ISCC'22
INTERNATIONAL SYMPOSIUM ON CONTAMINATION CONTROL
11-13 OCTOBER 2022
ANTALYA / TURKEY

ICCCS 50 years

50 articles in 50 years

THE CASCADE APPROACH: SEGREGATION BY AIRFLOW DESIGN N STEAD OF BY ROOM PRESSURE

Ir. Frans W. Saurwalt

03

CLEANROOM TECHNOLOGIES SOCIETY OF TURKEY

The cascade approach: Segregation by airflow design in stead of by room pressure

Ir. Frans W. Saurwalt[1]

fw.saurwalt@kropman.nl

[1]Kropman Contamination Control, Nijmegen, The Netherlands

Abstract

Governmental inspection bodies as well as internal quality departments have enforced adherence to monitoring of room pressure as a critical aspect. And because of that, the pharmaceutical and medical devices and healthcare industry puts a strong emphasis on controlling room pressure itself. As clean room construction becomes better and better, resulting in very limited leakage, active room pressure control becomes more and more complex. With a narrow focus on room pressure control and monitoring, the broader contamination control perspective and a useful different approach is overlooked. Room pressure control is only one aspect of the concept of segregation of zones of different classes. The broader view has many benefits. This approach is based on designing on airflow in stead of mere room pressure.
While citing ISO 14644-3, and -4 as well as the EU-GMP-vol 4 Annex 1 it can be demonstrated that there is a basis for designing an overflow / pressure cascade. This cascade approach when compared to various other systems shows to have many benefits; increased protection of the controlled environment, less complexity, better stability, reduced energy-consumption and reduced costs.

Key words: Segregation, Room pressure, Airflow/Pressure Cascade, Stability, Wind attack, Reduced Energy Consumption, reduced costs of installation.

1. Introduction

Specifying an overpressure in clean room design is a common contamination control concept. Normally a standard pressure interval (commonly 10 – 15 Pa) per step is added upwards along with the increase in classification. Depending on the number of steps the "nominal" pressure of the various rooms can ad up to about 75 Pa. Such a design could be illustrated as shown in figure 1.
In order to achieve this the HVAC needs to be designed to control the room pressure by some means. Most commonly this is done by utilizing pressure controlled actuated dampers in the return ducting. These dampers have to be designed to modulate in a certain airflow range and with a specific accuracy and speed of reaction. As this requires adequate understanding and designing specific to the situation, in many cases this is not fully successful. Understanding the mechanism that will create a room pressure is essential as well as those that influence it.

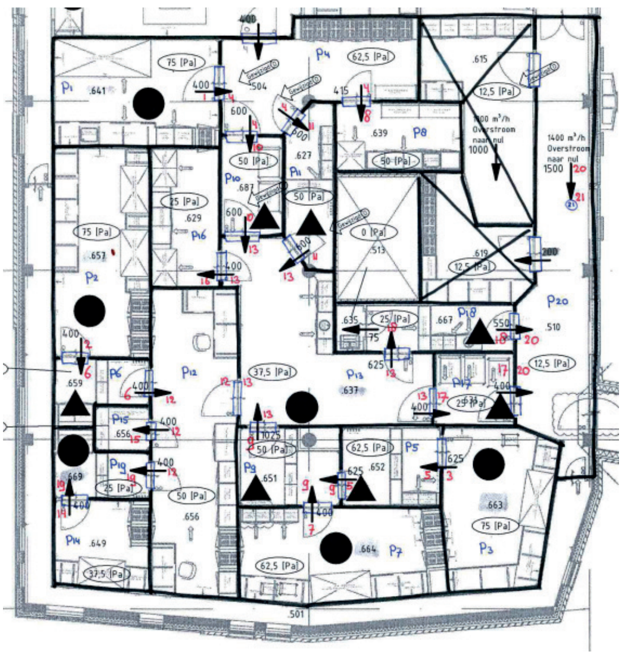

Figure 1. Room lay out showing pressure cascade and direct(□) or overflow (□) air circulation.

2. Basic understanding

To understand the principles ruling room pressurization we consider at first an ordinary room within and surrounded by an enveloping general building. This room will have the same pressure as the surrounding environment as the construction is usually far from airtight. Large amounts of air will be able to flow to and fro without any significant resistance. In this case the pressure can be increased by two means: 1) increasing the amount of air leaking away or 2) improving on the leakage. For solution 1) vast amounts of air will be required to achieve a even the slightest pressurization. Solution 2) will be a more useful approach. This is based on the simple relation that airflow over a "resistance" will generate a pressure drop □*p* [Pa]. This can be formulated as:

$$\Delta p_1 = \tfrac{1}{2} \cdot \rho \left(\frac{Q_l}{A_1 \cdot \mu_1} \right)^n \qquad (1)$$

were:

