / Radial / 24"x24"	On centerline away from main door, radial spread across laboratory	85,85c,108,108c,109,109c, 181
SM TAD A.1b	1 / Radial / 24"x24"	On centerline away from main door, radial spread along laboratory	97,97c,114,115,154
SM TAD A.2a	1 / Radial / 24"x24"	On centerline close to main door, radial spread across laboratory	95,95c,180
SM TAD A.2b	1 / Radial / 24"x24"	On centerline close to main door, radial spread along laboratory	96,96c
SM TAD A.3	1 / Radial / 24"x24"	Centered in front of the hood	116,116c,117,117c,120,120c, 128,128c,132,132c,136,136c, 152,186

Figure 4.16 Sash leakage factor vs. Box turbulence intensity for small laboratory TAD supply diffuser arrangement

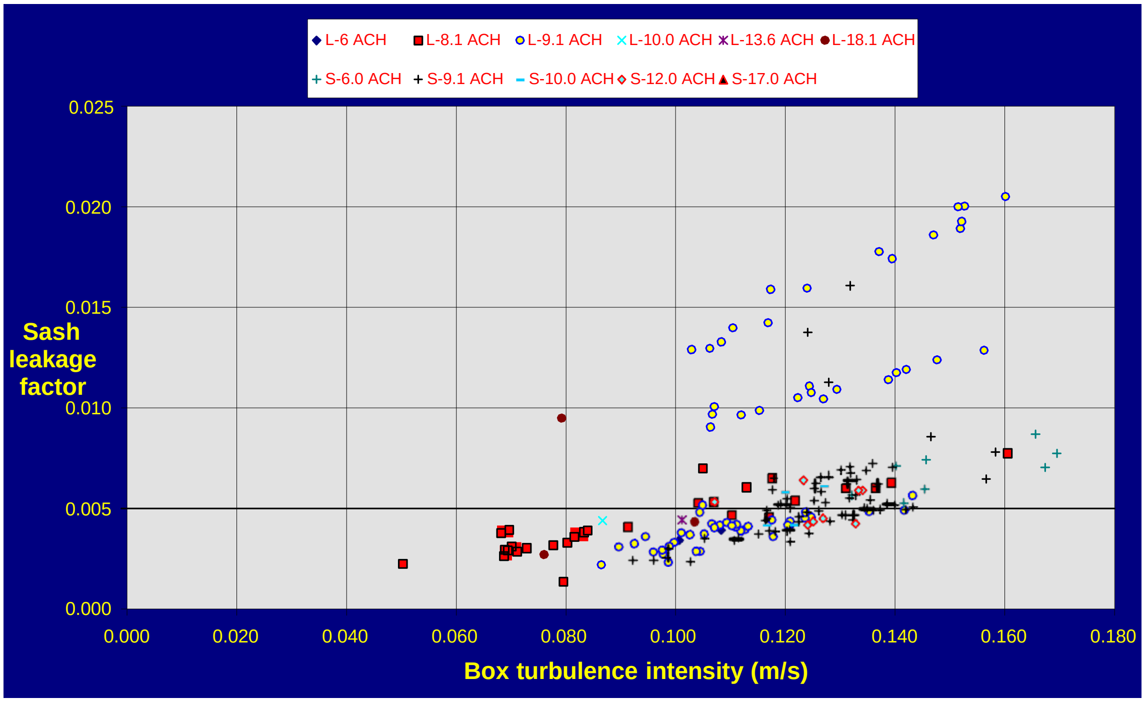


Figure 4.17 Sash leakage factor vs. Box turbulence intensity for laboratory size and supply ACH

whether two or four diffusers are used. This underlines the need to avoid a staggered diffuser layout. In both laboratory sizes, non-staggered TAD diffuser arrays are capable of providing performance within the best 20%, sash leakage factor less than 0.0036, but other factors appear to dominate performance creating up to three times the sash leakage for the same diffuser type and layout.

Figure 4.17 shows that for the supply air change rates simulated, poor containment occurs mainly for 9.1 air changes per hour from the diffusers. However, this is misleading since good containment is also achieved at this ventilation rate. This is probably only due to the statistically small sample of other ventilation rates and laboratory configurations. Performance in terms of sash leakage factor is extremely variable at all ventilation rates.

4.2.2 Box / Sash Leakage Proportion - Hood Scavenging

The box / sash leakage proportion is the percentage of contamination reaching the box or working zone that leaks out into the laboratory. It assumes that the hood is unaffected by time varying conditions such as people movement, door openings, etc. It is therefore a measure of the ability of the laboratory configuration to contain escaped contamination inside the box or working zone and thus prevent contamination of the lab. Figures 4.18 to 4.26 show the same sets of data for comparison of box / sash leakage proportion with cross-flow.

Figure 4.18 shows the opposite trend to that for the sash opening. That is containment is generally superior with a scientist present. In addition, the greater confinement of the small lab results in lower leakage. However, as for sash leakage factor, containment in the best 20% of box to sash leakage proportion (less than 1.6%) is achieved by both small and large lab configurations with and without a scientist present. The high leakage apparently associated with the large laboratory configuration is in fact a result of other parameters, which are described below.

Diffuser type, figure 4.19, correlates poorly with box / sash leakage proportion in particular, in that the low velocity diffusers, down-flow and radial TAD, exhibit a wide range of performances from good containment to bad. This confirms that the diffuser selection must be accompanied by good design for the remainder of the lab configuration.

The ability to achieve lower leakage due to the greater confinement of the laboratory air flow in the smaller laboratory appears to replicated and is in fact more effective when the hood is placed in the corner. The containment is below or close to the 20% box /

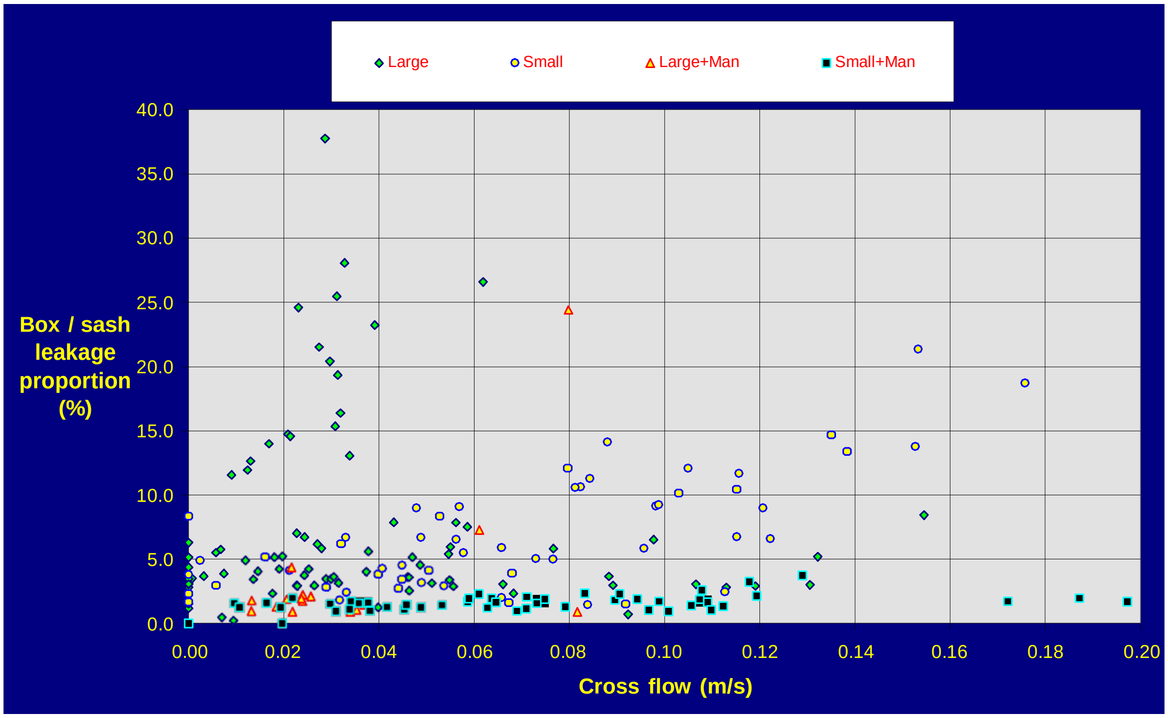


Figure 4.18 Box / sash leakage proportion vs. Cross flow for laboratory size and presence of a scientist

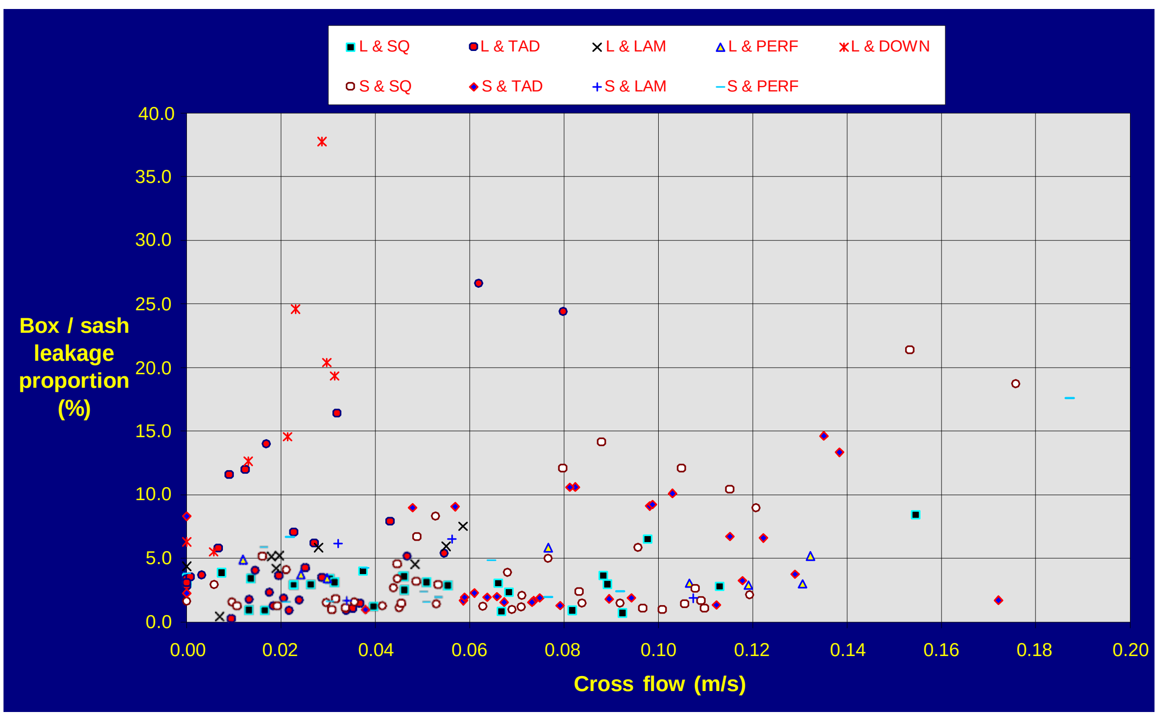


Figure 4.19 Box / sash leakage proportion vs. Cross flow for laboratory size and supply diffuser type

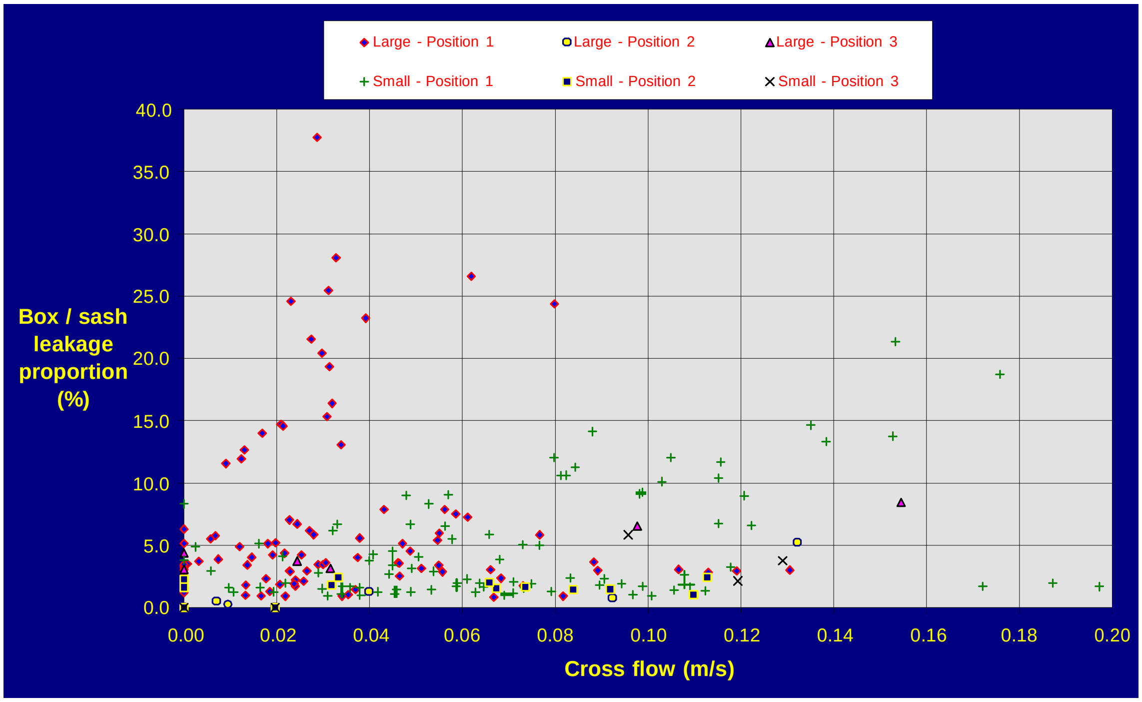


Figure 4.20 Box / sash leakage proportion vs. Cross flow for laboratory size and hood position

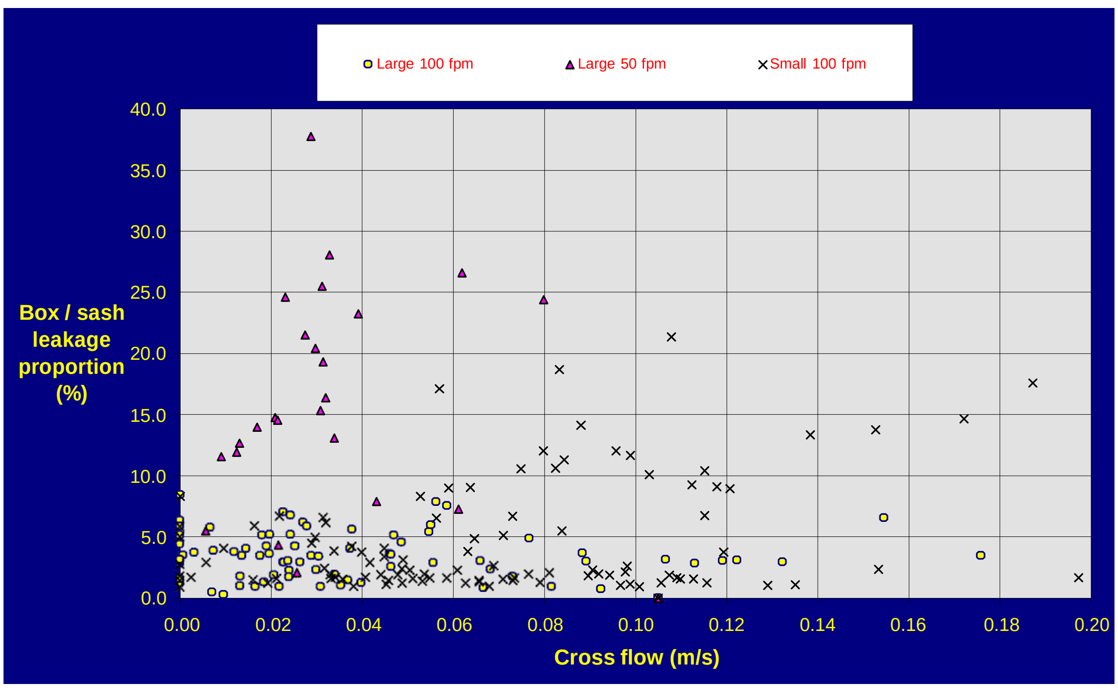
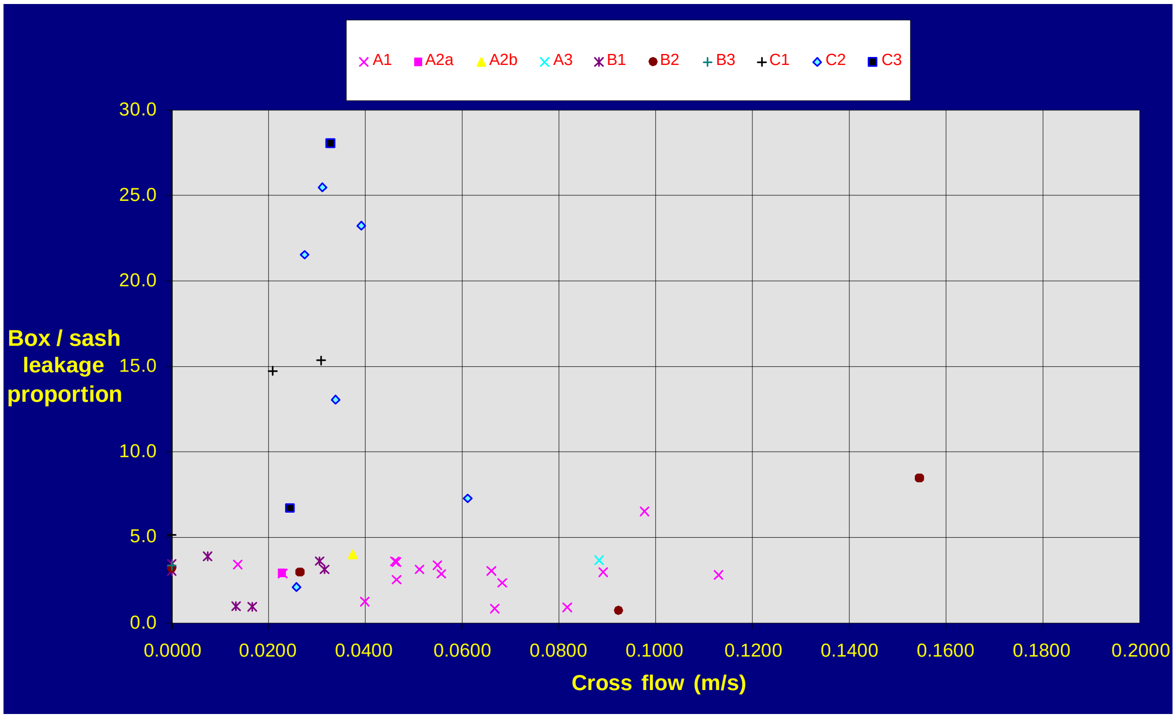
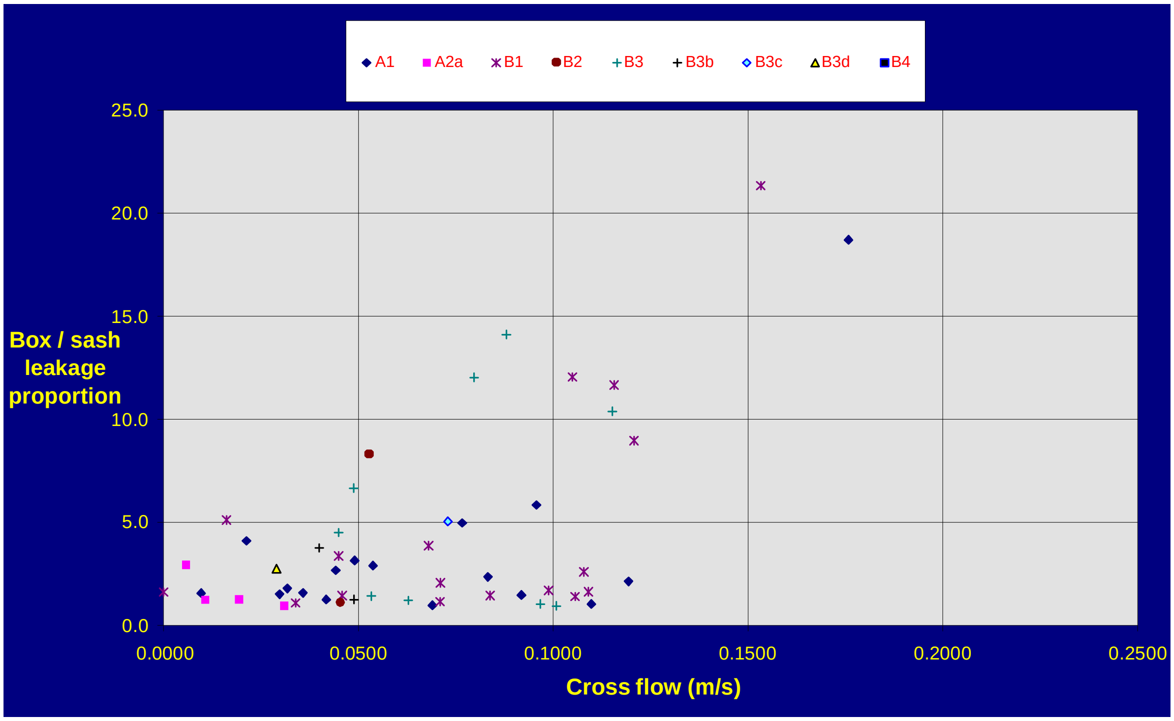


Figure 4.21 Box / sash leakage proportion vs. Cross flow for laboratory size and hood exhaust speed



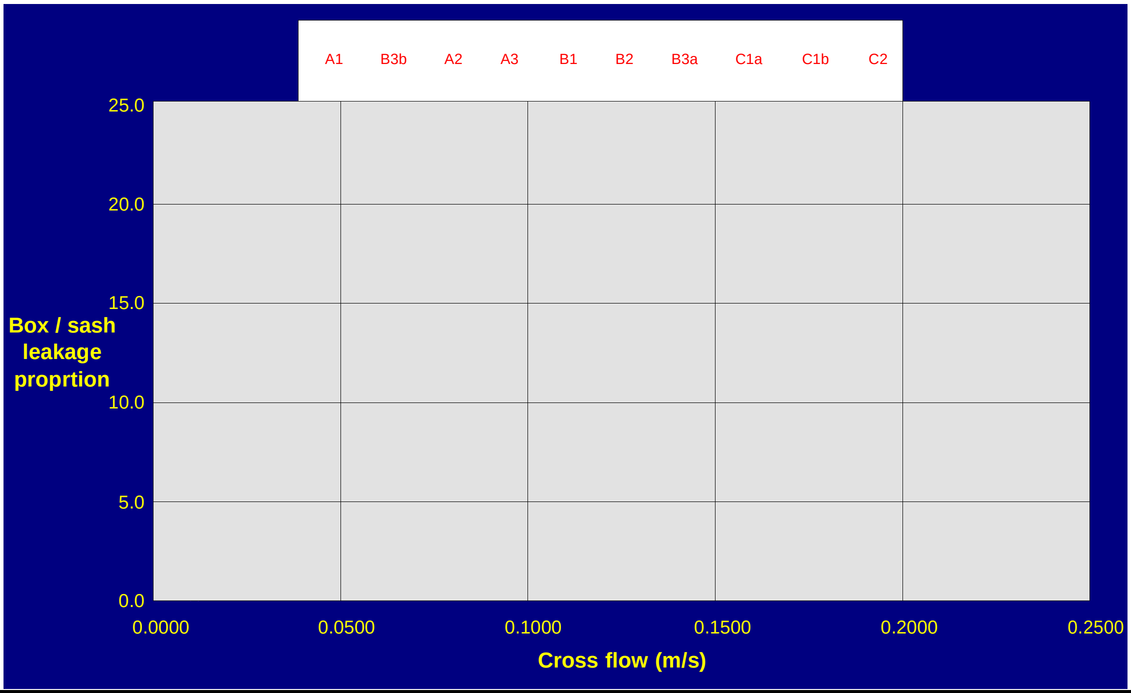
Layout Name	No. / Type / Size	Description	Simulation Nos.
SQ A.1	4 / Square / 12"	Laid out on quarters	41,43,44,52-58, 76-9,122,142
SQ A.2a	4 / Square / 12"	Spaced close to end walls	61
SQ A.2b	4 / Square / 12"	Spaced close to end walls, quadrants towards walls blanked	62
SQ A.3	4 / Square / 12"	Diffusers staggered	63
SQ B.1	2 / Square / 24"	Staggered spacing	42,45,46,106, 107,123,143
SQ B.2	2 / Square / 24"	Along centerline	64,86-88
SQ B.3	2 / Square / 24"	In line in front if hood, quadrant towards hood blanked	65
SQ C.1	4 / Square / 24"	Spaced close to end walls	2,10,18
SQ C.2	4 / Square / 24"	Laid out on quarters	3,15,19,25,28,31,33
SQ C.3	4 / Square / 24"	Diffusers staggered	4,11

Figure 4.22 Box / sash leakage proportion vs. Cross flow for large laboratory square supply diffuser arrangement



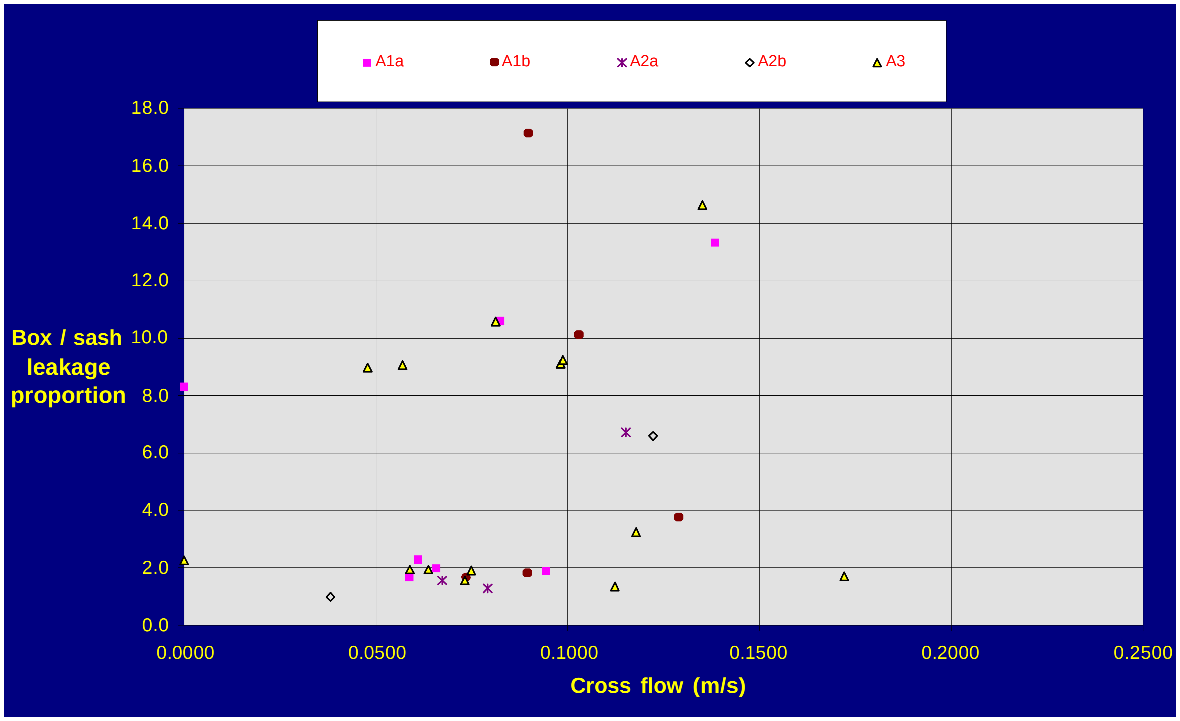
Layout Name	No. / Type / Size	Description	Simulation Nos.
SM SQ A.1	2 / Square / 12”	Even jet throw along centerline	82,82c,110,110c,118,118c, 126,126c,130,130c,134,138, 139,139c,148,153,155,183, 184,193
SM SQ A.2a	2 / Square / 12”	Staggered	102,102c,103, 148,149
SM SQ B.1	1 / Square / 24	On center line, away from main door	83,83c,119,119c,127,127c, 131,131c,135,135c,139,140, 140c,150,179,185
SM SQ B.2	1 / Square / 24	On centerline, close to main door	104,104c
SM SQ B.3	1 / Square / 24	On centerline, in front of hood	112,113,113c,189,190
SM SQ B.3b	1 / Square / 24	On centerline, in front of hood, quadrant towards hood blanked	105,105c,111,111c,151
SM SQ B3c	1 / Square / 24	1 foot further away from hood than SM SQ B3	191
SM SQ B3d	1 / Square / 24	1 foot nearer to hood than SM SQ B3	192
SM SQ B4	2 / Square / 24	Between SM SQ B.1 and SM SQ B.3	188

Figure 4.23 Box / sash leakage proportion vs. Cross flow for small laboratory square supply diffuser arrangement



Layout Name	No. / Type / Size	Description	Simulation Nos.
TAD A.1	2 / Radial / 48"x24"	Along centerline, radial spread across laboratory	16,17,20,26,29,32,34,49,49c, 92-94
TAD A.2	2 / Radial / 48"x24"	Staggered array, radial spread across laboratory	5,12, 69,69c
TAD A.3	2 / Radial / 48"x24"	Staggered array, diffusers close to hood, radial spread across laboratory	6,13, 70,70c
TAD B.1	2 / Radial / 24"x24"	Along centerline, radial spread across laboratory	50,50c,81,124, 144,147
TAD B.2	2 / Radial / 24"x24"	Staggered array, radial spread across laboratory	71,71c
TAD B.3a	2 / Radial / 24"x24"	Staggered array, diffusers close to hood, radial spread across laboratory	72,146
TAD B.3b	2 / Radial / 24"x24"	Staggered array, diffusers close to hood, radial spread along laboratory	73
TAD C.1a	4 / Radial / 24"x24"	Laid out on quarters, radial spread across laboratory	51
TAD C.1b	4 / Radial / 24"x24"	Laid out on quarters, radial spread along laboratory	74
TAD C.2	4 / Radial / 24"x24"	Staggered array, radial spread across laboratory	75,75c

Figure 4.24 Box / sash leakage proportion vs. Cross flow for large laboratory TAD supply diffuser arrangement



Layout Name	No. / Type / Size	Description	Simulation Nos.
SM TAD A.1a	1 / Radial / 24"x24"	On centerline away from main door, radial spread across laboratory	85,85c,108,108c,109,109c, 181
SM TAD A.1b	1 / Radial / 24"x24"	On centerline away from main door, radial spread along laboratory	97,97c,114,115,154
SM TAD A.2a	1 / Radial / 24"x24"	On centerline close to main door, radial spread across laboratory	95,95c,180
SM TAD A.2b	1 / Radial / 24"x24"	On centerline close to main door, radial spread along laboratory	96,96c
SM TAD A.3	1 / Radial / 24"x24"	Centered in front of the hood	116,116c,117,117c,120,120c, 128,128c,132,132c,136,136c, 152,186

Figure 4.25 Box / sash leakage proportion vs. Cross flow for small laboratory TAD supply diffuser arrangement

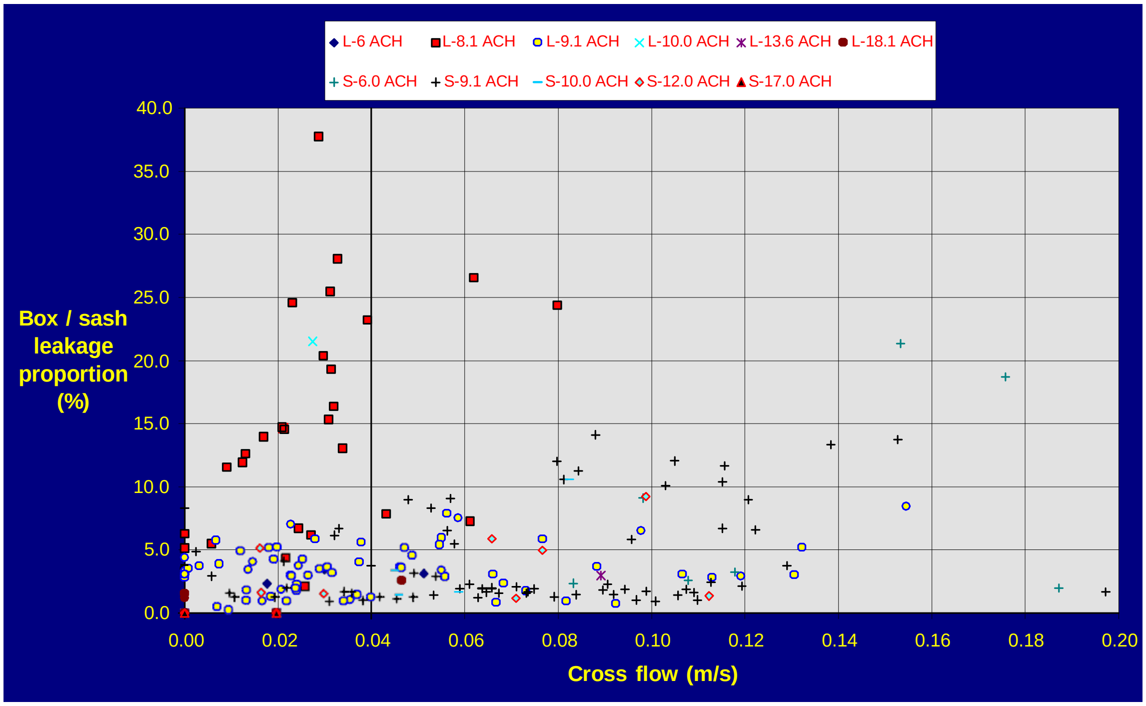


Figure 4.26 Box / sash leakage proportion vs. Cross flow for laboratory size and supply ACH

sash leakage proportion of 1.6% for all hood position 2 (hood in the corner) simulations - figure 4.20.

Contrary to sash containment, box containment is significantly impeded by the low sash velocity, figure 4.21, which can be easily disturbed by cross flows causing leakage. All the high box / sash leakage proportions (above 10%) with low cross-flows (less than 0.05 m/s) are for low sash velocities of 50 fpm. It is essential therefore that for a 50 fpm mean sash velocity there is little leakage through the sash opening.

Figure 4.22 and 4.23 show the box / sash leakage proportion for the large and small laboratories respectively. Both 12” and 24” diffusers show diverse performance in terms of leakage of contaminant reaching the box and this is true for most layouts. However, box leakage is likely to occur at a higher rate with larger 24” square diffusers than with 12” square diffusers.

Figures 4.24 and 4.25 deliver the same message for the TAD radial diffuser. The large 48” by 24” diffuser (large laboratory, TAD A.1, TAD A.2 and TAD A.3) provide both the worst and the best leakage of contaminant that has reached the box or working zone. Layout and orientation appear to have limited control.

Supply air ventilation rate, figure 4.26, has little apparent influence on a global scale with the exception of the large laboratory at 8.1 ACH. However, these simulations are for a sash opening velocity of 50 fpm and this is believed to be the cause of the poor box containment.

4.2.3 Box Leakage Factor

The box leakage factor represents the total leakage in to the laboratory from the imaginary box as a fraction of the flow in to the hood. It assumes that the air inside the hood is totally contaminated, and that the hood is unaffected by time varying conditions such as people movement, door openings etc. Figures 4.27 to 4.38 present the box leakage factor vs. the disruption factor.

The disruption factor, similar in form to the Peclet number, is the ratio between a parameter characteristic of the advective flow into the hood and a parameter characteristic of turbulent diffusion, figure 4.08. In this case the latter parameter is the average value of turbulence intensity at the five outer faces of the box. The former parameter is taken to be the ratio of average inflow velocity at the sash opening to the cross flow velocity.

Figure 4.27 shows that the overall leakage to the laboratory is significantly reduced with the scientist present and so design control of contamination reaching the laboratory from the working zone should be considered with the person absent. This reduction in leakage from the box is due to the acceleration of the air around the scientist. This reduction does not necessarily apply to the leakage through the sash opening, which depends more strongly on turbulence (that may be significantly increased by the presence of a scientist) rather than the velocity approaching it.

Figure 4.28 demonstrates that box leakage, like sash leakage, is unrelated to diffuser type, with significant scattering of the leakage from each of the different diffuser types.

Figure 4.29 confirms that the hood in a corner consistently outperforms other hood positions. Again the only hood position to achieve performances in the top 20% (box leakage factor less than 0.000089) is position 2 for both the small and large laboratory.

While overall hood sash velocity, figure 4.30, has no marked benefit or penalty to leakage to the laboratory in that both hood sash velocities produce a wide performance variation, none of the 50 fpm configurations perform in the best 20% for box leakage.

Figures 4.31 and 4.32 show box leakage factor vs. disruption factor for the square diffuser in the large and small laboratories respectively. It is apparent that the box performance rather than the sash performance dominates the leakage into the laboratory from the imaginary box. For example:

figure 4.31, 24” square diffuser layout C2 shows high box leakage factor
figure 4.22, 24” square diffuser layout C2 shows high box / sash leakage proportion
figure 4.13, 24” square diffuser layout C2 shows low sash leakage factor

Therefore diffuser size and layout can be made either on a premise of protecting the scientist or the laboratory knowing that the selected choice is likely to compromise performance of the other criterion. Joint optimization must be undertaken with other parameters.

Figures 4.33 and 4.34 show box leakage factor vs. disruption factor for the TAD diffuser in the large and small laboratories respectively. These show that like the square diffuser, the TAD diffuser configurations produce a wide variation in box leakage factor for any given layout. Unlike the square diffuser the larger TAD (large lab, 48” by 24” - A1, A2, A3) does not produce significantly more leakage than the smaller 24” by 24” air terminal used in the other TAD configurations. In a staggered configuration larger diffusers (48” by 24”, run069), figure 4.35, compared with smaller diffusers (24” by 24”, run073), figure 4.36 demonstrates a 28% lower box / sash leakage proportion for the larger diffuser (run069), which can be seen in the lack of contamination spread around the lab in figure 4.37.

Figure 4.38 shows that supply air ventilation rate has negligible effect on box leakage factor, which varies significantly for each ventilation rate.

4.2.4 General Indications

From the results presented in this section it is clear that the complex interaction of flows in the laboratory significantly affect the concentration leakage through the sash opening and its transport from just outside the sash around the laboratory. There are already some clear indications:

Low sash velocity (50 fpm) produces less leakage at the sash opening, but is not able to scavenge the working zone as well as high sash velocity (100fpm). It may therefore be acceptable for a turn-down condition when no scientist is present in the laboratory, but is almost certainly not acceptable when a scientist is working at the hood.

A hood in a corner is likely to contain better than a hood on a side wall - a detailed analysis is given in section 4.3.1.

While a simulation with a scientist in front of the hood merely amplifies the sash leakage, it prevents leakage that may occur from the working zone to the laboratory when the scientist is not present. If limited CFD calculation is to be undertaken to compare the performance of two or more designs, simulating without a mannequin is more likely to indicate the relative performance of both scenarios.

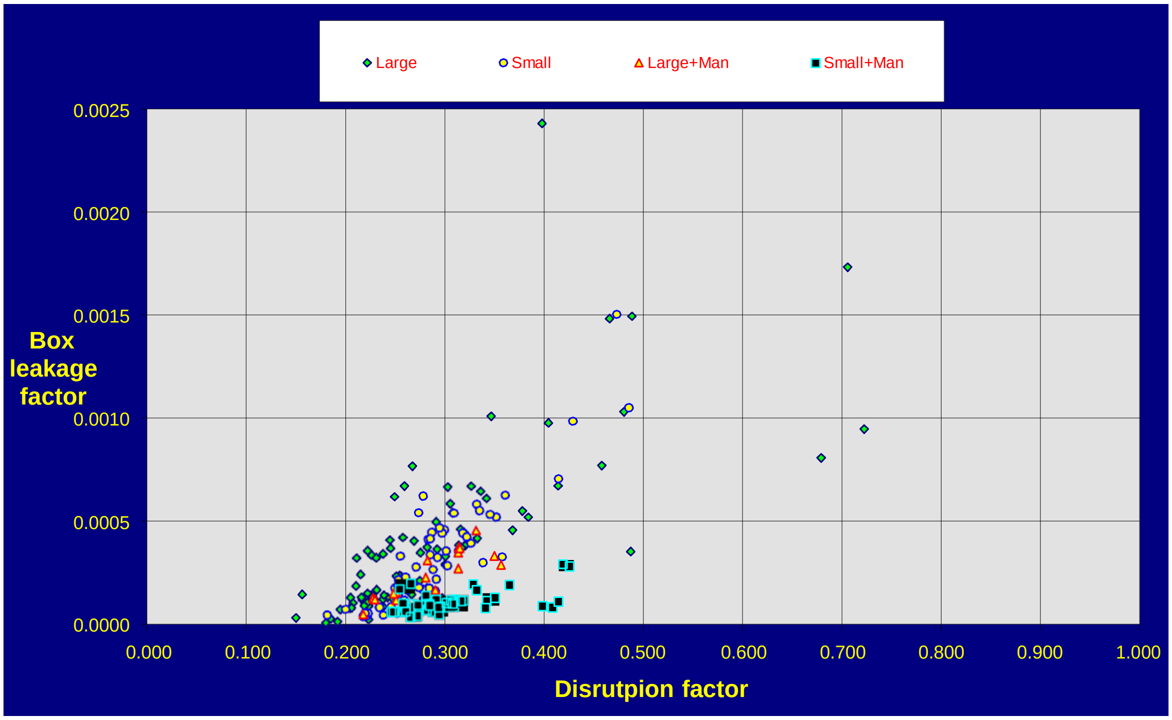


Figure 4.27 Box leakage factor vs. Disruption factor for laboratory size and presence of a scientist

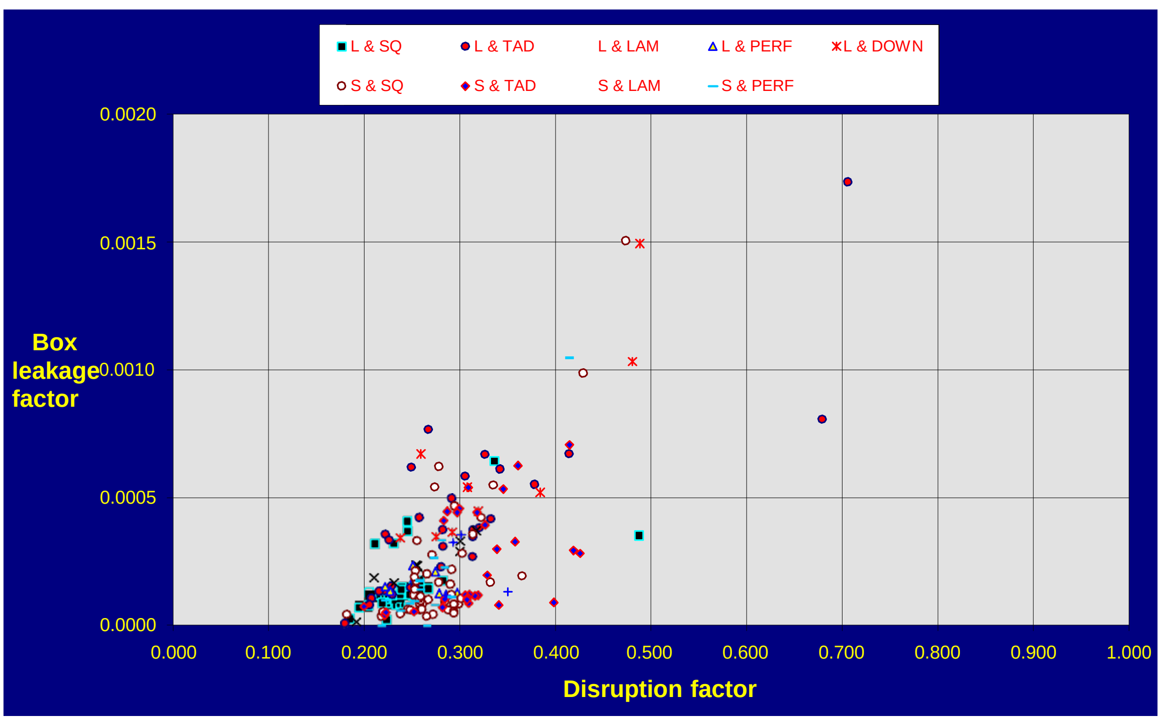


Figure 4.28 Box leakage factor vs. Disruption factor for laboratory size and supply diffuser arrangement

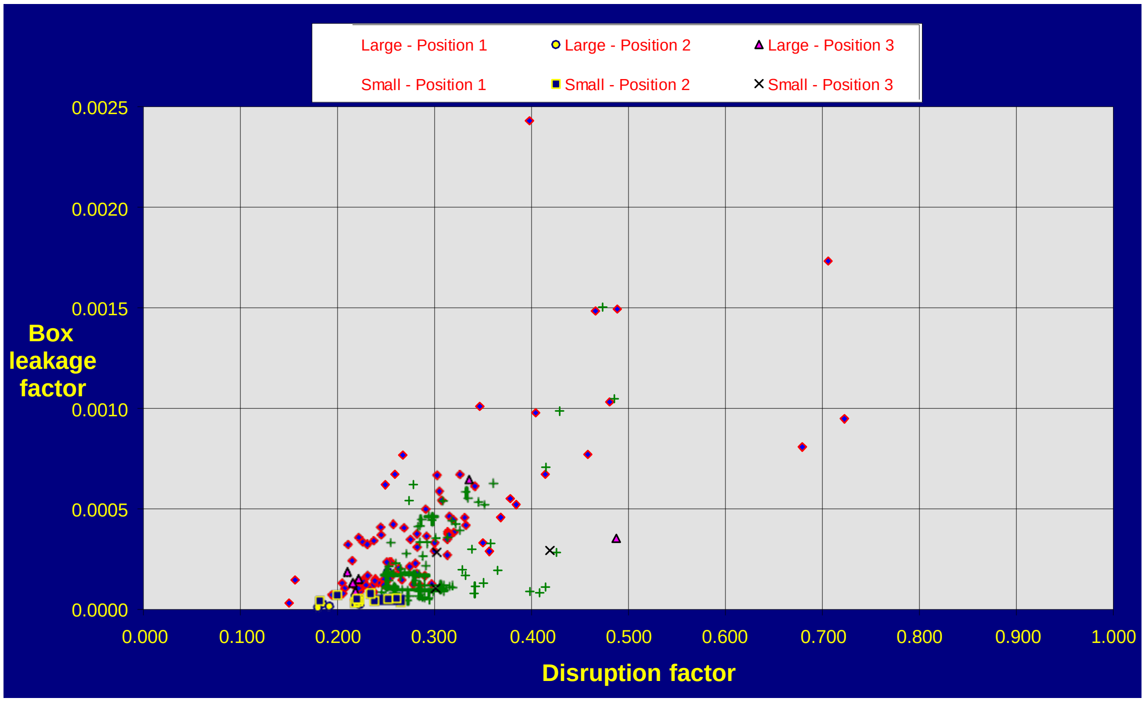


Figure 4.29 Box leakage factor vs. Disruption factor for laboratory size and hood position

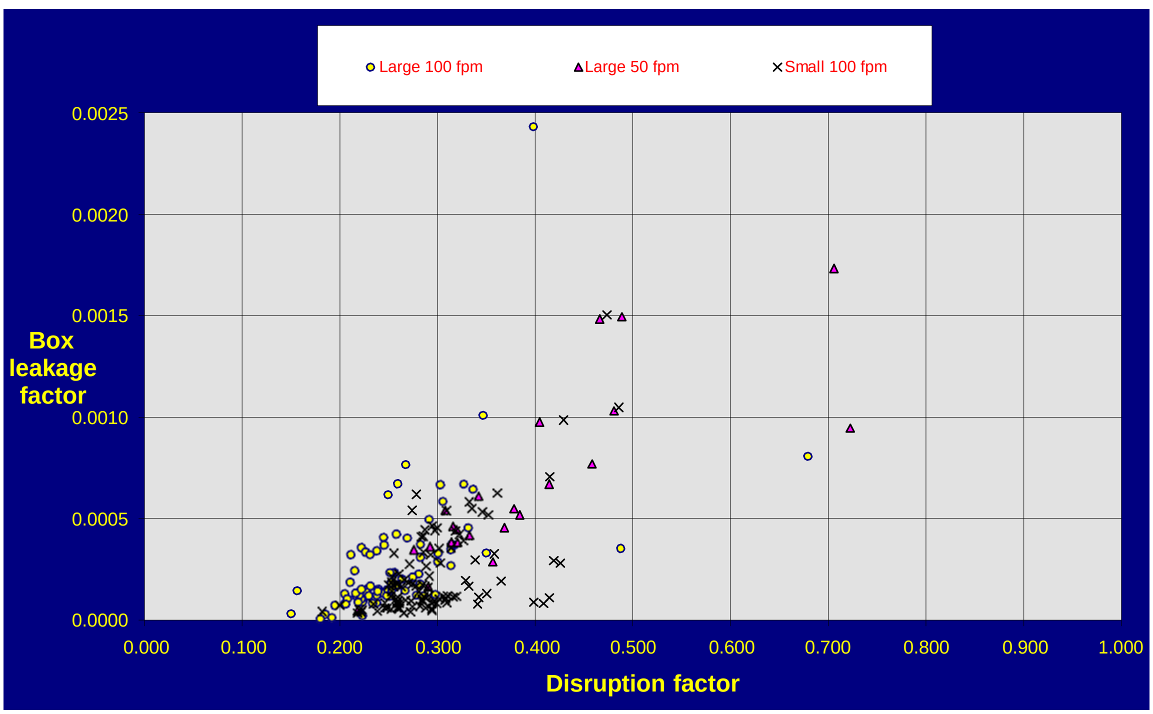
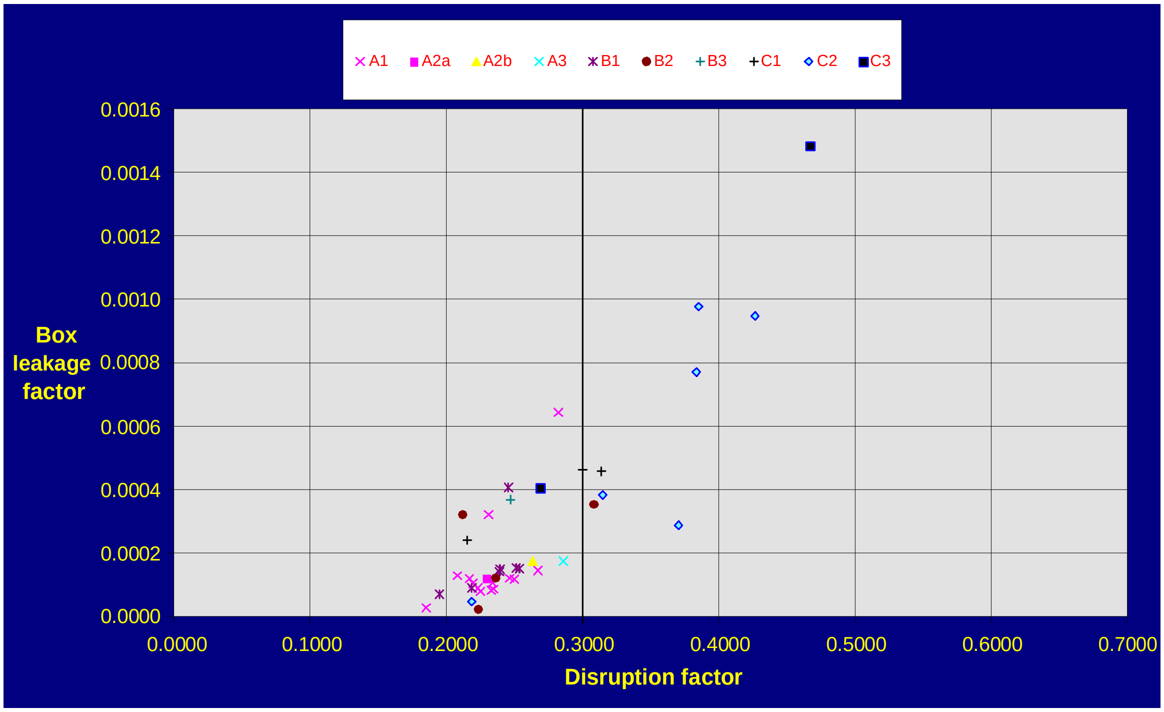
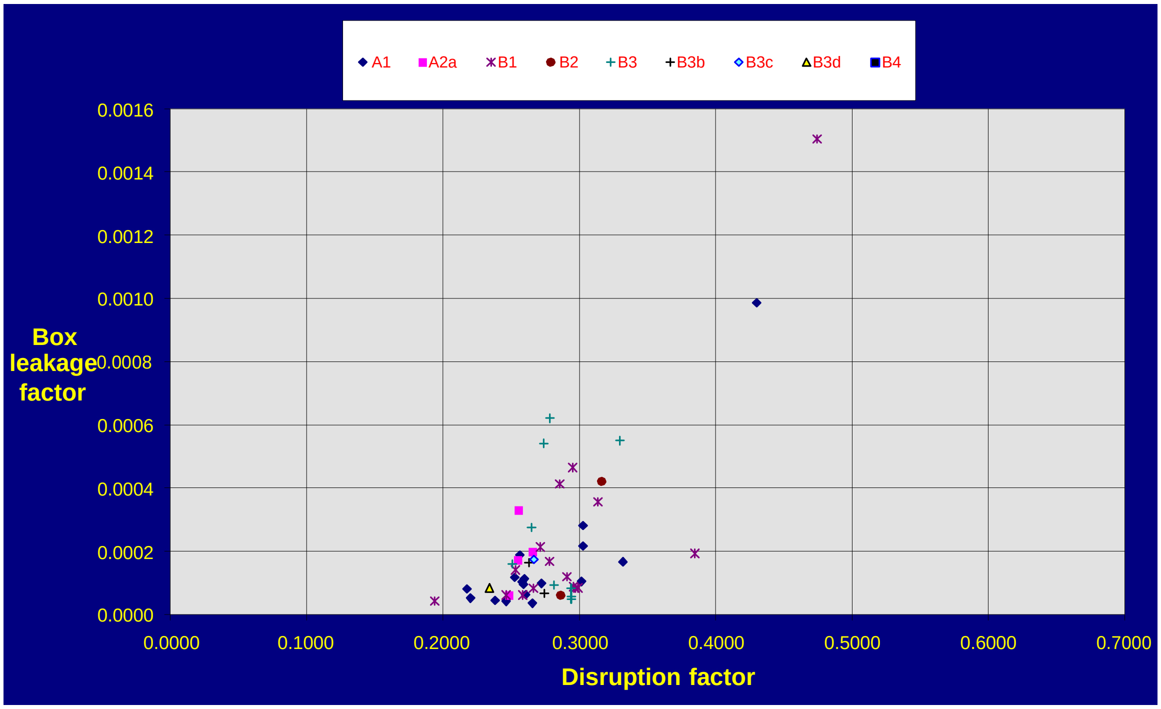


Figure 4.30 Box leakage factor vs. Disruption factor for laboratory size and hood exhaust speed



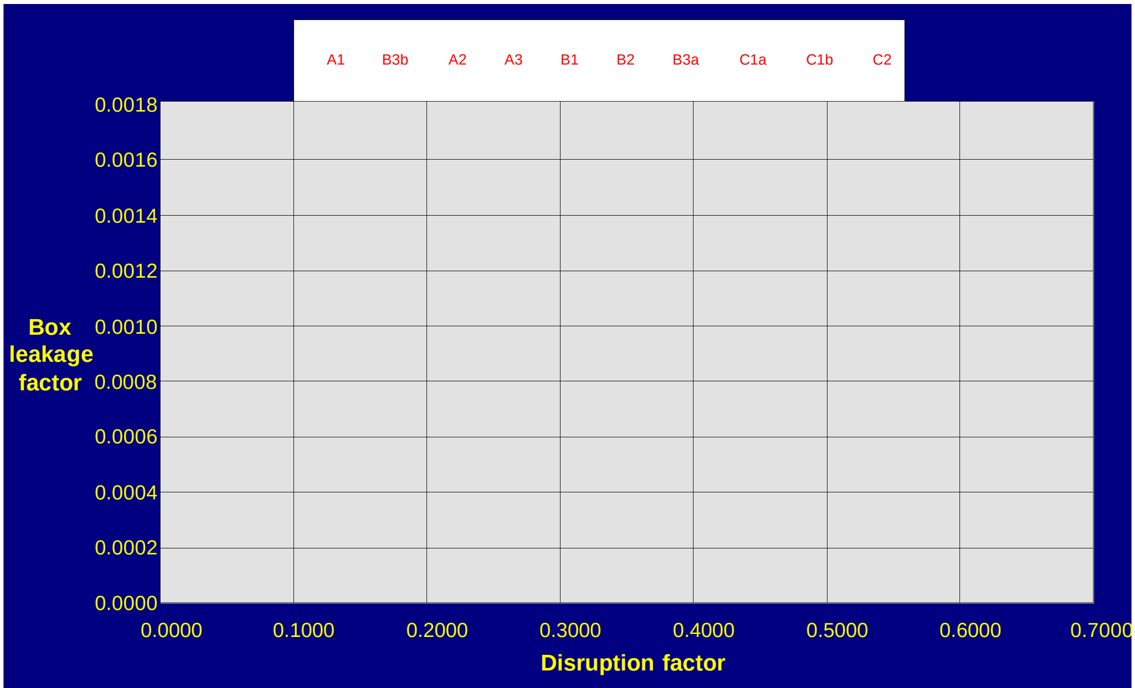
Layout Name	No. / Type / Size	Description	Simulation Nos.
SQ A.1	4 / Square / 12”	Laid out on quarters	41,43,44,52-58, 76-9,122,142
SQ A.2a	4 / Square / 12”	Spaced close to end walls	61
SQ A.2b	4 / Square / 12”	Spaced close to end walls, quadrants towards walls blanked	62
SQ A.3	4 / Square / 12”	Diffusers staggered	63
SQ B.1	2 / Square / 24”	Staggered spacing	42,45,46,106, 107,123,143
SQ B.2	2 / Square / 24”	Along centerline	64,86-88
SQ B.3	2 / Square / 24”	In line in front if hood, quadrant towards hood blanked	65
SQ C.1	4 / Square / 24”	Spaced close to end walls	2,10,18
SQ C.2	4 / Square / 24”	Laid out on quarters	3,15,19,25,28,31,33
SQ C.3	4 / Square / 24”	Diffusers staggered	4,11

Figure 4.31 Box leakage factor vs. Disruption factor for large laboratory square supply diffuser arrangement



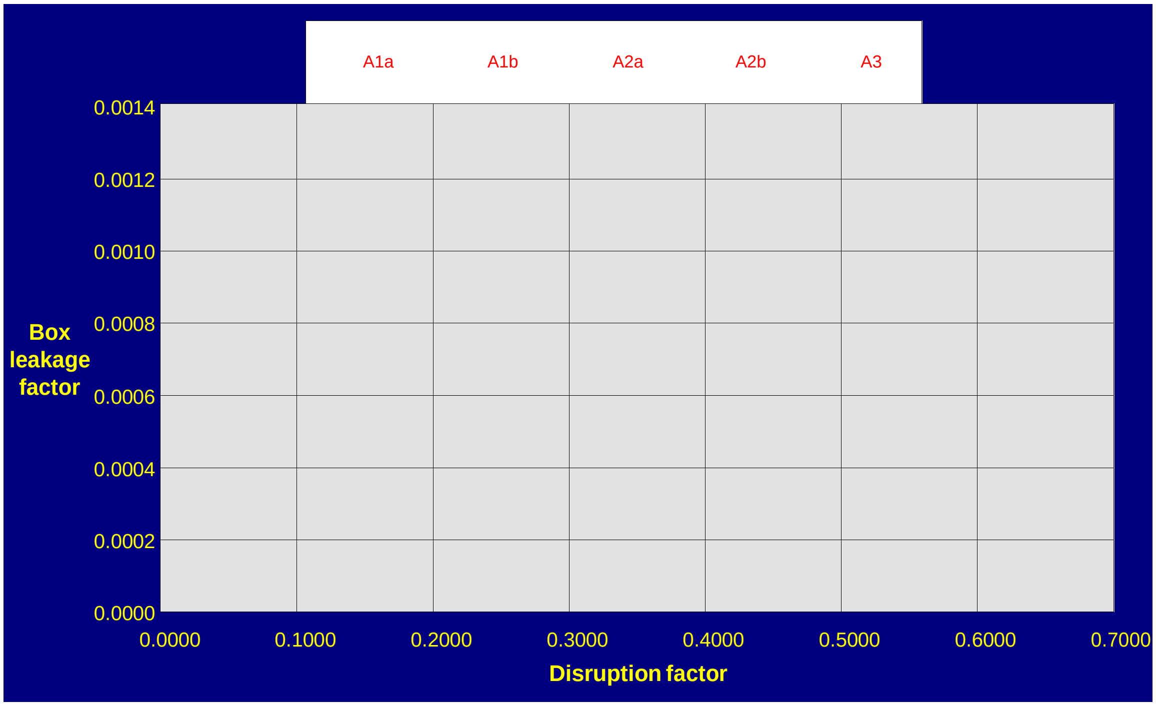
Layout Name	No. / Type / Size	Description	Simulation Nos.
SM SQ A.1	2 / Square / 12"	Even jet throw along centerline	82,82c,110,110c,118,118c, 126,126c,130,130c,134,138, 139,139c,148,153,155,183, 184,193
SM SQ A.2a	2 / Square / 12"	Staggered	102,102c,103, 148,149
SM SQ B.1	1 / Square / 24	On center line, away from main door	83,83c,119,119c,127,127c, 131,131c,135,135c,139,140, 140c,150,179,185
SM SQ B.2	1 / Square / 24	On centerline, close to main door	104,104c
SM SQ B.3	1 / Square / 24	On centerline, in front of hood	112,113,113c,189,190
SM SQ B.3b	1 / Square / 24	On centerline, in front of hood, quadrant towards hood blanked	105,105c,111,111c,151
SM SQ B3c	1 / Square / 24	1 foot further away from hood than SM SQ B3	191
SM SQ B3d	1 / Square / 24	1 foot nearer to hood than SM SQ B3	192
SM SQ B4	2 / Square / 24	Between SM SQ B.1 and SM SQ B.3	188

Figure 4.32 Box leakage factor vs. Disruption factor for small laboratory square supply diffuser arrangement



Layout Name	No. / Type / Size	Description	Simulation Nos.
TAD A.1	2 / Radial / 48”x24”	Along centerline, radial spread across laboratory	16,17,20,26,29,32,34,49,49c, 92-94
TAD A.2	2 / Radial / 48”x24”	Staggered array, radial spread across laboratory	5,12, 69,69c
TAD A.3	2 / Radial / 48”x24”	Staggered array, diffusers close to hood, radial spread across laboratory	6,13, 70,70c
TAD B.1	2 / Radial / 24”x24”	Along centerline, radial spread across laboratory	50,50c,81,124, 144,147
TAD B.2	2 / Radial / 24”x24”	Staggered array, radial spread across laboratory	71,71c
TAD B.3a	2 / Radial / 24”x24”	Staggered array, diffusers close to hood, radial spread across laboratory	72,146
TAD B.3b	2 / Radial / 24”x24”	Staggered array, diffusers close to hood, radial spread along laboratory	73
TAD C.1a	4 / Radial / 24”x24”	Laid out on quarters, radial spread across laboratory	51
TAD C.1b	4 / Radial / 24”x24”	Laid out on quarters, radial spread along laboratory	74
TAD C.2	4 / Radial / 24”x24”	Staggered array, radial spread across laboratory	75,75c

Figure 4.33 Box leakage factor vs. Disruption factor for large laboratory TAD supply diffuser arrangement



Layout Name	No. / Type / Size	Description	Simulation Nos.
SM TAD A.1a	1 / Radial / 24"x24"	On centerline away from main door, radial spread across laboratory	85,85c,108,108c,109,109c, 181
SM TAD A.1b	1 / Radial / 24"x24"	On centerline away from main door, radial spread along laboratory	97,97c,114,115,154
SM TAD A.2a	1 / Radial / 24"x24"	On centerline close to main door, radial spread across laboratory	95,95c,180
SM TAD A.2b	1 / Radial / 24"x24"	On centerline close to main door, radial spread along laboratory	96,96c
SM TAD A.3	1 / Radial / 24"x24"	Centered in front of the hood	116,116c,117,117c,120,120c, 128,128c,132,132c,136,136c, 152,186

Figure 4.34 Box leakage factor vs. Disruption factor for small laboratory TAD supply diffuser arrangement

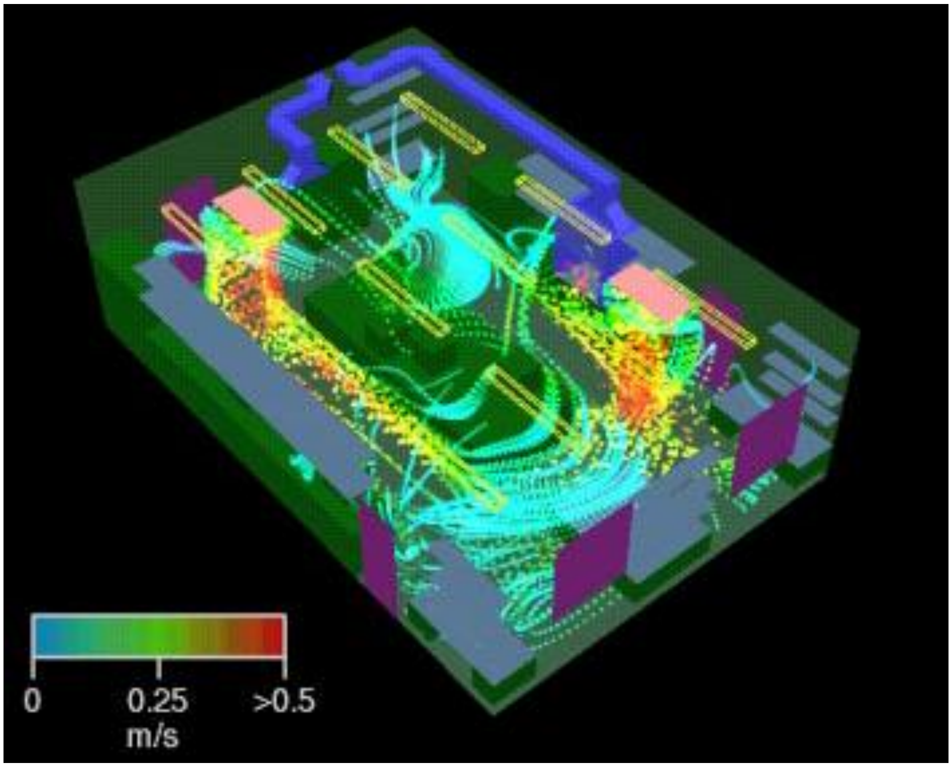


Figure 4.35 Two 4’ x 2’ radial diffusers blowing at right angle to hood.

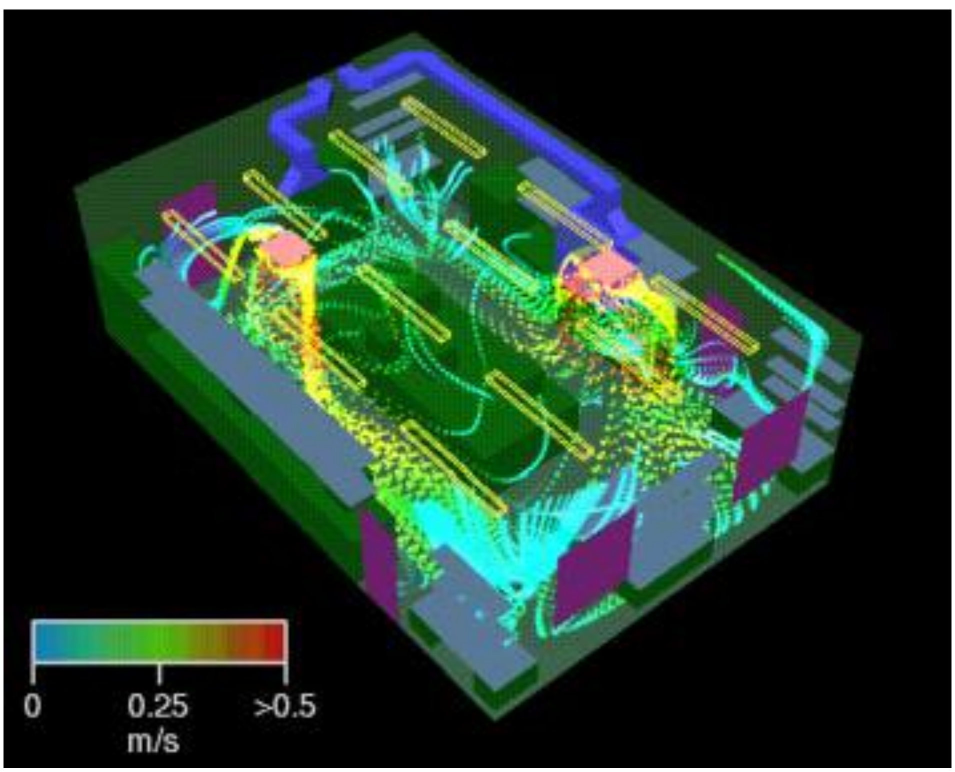
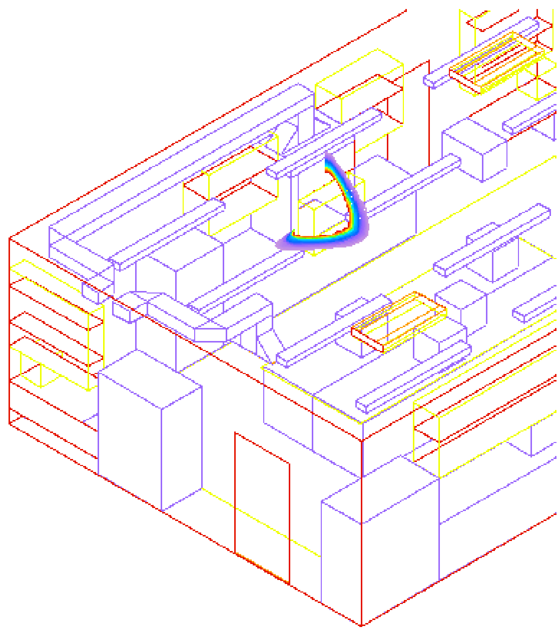
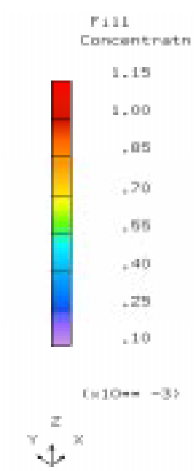


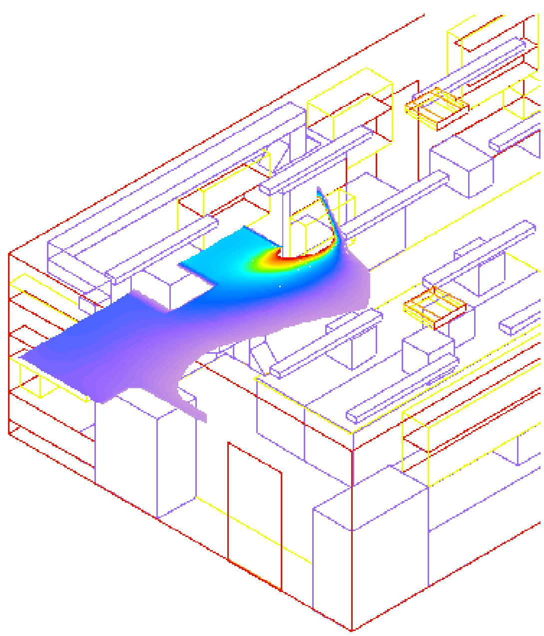
Figure 4.36 Two 2’ x 2’ radial diffusers blowing across face of hood.