Q_l	= Leakage air volume	$[m^3/s]$
□	= Specific density	$[kg/m^3]$
A_1	= Area of leakage	$[m^2]$
μ_1	= coefficient of contraction	[-]

For turbulent flow n = 2 for laminar flow n = 1
Common value for n=2 and μ≈0,75

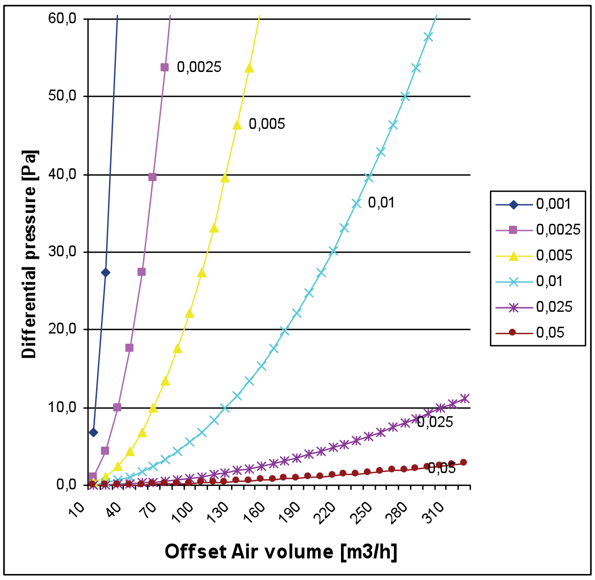

Figure 2.differential pressure[Pa] in relation to the offset air volume [m³/h] per area of leakage [m²].

Further more the dynamic reaction of the room tot pressure fluctuations can considered as a capacity. According to Boyle Gay-Lussac law pressure, volume, temperature and the amount of gas molecules are related.

At constant temperature Boyle's law can be applied. Applied for a given room volume here is a distinct relation to the (room-)pressure and the amount of gas in that given room volume. With Boyle's rule it can be clearly understood that when more air is supplied than exhausted, a large room will have a slower increase in pressure than a small room:

$$p_1 \cdot V_1 = C \qquad (2)$$

were:

P	= absolute pressure	[Pa}
V	= *Volume*	$[m^3\}$
C	= Constant (at given temperature)	$[Pa\ m^3]$

For two statuses:

$$p_1 \cdot V_1 = p_2 \cdot V_2 \qquad (3)$$

As V_2 could be considered as the room volume V_1 and the additional amount of air □Q added at pressure p_1 in a given time to the room.

$$p_1 \cdot (V_1 + \delta Q) = p_2 \cdot V_1 \qquad (4)$$

Where δp is the increase in pressure:

$$p_2 = p_1 + \delta p \qquad (5)$$

This will result in: $[m^3/s]$

= resistar

$$\delta p = p_1 \cdot \left(\frac{(V_1 + \delta Q)}{V_1} - 1 \right) \qquad (6)$$

.

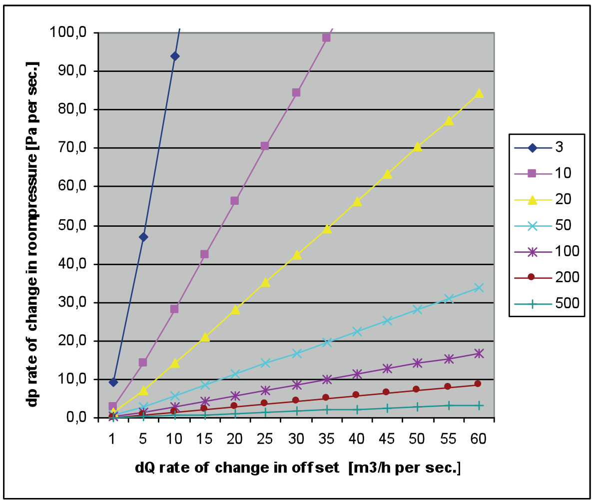

Figure 3.Rate of change δp in differential pressure[Pa] in relation to the rate of change δQ in offset air volume [m³/h per sec.] per room volume [m³].

As a large room has a larger absorption capacity for "off set" air than a small room, the latter will show more direct variations in room pressure with variations in "off set". On the other hand a small resistance to leakage will reduce the variation of the room pressure with variations in "off set" much more than a strong resistance to leakage. So over pressurization can be designed as the equilibrium of the differential pressure over the leaks of a room to the surroundings and the "offset" in the air handling, the difference between the supply and the return air volume. Heuristically speaking a small and very leak tight room is a very cruel one for stable control of the room pressure. (as shown by Van den Brink e.a.) In this respect unfortunately, modern clean room constructions have succeeded in leakage reduction over the last decades as well as many airlocks and separated small clean rooms. Various clean room commissioning activities have been bothered by the results of this effect. To over come these problems diverse configurations and specific actuator/damper combinations have been engineered to improve speed and accuracy of the airflow control to achieving the required room pressure ranges. However, a range of ± 4 Pa around a nominal value still is more common than exception.