Large radial diffuser blowing towards hood.

Run069





Small radial diffuser blowing across hood.

Figure 4.37 Effect of radial diffuser blowing across face versus right angles to face.

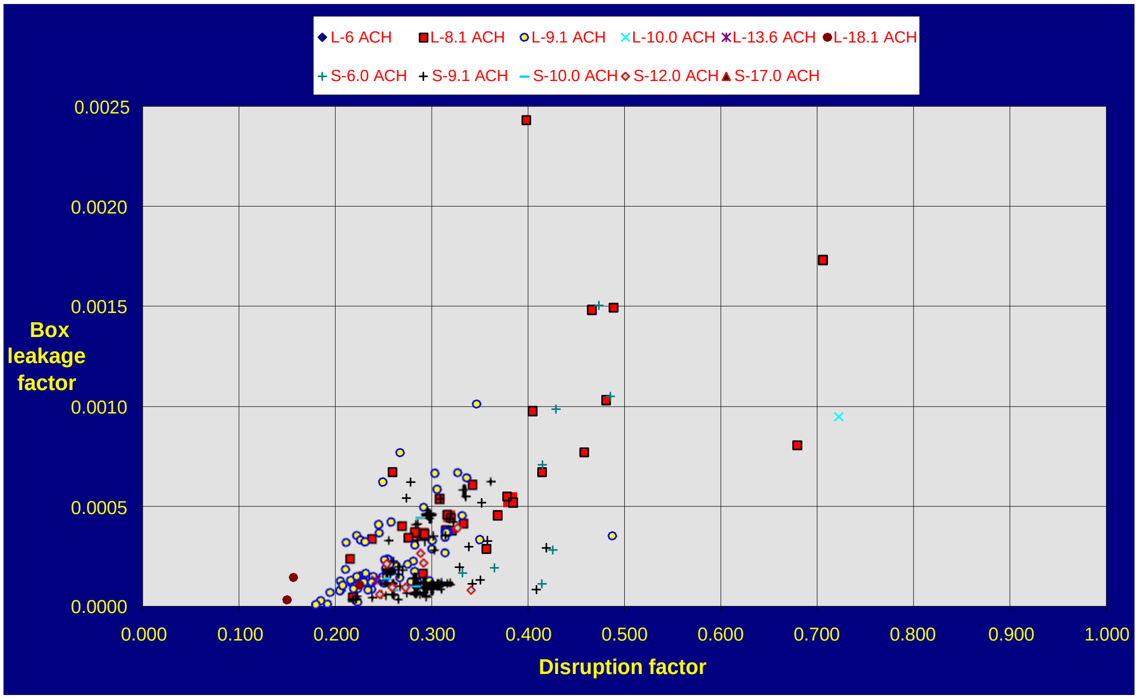


Figure 4.38 Box leakage factor vs. Disruption factor for laboratory size and supply ACH

4.3 Specific Configuration Recommendations

This section draws out specific conclusions and illustrates them using scatter diagrams of sash leakage factor vs. box / sash leakage proportion, diagrams of concentration spread, and flow diagrams. Many of these recommendations represent new knowledge based on the set of data presented from this research. Designers configuring laboratories along similar lines to those presented here should benefit by applying this information. The research does, however, show the sensitivity of hood containment performance to small changes in design and configuration so the designer should proceed with due diligence and caution.

4.3.1 Hood Position

Figure 4.39 shows the effect of moving the hood from the center of the long side wall to the corner to the center of the short end wall, indicated by the arrows. Six different laboratory configurations are considered where each uses a different supply type / configuration. For each of the six supply configurations a simulation is performed for each of three different hood positions. A separate symbol and color is used for each supply configuration. The first arrow for each configuration starts at hood position 1 with the arrowhead pointing to hood position 2. The second arrow starts at hood position 2 with the arrowhead pointing to hood position 3. Hood position 1 is nearly in the center of the long wall, hood position 2 is in a corner with it's back aligned with the long wall, and hood position 3 is near the center of the short wall.

As the diagram shows, the second position, in the corner, performs substantially better both in terms of sash and box leakage, for different supply air diffusers and different laboratory sizes. The only exception is that for SM SQ A.1 when the hood is moved into the corner adjacent to the transfer grille. In this case the jet from the transfer grille passes across just above and in front of the sash opening falling down into the occupied zone as it mixes with the cool supply air from the diffuser. It thus falls down in front of the open sash, figure 4.40 (0.5 m/s = 100fpm), to the detriment of hood containment in terms of box / sash leakage proportion, sash leakage factor is still significantly reduced by almost 50%.

Recommendation : Protect the hood by placing it in a corner avoiding jets impinging on the working zone outside the sash opening.

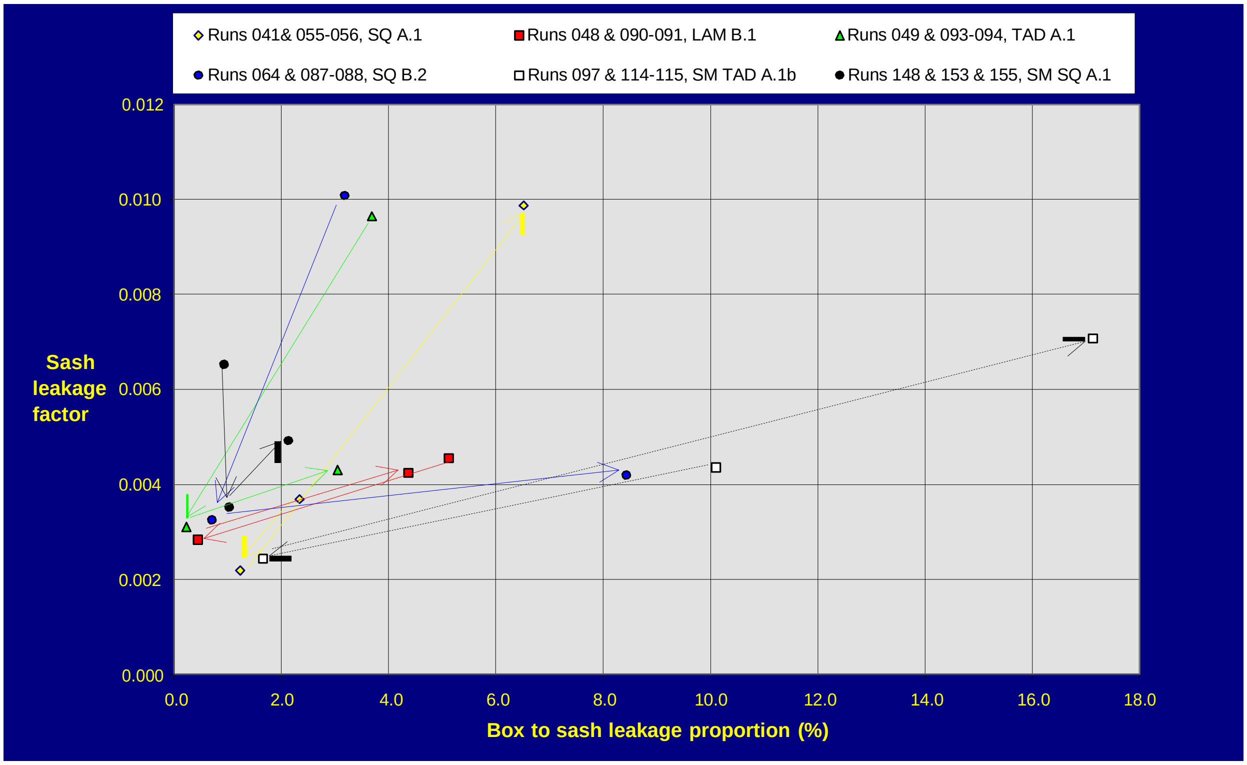


Figure 4.39 Sash leakage factor vs. Box / sash leakage proportion for the hood position at the center long wall to the corner of the room to the center of the short wall (as indicated by the arrows)

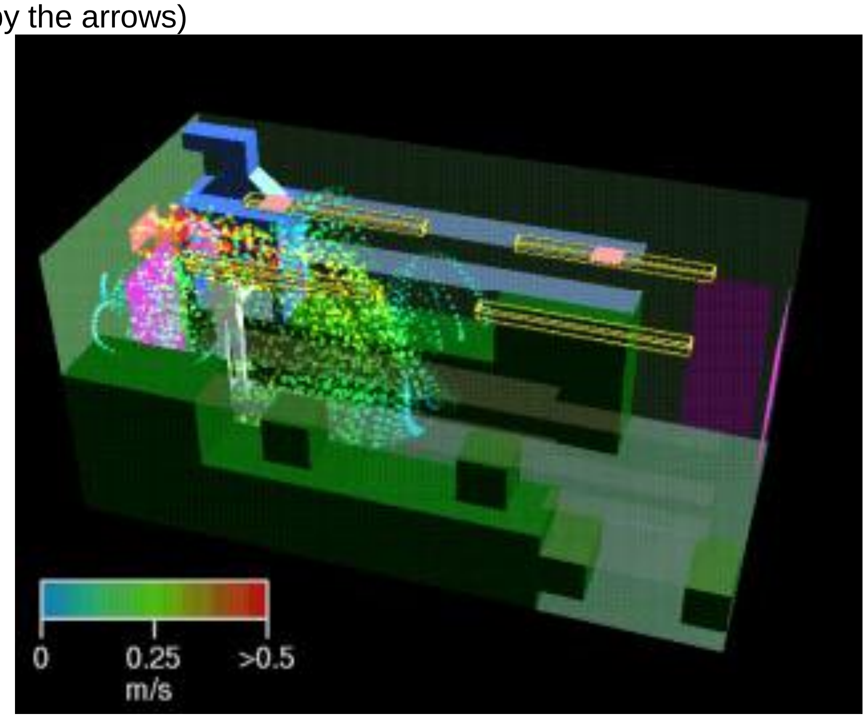


Figure 4.40 Hood containment disruption due to transfer grille.

4.3.2 Bulkhead or No Bulkhead

The results of six simulation pairs (bulkhead and no bulkhead) are shown to demonstrate the effect of including a bulkhead above the fume hood, that is to extend the fume hood cabinet up to the ceiling. Figure 4.41 shows the change in performance for each of the simulation pairs, and that the performance does not always respond in the same way. The arrow points from the simulation with no bulkhead to the simulation with the bulkhead.

Run054 is worse than run041, figure 4.42, (four 12” square diffusers laid out on quarters) since the bulkhead forces two jets, which meet above and in front of the of the hood, down. This causes the resulting jet to impact the air entering the hood. This is to be expected since the diffuser produces a thin jet with high velocity. A similar effect occurs in the small lab with a single 24” diffuser (SM SQ B.3a) close in front of the hood, although the jet is only sufficient to degrade box containment not sash containment. The thicker, lower velocity jet from the perforated diffuser (Perf A.1) appears not to penetrate and containment is unaffected.

For run064 and run086, figure 4.43, (two 24” square diffusers on the centerline) the effect is reversed - the colliding jets are further away and so the jet turned down by the bulkhead gently feeds the hood rather than disrupting the inflow. For run049 and run092, the TAD diffuser also feeds the hood better with the bulkhead present. Where the diffuser creates a thick, low velocity jet blowing at the hood sash, containment improves when the bulkhead is removed. However, care should be taken to avoid the jet rolling past the open sash. This can easily occur with a down-flow diffuser causing a loss of box containment (run047 LAM A.1 and run089 LAM B.1) where the bulkhead will enhance the circulation.

Recommendation : A bulkhead can be used to improve the containment performance by either :

- using a diffuser layout that will gently feed low velocity air to the hood.
- avoiding use of a diffuser layout which generates thin jets across the face of the hood from above.
- avoid using down-flow diffusers that cause a circulation in front of the hood so that the jet does not impinge.

Care should be taken to avoid indirect flows such as those from the converging jets SQ A.1, figure 4.42. In this case the bulkhead, run054, increases the contaminant leakage.

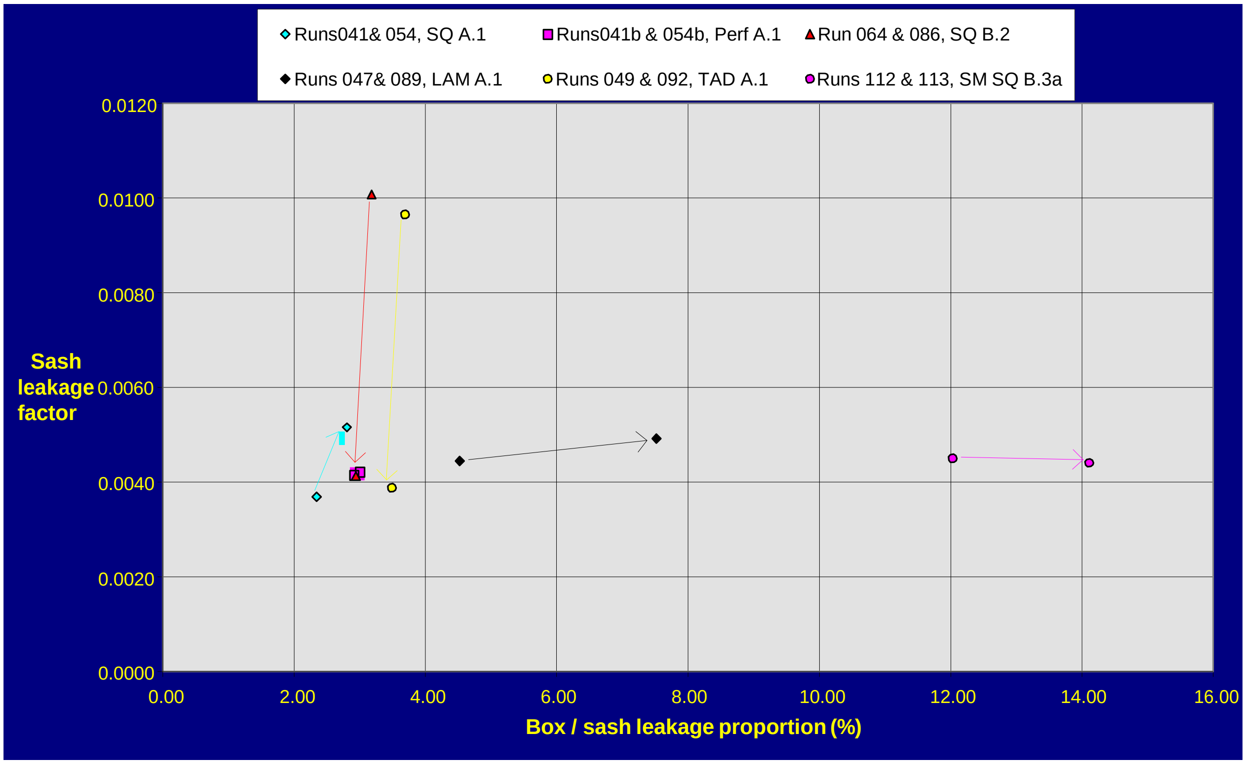
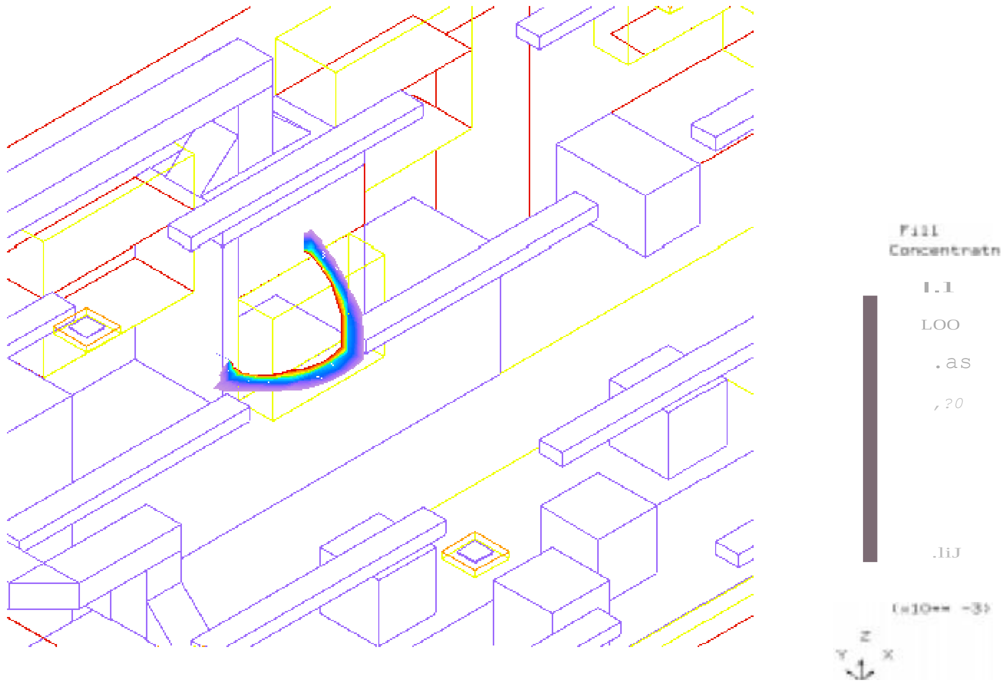
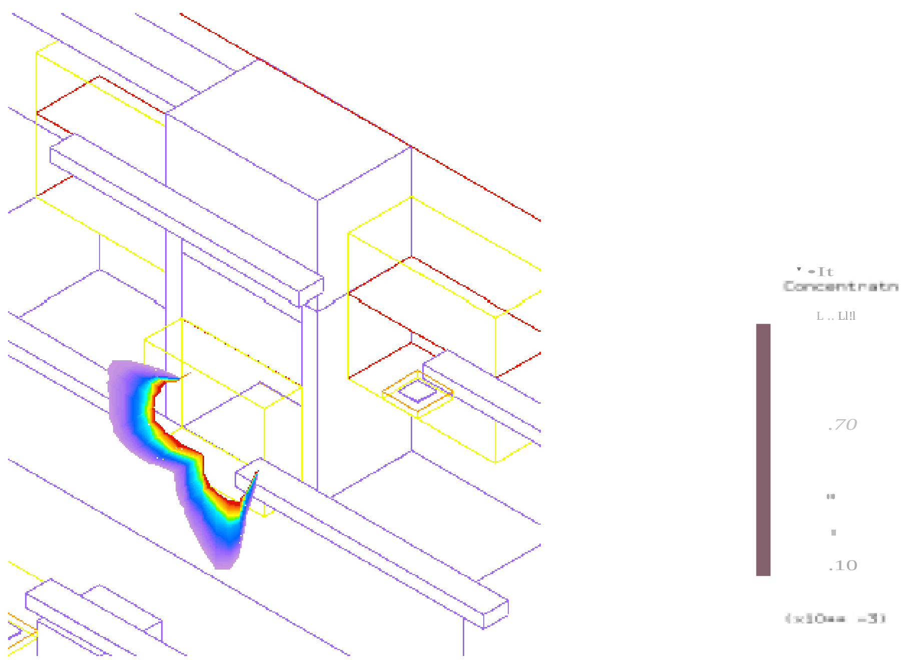


Figure 4.41 Sash leakage factor vs. Box / sash leakage proportion for inlcusion or exclusion of a bulkhead (as indicated by the arrows)



Run041



Run054

Figure 4.42 Effect of a bulkhead on a small jet.

4.3.3 The Effect of Diffuser Blanking

Where a diffuser is close to a laboratory hood or a side wall, blanking the jet in the direction of the hood or wall is a common solution. This can be dangerous, figure 4.44 (the arrows point towards the configuration with blanking), if the path of the other jets creates a circulation, they may move faster around the laboratory, thus disrupting the hood.

Run061 and run062 consist of four 12” square diffusers close to the end walls. Run062 has the quadrants towards the end walls blanked. As a result the jets toward the center of the room meet and pass down in front of the open sash faster than without blanking.

Run111 and run112 use a single 24” square diffuser above and in front of the hood. When the quadrant towards the hood is blanked off, run112, the box / sash leakage proportion reduces, but all the air enters the sash from below increasing the sash leakage factor. Figure 4.45 shows the increase in contaminant concentration in the lab as a result of introducing blanking, run112.

Recommendation : Avoid blanking where the increased velocity jets have a path back to the hood.

Run064

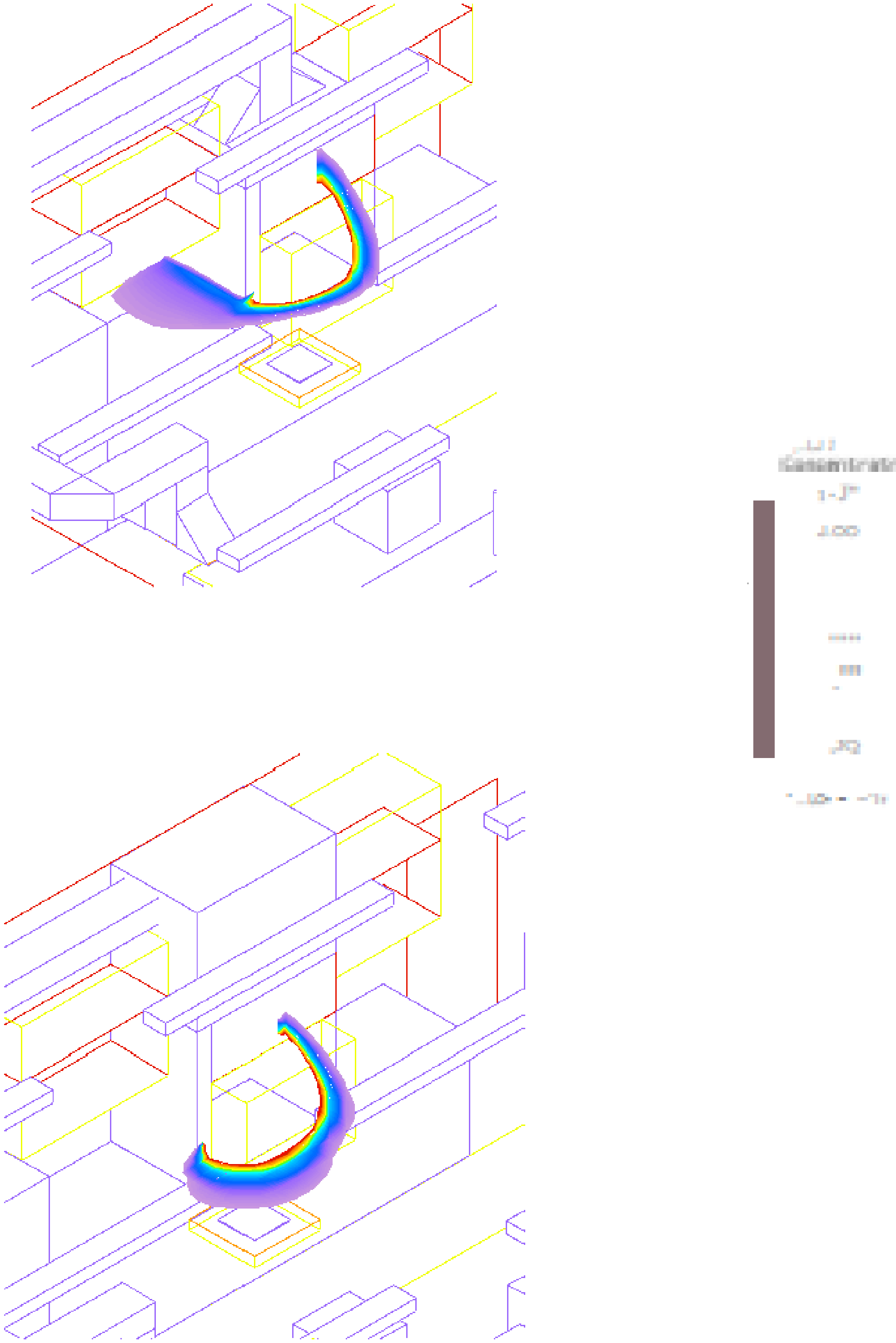


Figure 4.43 Bulkhead reducing the leakage from converging jets.

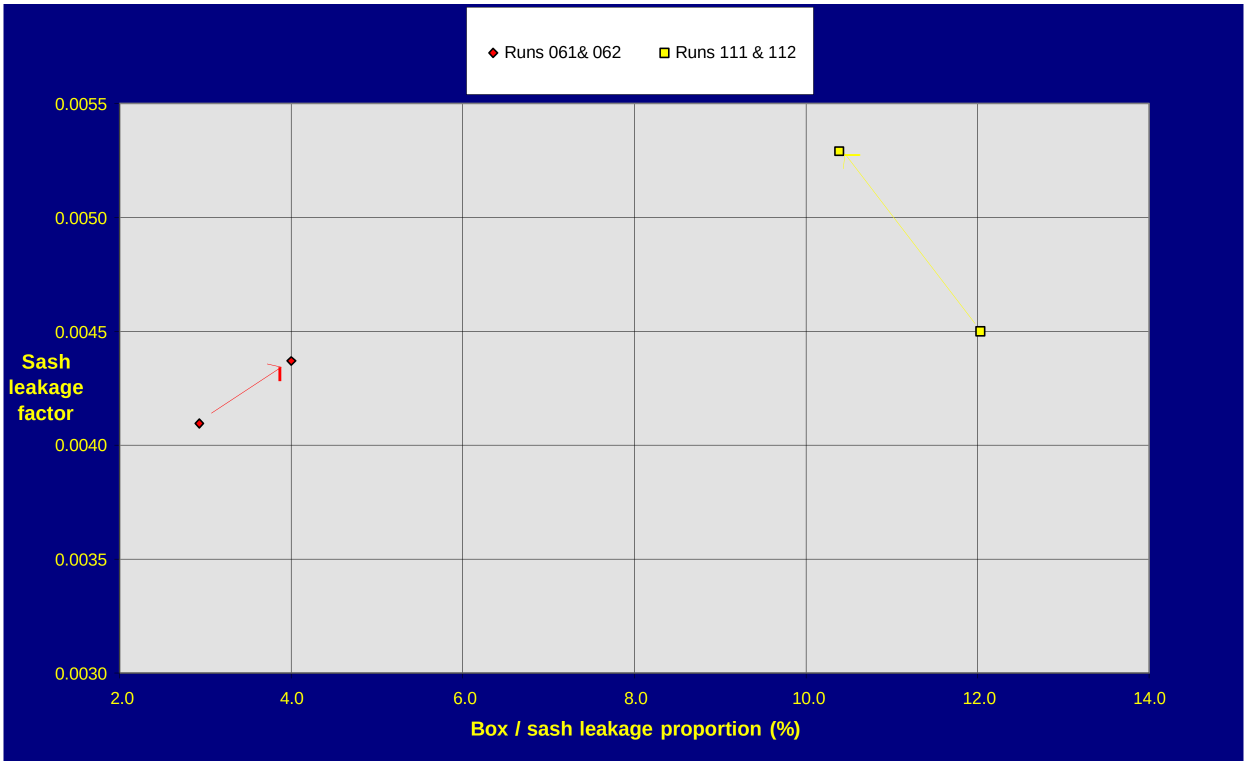
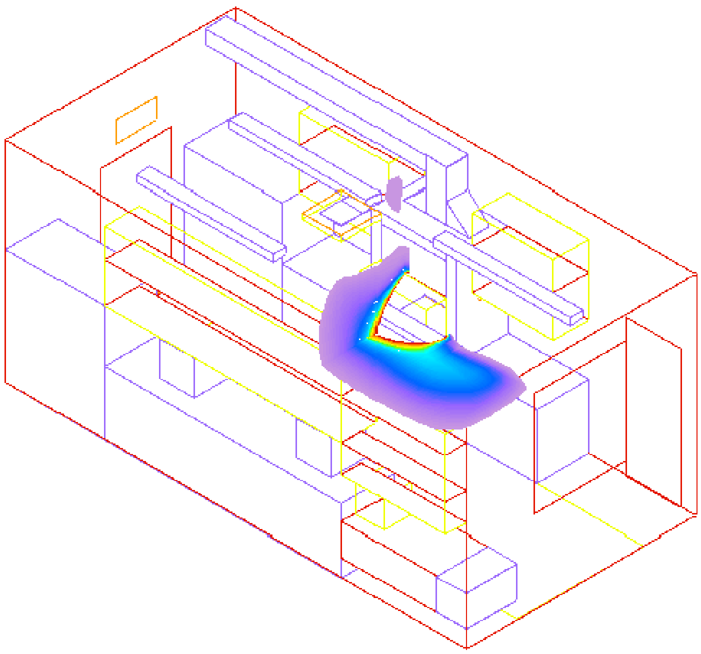
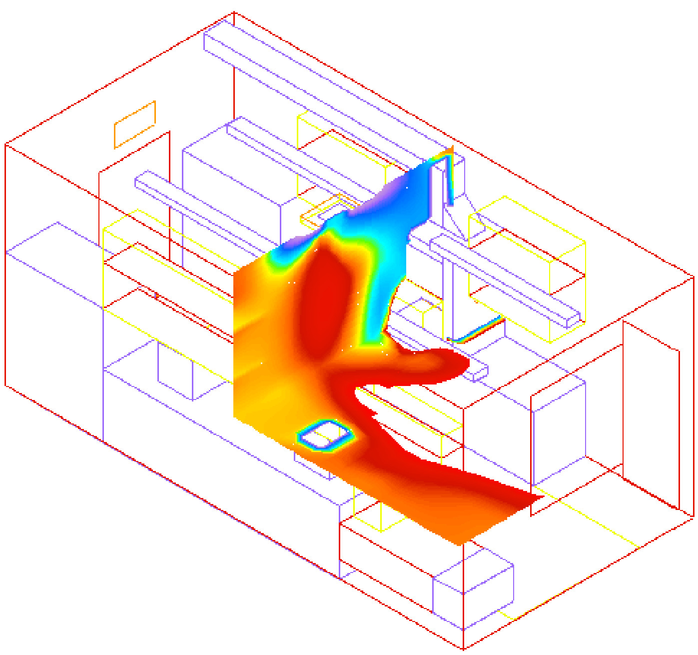
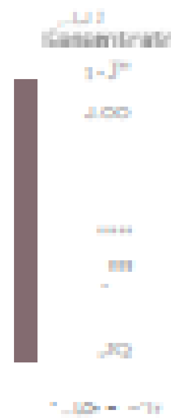


Figure 4.44 Sash leakage factor vs. Box / sash leakage proportion for inlcusion or exclusion of supply jet blanking (as indicated by the arrows)



Run111 • side of diffuser blowing towards hood blanked





Run112- all sides of diffi.Jser active

Figure 4.45 Effect of blanking one side of square diffuser.

4.3.4 Jet Thickness

While square diffusers of the same size are often assumed to perform similarly, jet thickness and angle can substantially affect the flow patterns generated, and thus the change the hood containment performance. Three simulations are used to investigate the effect of changing jet thickness (and velocity to maintain volume flow rate). A typical design is used as a reference, run041, with the 12" square diffusers laid out on the quarters. The jet thickness is doubled and the velocity halved, run053, and the jet thickness is halved and the velocity doubled run052. Figure 4.46 (arrows indicate decreasing jet thickness) shows that changing the jet thickness does not have a proportionate effect on containment.

The thick, jet run053, does not have enough momentum and does not attach to the ceiling, but dumps down into the occupied zone. This causes an asymmetric flow into the hood from below, figure 4.47, which in turn causes leakage from the sash opening, figure 4.48. These can be compared with figure 4.49 where the jet remains attached to the ceiling for some time and figure 4.50 showing the limited concentration spread and low velocities in front of the sash opening. Further jet thickness reduction increases penetration of the thin higher velocity jets, which cause a down-flow in front of the sash opening, figure 4.51. Although the thin jet reduces the sash leakage factor continuously, this is at the risk of increased box / sash leakage proportion. Figure 4.52 shows higher velocities in front of the sash opening resulting in higher leakage.

4.3.5 Diffuser Position (24" Square Diffuser)

Figure 4.53 shows the variation in hood containment performance as the diffuser is moved laterally from one side of the hood (run119, layout SM SQ B.1) to near the edge of the hood (run188, layout SM SQ B.5) to in front of the hood (run189, layout SM SQ B.3a). The yellow arrow indicates movement towards the centerline of the hood. The red arrows indicate perpendicular movement along the centerline of the hood and towards the front of the hood – farthest away (run191, layout SM SQ B3.c) through the centerline position (run190, layout SM SQ B.3c) to close to the hood (run192, layout SM SQ B.3d). For the latter three simulations a bulkhead is fitted.

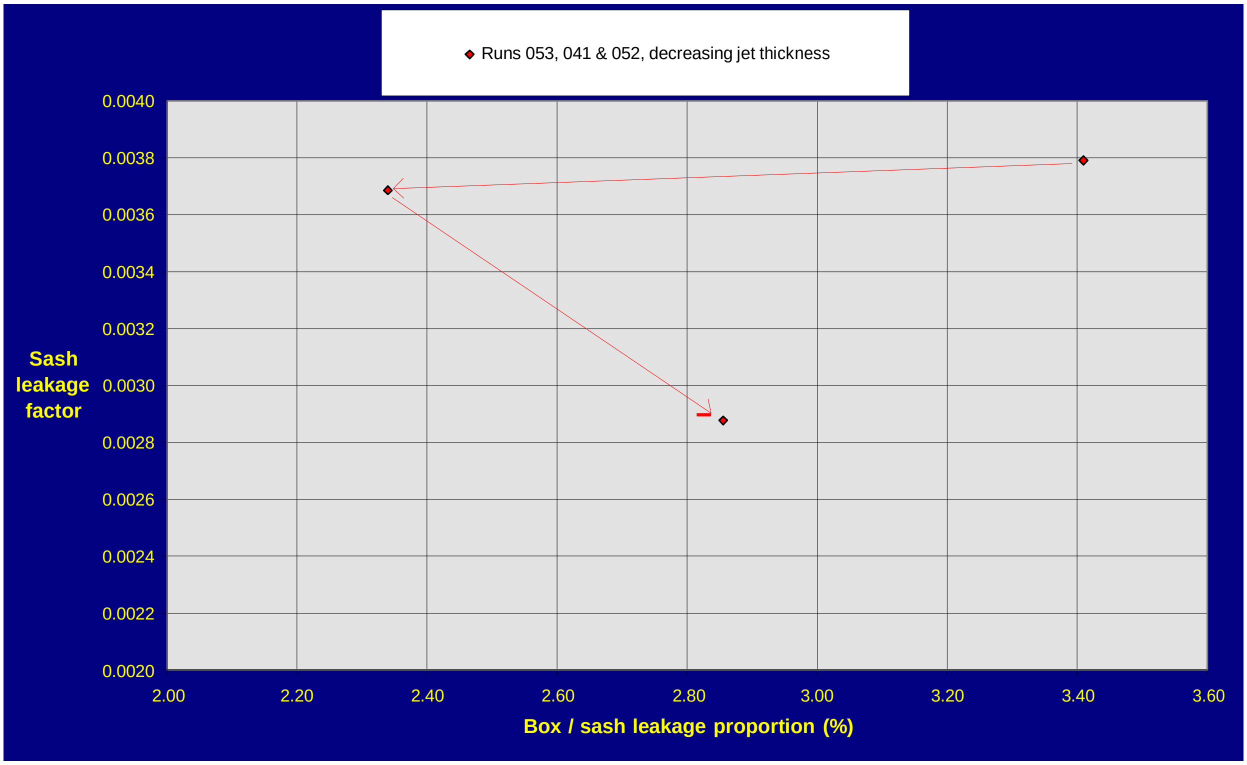


Figure 4.46 Sash leakage factor vs. Box / sash leakage proportion for decreasing jet thickness (as indicated by the arrows)

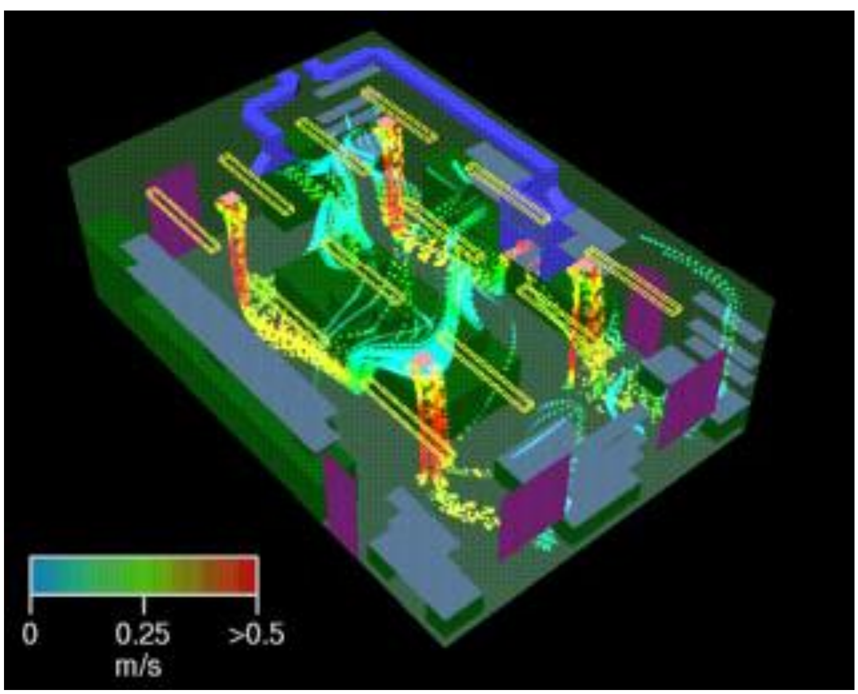


Figure 4.47 Jet thickness increased / initial jet velocity halved.

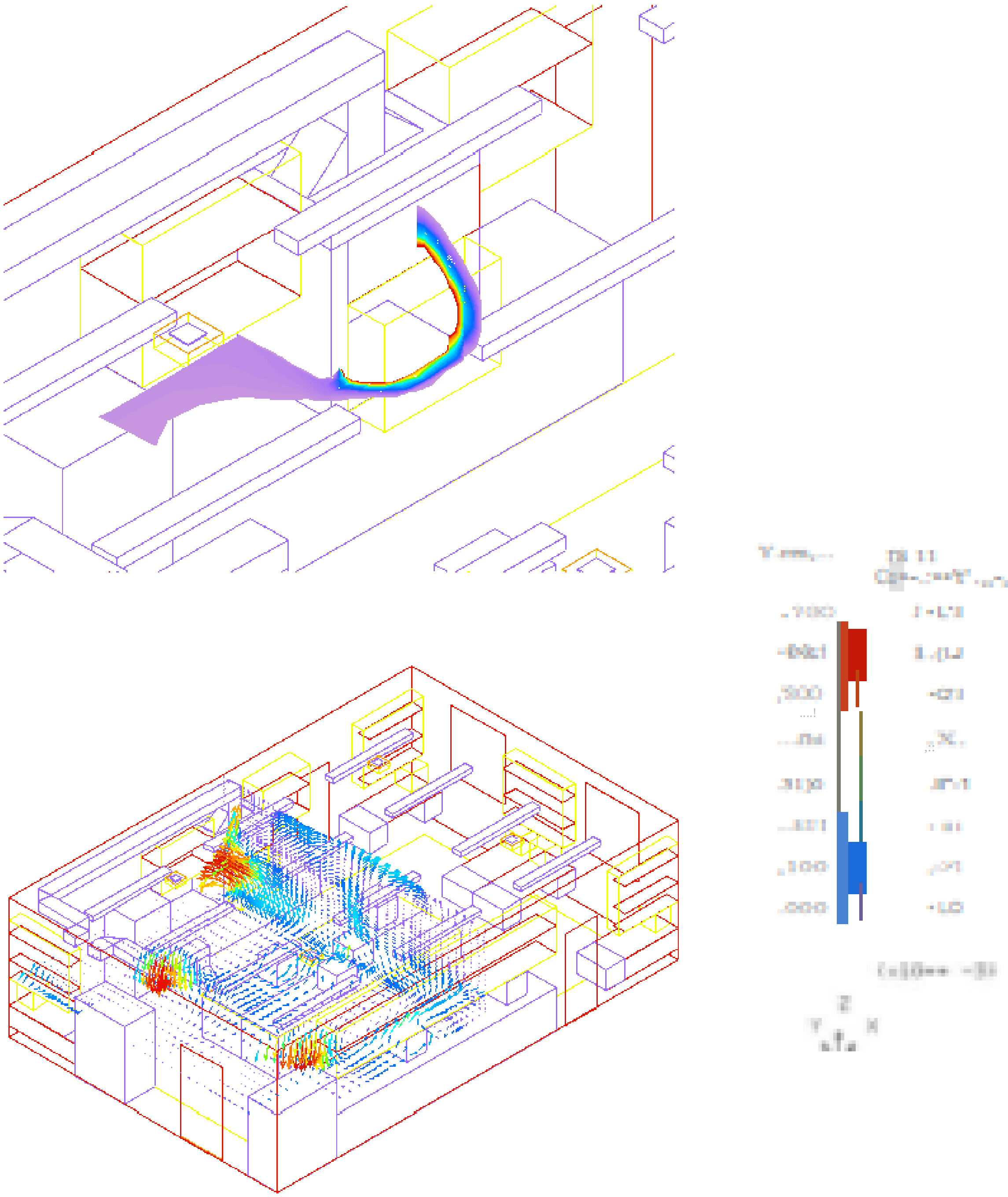


Figure 4.48 Example of thick supply jet (run053).

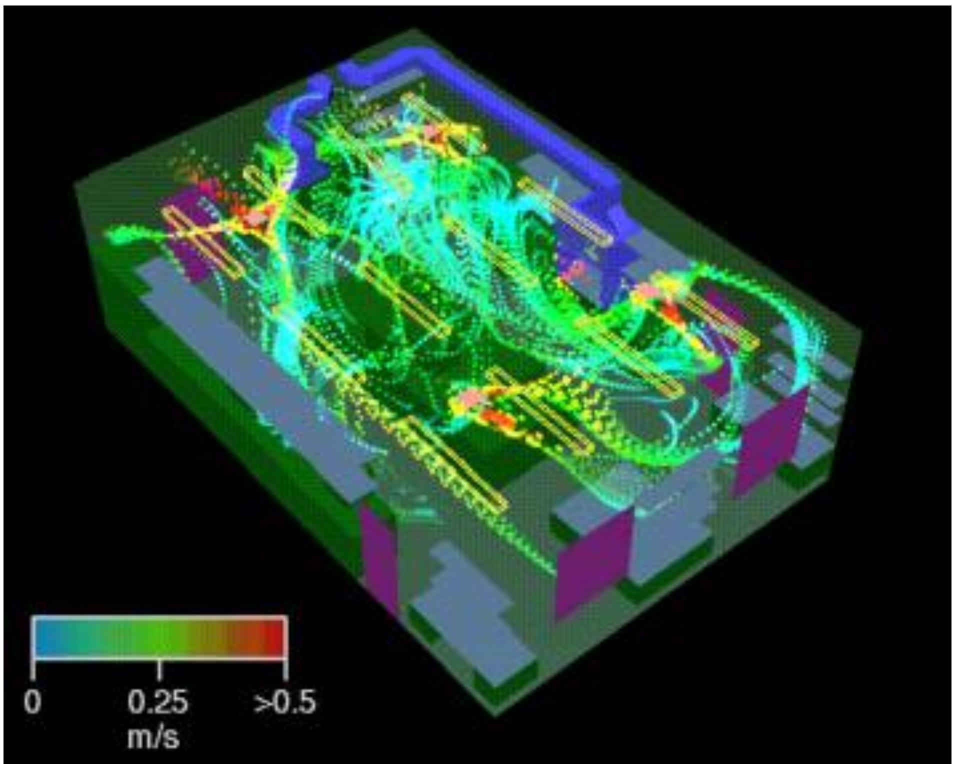


Figure 4.49 Default square diffuser conditions.

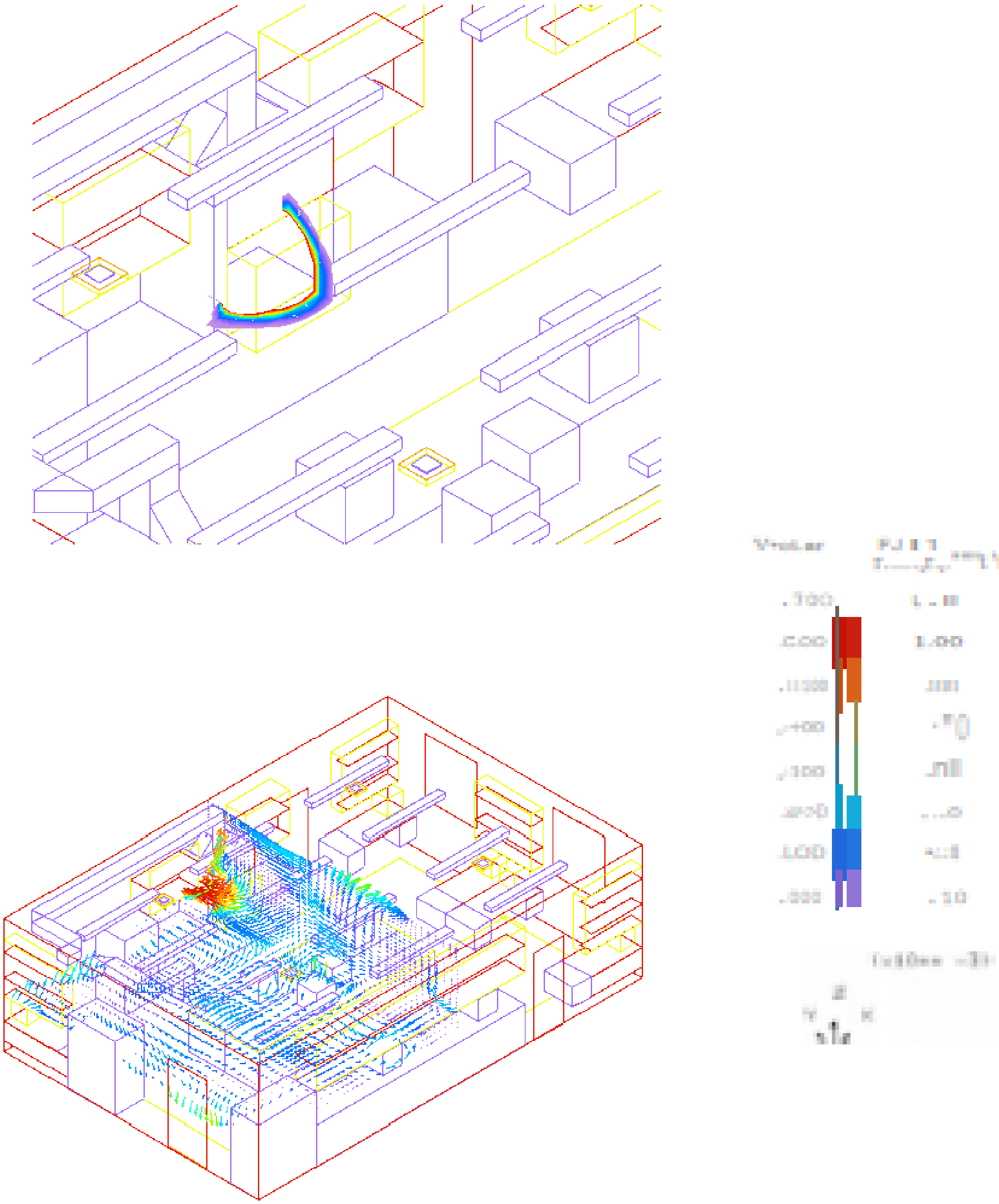


Figure 4.50 Example of the basic jet thickness (run041- base run).

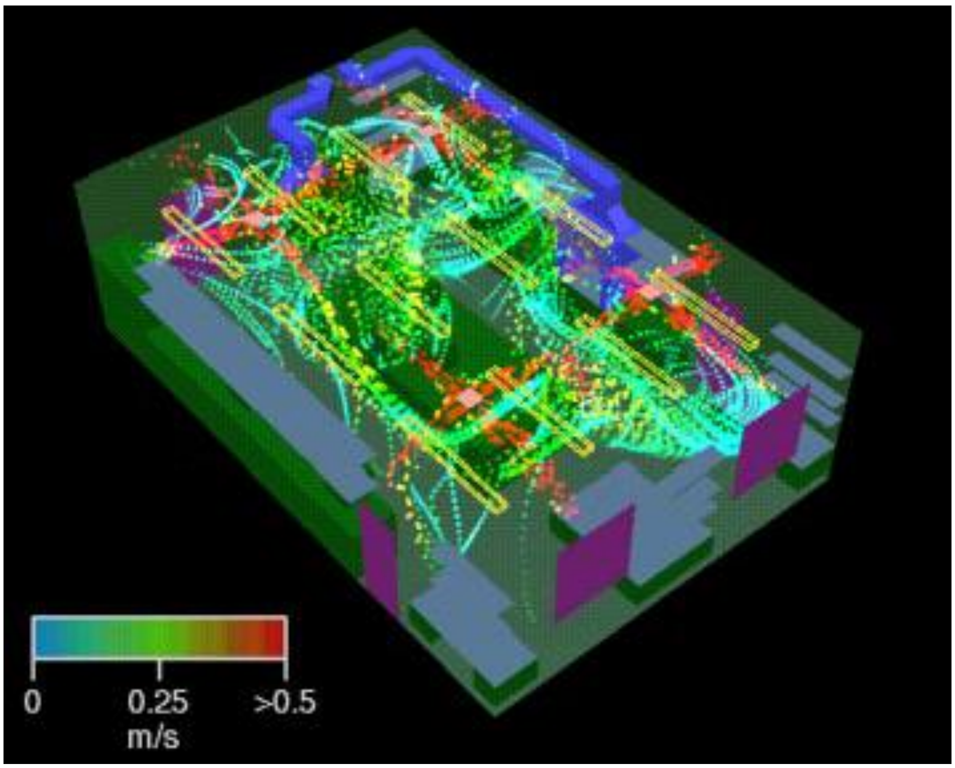


Figure 4.51 Jet thickness decreased / initial jet velocity doubled.

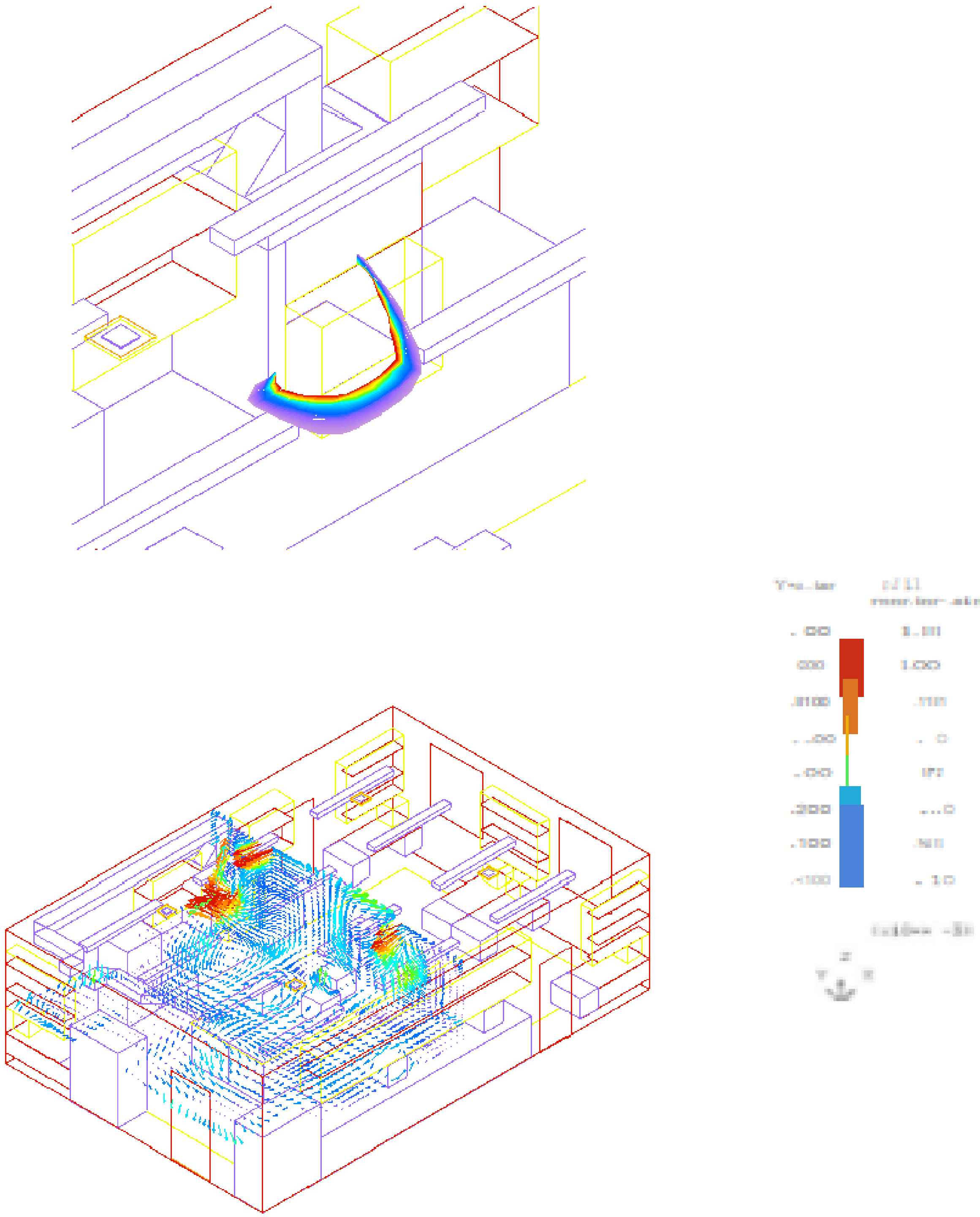


Figure 4.52 Example of thin supply jet (run052).

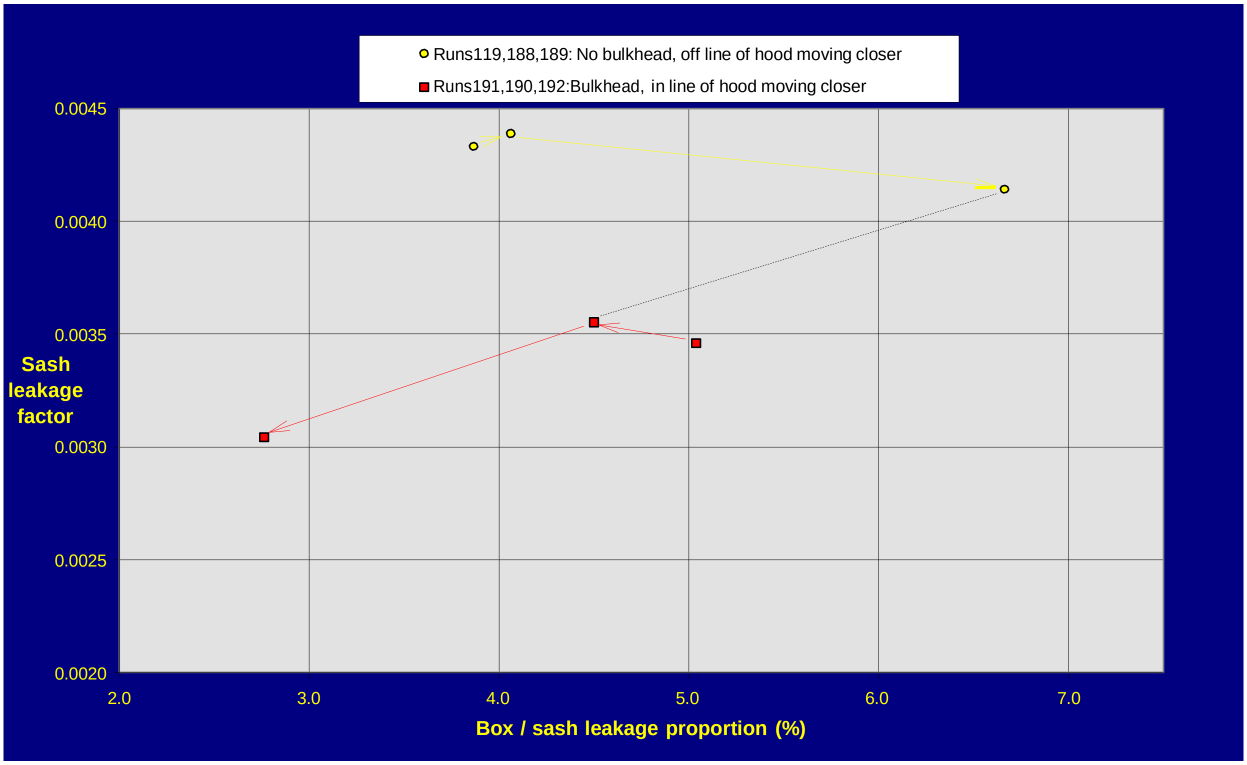


Figure 4.53 Sash leakage factor vs. Box / sash leakage proportion for diffuser moving laterally or perpendicular to the front of the hood (as indicated by the arrows)

As the diffuser is moved laterally the sash leakage is highest when the diffuser is aligned with the side edge of the sash opening although the difference between all three cases is small. The overall result in the laboratory is dominated by containment at the box. There is only a small change between the layout with the largest offset (run119, figure 4.54) and the layout near the edge of the hood (run188 figure 4.55). However, greatest leakage into the bulk of the laboratory occurs when the diffuser is in line with the center of the hood (run189 figure 4.56). Although the sash leakage reduced by approximately 5% by placing the diffuser in front of the hood, the box / sash leakage proportion increased by around 70% resulting in much larger spread around the lab.

Recommendation : Avoid placing a square diffuser asymmetrically in front of the hood, since this increases exposure to the scientist by increasing sash leakage.

For this configuration the leakage was reduced by including a bulkhead (run190, layout SM SQ B.3a, figure 4.57), sash leakage factor by around 15% and box / sash leakage proportion by around 30%. Intuitively it might be anticipated that moving the diffuser farther away will reduce leakage. Although this is true for sash leakage factor, the improvement is less than 3% and substantial further movement is constrained by the width of the laboratory. The box / sash leakage proportion increases by almost 12% since in both these cases the jet turns strongly down the bulkhead reducing uniformity of flow into the sash opening and producing a loss of containment particularly beneath the sash (see also figure 4.58, run191, layout SM SQ B.3c). Moving the diffuser closer to the hood reduces the time the jet has to thicken preventing the thick jet forming down the front of the hood with more air escaping sideways from the bulkhead at high level (figure 4.59, run192, layout SM SQ B.3d). As a result there is substantially reduced leakage into the lab – sash leakage factor is reduced by 14% compared with run190, and box / sash leakage drops by 39%.

Recommendation : Where there is insufficient distance to move the diffuser well away from the hood in line with current guidance, position the diffuser in line with the center of the hood, close to the bulkhead. This stops the jet developing fully, dissipating the momentum to the side reducing the size of the jet turning down towards the sash opening.

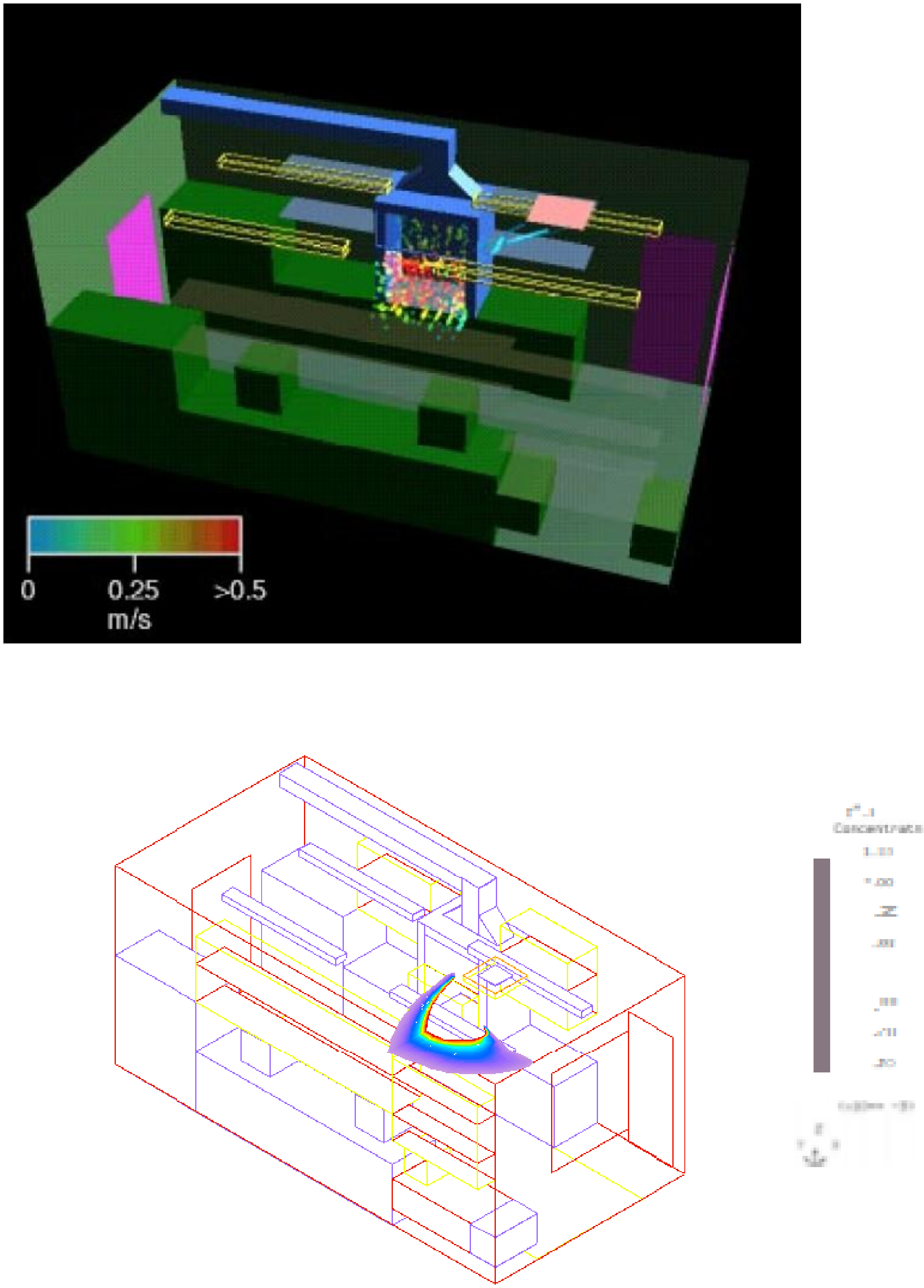


Figure 4.54 Diffuser offset from hood (run119).

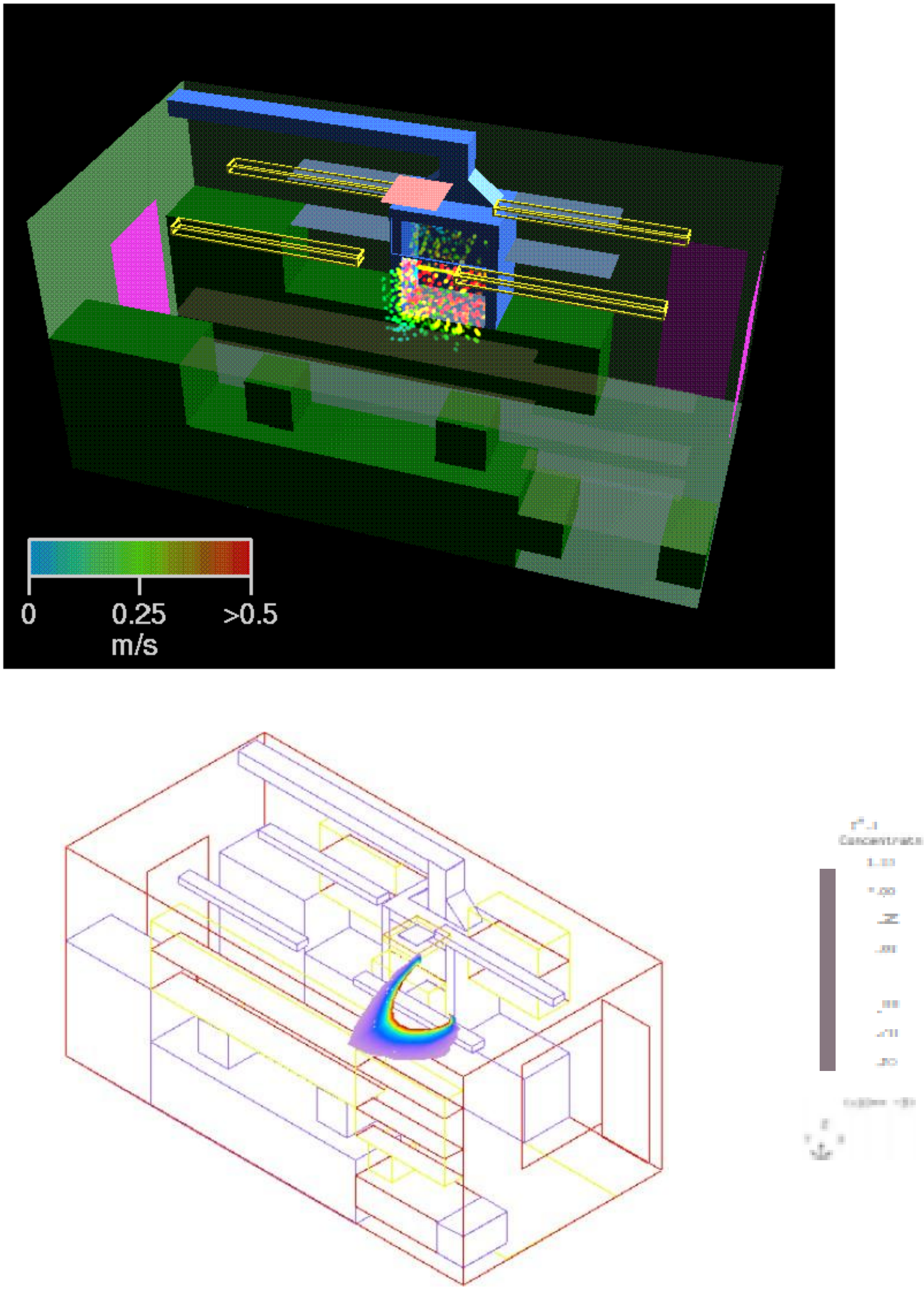


Figure 4.55 Diffuser aligned with side of hood (run188).

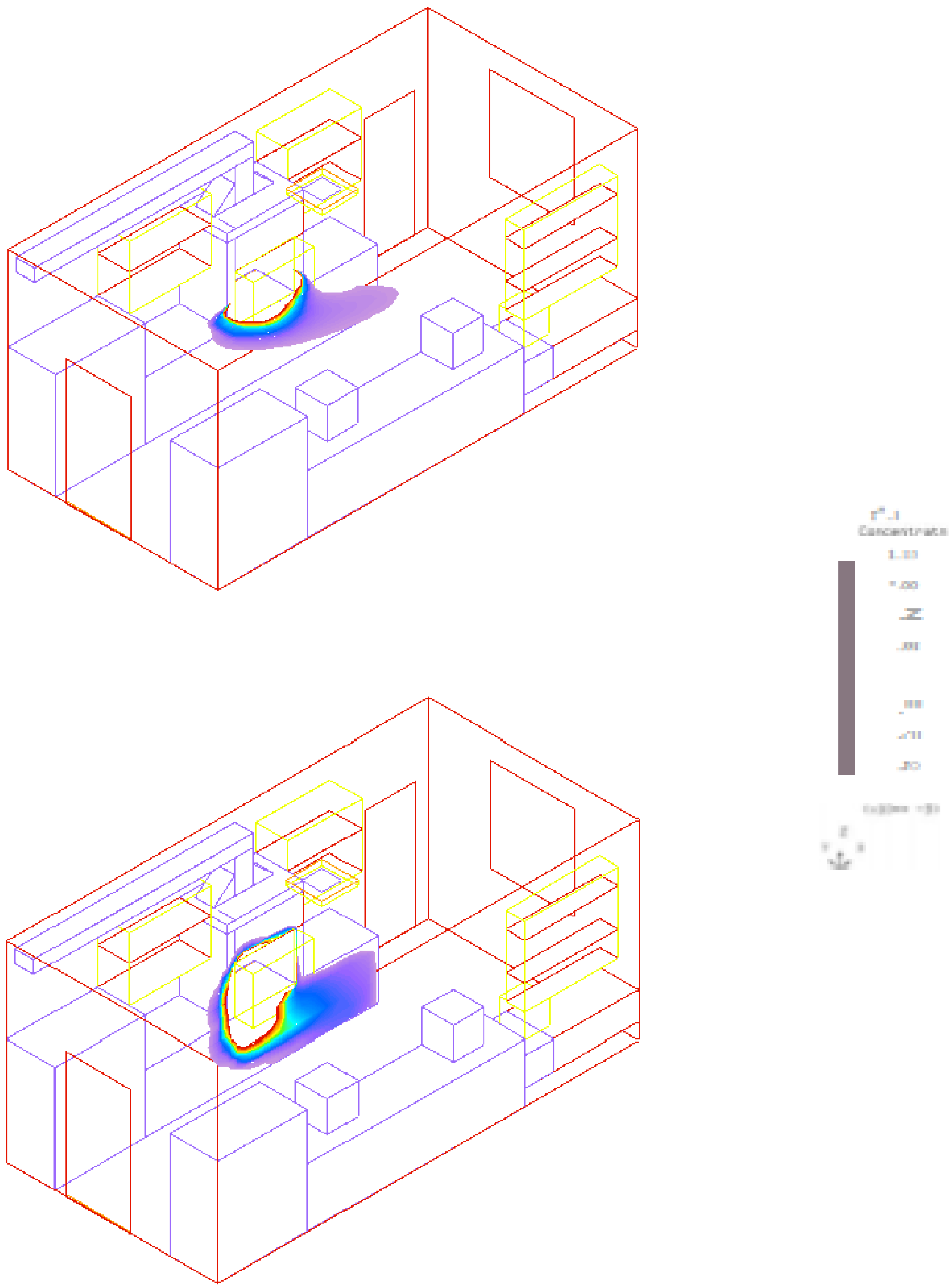


Figure 4.56 Diffuser in front of hood (run189).

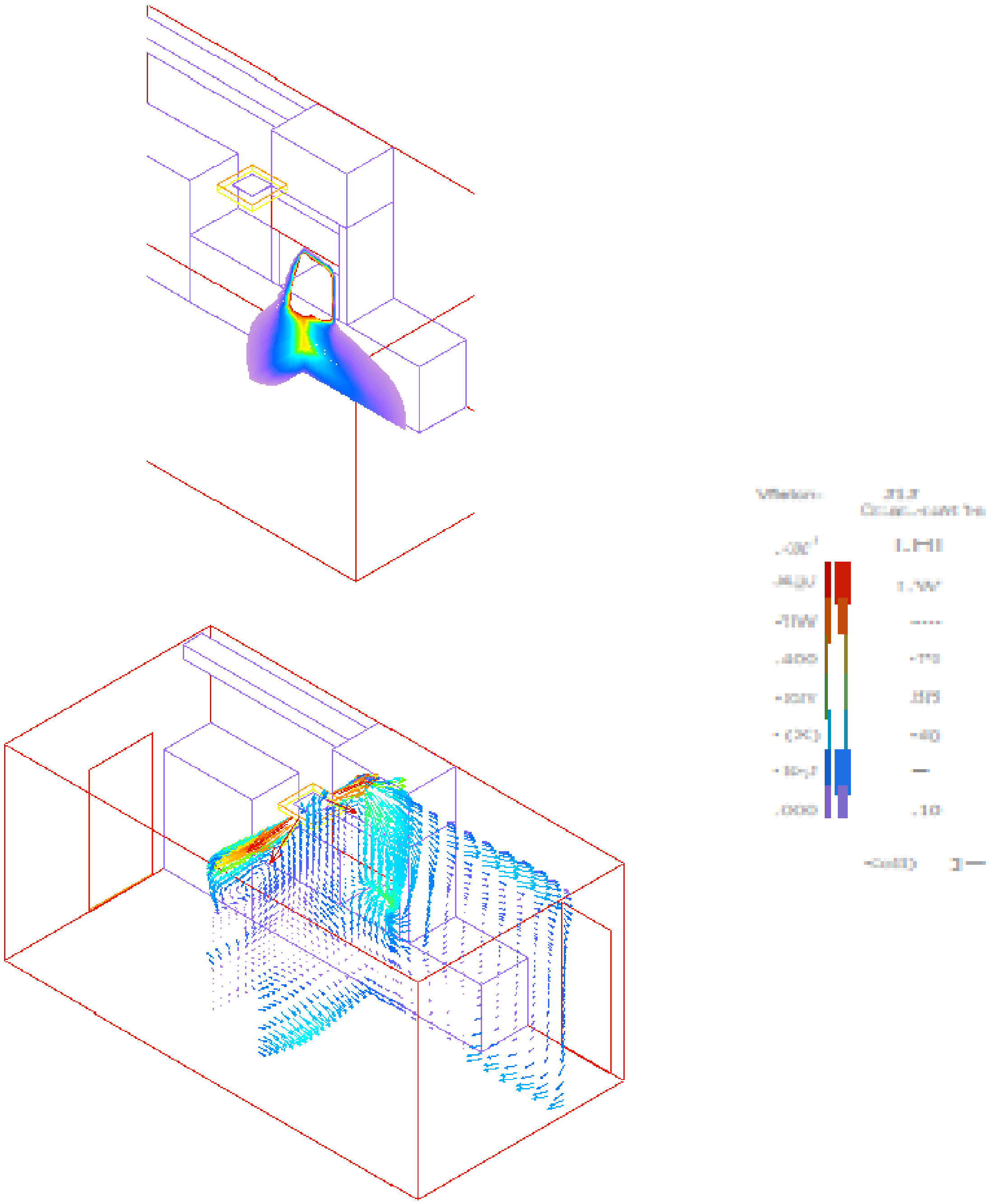


Figure 4.57 Diffuser in center of room aligned with hood and bulkhead configuration (run190).

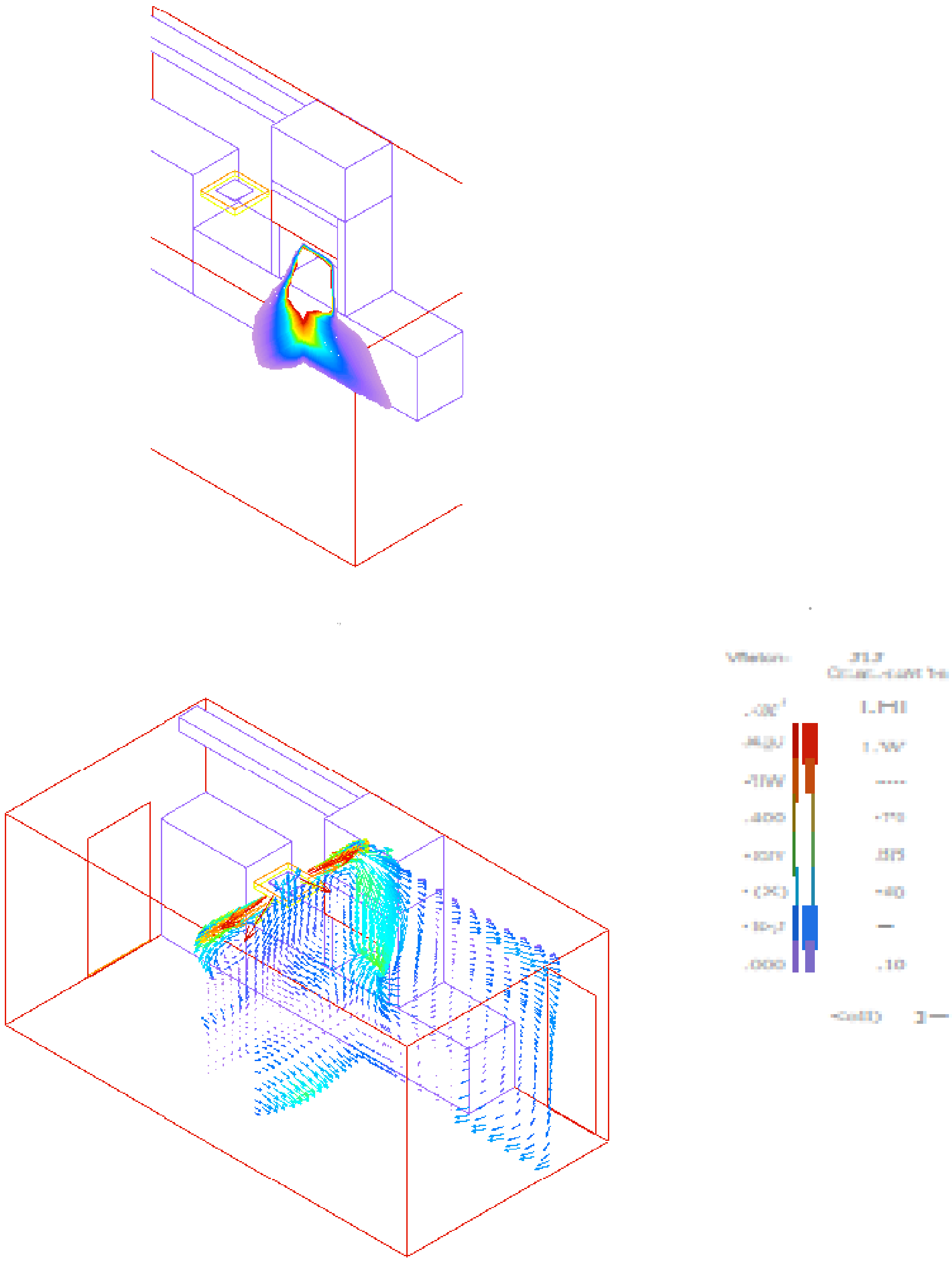


Figure 4.58 Diffuser moved back from hood and bulkhead combination (run191)

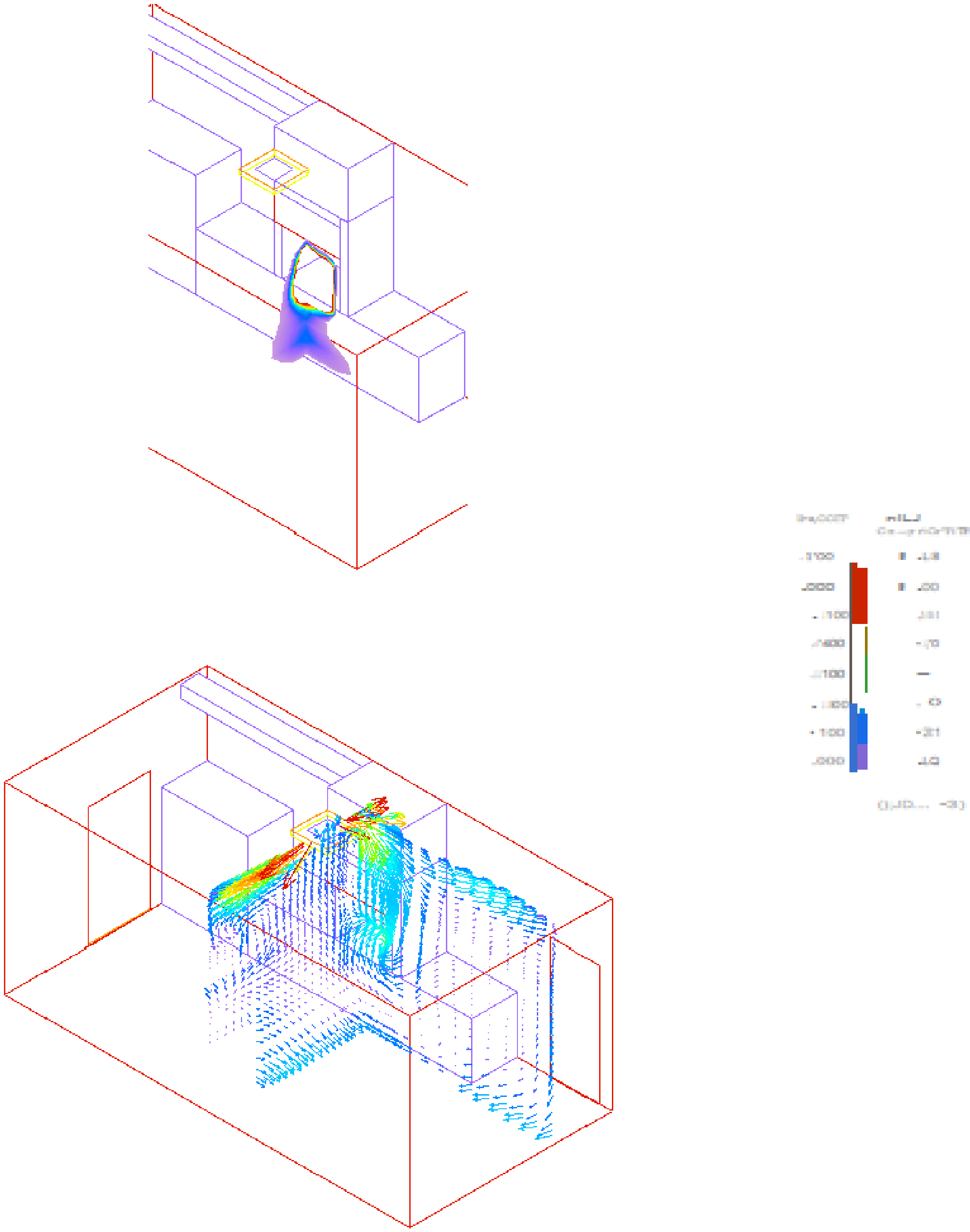


Figure 4.59 Diffuser moved closer to hood and bulkhead combination (run192).

4.3.6 Two Hoods in the Laboratory

This section presents data for configurations with two laboratory hoods. In general, simulations show that with two hoods it is extremely difficult to achieve containment as good as with just one hood where the ventilation rate is dominated by the hood flow rate. Data are presented for configurations where hoods are separated on the same wall, on opposite walls, or on perpendicular walls.

4.3.6.1 Hoods on the same wall

Figure 4.60 shows performance for two hoods on the same wall with separation increasing from two feet to eight feet. Each pair of hood performance data for each of the double hood configurations is joined by an arrow. As a reference, a single hood, run193, layout SM SQ A.1 is marked by a + for comparison. These simulations are for a low transfer grille flow rate of 66 cfm.

When the two hoods are only separated by 2', the hood with the sash leakage factor and the box / sash leakage proportion are almost double in the worst hood compared with the leakage for the single hood. Sash leakage factor for the worst hood is reduced to about 65% above that for the single hood for hoods separated by 4' or 6'. Box / sash leakage is only degraded by around 40%. Leakage is further improved at 8' separation possibly because one hood is now near the corner. Figures 4.61 and 4.62 show the configurations with the air inflow patterns from the supply air diffusers and the transfer grille for the 2' and 8' hood separations respectively.

Recommendation : Place hoods at least 4' apart preferably selecting corner positions if available.

In line with the single hood simulations, increased transfer grille flow rate (six times the low flow rate, 367 cfm compared with 66 cfm) causes higher box / sash leakage factor, figure 4.63, more than double that for the single hood. This compares with a 40% increase over the single hood for the low flow rate case. There are exceptions with high flow rates where both the sash leakage factor and the box / sash leakage proportion are much lower, specifically run156 and run166, but this is only for one of each hood pair.

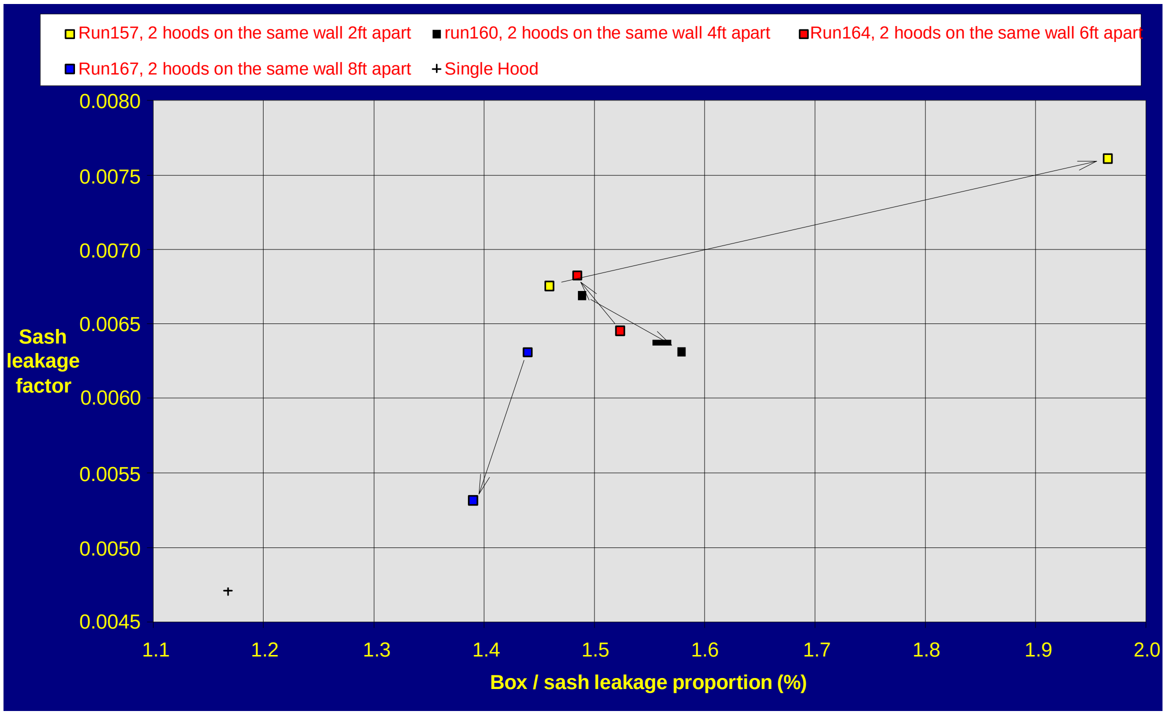


Figure 4.60 Sash leakage factor vs. Box / sash leakage proportion for 2 hoods moving apart on the same wall.

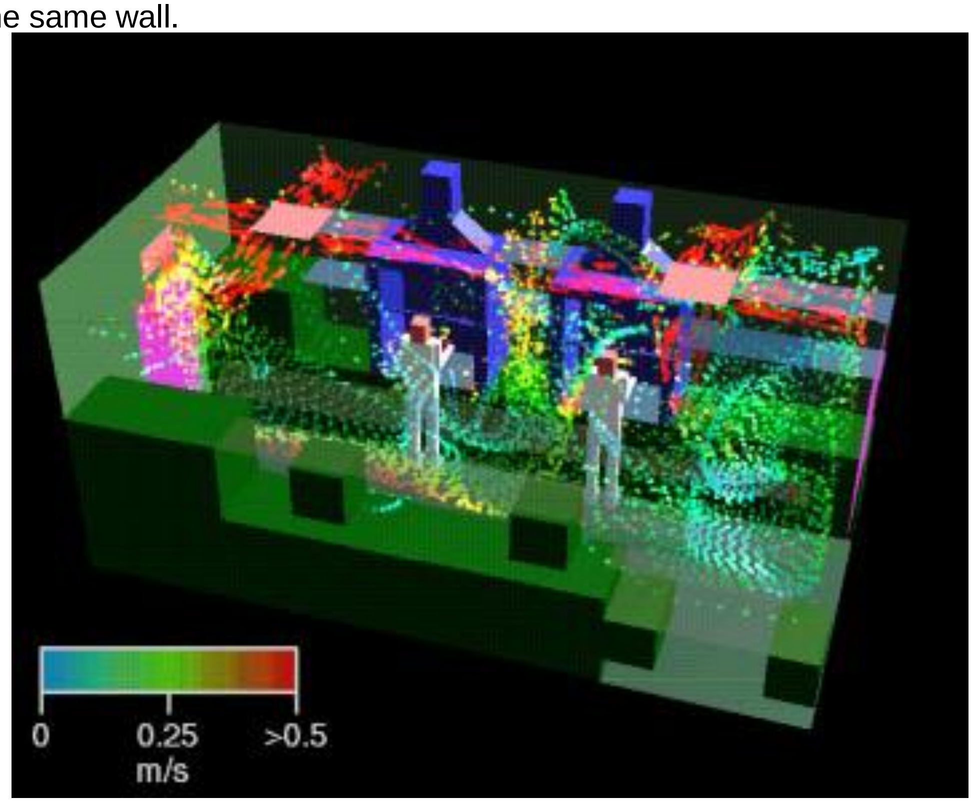


Figure 4.61 Hoods 4ft apart.

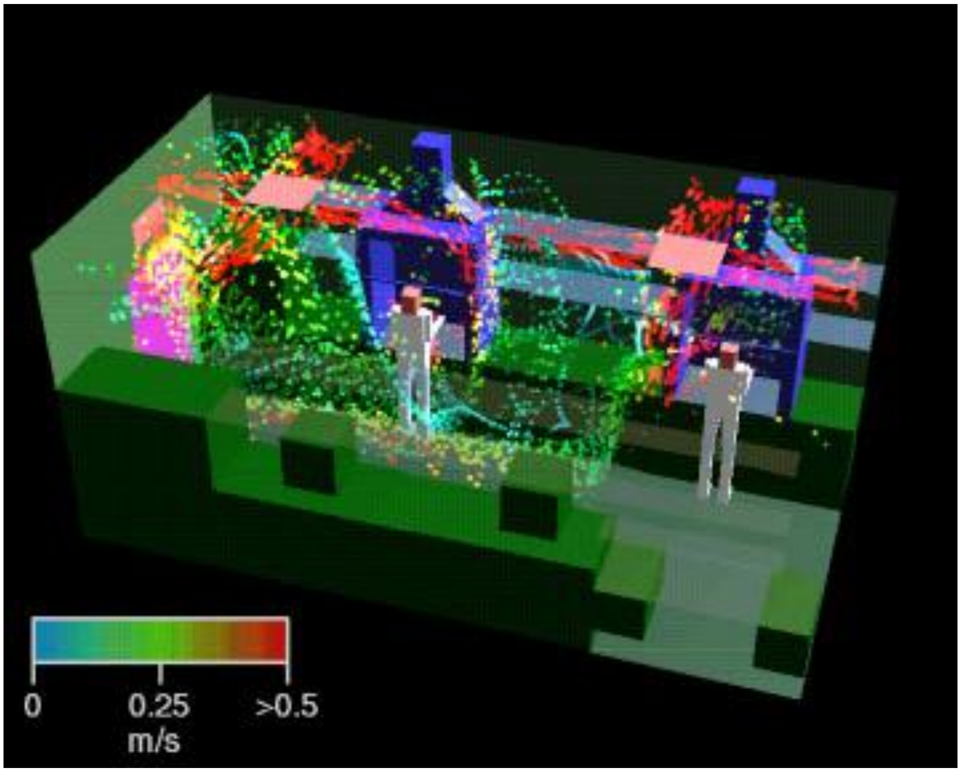


Figure 4.62 Hoods 8ft apart, low transfer grille flow rate.

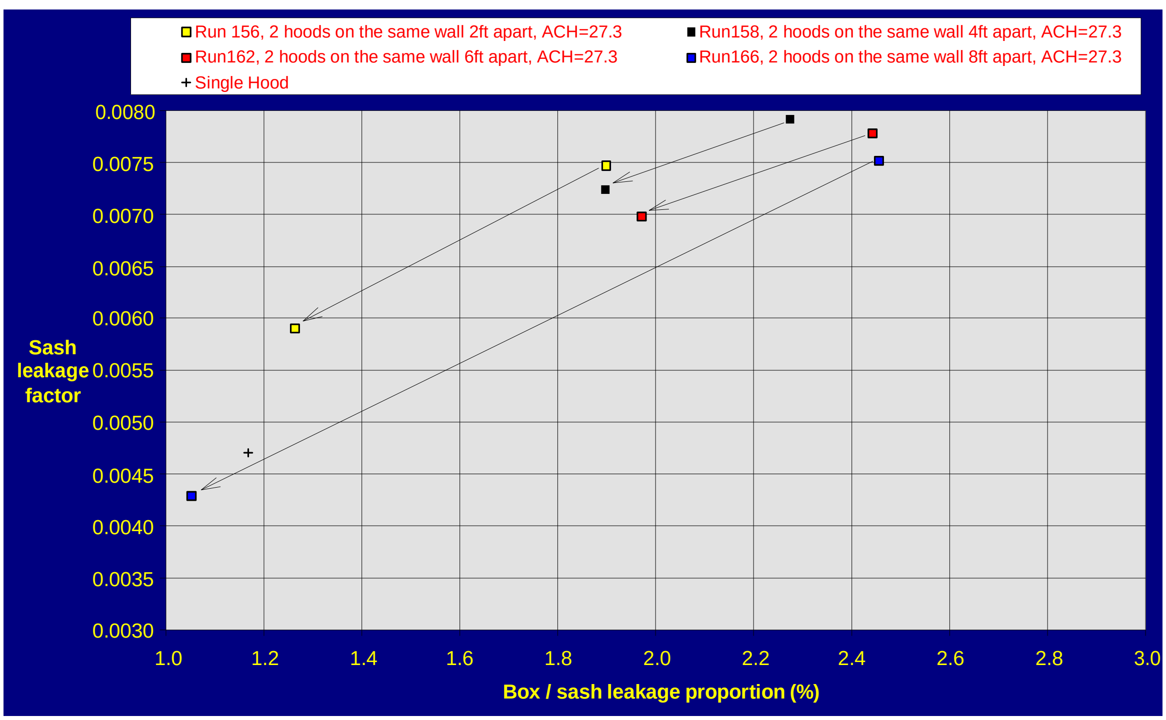


Figure 4.63 Sash leakage factor vs. Box / sash leakage proportion for 2 hoods moving apart on the same wall at a supply of 27.3 ACH.

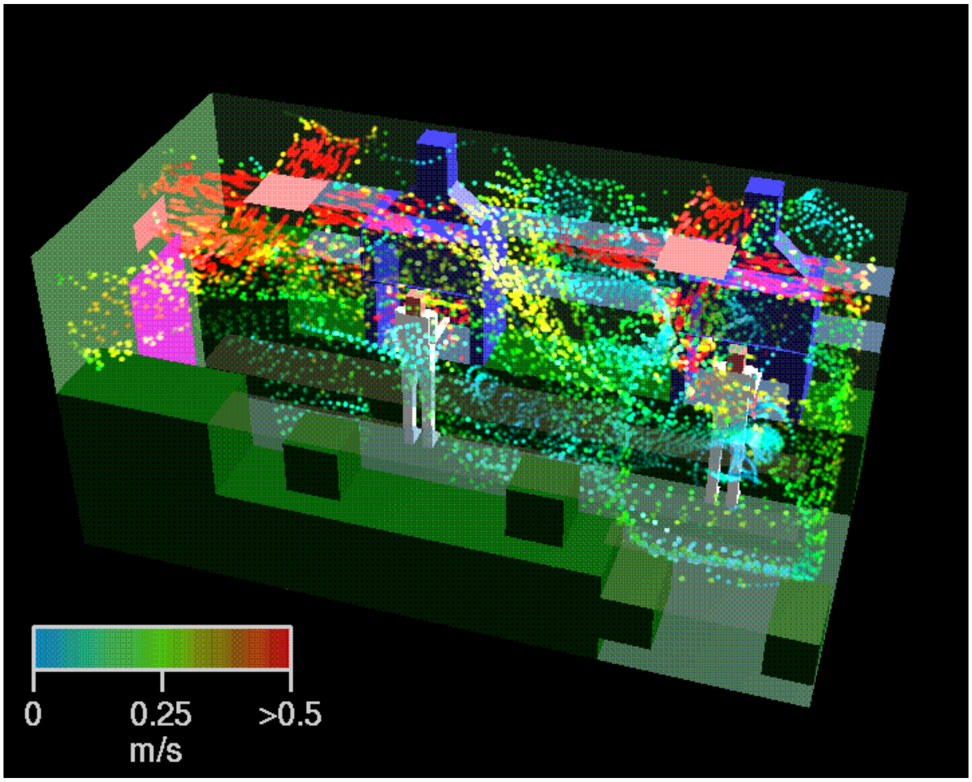


Figure 4.64 Hoods 8ft apart, high transfer grille flow rate.

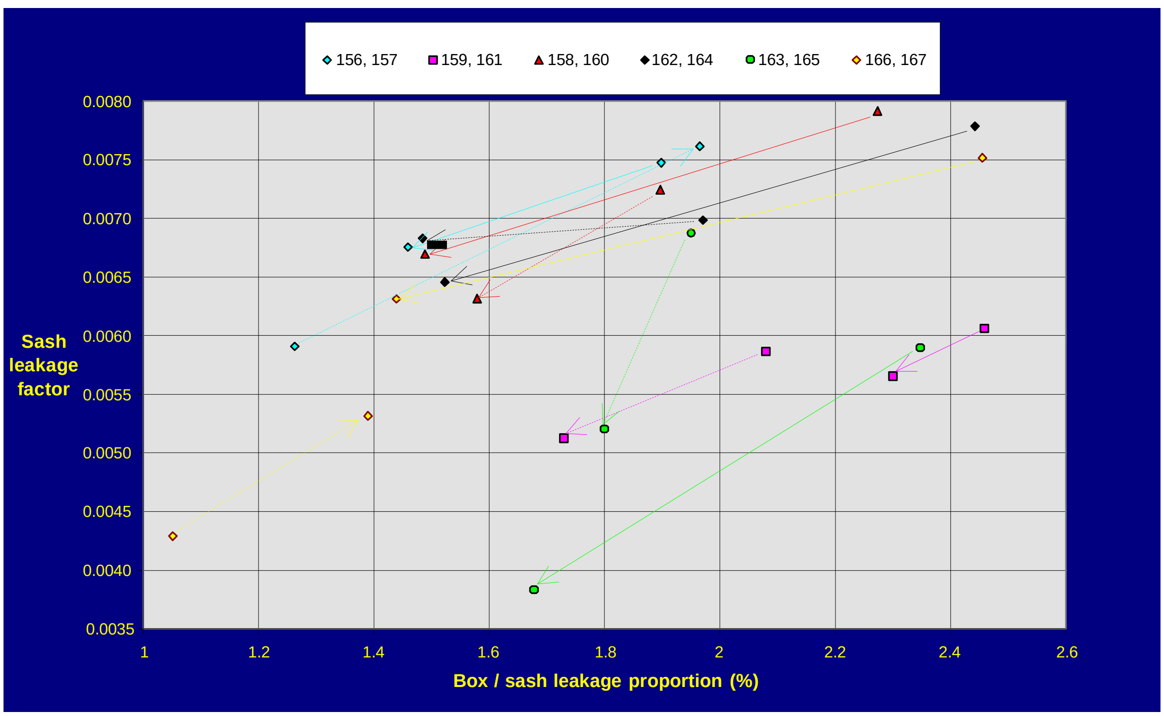


Figure 4.65 Sash leakage factor vs. Box / sash leakage proportion for high to low transfer grille flow rates (as indicated by the arrows).

Figure 4.64 shows the high transfer grille flow crosses in front of the nearer hood providing air to the far end of the room for the second hood. The first hood is therefore disrupted and the second well contained.

Figure 4.65 shows the data with the performance for high and low transfer grille flow rates for each hood of each configuration joined by arrows. With the exception of one hood in each of the two simulations, run156 and run166, all the hoods perform much worse with the high transfer grille flow rate.

Recommendation : Avoid high transfer grille flow rates. Transfer grille flow rates of 100 cfm or less have been shown to provide better containment with both single and double hood configurations.

4.3.6.2 Hoods on opposite walls

Sash leakage factor and box / sash leakage proportion are presented for double hoods on opposite walls with the low transfer grille flow rate (66 cfm). Figure 4.66 is for where one hood moves and figure 4.67 for when both hoods are moved.

The containment is generally better than for hoods on the same wall except, however, where two hoods are opposite or separated by two just feet, either side of the original position (figure 4.67, run169, run170), box / sash leakage factor is greater than for hoods on the same wall with separations of 4' or more.

Recommendation : For hoods on opposite walls avoid opposite or 2' separations of the hood.

4.3.6.3 Hoods on perpendicular walls

Hoods on perpendicular walls perform best (figure 4.68) and can achieve box / sash leakage proportion lower (more than half) than for the single hood, with sash leakage less than 20% higher. The worst case is a 30% increase in sash leakage compared with a single hood with an 8' separation.

Recommendation : Separate hoods by more than 4'. Placing two hoods on perpendicular walls is likely to produce a better performance than on opposite walls. In turn either of these configurations can be expected to achieve lower leakage than hoods on the same wall. Maximize the distance between the two hoods and the transfer grille.

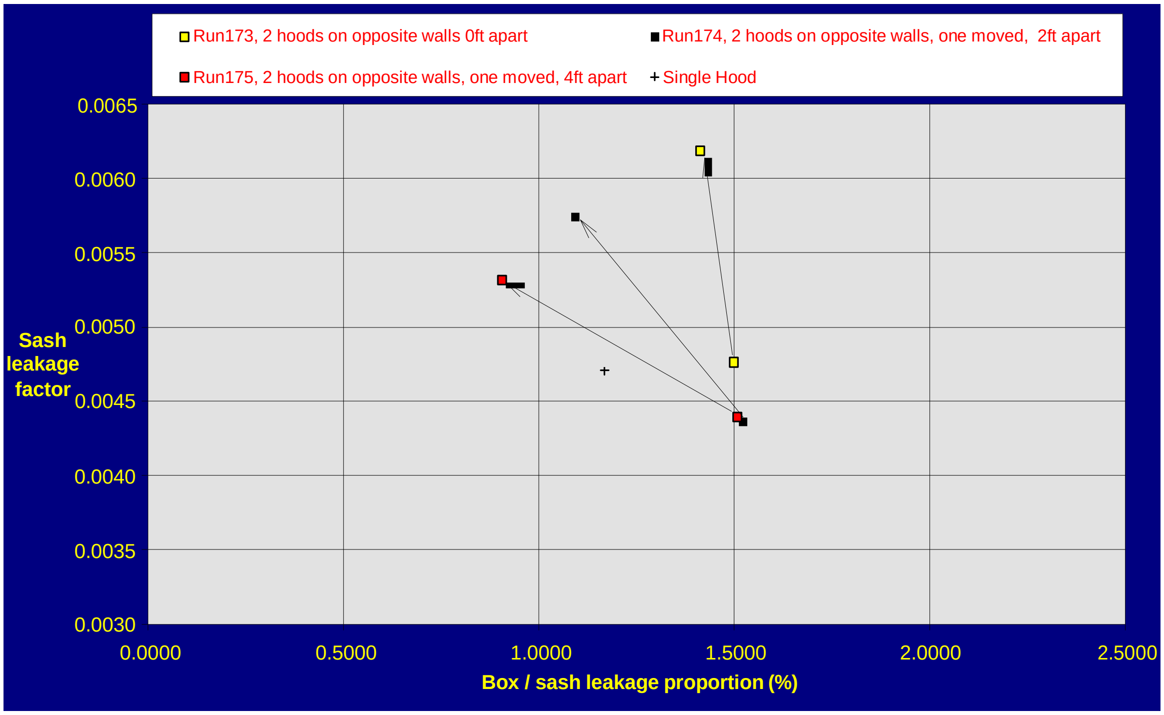


Figure 4.66 Sash leakage factor vs. Box / sash leakage proportion for 2 hoods on opposite walls with one hood moving

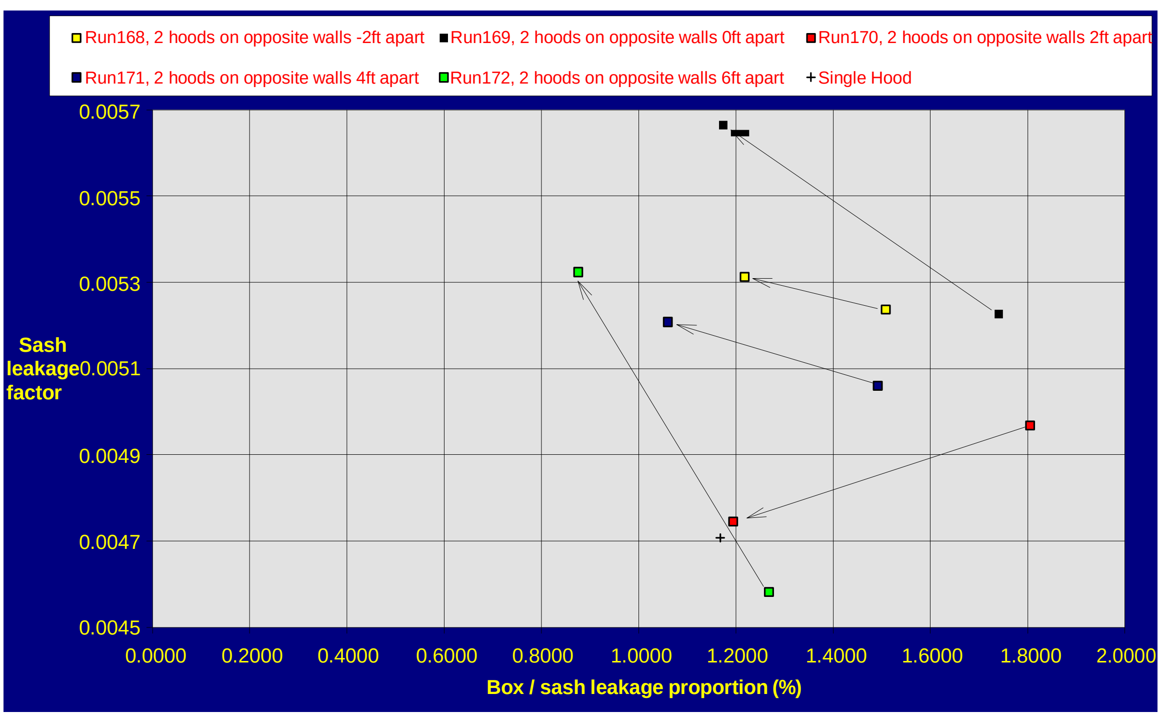


Figure 4.67 Sash leakage factor vs. Box / sash leakage proportion for 2 hoods on opposite walls both hoods moving

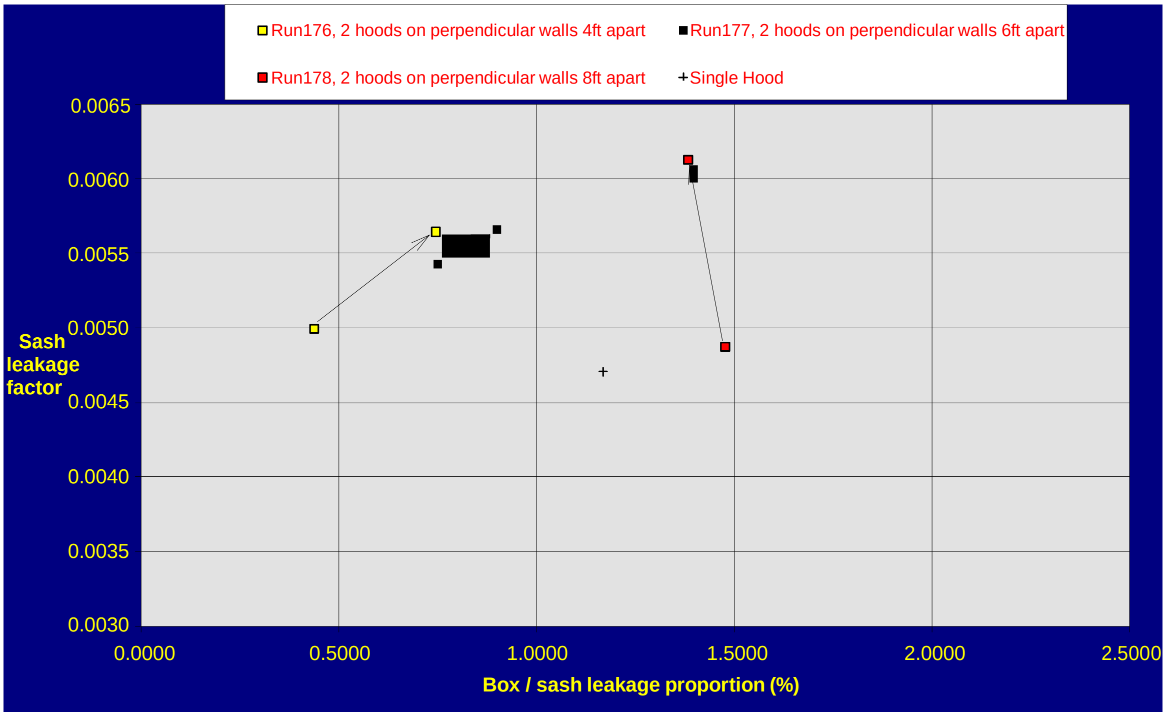
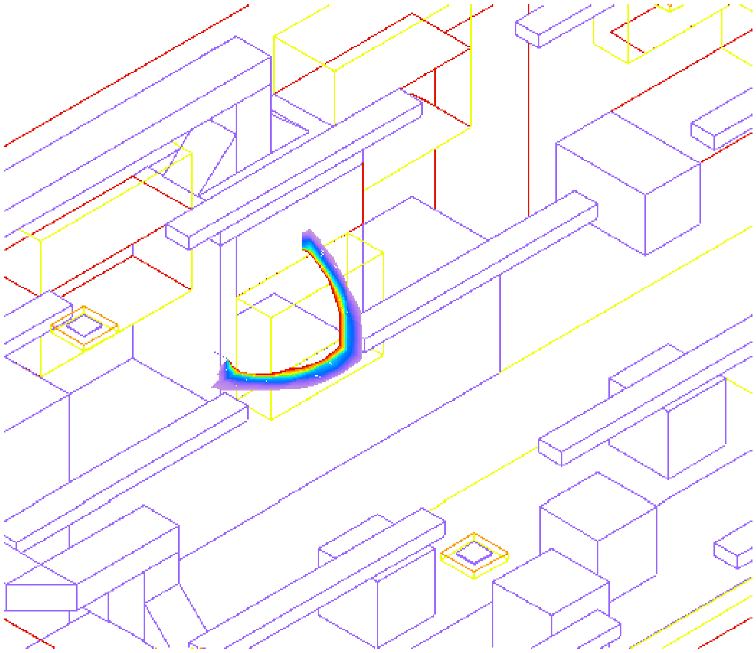
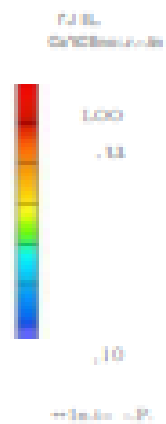
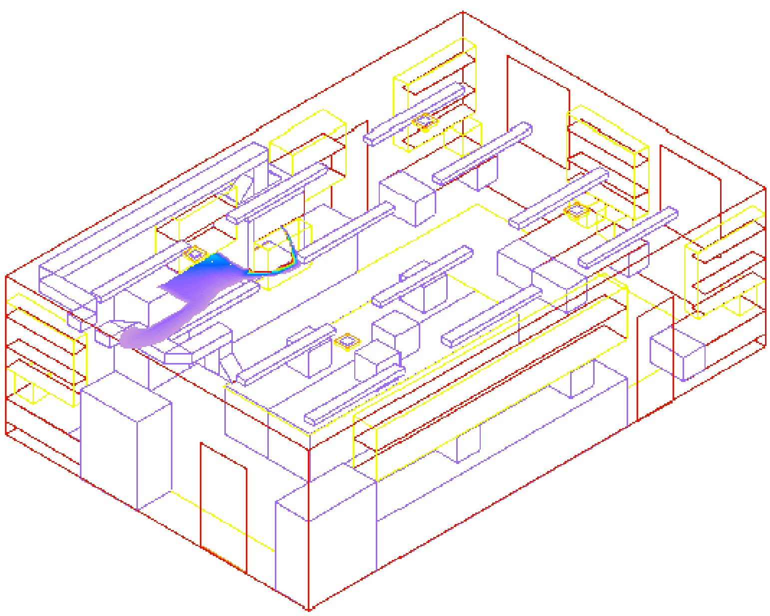


Figure 4.68 Sash leakage factor vs. Box / sash leakage proportion for 2 hoods on perpendicular walls both hoods moving





Supply temperature 55°F (run041)



Supply temperature 63.5°F (run058)

Figure 4.69 Effect of altering the supply temperature.

4.3.7 Supply Air Temperature

The supply temperature in the base case (run041) was specified as 55°F (12.8°C). When this was increased (run058) to 63.5°F (17.5°C) the cloud of concentration increased in size, figure 4.69. This is probably a result of the supply flow rate increasing in order to maintain the same cooling load.

4.4 Experimental Validation for Laboratories

This new experimental validation methodology for testing laboratory hood containment performance can be considered separately or in conjunction with existing methodologies available. It provides a method of ensuring that the turbulence (which correlated well with leakage through the sash opening), and the cross flow (as defined in section 4.1.2) are of an acceptable level.

4.4.1 Procedure

Measure the turbulence intensity on a grid of points either at the sash opening or on the five faces of the box. For empirical verification of an installation the strength of these velocity fluctuations can be measured (averaged from a measurement grid across the plane in question) using a hot film anemometer. Some commercially available anemometers automatically calculate a non-dimensional turbulence intensity as the root mean square (rms) of the fluctuating velocity divided by the mean velocity. This clearly relies upon a sufficient sampling frequency and duration. For this analysis the turbulence intensity is defined as:

$$\text{Turbulence intensity} = \sqrt{\overline{u_i^{2}}} = \sqrt{\tfrac{2}{3}k}$$

The measured value described above can therefore be converted to the definition used in this document by multiplying the measured value by the mean velocity.

The values measured and converted for each point on the grid can then be averaged to provide a mean value of turbulence intensity.

For empirical verification the cross flow can be calculated by measuring the velocities perpendicular to the four notional faces on a measurement grid.

To calculate this cross flow, calculate an average velocity for each of the four perpendicular faces of the 12” box.

Calculate the mean cross flow velocities (for horizontal and vertical) by adding and halving the mean velocities for each pair of the opposite faces.

Calculate the resultant vector by taking the square root of the sum of the squares the horizontal and vertical mean velocities. This is the cross flow parameter.

Compare the values with the appropriate performance graphs between figures 4.05 and 4.38 to identify whether an acceptable leakage level is likely.

4.5 Using the Research Data – Ranking and Comparison

These data represent the complete data produced by the analysis approaches adopted by this research project . This section does not intend to draw specific conclusions from the data (although some that are obvious from the total data set are identified here), but provides:

design verification by comparison

a basis for analysis by others.

It can be used by people involved with laboratories from a diverse variety of backgrounds in order to assess the performance of their proposed or existing laboratories.

4.5.1 Full Analysis Data

It is impossible to present all the data produced by the CFD calculations, even the analysis data presents an enormous quantity of data that would be difficult to present and interpret. Indeed even the summary data from the analysis of the simulations represent around 200,000 items. A subset of the total data set, in numerical form, is provided in Volume II.

The data for each simulation are provided on a single sheet in Volume II and comprises two parts. First, a description of each laboratory configuration, followed by summary results of the analysis. The entries are described below.

4.5.1.1 Laboratory configuration - description

The database contains the following information for describing each simulation.

Casename : The part of the filename to which file extensions are added to form the names of the input and output files.

Date : The date the data were entered, or last modified on the database.

Model : Whether the flow modeled is inside or outside the building; an internal or an external flow.

Flow : Whether the flow is primarily forced convection, natural convection, or mixed.

Application Types : What type of application the simulation represents - building type, room function, and specific equipment, e.g., hood.

Case Description : General description of the simulation.

Parametric Variation : What particular parameters changed for this case ?

Specialist Devices : What special devices were in use ? For example, what were the ventilation diffusers ?

Thermal : Was the temperature variable active ?

Buoyancy : Were gravitational effects accounted for and if so how was buoyancy modeled ?

Radiation : Has radiation been accounted for internally and/or externally?

Comfort Temperature : Has a comfort temperature calculation been undertaken to look at the effect of combining air temperature, radiant temperature, and air speed ?

Concentration : Was the concentration model active with a concentration inside the hood ?

Turbulence : What turbulence model is used?

Special : Indicates any special functionality used in the software beyond the regular menu system.

Dimensionality : The physical and time dimensions used for the case. For example, 3d Steady would indicate that the case was modeled in three dimensions and assumed to be in a steady state condition - no time varying boundary conditions.

A-Array Size : The size of the data array required to run the calculation. Allows the user to ensure they have sufficient memory.

Grid Dimensions : The number of calculation cells in each of the three Cartesian directions.

4.5.1.2 Analysis results

The detailed results of CFD calculations provide an enormous quantity of data, which is commonly interpreted visually. This is practical when only a few simulations need to be compared. However, in this project, more than 200 simulations are performed, and so such an approach is not viable. The progress meeting participants identified six different ways of estimating the effect of room air movement on hood performance. These still provide more than 700 pieces of data for each case/simulation. This summary has selected a subset of that data for hood configurations on the long wall for each of the analyses. In general, ratios of differences have been used to allow comparison of simulations with different sash velocities and hood flows. The data used are as follows :

Dalle Valle Ratio : Dalle Valle identified the velocity distribution on the five surfaces of a box extending out from the exhaust (not the plane of the exhaust) for a perfect exhaust. A perfect exhaust, as defined by Dalle Valle is one where the flow into it is developed as a result of the exhaust suction rather than other sources of velocity / momentum in the space. The resulting distribution is non-uniform and depends on the shape of the exhaust. By calculating the difference between the velocity distribution from the laboratory simulations (V_s) and the so-called perfect exhaust velocity distribution (V_{DV}), then normalizing it by dividing the difference by the perfect exhaust velocity, a measure of the disturbance of the hood flow can be achieved. This is repeated for a grid of points on the five surfaces of a 12” box extending from the sash opening into the laboratory and a mean calculated. The sixth face, the sash opening itself is not used. This mean is the Dalle Valle Ratio as used here.

$$\text{Dalle Valle ratio} = \text{mean of } [(V_S - V_{DV}) / V_{DV}]$$

The standard deviation and maximum are also calculated.

Performance Index (PI) : An index based on the difference of the velocity from the desired sash set-point. Three terms are included in the index :

the velocity difference
the turbulence intensity
any reverse flows

$$PI = (d^2 + U_s^2 + U_t^2)$$

where d is 1 if the flow is reversed, U_s is $(V - V_{sash})/ V_{sash}$, where V may be the calculated perpendicular velocity or the 3 dimensional air speed.

The mean and maximum values are listed for the hood sash opening and the box for both perpendicular velocity and air speed.

TIME : The time for the air to reach each calculation cell on the hood sash opening from outside the box is computed. The mean, standard deviation, and maximum are listed. For air traveling at 100 feet per minute it would take approximately 0.6 seconds to travel through the box. High values represent an indirect path and therefore circulation.

REVERSE VELOCITY : Reverse flows are detected and listed for the hood sash opening and the box. The maximum reverse velocity is listed with the total flow and the proportion of the sash opening or box that has reverse flow. The same analysis data is printed for reverse velocities calculated by:

increasing the reverse velocities by 20% of the sash opening velocity to identify sensitivity to disruption,

or alternatively by:

increasing the reverse velocity by adding the turbulence intensity, to provide a measure of velocity allowing for time averaged turbulent fluctuation.

LEAKAGE FACTOR : An artificial source of contamination is provided across the sash opening just inside the hood such that the entire air flow into the hood is completely contaminated. This allows the program to calculate dilution out into the laboratory and the flux of contamination moving out and away from hood. This listing identifies the leakage as the sum of the convective and diffusive fluxes that produce a concentration flow out of the sash opening into the ‘working zone’ or box around it, and through the box surface into the body of the laboratory thus representing the potential for leakage. The calculation is further described in section 2.56.

The sash opening is considered as this opening, where the air enters the hood, representing the boundary of the containment device, beyond which the chemicals may be used.

> The working zone or box is considered to represent the boundary of the volume just outside the sash opening in which a scientist may work.

The leakage from the sash opening represents the contamination that may affect the scientist working at the hood, while the leakage from the box represents that which may affect scientists working elsewhere in the laboratory.

The leakage through the sash opening can be characterized by a leakage factor as follows:

> The sash leakage factor is the concentration, as a fraction of the hood flow, that leaks backwards against the flow and out of the hood through the sash opening into the laboratory, or more specifically the working zone or box. For example, in the large laboratory base case (run041) the leakage is 0.00369, which represents 0.369% of the design hood flow-rate.

The box leakage can be characterized in a similar manner:

> The box leakage factor represents the concentration leakage as a fraction of the hood flow out through the five faces of the box into the laboratory, away from the hood. For the large laboratory base case (run041), 0.000086 represents less than $^{1}/100^{th}$ of 1% leaking backwards against the flow. This is the amount of contamination leaking from the imaginary box (working zone) into the laboratory space if the hood is filled with contaminant.

The box leakage factor represents the overall leakage into the laboratory, which itself is dependent on the quantity of concentration that has already leaked through the sash opening.

4.5.1.3 Menu selection - Identifying configuration performance

This section describes a method that allows the designer to identify a configuration that delivers the required containment performance, or whether or not their design achieves the required performance.

Figures 4.70 to 4.76 show the performance at the hood sash opening - sash leakage factor against the leakage from the box / sash leakage proportion. Moving down the ‘Y’ axis indicates better containment or less leakage through the sash opening. Moving left along the ‘X’ axis indicates lower leakage into the laboratory from the working zone.

Identifying acceptable configurations

For the designer or hygienist to determine the configurations that meet the necessary performance they must:

identify likely mean fraction concentration of substance inside the hood and call this ‘A’

identify acceptable leakage rate through the sash opening for the substance in question and call this ‘B’

calculate an acceptable sash leakage factor as follows:

$$\text{maximum sash leakage factor} = \frac{B}{A \times \text{hood flow rate}}$$

identify an acceptable leakage rate from the working zone into the laboratory and call this ‘C’

calculate an acceptable box / sash leakage proportion

maximum box / sash leakage proportion = C/(B/A)

examine figures in conjunction with Volume II to identify configurations that have a sash leakage factor less than B/(A x hood flow rate), and a box to sash leakage proportion less than C/(B/A)

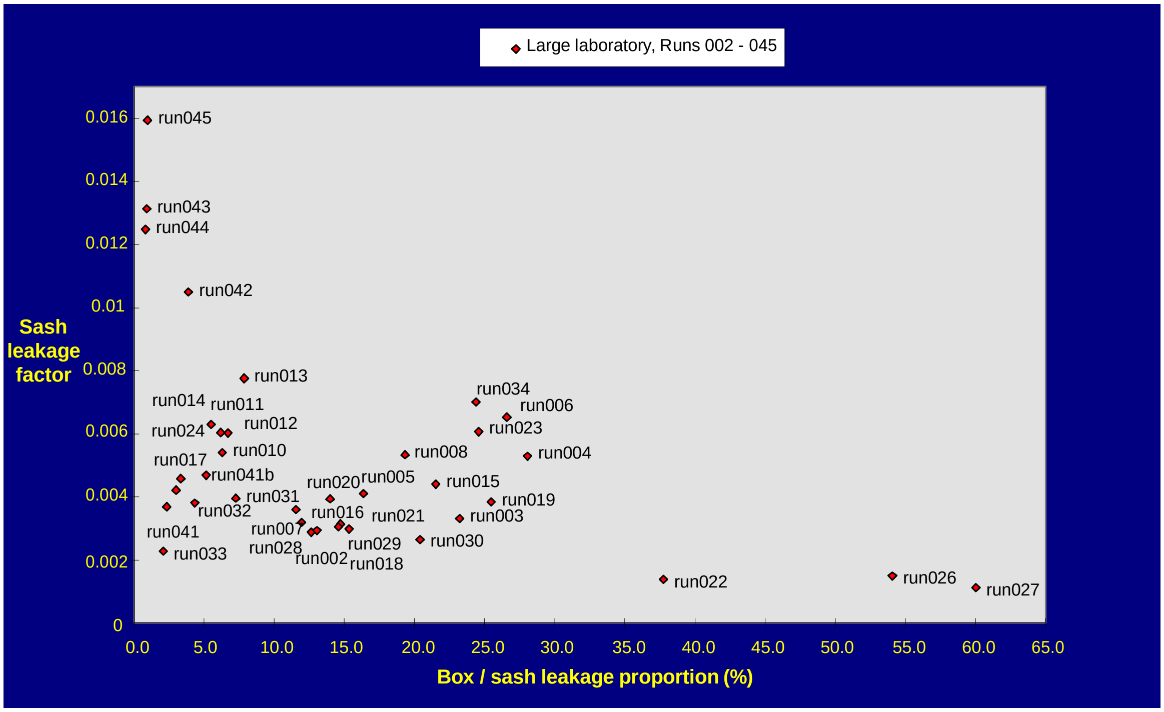


Figure 4.70 Sash leakage factor vs. Box / sash leakage proportion for large laboratory Run002-045

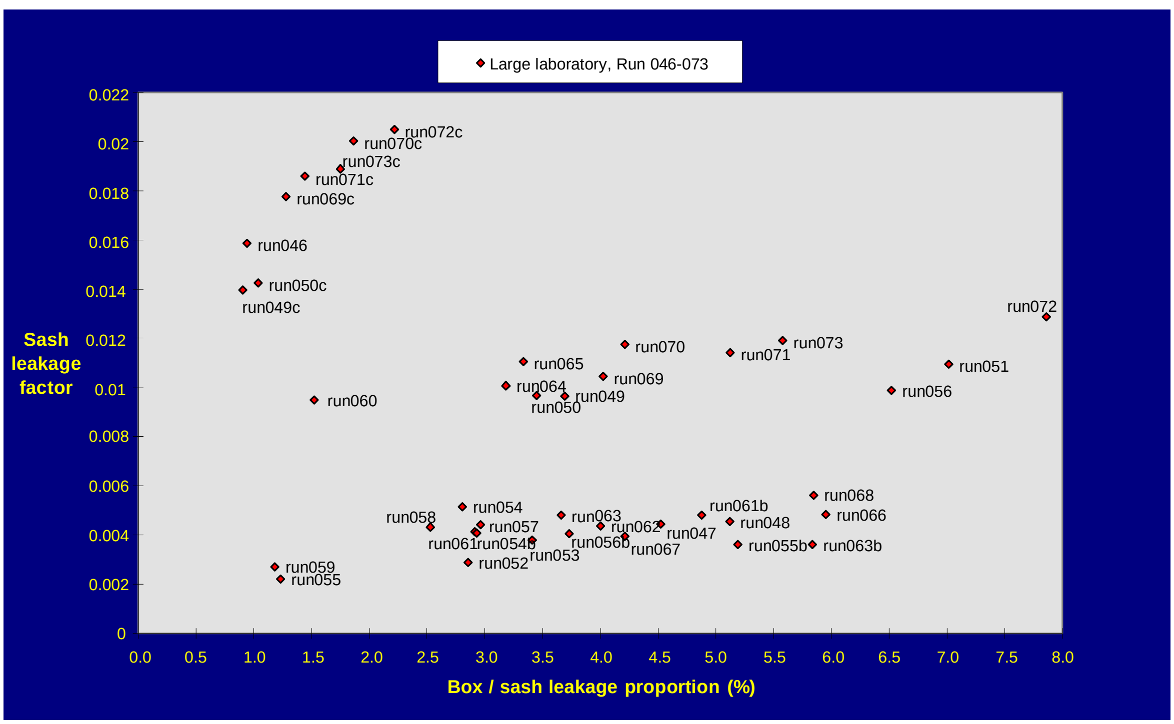


Figure 4.71 Sash leakage factor vs. Box / sash leakage proportion for large laboratory Run046-073

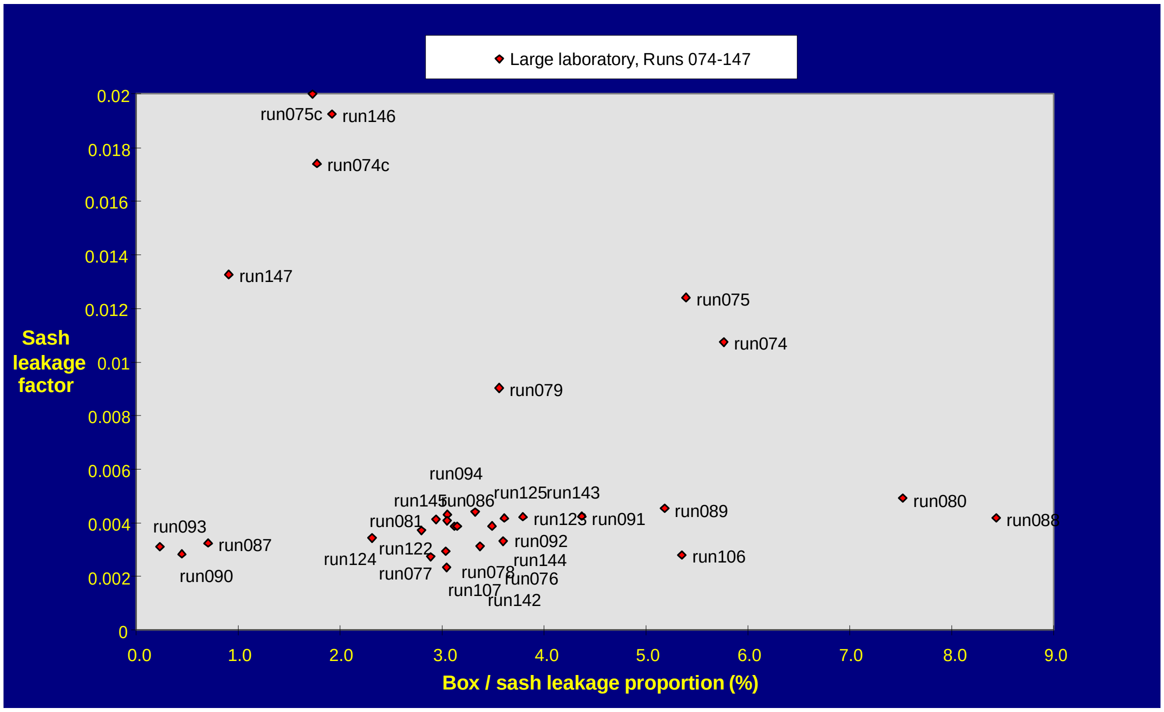


Figure 4.72 Sash leakage factor vs. Box / sash leakage proportion for large laboratory Run074-147

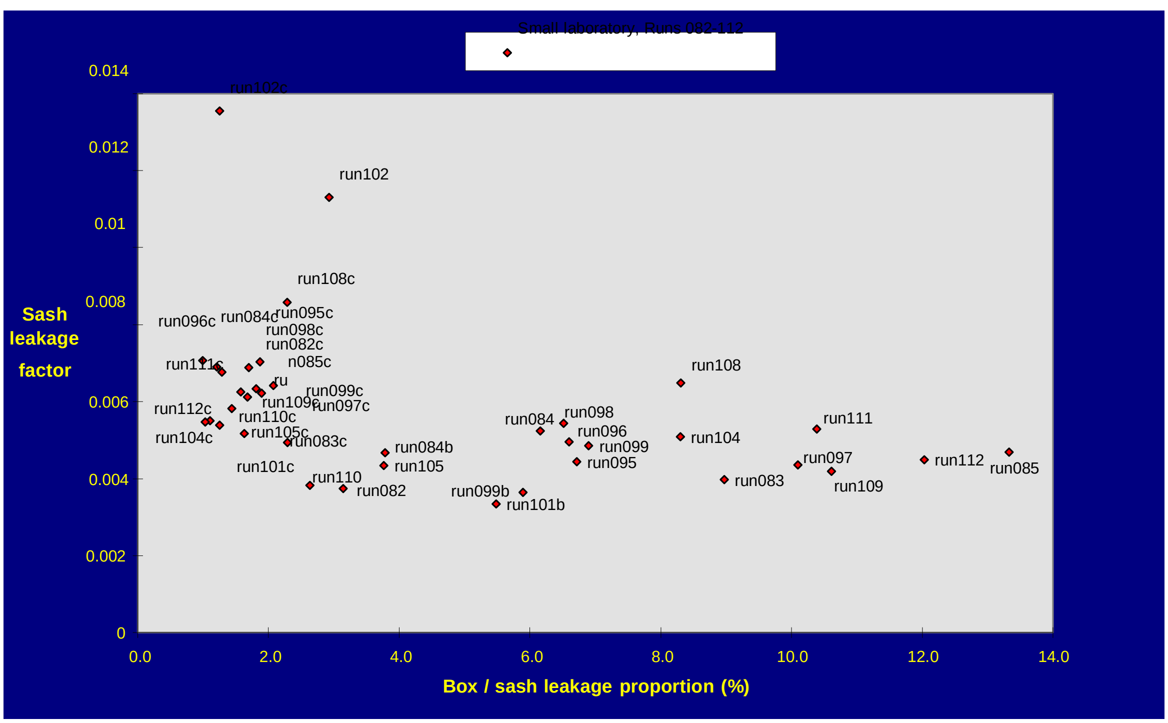


Figure 4.73 Sash leakage factor vs. Box / sash leakage proportion for small laboratory Run082-112

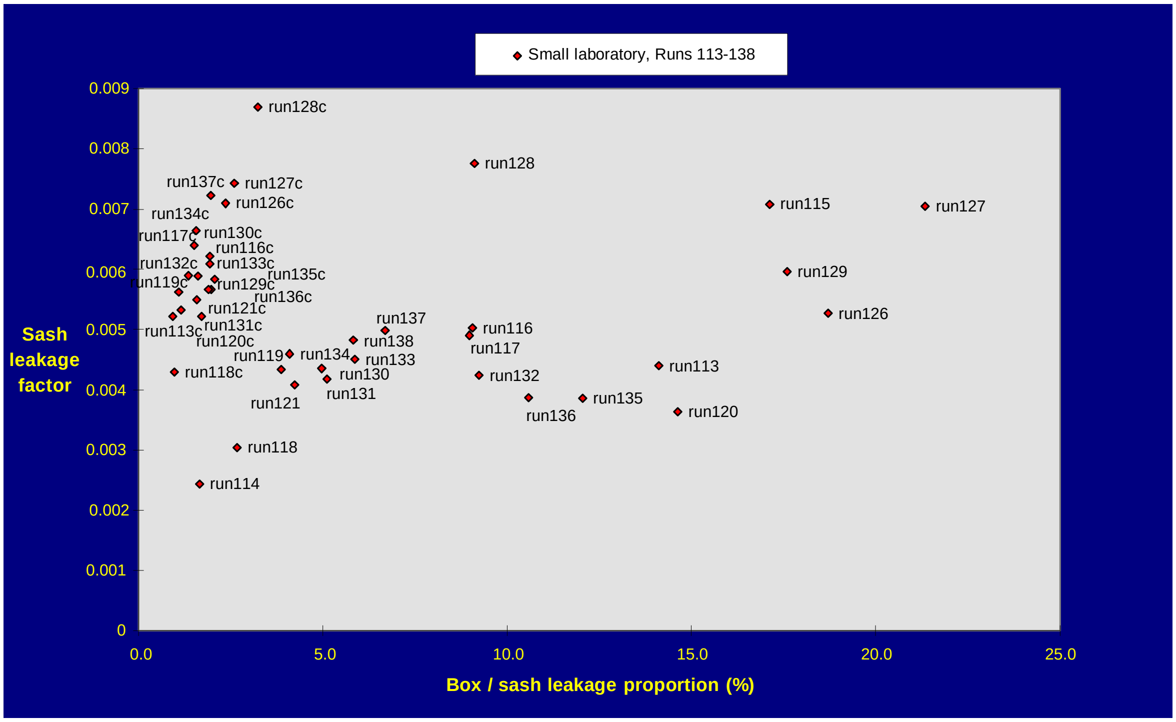


Figure 4.74 Sash leakage factor vs. Box / sash leakage proportion for small laboratory Run113-138

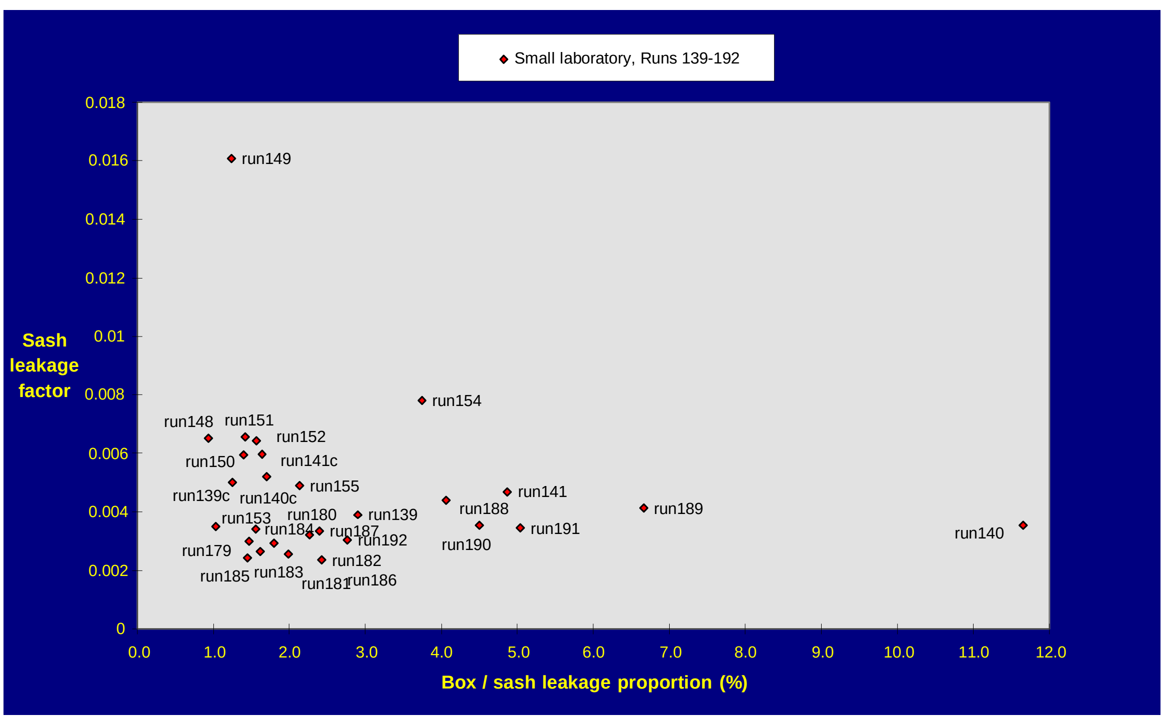


Figure 4.75 Sash leakage factor vs. Box / sash leakage proportion for small laboratory Run139-192

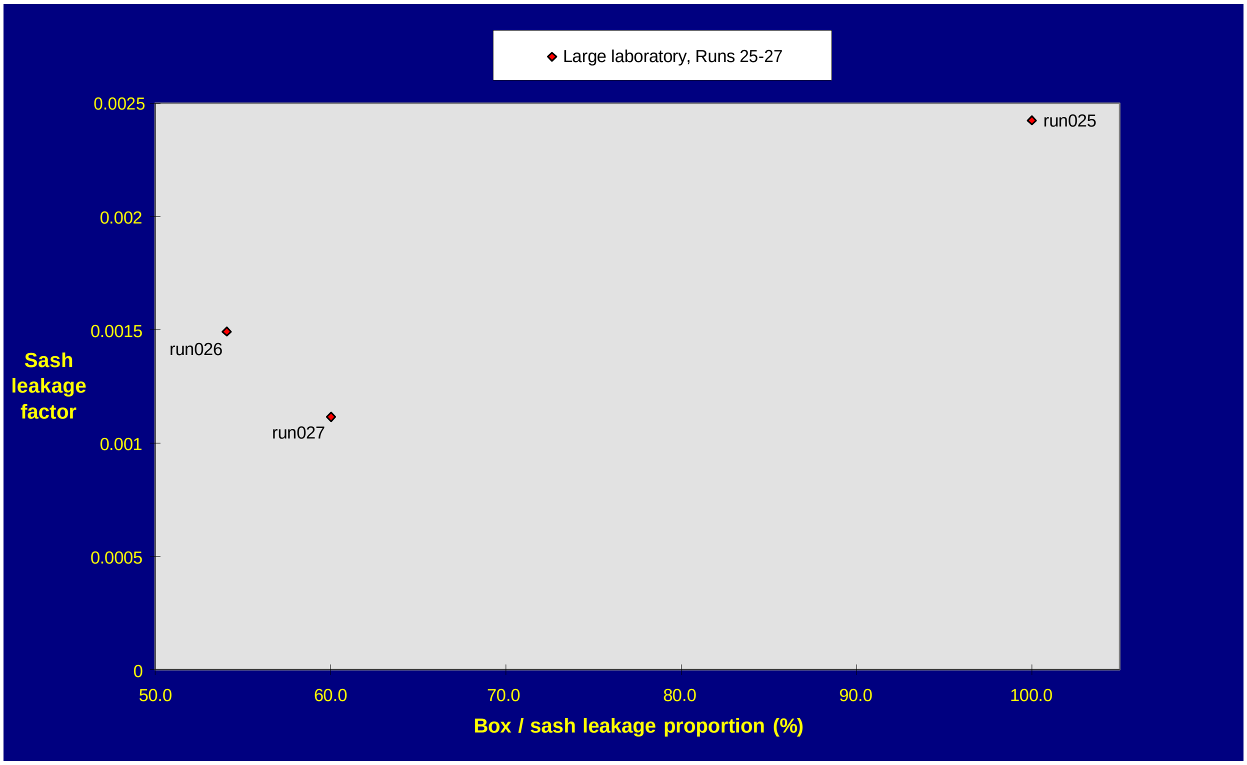


Figure 4.76 Sash leakage factor vs. Box / sash leakage proportion for large laboratory Run025-027

Determining configuration performance

To determine a specified laboratory configuration performance, identify a simulation from the database that closely represents the chosen configuration. This can be achieved most easily by inspection of tables 3.04 to 3.07. It is important to recognize that should a close match not be found, it may be necessary to undertake CFD simulation or some other method of design verification. The performance at the sash opening and box can then be obtained directly from the database entry for that simulation or figures 4.70 to 4.76. Note that figure 4.76 represents the three simulations with the sash only open 25% of the maximum height.

For example:

If the laboratory is a large laboratory measuring 33ft by 11ft, with four 12” square diffusers laid out on the quarters, table 3.04 (table 3.05 deals with 22ft by 11ft laboratory size) identifies simulations 41,43,44,52-58, 76-9,122,142 to be configured in this way.

These simulations can be checked for equivalence of other parameters to the design in table 3.06, or the main database in Volume II.

Further if the configuration is intended to operate with a supply air ventilation rate of 6 ach at 55^{o}F, table 3.06 shows that only run122 represents this configuration.

A check that no other configuration parameters are in conflict can be made by referring to table 3.07.

Having selected the equivalent simulation, the performance can be obtained from figure 4.62. In this case the sash leakage factor is low, just under 0.004 with a fair box / sash leakage proportion of around 3%.

Lower box / sash leakage performance can be achieved, if required by modifying the configuration according to the details for simulations showing lower leakage on the graphs (figures 4.70 to 4.76). The only simulation using this type of diffuser and layout is run041.

Ranking the data

An alternative method for categorizing performance is to rank the data based upon performance and thus identify the configuration parameters that have an effect on containment. To allow further analysis, these rankings are provided here, tables 4.01 to 4.62. They have been subdivided for comparison by laboratory size, large and small, and by whether or not a person is present. The tables are further subdivided by the diffuser type and layout, each subdivision being presented in a separate table. Each ranking is performed three times, sorting first on sash leakage factor, then on box leakage factor, and finally on box / sash leakage proportion. The parameter used for ranking is denoted by a series of asterisks above the heading sash, box, or proportion respectively. The parameters ranked are:

the supply air temperature (^{o}F), 'Temp'
the laboratory heat gain (W/ft^{2}), 'Power'
hood position, 'hood posn'
sash opening velocity (fpm), 'sash vel'
ventilation rate (Supply air changes per hour), 'vent rate'
makeup air location, 'm/up posn'
makeup air quantity as a proportion of the total in flow rate, 'm/up prop'.

Where no difference is apparent from the rankings, the differences between simulations can be determined by reference to the appropriate database entries in Volume II.

Table 4.01 Ranking of large laboratory with person - diffuser type SQ A.1

Diffuser Type SQ A.1										
Run	********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run044	0.01288	0.00011	0.82905	55	8.07	1	100	9.1	crack	0.0808
run043	0.01296	0.00012	0.90464	55	8.07	1	100	9.1	crack	0.0808
Run	sash	********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run044	0.01288	0.00011	0.82905	55	8.07	1	100	9.1	crack	0.0808
run043	0.01296	0.00012	0.90464	55	8.07	1	100	9.1	crack	0.0808
Run	sash	box	********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run044	0.01288	0.00011	0.82905	55	8.07	1	100	9.1	crack	0.0808
run043	0.01296	0.00012	0.90464	55	8.07	1	100	9.1	crack	0.0808

Table 4.02 Ranking of large laboratory with person - diffuser type SQ B.1

Diffuser Type SQ B.1										
Run	********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run046	0.01587	0.00015	0.94197	55	8.07	1	100	9.1	crack	0.0808
run045	0.01594	0.00015	0.96295	55	8.07	1	100	9.1	crack	0.0808
Run	sash	********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run046	0.01587	0.00015	0.94197	55	8.07	1	100	9.1	crack	0.0808
run045	0.01594	0.00015	0.96295	55	8.07	1	100	9.1	crack	0.0808
Run	sash	box	********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run046	0.01587	0.00015	0.94197	55	8.07	1	100	9.1	crack	0.0808
run045	0.01594	0.00015	0.96295	55	8.07	1	100	9.1	crack	0.0808

Table 4.03 Ranking of large laboratory with person - diffuser type SQ C.2

Diffuser Type SQ C.2										
Run	********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run033	0.00227	4.8E-05	2.09916	53	7.11	1	50	8.1	crack	0.0899
run031	0.00395	0.00029	7.26934	53	7.11	1	50	8.1	crack	0.0899
Run	sash	********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run033	0.00227	4.8E-05	2.09916	53	7.11	1	50	8.1	crack	0.0899
run031	0.00395	0.00029	7.26934	53	7.11	1	50	8.1	crack	0.0899
Run	sash	box	********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run033	0.00227	4.8E-05	2.09916	53	7.11	1	50	8.1	crack	0.0899
run031	0.00395	0.00029	7.26934	53	7.11	1	50	8.1	crack	0.0899

Table 4.04 Ranking of large laboratory with person - diffuser type TAD A.1

Diffuser Type TAD A.1										
Run	********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run032	0.00381	0.00017	4.3437	53	7.11	1	50	8.1	crack	0.0899
run034	0.007	0.00171	24.3939	53	7.11	1	50	8.1	crack	0.0899
run049c	0.01399	0.00013	0.90447	55	8.07	1	100	9.1	crack	0.0808
Run	sash	********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run049c	0.01399	0.00013	0.90447	55	8.07	1	100	9.1	crack	0.0808
run032	0.00381	0.00017	4.3437	53	7.11	1	50	8.1	crack	0.0899
run034	0.007	0.00171	24.3939	53	7.11	1	50	8.1	crack	0.0899
Run	sash	box	********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run049c	0.01399	0.00013	0.90447	55	8.07	1	100	9.1	crack	0.0808
run032	0.00381	0.00017	4.3437	53	7.11	1	50	8.1	crack	0.0899
run034	0.007	0.00171	24.3939	53	7.11	1	50	8.1	crack	0.0899

Table 4.05 Ranking of large laboratory with person - diffuser type TAD A.2

Diffuser Type TAD A.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run069c	0.01777	0.00023	1.2797	55	8.07	1	100	9.1	crack	0.0808

Table 4.06 Ranking of large laboratory with person - diffuser type TAD A.3

Diffuser Type TAD A.3										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run070c	0.02004	0.00037	1.86408	55	8.07	1	100	9.1	crack	0.0808

Table 4.07 Ranking of large laboratory with person - diffuser type TAD B.1

Diffuser Type TAD B.1										
Run	********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run147	0.01327	0.00012	0.90577	55	8.07	1	100	9.1	grille+crack	0.0808
run050c	0.01424	0.00015	1.03862	55	8.07	1	100	9.1	crack	0.0808
Run	sash	********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run147	0.01327	0.00012	0.90577	55	8.07	1	100	9.1	grille+crack	0.0808
run050c	0.01424	0.00015	1.03862	55	8.07	1	100	9.1	crack	0.0808
Run	sash	box	********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run147	0.01327	0.00012	0.90577	55	8.07	1	100	9.1	grille+crack	0.0808
run050c	0.01424	0.00015	1.03862	55	8.07	1	100	9.1	crack	0.0808

Table 4.08 Ranking of large laboratory with person - diffuser type TAD B.2

Diffuser Type TAD B.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run071c	0.0186	0.00027	1.44167	55	8.07	1	100	9.1	crack	0.0808

Table 4.09 Ranking of large laboratory with person - diffuser type TAD B.3

Diffuser Type TAD B.3										
Run	********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run073c	0.0189	0.00033	1.75058	55	8.07	1	100	9.1	crack	0.0808
run146	0.01925	0.00037	1.92102	55	8.07	1	100	9.1	crack	0.0808
run072c	0.0205	0.00045	2.21761	55	8.07	1	100	9.1	crack	0.0808
Run	sash	********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run073c	0.0189	0.00033	1.75058	55	8.07	1	100	9.1	crack	0.0808
run146	0.01925	0.00037	1.92102	55	8.07	1	100	9.1	crack	0.0808
run072c	0.0205	0.00045	2.21761	55	8.07	1	100	9.1	crack	0.0808
Run	sash	box	********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run073c	0.0189	0.00033	1.75058	55	8.07	1	100	9.1	crack	0.0808
run146	0.01925	0.00037	1.92102	55	8.07	1	100	9.1	crack	0.0808
run072c	0.0205	0.00045	2.21761	55	8.07	1	100	9.1	crack	0.0808

Table 4.10 Ranking of large laboratory with person - diffuser type TAD C.1b

Diffuser Type TAD C.1b										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run074c	0.0174	0.00031	1.77443	55	8.07	1	100	9.1	crack	0.0808

Table 4.11 Ranking of large laboratory with person - diffuser type TAD C.2

Diffuser Type TAD C.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run075c	0.02	0.00035	1.72855	55	8.07	1	100	9.1	crack	0.0808

Table 4.12 Ranking of large laboratory without person - diffuser type SQ A.1

Diffuser Type SQ A.1										
Run	********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run055	2.19E-03	2.70E-05	1.23E+00	55.0	8.07	2.0	100	9.10	crack	0.0808
run077	2.73E-03	7.90E-05	2.89E+00	55.0	8.07	1.0	100	9.10	grille	0.0808
run052	2.88E-03	8.22E-05	2.86E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run078	2.93E-03	8.90E-05	3.04E+00	55.0	8.07	1.0	100	9.10	grille	0.0808
run142	3.11E-03	1.05E-04	3.37E+00	55.0	8.07	1.4	100	9.10	crack	0.0808
run076	3.31E-03	1.19E-04	3.60E+00	55.0	8.07	1.0	100	9.10	crack 1,2,3	0.0808
run041	3.69E-03	8.62E-05	2.34E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run053	3.79E-03	1.29E-04	3.41E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run122	3.87E-03	1.21E-04	3.12E+00	55.0	5.32	1.0	100	6.00	crack	0.0712
run058	4.32E-03	1.09E-04	2.53E+00	63.5	8.00	1.0	100	18.10	crack	0.0423
run057	4.42E-03	1.31E-04	2.96E+00	55.0	12.05	1.0	100	13.60	crack	0.0556
run054	5.16E-03	1.45E-04	2.80E+00	55.0	8.07	1.2	100	9.10	crack	0.0808
run079	9.03E-03	3.22E-04	3.56E+00	55.0	8.07	1.0	100	9.10	grille	0.1495
run056	9.87E-03	6.44E-04	6.52E+00	55.0	8.07	3.0	100	9.10	crack	0.0808

Run	sash	********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run055	2.19E-03	2.70E-05	1.23E+00	55.0	8.07	2.0	100	9.10	crack	0.0808
run077	2.73E-03	7.90E-05	2.89E+00	55.0	8.07	1.0	100	9.10	grille	0.0808
run052	2.88E-03	8.22E-05	2.86E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run041	3.69E-03	8.62E-05	2.34E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run078	2.93E-03	8.90E-05	3.04E+00	55.0	8.07	1.0	100	9.10	grille	0.0808
run142	3.11E-03	1.05E-04	3.37E+00	55.0	8.07	1.4	100	9.10	crack	0.0808
run058	4.32E-03	1.09E-04	2.53E+00	63.5	8.00	1.0	100	18.10	crack	0.0423
run076	3.31E-03	1.19E-04	3.60E+00	55.0	8.07	1.0	100	9.10	crack 1,2,3	0.0808
run122	3.87E-03	1.21E-04	3.12E+00	55.0	5.32	1.0	100	6.00	crack	0.0712
run053	3.79E-03	1.29E-04	3.41E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run057	4.42E-03	1.31E-04	2.96E+00	55.0	12.05	1.0	100	13.60	crack	0.0556
run054	5.16E-03	1.45E-04	2.80E+00	55.0	8.07	1.2	100	9.10	crack	0.0808
run079	9.03E-03	3.22E-04	3.56E+00	55.0	8.07	1.0	100	9.10	grille	0.1495
run056	9.87E-03	6.44E-04	6.52E+00	55.0	8.07	3.0	100	9.10	crack	0.0808

Diffuser Type SQ A.1 cont.										
Run	sash	box	********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run055	2.19E-03	2.70E-05	1.23E+00	55.0	8.07	2.0	100	9.10	crack	0.0808
run041	3.69E-03	8.62E-05	2.34E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run058	4.32E-03	1.09E-04	2.53E+00	63.5	8.00	1.0	100	18.10	crack	0.0423
run054	5.16E-03	1.45E-04	2.80E+00	55.0	8.07	1.2	100	9.10	crack	0.0808
run052	2.88E-03	8.22E-05	2.86E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run077	2.73E-03	7.90E-05	2.89E+00	55.0	8.07	1.0	100	9.10	grille	0.0808
run057	4.42E-03	1.31E-04	2.96E+00	55.0	12.05	1.0	100	13.60	crack	0.0556
run078	2.93E-03	8.90E-05	3.04E+00	55.0	8.07	1.0	100	9.10	grille	0.0808
run122	3.87E-03	1.21E-04	3.12E+00	55.0	5.32	1.0	100	6.00	crack	0.0712
run142	3.11E-03	1.05E-04	3.37E+00	55.0	8.07	1.4	100	9.10	crack	0.0808
run053	3.79E-03	1.29E-04	3.41E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run079	9.03E-03	3.22E-04	3.56E+00	55.0	8.07	1.0	100	9.10	grille	0.1495
run076	3.31E-03	1.19E-04	3.60E+00	55.0	8.07	1.0	100	9.10	crack 1,2,3	0.0808
run056	9.87E-03	6.44E-04	6.52E+00	55.0	8.07	3.0	100	9.10	crack	0.0808

Table 4.13 Ranking of large laboratory without person - diffuser type SQ A.2

Diffuser Type SQ A.2										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run061	0.0041	0.00012	2.93005	55.0	8.07	1	100	9.1	crack	0.0808
run062	0.00437	0.00017	4.00138	55.0	8.07	1	100	9.1	crack	0.0808
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run061	0.0041	0.00012	2.93005	55.0	8.07	1	100	9.1	crack	0.0808
run062	0.00437	0.00017	4.00138	55.0	8.07	1	100	9.1	crack	0.0808
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run061	0.0041	0.00012	2.93005	55.0	8.07	1	100	9.1	crack	0.0808
run062	0.00437	0.00017	4.00138	55.0	8.07	1	100	9.1	crack	0.0808

Table 4.14 Ranking of large laboratory without person - diffuser type SQ A.3

Diffuser Type SQ A.3										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run063	0.0048	0.00018	3.66111	55.0	8.07	1	100	9.1	crack	0.0808

Table 4.15 Ranking of large laboratory without person - diffuser type SQ B.1

Diffuser Type SQ B.1										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run107	0.00233	7.1E-05	3.04449	55.0	8.07	1	100	9.1	grille	0.0808
run106	0.00286	9E-05	3.13424	55.0	8.07	3	100	9.1	grille+crack	0.0808
run123	0.00409	0.00014	3.46323	55.0	5.32	1	100	6	crack	0.0712
run143	0.00418	0.00015	3.6105	55.0	8.07	1.4	100	9.1	crack	0.0808
run042	0.0105	0.00041	3.88033	55.0	8.07	1	100	9.1	crack	0.0808
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run107	0.00233	7.1E-05	3.04449	55.0	8.07	1	100	9.1	grille	0.0808
run106	0.00286	9E-05	3.13424	55.0	8.07	3	100	9.1	grille+crack	0.0808
run123	0.00409	0.00014	3.46323	55.0	5.32	1	100	6	crack	0.0712
run143	0.00418	0.00015	3.6105	55.0	8.07	1.4	100	9.1	crack	0.0808
run042	0.0105	0.00041	3.88033	55.0	8.07	1	100	9.1	crack	0.0808
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run107	0.00233	7.1E-05	3.04449	55.0	8.07	1	100	9.1	grille	0.0808
run106	0.00286	9E-05	3.13424	55.0	8.07	3	100	9.1	grille+crack	0.0808
run123	0.00409	0.00014	3.46323	55.0	5.32	1	100	6	crack	0.0712
run143	0.00418	0.00015	3.6105	55.0	8.07	1.4	100	9.1	crack	0.0808
run042	0.0105	0.00041	3.88033	55.0	8.07	1	100	9.1	crack	0.0808

Table 4.16 Ranking of large laboratory without person - diffuser type SQ B.2

Diffuser Type SQ B.2										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run087	0.00324	2.3E-05	0.70606	55.0	8.07	2	100	9.1	crack	0.0808
run086	0.00413	0.00012	2.94103	55.0	8.07	1.2	100	9.1	crack	0.0808
run088	0.00418	0.00035	8.43461	55.0	8.07	3	100	9.1	crack	0.0808
run064	0.01008	0.00032	3.1819	55.0	8.07	1	100	9.1	crack	0.0808
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run087	0.00324	2.3E-05	0.70606	55.0	8.07	2	100	9.1	crack	0.0808
run086	0.00413	0.00012	2.94103	55.0	8.07	1.2	100	9.1	crack	0.0808
run064	0.01008	0.00032	3.1819	55.0	8.07	1	100	9.1	crack	0.0808
run088	0.00418	0.00035	8.43461	55.0	8.07	3	100	9.1	crack	0.0808
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run087	0.00324	2.3E-05	0.70606	55.0	8.07	2	100	9.1	crack	0.0808
run086	0.00413	0.00012	2.94103	55.0	8.07	1.2	100	9.1	crack	0.0808
run064	0.01008	0.00032	3.1819	55.0	8.07	1	100	9.1	crack	0.0808
run088	0.00418	0.00035	8.43461	55.0	8.07	3	100	9.1	crack	0.0808

Table 4.17 Ranking of large laboratory without person - diffuser type SQ B.3

Diffuser Type SQ B.3										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run065	0.01107	0.00037	3.33417	55.0	8.07	1	100	9.1	crack	0.0808

Table 4.18 Ranking of large laboratory without person - diffuser type SQ C.1

Diffuser Type SQ C.1										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run018	0.00298	0.00046	15.3442	53.0	7.11	1	50	8.1	none	0.0000
run002	0.00313	0.00046	14.7299	53.0	7.11	1	50	8.1	crack	0.0899
run010	0.00469	0.00024	5.14131	53.0	7.11	1	100	8.1	crack	0.0899
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run010	0.00469	0.00024	5.14131	53.0	7.11	1	100	8.1	crack	0.0899
run018	0.00298	0.00046	15.3442	53.0	7.11	1	50	8.1	none	0.0000
run002	0.00313	0.00046	14.7299	53.0	7.11	1	50	8.1	crack	0.0899
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run010	0.00469	0.00024	5.14131	53.0	7.11	1	100	8.1	crack	0.0899
run002	0.00313	0.00046	14.7299	53.0	7.11	1	50	8.1	crack	0.0899
run018	0.00298	0.00046	15.3442	53.0	7.11	1	50	8.1	none	0.0000

Table 4.19 Ranking of large laboratory without person - diffuser type SQ C.2

Diffuser Type SQ C.2										
Run	******** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run025	0.00242	0.00243	100.262	53.0	7.11	1	50x25%	8.1	crack	0.0899
run028	0.00294	0.00038	13.0511	62.3	3.17	1	50	8.1	crack	0.0899
run003	0.00332	0.00077	23.2237	53.0	7.11	1	50	8.1	crack	0.0899
run019	0.00384	0.00098	25.4715	53.0	7.11	1	50	8.1	none	0.0000
run015	0.0044	0.00095	21.5282	58.8	5.75	1	50	10	crack	0.0741
Run	sash	******** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run028	0.00294	0.00038	13.0511	62.3	3.17	1	50	8.1	crack	0.0899
run003	0.00332	0.00077	23.2237	53.0	7.11	1	50	8.1	crack	0.0899
run015	0.0044	0.00095	21.5282	58.8	5.75	1	50	10	crack	0.0741
run019	0.00384	0.00098	25.4715	53.0	7.11	1	50	8.1	none	0.0000
run025	0.00242	0.00243	100.262	53.0	7.11	1	50x25%	8.1	crack	0.0899
Run	sash	box	******** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run028	0.00294	0.00038	13.0511	62.3	3.17	1	50	8.1	crack	0.0899
run015	0.0044	0.00095	21.5282	58.8	5.75	1	50	10	crack	0.0741
run003	0.00332	0.00077	23.2237	53.0	7.11	1	50	8.1	crack	0.0899
run019	0.00384	0.00098	25.4715	53.0	7.11	1	50	8.1	none	0.0000
run025	0.00242	0.00243	100.262	53.0	7.11	1	50x25%	8.1	crack	0.0899

Table 4.20 Ranking of large laboratory without person - diffuser type SQ C.3

Diffuser Type SQ C.3										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run004	0.00529	0.00148	28.0646	53.0	7.11	1	50	8.1	crack	0.0899
run011	0.00603	0.0004	6.71046	53.0	7.11	1	100	8.1	crack	0.0899
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run011	0.00603	0.0004	6.71046	53.0	7.11	1	100	8.1	crack	0.0899
run004	0.00529	0.00148	28.0646	53.0	7.11	1	50	8.1	crack	0.0899
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run011	0.00603	0.0004	6.71046	53.0	7.11	1	100	8.1	crack	0.0899
run004	0.00529	0.00148	28.0646	53.0	7.11	1	50	8.1	crack	0.0899

Table 4.21 Ranking of large laboratory without person - diffuser type PERF A.1

Diffuser Type PERF A.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run055b	3.61E-03	1.87E-04	5.19E+00	55.0	8.07	2.0	100	9.10	crack	0.0808
run125	3.92E-03	1.34E-04	3.43E+00	55.0	5.32	1.0	100	6.00	crack	0.0712
run056b	4.04E-03	1.51E-04	3.73E+00	55.0	8.07	3.0	100	9.10	crack	0.0808
run145	4.07E-03	1.24E-04	3.05E+00	55.0	8.07	1.4	100	9.10	crack	0.0808
run054b	4.14E-03	1.21E-04	2.91E+00	55.0	8.07	1.2	100	9.10	crack	0.0808
run041b	4.21E-03	1.26E-04	3.00E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run054b	4.14E-03	1.21E-04	2.91E+00	55.0	8.07	1.2	100	9.10	crack	0.0808
run145	4.07E-03	1.24E-04	3.05E+00	55.0	8.07	1.4	100	9.10	crack	0.0808
run041b	4.21E-03	1.26E-04	3.00E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run125	3.92E-03	1.34E-04	3.43E+00	55.0	5.32	1.0	100	6.00	crack	0.0712
run056b	4.04E-03	1.51E-04	3.73E+00	55.0	8.07	3.0	100	9.10	crack	0.0808
run055b	3.61E-03	1.87E-04	5.19E+00	55.0	8.07	2.0	100	9.10	crack	0.0808
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run054b	4.14E-03	1.21E-04	2.91E+00	55.0	8.07	1.2	100	9.10	crack	0.0808
run041b	4.21E-03	1.26E-04	3.00E+00	55.0	8.07	1.0	100	9.10	crack	0.0808
run145	4.07E-03	1.24E-04	3.05E+00	55.0	8.07	1.4	100	9.10	crack	0.0808
run125	3.92E-03	1.34E-04	3.43E+00	55.0	5.32	1.0	100	6.00	crack	0.0712
run056b	4.04E-03	1.51E-04	3.73E+00	55.0	8.07	3.0	100	9.10	crack	0.0808
run055b	3.61E-03	1.87E-04	5.19E+00	55.0	8.07	2.0	100	9.10	crack	0.0808

Table 4.22 Ranking of large laboratory without person - diffuser type PERF A.2a

Diffuser Type PERF A.2a										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run061b	0.00479	0.00023	4.87587	55.0	8.07	1	100	9.1	crack	0.0808

Table 4.23 Ranking of large laboratory without person - diffuser type TAD A.1

Diffuser Type TAD A.1										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run026	0.00149	0.00081	54.0823	53.0	7.11	1	50x25%	8.1	crack	0.0899
run093	0.0031	7.2E-06	0.23227	55	8.07	2	100	9.1	crack	0.0808
run029	0.0032	0.00038	11.9487	62.3	3.17	1	50	8.1	crack	0.0899
run016	0.0036	0.00042	11.5514	53	7.11	1	50	8.1	crack	0.0899
run092	0.00387	0.00014	3.48961	55	8.07	1.2	100	9.1	crack	0.0808
run020	0.00393	0.00055	13.9805	53	7.11	1	50	8.1	none	0.0899
run094	0.0043	0.00013	3.05155	55	8.07	3	100	9.1	crack	0.0808
run017	0.00457	0.00015	3.34537	53	7.11	1	100	8.1	crack	0.0899
run049	0.00965	0.00036	3.69015	55	8.07	1	100	9.1	crack	0.0808
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run093	0.0031	7.2E-06	0.23227	55	8.07	2	100	9.1	crack	0.0808
run094	0.0043	0.00013	3.05155	55	8.07	3	100	9.1	crack	0.0808
run092	0.00387	0.00014	3.48961	55	8.07	1.2	100	9.1	crack	0.0808
run017	0.00457	0.00015	3.34537	53	7.11	1	100	8.1	crack	0.0899
run049	0.00965	0.00036	3.69015	55	8.07	1	100	9.1	crack	0.0808
run029	0.0032	0.00038	11.9487	62.3	3.17	1	50	8.1	crack	0.0899
run016	0.0036	0.00042	11.5514	53	7.11	1	50	8.1	crack	0.0899
run020	0.00393	0.00055	13.9805	53	7.11	1	50	8.1	none	0.0899
run026	0.00149	0.00081	54.0823	53.0	7.11	1	50x25%	8.1	crack	0.0899
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run093	0.0031	7.2E-06	0.23227	55	8.07	2	100	9.1	crack	0.0808
run094	0.0043	0.00013	3.05155	55	8.07	3	100	9.1	crack	0.0808
run017	0.00457	0.00015	3.34537	53	7.11	1	100	8.1	crack	0.0899
run092	0.00387	0.00014	3.48961	55	8.07	1.2	100	9.1	crack	0.0808
run049	0.00965	0.00036	3.69015	55	8.07	1	100	9.1	crack	0.0808
run016	0.0036	0.00042	11.5514	53	7.11	1	50	8.1	crack	0.0899
run029	0.0032	0.00038	11.9487	62.3	3.17	1	50	8.1	crack	0.0899
run020	0.00393	0.00055	13.9805	53	7.11	1	50	8.1	none	0.0899
run026	0.00149	0.00081	54.0823	53.0	7.11	1	50x25%	8.1	crack	0.0899

Table 4.24 Ranking of large laboratory without person - diffuser type PERF A.3

Diffuser Type PERF A.3										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run063b	0.0036	0.00021	5.83514	55.0	8.07	1	100	9.1	crack	0.0808

Table 4.25 Ranking of large laboratory without person - diffuser type TAD A.2

Diffuser Type TAD A.2										
Run	******** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run005	0.0041	0.00067	16.3778	53	7.11	1	50	8.1	crack	0.0899
run012	0.00604	0.00037	6.17625	53	7.11	1	100	8.1	crack	0.0899
run069	0.01045	0.00042	4.02648	55	8.07	1	100	9.1	crack	0.0808
Run	sash	******** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run012	0.00604	0.00037	6.17625	53	7.11	1	100	8.1	crack	0.0899
run069	0.01045	0.00042	4.02648	55	8.07	1	100	9.1	crack	0.0808
run005	0.0041	0.00067	16.3778	53	7.11	1	50	8.1	crack	0.0899
Run	sash	box	******** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run069	0.01045	0.00042	4.02648	55	8.07	1	100	9.1	crack	0.0808
run012	0.00604	0.00037	6.17625	53	7.11	1	100	8.1	crack	0.0899
run005	0.0041	0.00067	16.3778	53	7.11	1	50	8.1	crack	0.0899

Table 4.26 Ranking of large laboratory without person - diffuser type TAD A.3

Diffuser Type TAD A.3										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run013	0.00775	0.00061	7.86279	53	7.11	1	50	8.1	crack	0.0899
run070	0.01176	0.0005	4.21256	55	8.07	1	100	9.1	crack	0.0808
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run070	0.01176	0.0005	4.21256	55	8.07	1	100	9.1	crack	0.0808
run013	0.00775	0.00061	7.86279	53	7.11	1	50	8.1	crack	0.0899
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run070	0.01176	0.0005	4.21256	55	8.07	1	100	9.1	crack	0.0808
run013	0.00775	0.00061	7.86279	53	7.11	1	50	8.1	crack	0.0899

Table 4.27 Ranking of large laboratory without person - diffuser type TAD B.1

Diffuser Type TAD B.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run124	0.00343	7.9E-05	2.31479	55	5.32	1	100	6	crack	0.0712
run081	0.00371	0.0001	2.79804	55	8.07	1	100	9.1	grille	0.0808
run144	0.00387	0.00012	3.14732	55	8.07	1.4	100	9.1	crack	0.0808
run050	0.00969	0.00033	3.44636	55	8.07	1	100	9.1	crack	0.0808
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run124	0.00343	7.9E-05	2.31479	55	5.32	1	100	6	crack	0.0712
run081	0.00371	0.0001	2.79804	55	8.07	1	100	9.1	grille	0.0808
run144	0.00387	0.00012	3.14732	55	8.07	1.4	100	9.1	crack	0.0808
run050	0.00969	0.00033	3.44636	55	8.07	1	100	9.1	crack	0.0808
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run124	0.00343	7.9E-05	2.31479	55	5.32	1	100	6	crack	0.0712
run081	0.00371	0.0001	2.79804	55	8.07	1	100	9.1	grille	0.0808
run144	0.00387	0.00012	3.14732	55	8.07	1.4	100	9.1	crack	0.0808
run050	0.00969	0.00033	3.44636	55	8.07	1	100	9.1	crack	0.0808

Table 4.28 Ranking of large laboratory without person - diffuser type TAD B.2

Diffuser Type TAD B.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run071	0.0114	0.00058	5.12414	55	8.07	1	100	9.1	crack	0.0808

Table 4.29 Ranking of large laboratory without person - diffuser type TAD B.3

Diffuser Type TAD B.3										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run073	0.0119	0.00066	5.5772	55	8.07	1	100	9.1	crack	0.0808
run072	0.01286	0.00101	7.85839	55	8.07	1	100	9.1	crack	0.0808
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run073	0.0119	0.00066	5.5772	55	8.07	1	100	9.1	crack	0.0808
run072	0.01286	0.00101	7.85839	55	8.07	1	100	9.1	crack	0.0808
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run073	0.0119	0.00066	5.5772	55	8.07	1	100	9.1	crack	0.0808
run072	0.01286	0.00101	7.85839	55	8.07	1	100	9.1	crack	0.0808

Table 4.30 Ranking of large laboratory without person - diffuser type TAD C.1

Diffuser Type TAD C.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run074	0.01075	0.00062	5.76237	55	8.07	1	100	9.1	crack	0.0808
run051	0.01094	0.00077	7.01457	55	8.07	1	100	9.1	crack	0.0808
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run074	0.01075	0.00062	5.76237	55	8.07	1	100	9.1	crack	0.0808
run051	0.01094	0.00077	7.01457	55	8.07	1	100	9.1	crack	0.0808
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run074	0.01075	0.00062	5.76237	55	8.07	1	100	9.1	crack	0.0808
run051	0.01094	0.00077	7.01457	55	8.07	1	100	9.1	crack	0.0808

Table 4.31 Ranking of large laboratory without person - diffuser type TAD C.2

Diffuser Type TAD C.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run075	0.0124	0.00067	5.39331	55	8.07	1	100	9.1	crack	0.0808

Table 4.32 Ranking of large laboratory without person - diffuser type LAM A.1

Diffuser Type LAM A.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run047	0.00444	0.0002	4.52384	55.0	8.07	1	100	9.1	crack	0.0808
run080	0.00492	0.00037	7.51847	55.0	8.07	1	100	9.1	grille	0.0808
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run047	0.00444	0.0002	4.52384	55.0	8.07	1	100	9.1	crack	0.0808
run080	0.00492	0.00037	7.51847	55.0	8.07	1	100	9.1	grille	0.0808
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run047	0.00444	0.0002	4.52384	55.0	8.07	1	100	9.1	crack	0.0808
run080	0.00492	0.00037	7.51847	55.0	8.07	1	100	9.1	grille	0.0808

Table 4.33 Ranking of large laboratory without person - diffuser type LAM A.2

Diffuser Type LAM A.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run066	0.00484	0.00029	5.95235	55.0	8.07	1	100	9.1	crack	0.0808

Table 4.34 Ranking of large laboratory without person - diffuser type LAM B.1

Diffuser Type LAM B.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run090	0.00284	1.3E-05	0.44818	55.0	8.07	2	100	9.1	crack	0.0808
run091	0.00424	0.00019	4.37109	55.0	8.07	3	100	9.1	crack	0.0808
run089	0.00454	0.00024	5.1823	55.0	8.07	1.2	100	9.1	crack	0.0808
run048	0.00455	0.00023	5.11944	55.0	8.07	1	100	9.1	crack	0.0808
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run090	0.00284	1.3E-05	0.44818	55.0	8.07	2	100	9.1	crack	0.0808
run091	0.00424	0.00019	4.37109	55.0	8.07	3	100	9.1	crack	0.0808
run048	0.00455	0.00023	5.11944	55.0	8.07	1	100	9.1	crack	0.0808
run089	0.00454	0.00024	5.1823	55.0	8.07	1.2	100	9.1	crack	0.0808
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run090	0.00284	1.3E-05	0.44818	55.0	8.07	2	100	9.1	crack	0.0808
run091	0.00424	0.00019	4.37109	55.0	8.07	3	100	9.1	crack	0.0808
run048	0.00455	0.00023	5.11944	55.0	8.07	1	100	9.1	crack	0.0808
run089	0.00454	0.00024	5.1823	55.0	8.07	1.2	100	9.1	crack	0.0808

Table 4.35 Ranking of large laboratory without person - diffuser type DISP

Diffuser Type Displacement										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run059	0.00272	3.2E-05	1.18098	63.5	8.00	1	100	18.1	crack	0.0423
run060	0.0095	0.00014	1.52337	63.5	8.00	1	100	18.1	crack	0.0423
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run059	0.00272	3.2E-05	1.18098	63.5	8.00	1	100	18.1	crack	0.0423
run060	0.0095	0.00014	1.52337	63.5	8.00	1	100	18.1	crack	0.0423
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run059	0.00272	3.2E-05	1.18098	63.5	8.00	1	100	18.1	crack	0.0423
run060	0.0095	0.00014	1.52337	63.5	8.00	1	100	18.1	crack	0.0423

Table 4.36 Ranking of small laboratory with person - diffuser type SM SQ A.1

Diffuser Type SM S) A.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run153	3.50E-03	3.61E-05	1.03E+00	55.0	8.06	2.0	100	9.10	grille+crack	0.531
run118c	4.30E-03	4.19E-05	9.75E-01	63.0	7.95	1.0	100	17.00	crack	0.124
run155	4.91E-03	1.05E-04	2.13E+00	55.0	8.06	3.0	100	9.10	grille+crack	0.531
run139c	5.02E-03	6.30E-05	1.26E+00	55.0	8.06	1.2	100	9.10	grille+crack	0.531
run110c	5.81E-03	8.37E-05	1.44E+00	57.0	7.81	1.0	100	10.00	grille+crack	0.485
run082c	6.26E-03	9.85E-05	1.57E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run130c	6.39E-03	9.63E-05	1.51E+00	55.0	10.63	1.0	100	12.00	grille+crack	0.381
run148	6.51E-03	6.09E-05	9.36E-01	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run134c	6.64E-03	1.04E-04	1.57E+00	50.0	10.43	1.0	100	9.10	grille+crack	0.531
run126c	7.09E-03	1.67E-04	2.36E+00	55.0	5.31	1.0	100	6.00	grille+crack	0.691
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run153	3.50E-03	3.61E-05	1.03E+00	55.0	8.06	2.0	100	9.10	grille+crack	0.531
run118c	4.30E-03	4.19E-05	9.75E-01	63.0	7.95	1.0	100	17.00	crack	0.124
run148	6.51E-03	6.09E-05	9.36E-01	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run139c	5.02E-03	6.30E-05	1.26E+00	55.0	8.06	1.2	100	9.10	grille+crack	0.531
run110c	5.81E-03	8.37E-05	1.44E+00	57.0	7.81	1.0	100	10.00	grille+crack	0.485
run130c	6.39E-03	9.63E-05	1.51E+00	55.0	10.63	1.0	100	12.00	grille+crack	0.381
run082c	6.26E-03	9.85E-05	1.57E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run134c	6.64E-03	1.04E-04	1.57E+00	50.0	10.43	1.0	100	9.10	grille+crack	0.531
run155	4.91E-03	1.05E-04	2.13E+00	55.0	8.06	3.0	100	9.10	grille+crack	0.531
run126c	7.09E-03	1.67E-04	2.36E+00	55.0	5.31	1.0	100	6.00	grille+crack	0.691
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run148	6.51E-03	6.09E-05	9.36E-01	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run118c	4.30E-03	4.19E-05	9.75E-01	63.0	7.95	1.0	100	17.00	crack	0.124
run153	3.50E-03	3.61E-05	1.03E+00	55.0	8.06	2.0	100	9.10	grille+crack	0.531
run139c	5.02E-03	6.30E-05	1.26E+00	55.0	8.06	1.2	100	9.10	grille+crack	0.531
run110c	5.81E-03	8.37E-05	1.44E+00	57.0	7.81	1.0	100	10.00	grille+crack	0.485
run130c	6.39E-03	9.63E-05	1.51E+00	55.0	10.63	1.0	100	12.00	grille+crack	0.381
run134c	6.64E-03	1.04E-04	1.57E+00	50.0	10.43	1.0	100	9.10	grille+crack	0.531
run082c	6.26E-03	9.85E-05	1.57E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run155	4.91E-03	1.05E-04	2.13E+00	55.0	8.06	3.0	100	9.10	grille+crack	0.531
run126c	7.09E-03	1.67E-04	2.36E+00	55.0	5.31	1.0	100	6.00	grille+crack	0.691

Table 4.37 Ranking of small laboratory with person - diffuser type SM SQ A.2

Diffuser Type SM SQ A.2										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run103c	0.01374	0.00017	1.24992	55.0	8.06	1	100	9.1	grille+crack	0.531
run149	0.01606	0.0002	1.23681	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run103c	0.01374	0.00017	1.24992	55.0	8.06	1	100	9.1	grille+crack	0.531
run149	0.01606	0.0002	1.23681	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run149	0.01606	0.0002	1.23681	55.0	8.06	1	100	9.1	grille+crack	0.531
run103c	0.01374	0.00017	1.24992	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.38 Ranking of small laboratory with person - diffuser type SM SQ B.1

Diffuser Type SM SQ B.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run083c	5.16E-03	8.40E-05	1.63E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run140c	5.20E-03	8.84E-05	1.70E+00	55.0	8.06	1.2	100	9.10	grille+crack	0.531
run131c	5.32E-03	6.13E-05	1.15E+00	55.0	10.63	1.0	100	12.00	grille+crack	0.381
run119c	5.62E-03	6.10E-05	1.09E+00	63.0	7.95	1.0	100	17.00	crack	0.124
run135c	5.84E-03	1.20E-04	2.06E+00	50.0	10.43	1.0	100	9.10	grille+crack	0.531
run150	5.94E-03	8.31E-05	1.40E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run127c	7.43E-03	1.93E-04	2.60E+00	55.0	5.31	1.0	100	6.00	grille+crack	0.691
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run119c	5.62E-03	6.10E-05	1.09E+00	63.0	7.95	1.0	100	17.00	crack	0.124
run131c	5.32E-03	6.13E-05	1.15E+00	55.0	10.63	1.0	100	12.00	grille+crack	0.381
run150	5.94E-03	8.31E-05	1.40E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run083c	5.16E-03	8.40E-05	1.63E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run140c	5.20E-03	8.84E-05	1.70E+00	55.0	8.06	1.2	100	9.10	grille+crack	0.531
run135c	5.84E-03	1.20E-04	2.06E+00	50.0	10.43	1.0	100	9.10	grille+crack	0.531
run127c	7.43E-03	1.93E-04	2.60E+00	55.0	5.31	1.0	100	6.00	grille+crack	0.691
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run119c	5.62E-03	6.10E-05	1.09E+00	63.0	7.95	1.0	100	17.00	crack	0.124
run131c	5.32E-03	6.13E-05	1.15E+00	55.0	10.63	1.0	100	12.00	grille+crack	0.381
run150	5.94E-03	8.31E-05	1.40E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run083c	5.16E-03	8.40E-05	1.63E+00	55.0	8.06	1.0	100	9.10	grille+crack	0.531
run140c	5.20E-03	8.84E-05	1.70E+00	55.0	8.06	1.2	100	9.10	grille+crack	0.531
run135c	5.84E-03	1.20E-04	2.06E+00	50.0	10.43	1.0	100	9.10	grille+crack	0.531
run127c	7.43E-03	1.93E-04	2.60E+00	55.0	5.31	1.0	100	6.00	grille+crack	0.691

Table 4.39 Ranking of small laboratory with person - diffuser type SM SQ B.2

Diffuser Type SM SQ B.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run104c	0.0055	6.1E-05	1.10537	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.40 Ranking of small laboratory with person - diffuser type SM SQ B.3

Diffuser Type SM SQ B.3										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run113c	0.00522	4.9E-05	0.93634	55.0	8.06	1	100	9.1	grille+crack	0.531
run105c	0.0054	6.7E-05	1.24958	55.0	8.06	1	100	9.1	grille+crack	0.531
run112c	0.00547	5.6E-05	1.03178	55.0	8.06	1	100	9.1	grille+crack	0.531
run151	0.00655	9.3E-05	1.421	55.0	8.06	1	100	9.1	grille+crack	0.531
run111c	0.0069	8.3E-05	1.21061	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run113c	0.00522	4.9E-05	0.93634	55.0	8.06	1	100	9.1	grille+crack	0.531
run112c	0.00547	5.6E-05	1.03178	55.0	8.06	1	100	9.1	grille+crack	0.531
run105c	0.0054	6.7E-05	1.24958	55.0	8.06	1	100	9.1	grille+crack	0.531
run111c	0.0069	8.3E-05	1.21061	55.0	8.06	1	100	9.1	grille+crack	0.531
run151	0.00655	9.3E-05	1.421	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run113c	0.00522	4.9E-05	0.93634	55.0	8.06	1	100	9.1	grille+crack	0.531
run112c	0.00547	5.6E-05	1.03178	55.0	8.06	1	100	9.1	grille+crack	0.531
run111c	0.0069	8.3E-05	1.21061	55.0	8.06	1	100	9.1	grille+crack	0.531
run105c	0.0054	6.7E-05	1.24958	55.0	8.06	1	100	9.1	grille+crack	0.531
run151	0.00655	9.3E-05	1.421	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.41 Ranking of small laboratory with person - diffuser type SM PERF A.1

Diffuser Type SM PERF A.1										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run121c	0.0055	8.7E-05	1.58513	55.0	15.05	1	100	17	crack	0.124
run129c	0.00566	0.00011	1.9669	55.0	5.31	1	100	6	grille+crack	0.691
run133c	0.00589	9.5E-05	1.60973	55.0	10.63	1	100	12	grille+crack	0.381
run141c	0.00598	9.8E-05	1.64158	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run137c	0.00723	0.00014	1.95887	50.0	10.43	1	100	9.1	grille+crack	0.531
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run121c	0.0055	8.7E-05	1.58513	55.0	15.05	1	100	17	crack	0.124
run133c	0.00589	9.5E-05	1.60973	55.0	10.63	1	100	12	grille+crack	0.381
run141c	0.00598	9.8E-05	1.64158	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run129c	0.00566	0.00011	1.9669	55.0	5.31	1	100	6	grille+crack	0.691
run137c	0.00723	0.00014	1.95887	50.0	10.43	1	100	9.1	grille+crack	0.531
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run121c	0.0055	8.7E-05	1.58513	55.0	15.05	1	100	17	crack	0.124
run133c	0.00589	9.5E-05	1.60973	55.0	10.63	1	100	12	grille+crack	0.381
run141c	0.00598	9.8E-05	1.64158	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run137c	0.00723	0.00014	1.95887	50.0	10.43	1	100	9.1	grille+crack	0.531
run129c	0.00566	0.00011	1.9669	55.0	5.31	1	100	6	grille+crack	0.691

Table 4.42 Ranking of small laboratory with person - diffuser type SM TAD A.1

Diffuser Type SM TAD A.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run109c	0.00611	0.0001	1.68005	57.0	7.81	1	100	10	grille+crack	0.485
run085c	0.00622	0.00012	1.89389	55.0	8.06	1	100	9.1	grille+crack	0.531
run097c	0.00633	0.00011	1.80829	55.0	8.06	1	100	9.1	grille+crack	0.531
run154	0.0078	0.00029	3.74709	55.0	8.06	3	100	9.1	grille+crack	0.531
run108c	0.00858	0.0002	2.28332	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run109c	0.00611	0.0001	1.68005	57.0	7.81	1	100	10	grille+crack	0.485
run097c	0.00633	0.00011	1.80829	55.0	8.06	1	100	9.1	grille+crack	0.531
run085c	0.00622	0.00012	1.89389	55.0	8.06	1	100	9.1	grille+crack	0.531
run108c	0.00858	0.0002	2.28332	55.0	8.06	1	100	9.1	grille+crack	0.531
run154	0.0078	0.00029	3.74709	55.0	8.06	3	100	9.1	grille+crack	0.531
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run109c	0.00611	0.0001	1.68005	57.0	7.81	1	100	10	grille+crack	0.485
run097c	0.00633	0.00011	1.80829	55.0	8.06	1	100	9.1	grille+crack	0.531
run085c	0.00622	0.00012	1.89389	55.0	8.06	1	100	9.1	grille+crack	0.531
run108c	0.00858	0.0002	2.28332	55.0	8.06	1	100	9.1	grille+crack	0.531
run154	0.0078	0.00029	3.74709	55.0	8.06	3	100	9.1	grille+crack	0.531

Table 4.43 Ranking of small laboratory with person - diffuser type SM TAD A.2

Diffuser Type SM TAD A.2										
Run	*********** sash**	**box**	**proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run095c	0.00677	8.7E-05	1.28471	55.0	8.06	1	100	9.1	grille+crack	0.531
run096c	0.00707	7E-05	0.9924	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	**sash**	*********** box**	**proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run096c	0.00707	7E-05	0.9924	55.0	8.06	1	100	9.1	grille+crack	0.531
run095c	0.00677	8.7E-05	1.28471	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	**sash**	**box**	*********** proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run096c	0.00707	7E-05	0.9924	55.0	8.06	1	100	9.1	grille+crack	0.531
run095c	0.00677	8.7E-05	1.28471	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.44 Ranking of small laboratory with person - diffuser type SM LAM A.1

Diffuser Type SM LAM A.1										
Run	************* sash**	**box**	**proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run084c	0.00703	0.00013	1.86824	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.45 Ranking of small laboratory with person - diffuser type SM LAM A.2

Diffuser Type SM LAM A.2										
Run	************* sash**	**box**	**proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run098c	0.00688	0.00012	1.69811	55.0	8.06	1.2	100	9.1	grille+crack	0.531

Table 4.46 Ranking of small laboratory with person - diffuser type SM LAM A.4

Diffuser Type SM LAM A.4										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run100c	0.00489	8.2E-05	1.67478	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.47 Ranking of small laboratory with person - diffuser type SM LAM A.5

Diffuser Type SM LAM A.5										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run101c	0.00494	0.00011	2.29368	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.48 Ranking of small laboratory without person - diffuser type SM SQ A.1

Diffuser Type SM SQ A.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run184	0.00292	5.2E-05	1.79622	63.0	7.95	2	100	17	crack	0.124
run183	0.003	4.4E-05	1.47005	55.0	8.06	2	100	9.1	grille+crack	0.531
run118	0.00304	8.1E-05	2.67435	63.0	7.95	1	100	17	crack	0.124
run082	0.00374	0.00012	3.14432	55.0	8.06	1	100	9.1	grille+crack	0.531
run139	0.0039	0.00011	2.89715	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run110	0.00418	0.00014	3.37032	57.0	7.81	1	100	10	grille+crack	0.485
run130	0.00435	0.00022	4.97575	55.0	10.63	1	100	12	grille+crack	0.381
run134	0.0046	0.00019	4.09675	50.0	10.43	1	100	9.1	grille+crack	0.531
run138	0.00482	0.00028	5.83507	55.0	8.06	3	100	9.1	grille+crack	0.531
run126	0.00527	0.00099	18.7103	55.0	5.31	1	100	6	grille+crack	0.691
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run183	0.003	4.4E-05	1.47005	55.0	8.06	2	100	9.1	grille+crack	0.531
run184	0.00292	5.2E-05	1.79622	63.0	7.95	2	100	17	crack	0.124
run118	0.00304	8.1E-05	2.67435	63.0	7.95	1	100	17	crack	0.124
run139	0.0039	0.00011	2.89715	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run082	0.00374	0.00012	3.14432	55.0	8.06	1	100	9.1	grille+crack	0.531
run110	0.00418	0.00014	3.37032	57.0	7.81	1	100	10	grille+crack	0.485
run134	0.0046	0.00019	4.09675	50.0	10.43	1	100	9.1	grille+crack	0.531
run130	0.00435	0.00022	4.97575	55.0	10.63	1	100	12	grille+crack	0.381
run138	0.00482	0.00028	5.83507	55.0	8.06	3	100	9.1	grille+crack	0.531
run126	0.00527	0.00099	18.7103	55.0	5.31	1	100	6	grille+crack	0.691
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run183	0.003	4.4E-05	1.47005	55.0	8.06	2	100	9.1	grille+crack	0.531
run184	0.00292	5.2E-05	1.79622	63.0	7.95	2	100	17	crack	0.124
run118	0.00304	8.1E-05	2.67435	63.0	7.95	1	100	17	crack	0.124
run139	0.0039	0.00011	2.89715	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run082	0.00374	0.00012	3.14432	55.0	8.06	1	100	9.1	grille+crack	0.531
run110	0.00418	0.00014	3.37032	57.0	7.81	1	100	10	grille+crack	0.485
run134	0.0046	0.00019	4.09675	50.0	10.43	1	100	9.1	grille+crack	0.531
run130	0.00435	0.00022	4.97575	55.0	10.63	1	100	12	grille+crack	0.381
run138	0.00482	0.00028	5.83507	55.0	8.06	3	100	9.1	grille+crack	0.531
run126	0.00527	0.00099	18.7103	55.0	5.31	1	100	6	grille+crack	0.691

Table 4.49 Ranking of small laboratory without person - diffuser type SM SQ B.1

Diffuser Type SM SQ B.1										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run179	0.00243	3.5E-05	1.45126	55.0	8.06	2	100	9.1	grille+crack	0.531
run185	0.00264	4.3E-05	1.6149	63.0	7.95	2	100	17	crack	0.124
run140	0.00354	0.00041	11.6535	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run135	0.00386	0.00046	12.0462	50.0	10.43	1	100	9.1	grille+crack	0.531
run083	0.00397	0.00036	8.96901	55.0	8.06	1	100	9.1	grille+crack	0.531
run131	0.00417	0.00021	5.11743	55.0	10.63	1	100	12	grille+crack	0.381
run119	0.00433	0.00017	3.8676	63.0	7.95	1	100	17	crack	0.124
run127	0.00705	0.0015	21.3368	55.0	5.31	1	100	6	grille+crack	0.691
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run179	0.00243	3.5E-05	1.45126	55.0	8.06	2	100	9.1	grille+crack	0.531
run185	0.00264	4.3E-05	1.6149	63.0	7.95	2	100	17	crack	0.124
run119	0.00433	0.00017	3.8676	63.0	7.95	1	100	17	crack	0.124
run131	0.00417	0.00021	5.11743	55.0	10.63	1	100	12	grille+crack	0.381
run083	0.00397	0.00036	8.96901	55.0	8.06	1	100	9.1	grille+crack	0.531
run140	0.00354	0.00041	11.6535	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run135	0.00386	0.00046	12.0462	50.0	10.43	1	100	9.1	grille+crack	0.531
run127	0.00705	0.0015	21.3368	55.0	5.31	1	100	6	grille+crack	0.691
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run179	0.00243	3.5E-05	1.45126	55.0	8.06	2	100	9.1	grille+crack	0.531
run185	0.00264	4.3E-05	1.6149	63.0	7.95	2	100	17	crack	0.124
run119	0.00433	0.00017	3.8676	63.0	7.95	1	100	17	crack	0.124
run131	0.00417	0.00021	5.11743	55.0	10.63	1	100	12	grille+crack	0.381
run083	0.00397	0.00036	8.96901	55.0	8.06	1	100	9.1	grille+crack	0.531
run140	0.00354	0.00041	11.6535	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run135	0.00386	0.00046	12.0462	50.0	10.43	1	100	9.1	grille+crack	0.531
run127	0.00705	0.0015	21.3368	55.0	5.31	1	100	6	grille+crack	0.691

Table 4.50 Ranking of small laboratory without person - diffuser type SM SQ B.3

Diffuser Type SM SQ B.3										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run192	0.00304	8.4E-05	2.76335	63.0	7.95	1.2	100	17	0	0.124
run191	0.00346	0.00017	5.03814	63.0	7.95	1.2	100	17	0	0.124
run190	0.00355	0.00016	4.50084	63.0	7.95	1.2	100	17	0	0.124
run189	0.00414	0.00028	6.66329	63.0	7.95	1	100	17	0	0.124
run113	0.0044	0.00062	14.1118	55.0	8.06	1	100	9.1	grille+crack	0.531
run112	0.0045	0.00054	12.0309	55.0	8.06	1	100	9.1	grille+crack	0.531
run111	0.00529	0.00055	10.3862	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run192	0.00304	8.4E-05	2.76335	63.0	7.95	1.2	100	17	0	0.124
run190	0.00355	0.00016	4.50084	63.0	7.95	1.2	100	17	0	0.124
run191	0.00346	0.00017	5.03814	63.0	7.95	1.2	100	17	0	0.124
run189	0.00414	0.00028	6.66329	63.0	7.95	1	100	17	0	0.124
run112	0.0045	0.00054	12.0309	55.0	8.06	1	100	9.1	grille+crack	0.531
run111	0.00529	0.00055	10.3862	55.0	8.06	1	100	9.1	grille+crack	0.531
run113	0.0044	0.00062	14.1118	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run192	0.00304	8.4E-05	2.76335	63.0	7.95	1.2	100	17	0	0.124
run190	0.00355	0.00016	4.50084	63.0	7.95	1.2	100	17	0	0.124
run191	0.00346	0.00017	5.03814	63.0	7.95	1.2	100	17	0	0.124
run189	0.00414	0.00028	6.66329	63.0	7.95	1	100	17	0	0.124
run111	0.00529	0.00055	10.3862	55.0	8.06	1	100	9.1	grille+crack	0.531
run112	0.0045	0.00054	12.0309	55.0	8.06	1	100	9.1	grille+crack	0.531
run113	0.0044	0.00062	14.1118	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.51 Ranking of small laboratory without person - diffuser type SM PERF A.1

Diffuser Type SM PERF A.1										
Run	*********** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run182	0.00237	5.7E-05	2.42691	55.0	8.06	2	100	9.1	grille+crack	0.531
run187	0.00336	8E-05	2.39604	63.0	7.95	2	100	17	crack	0.124
run121	0.00408	0.00017	4.24098	63.0	7.95	1	100	17	crack	0.124
run133	0.00451	0.00026	5.87605	55.0	10.63	1	100	12	grille+crack	0.381
run141	0.00467	0.00023	4.86563	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run084b	0.00468	0.00018	3.78504	55.0	8.06	1	100	9.1	grille+crack	0.531
run137	0.00499	0.00033	6.68539	50.0	10.43	1	100	9.1	grille+crack	0.531
run129	0.00596	0.00105	17.594	55.0	5.31	1	100	6	grille+crack	0.691
Run	sash	*********** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run182	0.00237	5.7E-05	2.42691	55.0	8.06	2	100	9.1	grille+crack	0.531
run187	0.00336	8E-05	2.39604	63.0	7.95	2	100	17	crack	0.124
run121	0.00408	0.00017	4.24098	63.0	7.95	1	100	17	crack	0.124
run084b	0.00468	0.00018	3.78504	55.0	8.06	1	100	9.1	grille+crack	0.531
run141	0.00467	0.00023	4.86563	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run133	0.00451	0.00026	5.87605	55.0	10.63	1	100	12	grille+crack	0.381
run137	0.00499	0.00033	6.68539	50.0	10.43	1	100	9.1	grille+crack	0.531
run129	0.00596	0.00105	17.594	55.0	5.31	1	100	6	grille+crack	0.691
Run	sash	box	*********** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run187	0.00336	8E-05	2.39604	63.0	7.95	2	100	17	crack	0.124
run182	0.00237	5.7E-05	2.42691	55.0	8.06	2	100	9.1	grille+crack	0.531
run084b	0.00468	0.00018	3.78504	55.0	8.06	1	100	9.1	grille+crack	0.531
run121	0.00408	0.00017	4.24098	63.0	7.95	1	100	17	crack	0.124
run141	0.00467	0.00023	4.86563	55.0	8.06	1.2	100	9.1	grille+crack	0.531
run133	0.00451	0.00026	5.87605	55.0	10.63	1	100	12	grille+crack	0.381
run137	0.00499	0.00033	6.68539	50.0	10.43	1	100	9.1	grille+crack	0.531
run129	0.00596	0.00105	17.594	55.0	5.31	1	100	6	grille+crack	0.691

Table 4.52 Ranking of small laboratory without person - diffuser type SM SQ A.2

Diffuser Type SM SQ A.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run103	1.13E-02	3.31E-04	2.93E+00	55.0	8.06	1.2	100	9.10	grille+crack	0.531

Table 4.53 Ranking of small laboratory without person - diffuser type SM SQ B.2

Diffuser Type SM SQ B.2										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run104	0.00508	0.00042	8.30001	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.54 Ranking of small laboratory without person - diffuser type SM SQ B.5

Diffuser Type SM SQ B.5										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run188	0.00439	0.00018	4.06149	63.0	7.95	1	100	17	crack	0.124

Table 4.55 Ranking of small laboratory without person - diffuser type SM PERF A.5

Diffuser Type SM PERF A.5										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run101b	0.00335	0.00018	5.48425	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.56 Ranking of small laboratory without person - diffuser type SM TAD A.1

Diffuser Type SM TAD A.1										
Run	********** sash**	**box**	**proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run114	0.00244	4E-05	1.66019	55.0	8.06	2	100	9.1	grille+crack	0.531
run181	0.00256	5.1E-05	1.98858	55.0	8.06	2	100	9.1	grille+crack	0.531
run109	0.00419	0.00044	10.6078	57.0	7.81	1	100	10.0	grille+crack	0.485
run097	0.00436	0.00044	10.1005	55.0	8.06	1	100	9.1	grille+crack	0.531
run085	0.00469	0.00062	13.3324	55.0	8.06	1	100	9.1	grille+crack	0.531
run108	0.00648	0.00054	8.30933	55.0	8.06	1	100	9.1	grille+crack	0.531
run115	0.00707	0.00121	17.1264	55.0	8.06	3	100	9.1	grille+crack	0.531
Run	**sash**	********** box**	**proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run114	0.00244	4E-05	1.66019	55.0	8.06	2	100	9.1	grille+crack	0.531
run181	0.00256	5.1E-05	1.98858	55.0	8.06	2	100	9.1	grille+crack	0.531
run097	0.00436	0.00044	10.1005	55.0	8.06	1	100	9.1	grille+crack	0.531
run109	0.00419	0.00044	10.6078	57.0	7.81	1	100	10.0	grille+crack	0.485
run108	0.00648	0.00054	8.30933	55.0	8.06	1	100	9.1	grille+crack	0.531
run085	0.00469	0.00062	13.3324	55.0	8.06	1	100	9.1	grille+crack	0.531
run115	0.00707	0.00121	17.1264	55.0	8.06	3	100	9.1	grille+crack	0.531
Run	**sash**	**box**	********** proportion**	**Temp**	**Power**	**hood posn**	**sash vel**	**vent rate**	**m/up posn**	**m/up prop**
run114	0.00244	4E-05	1.66019	55.0	8.06	2	100	9.1	grille+crack	0.531
run181	0.00256	5.1E-05	1.98858	55.0	8.06	2	100	9.1	grille+crack	0.531
run108	0.00648	0.00054	8.30933	55.0	8.06	1	100	9.1	grille+crack	0.531
run097	0.00436	0.00044	10.1005	55.0	8.06	1	100	9.1	grille+crack	0.531
run109	0.00419	0.00044	10.6078	57.0	7.81	1	100	10.0	grille+crack	0.485
run085	0.00469	0.00062	13.3324	55.0	8.06	1	100	9.1	grille+crack	0.531
run115	0.00707	0.00121	17.1264	55.0	8.06	3	100	9.1	grille+crack	0.531

Table 4.57 Ranking of small laboratory without person - diffuser type SM TAD A.2

Diffuser Type SM TAD A.2										
Run	******** sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run180	0.00341	5.3E-05	1.55958	55.0	8.06	2	100	9.1	grille+crack	0.531
run095	0.00443	0.0003	6.71467	55.0	8.06	1	100	9.1	grille+crack	0.531
run096	0.00496	0.00033	6.59587	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	******** box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run180	0.00341	5.3E-05	1.55958	55.0	8.06	2	100	9.1	grille+crack	0.531
run095	0.00443	0.0003	6.71467	55.0	8.06	1	100	9.1	grille+crack	0.531
run096	0.00496	0.00033	6.59587	55.0	8.06	1	100	9.1	grille+crack	0.531
Run	sash	box	******** proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run180	0.00341	5.3E-05	1.55958	55.0	8.06	2	100	9.1	grille+crack	0.531
run096	0.00496	0.00033	6.59587	55.0	8.06	1	100	9.1	grille+crack	0.531
run095	0.00443	0.0003	6.71467	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.58 Ranking of small laboratory without person - diffuser type SM TAD A.3

Diffuser Type SM TAD A.3										
Run	********* sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run186	0.00323	7.3E-05	2.26455	63.0	7.95	2	100	17.0	crack	0.124
run120	0.00364	0.00053	14.6285	63.0	7.95	1	100	17.0	crack	0.124
run136	0.00387	0.00041	10.5794	50.0	10.43	1	100	9.1	grille+crack	0.531
run132	0.00424	0.00039	9.23574	55.0	10.63	1	100	12.0	grille+crack	0.381
run117	0.00491	0.00044	8.97828	55.0	8.06	1	100	9.1	grille+crack	0.531
run116	0.00503	0.00046	9.0606	55.0	8.06	1	100	9.1	grille+crack	0.531
run128	0.00775	0.00071	9.11323	55.0	5.31	1	100	6.0	grille+crack	0.691
Run	sash	********* box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run186	0.00323	7.3E-05	2.26455	63.0	7.95	2	100	17.0	crack	0.124
run132	0.00424	0.00039	9.23574	55.0	10.63	1	100	12.0	grille+crack	0.381
run136	0.00387	0.00041	10.5794	50.0	10.43	1	100	9.1	grille+crack	0.531
run117	0.00491	0.00044	8.97828	55.0	8.06	1	100	9.1	grille+crack	0.531
run116	0.00503	0.00046	9.0606	55.0	8.06	1	100	9.1	grille+crack	0.531
run120	0.00364	0.00053	14.6285	63.0	7.95	1	100	17.0	crack	0.124
run128	0.00775	0.00071	9.11323	55.0	5.31	1	100	6.0	grille+crack	0.691
Run	sash	box	********* proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run186	0.00323	7.3E-05	2.26455	63.0	7.95	2	100	17.0	crack	0.124
run117	0.00491	0.00044	8.97828	55.0	8.06	1	100	9.1	grille+crack	0.531
run116	0.00503	0.00046	9.0606	55.0	8.06	1	100	9.1	grille+crack	0.531
run128	0.00775	0.00071	9.11323	55.0	5.31	1	100	6.0	grille+crack	0.691
run132	0.00424	0.00039	9.23574	55.0	10.63	1	100	12.0	grille+crack	0.381
run136	0.00387	0.00041	10.5794	50.0	10.43	1	100	9.1	grille+crack	0.531
run120	0.00364	0.00053	14.6285	63.0	7.95	1	100	17.0	crack	0.124

Table 4.59 Ranking of small laboratory without person - diffuser type SM LAM A.1

Diffuser Type SM LAM A.1										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run084	0.00525	0.00032	6.1558	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.60 Ranking of small laboratory without person - diffuser type SM LAM A.2

Diffuser Type SM LAM A.2										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run098	0.00543	0.00035	6.51815	55.0	8.06	1.2	100	9.1	grille+crack	0.531

Table 4.61 Ranking of small laboratory without person - diffuser type SM LAM A.4

Diffuser Type SM LAM A.4										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run100	0.00376	0.00052	13.755	55.0	8.06	1	100	9.1	grille+crack	0.531

Table 4.62 Ranking of small laboratory without person - diffuser type SM LAM A.5

Diffuser Type SM LAM A.5										
Run	sash	box	proportion	Temp	Power	hood posn	sash vel	vent rate	m/up posn	m/up prop
run101	0.00516	0.00058	11.2713	55.0	8.06	1	100	9.1	grille+crack	0.531

4.6 Summary of Recommendations

This section provides a summary of the specific recommendations identified in this report. Implementing the recommendations can be expected to reduce the risk of poor containment. A more complete description and justification are given in the section identified at the end of each recommendation.

Recommendation – hood position: Protect the hood by placing it in a corner avoiding jets impinging on the working zone outside the sash opening, see section 4.3.1.

Recommendation -- bulkhead: A bulkhead can be used to improve the containment performance by either :

- using a diffuser layout that will gently feed low velocity air to the hood.
- avoiding use of a diffuser layout which generates thin jets across the face of the hood from above.
- avoid using down-flow diffusers that cause a circulation in front of the hood so that the jet does not impinge.

Care should be taken to avoid indirect flows such as those from the converging jets SQ A.1, figure 4.40. In this case the bulkhead, run 054, increases the contaminant leakage, see section 4.3.2.

Recommendation – diffuser blanking: Avoid blanking where the increased velocity jets have a path back to the hood, see section 4.3.3.

Recommendation – diffuser / hood position: Avoid placing a square diffuser asymmetrically in front of the hood, since this increases exposure to the scientist by increasing sash leakage, see section 4.3.5.

Recommendation – diffuser / hood separation: Where there is insufficient distance to move the diffuser well away from the hood in line with current guidance, position the diffuser in line with the center of the hood, close to the bulkhead to prevent the square diffuser jet blowing towards the diffuser, see section 4.3.5.

Recommendation – transfer grilles: Avoid large bulky jets from makeup air and consequent high transfer grille flow rates. Using transfer grilles is beneficial at low volumes compared with high velocity jets from door cracks. Transfer grille flow rates of 100 cfm or less have been shown to provide better containment with both single and double hood configurations, see sections 4.3.6 and 4.3.7.

Recommendation – hood separation, same wall: Place hoods at least 4' apart preferably selecting corner positions if available, see section 4.3.7.

Recommendation – hood separation, opposite walls: For hoods on opposite walls avoid opposite or 2' separations ot the hood, see section 4.3.7.

Recommendation – hood separation, perpendicular walls: Separate hoods by more than 4'. Placing two hoods on perpendicular walls is likely to produce a better performance than on opposite walls. In turn either of these configurations can be expected to achieve lower leakage than hoods on the same wall. Maximize distance between the two hoods and the transfer grille, see section 4.3.7.

4.7 Future Research

These results show that there is considerable sensitivity in hood containment from laboratory air motion. This work extends far beyond published guidelines, but identifies that investigating sensitivity due to individual issues such as jet thickness, makeup air proportion and location, and diffuser position is required to quantify rules for optimum design. In addition, as well as further analysis of this data, it is important to extend this work to include the performance in respect of microbiological safety cabinets and down-flow hoods where hazardous substances are also handled.