2. Segregation by pressure or flow?

Having designed and commissioned elaborated room pressure it appears to be possible to control a room pressure within certain margins of accuracy. To understand what is the intent of this effort Eudralex GMP, Vol 4 Annex 1 states:
"53. A filtered air supply should maintain a positive pressure and an air flow relative to surrounding areas of a lower grade under all operational conditions and should flush the area effectively. Adjacent rooms of different grades should have a pressure differential of 10 – 15 Pascal's (guidance values)……"
This statement makes a combination between positive pressure and air flow direction! Indeed, these are related and yes the significant one for contamination control is the air flow! This can be found in ISO14644-4-2001 Cleanrooms and associated controlled environments -Part 4 Design-construction and start-up: section A.5: "Concepts to achieve segregation of clean rooms and clean zones" were 3 principles for segregation are presented:

A.5.2 Displacement concept (low pressure differential, high airflow)
A.5.3 Pressure differential concept (high pressure differential, low airflow)
A.5.4 Physical barrier concept

Considering the physical barrier concept as non leaking, both the displacement concept as the pressure difference concept are based on air flow from one area, generally the cleaner one, area towards the other, generally the less clean one.
As we have seen that 1) airflow is the protecting effect when no physical barrier is there and 2) airflow over a leak or any form of "resistance" will result in an pressure drop, it is clear that this can be utilized when designed for. As the airflow will always be directed from higher pressure towards lower pressure this can be called the pressure/flow cascade design.

3. The cascade design

Using the pressure/flow cascade in a design requires the following steps to be taken;

1. Identify on a lay-out the classification and preferred, allowed and prohibited air overflow directions.
2. Establish the supply air volume and the return air volume.
3. Define the overflow air volume and adjust the air balance accordingly.

Step 1 contains one aspect additional to a standard room pressure layout: the allowed overflow directions. In step 3 this comes to the final design. Here the beneficial effect of overflow can be exploited: Having higher classified rooms with a greater number of air changes and an allowed overflow to an adjacent room, makes it possible to increase the amount of overflow. So, depending on the size, class and use, the required supply air to that room can be significantly reduced or even avoided.
An overflow design thus reduces the required capacity of the HVAC system. An other benefit is gained as well: A clean room with all doors closed will normally be capable to provide the required protection against infiltration of contaminated air. When a door is opened in many a clean room a significant infiltration will take place. This requires a certain recovery time and a room/process lay out that manages this aspect. When an abundant airflow is designed towards the adjacent room with the door closed, the airflow will take the door opening when the door is opened. Thus protecting against or at least limiting the exchanges and infiltration of contamination.
For certain situations this can be designed such that an additional material airlock can be saved.

4. Wind attack challenge

To protect a controlled environment the relative pressure flow cascade as designed can be utilized. A challenge to be countered is the pressure around the building that envelops the clean rooms. Depending on whether conditions, building height and configuration and relative position to surrounding structures, static wind pressures on the building façade can be in the range up to 600 Pa. A mere over pressurization in the normal order of magnitude of 50- 60 Pa will not provide protection. Even a very air tight construction will have an amount of infiltration at high external pressures, compromising the contamination control. The only way to protect clean rooms against a wind attack is isolating the clean room from the building façade. This not only requires a spaced construction but also requires such an arrangement that the intermediate space can freely release air infiltrating through the façade. This configuration which can be referred to as box in box arrangement, is shown in figure 4.

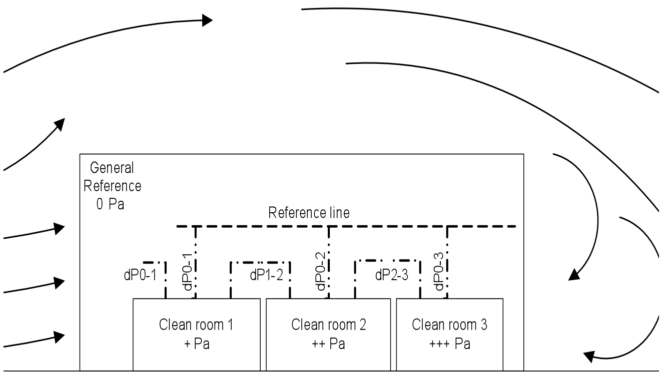

Figure 4.Box in box arrangement as well as differential pressure drop measurement and measurement against a reference line.

5. Monitoring the cascade design

As the concept of a clean room contains the element of protection against infiltration this is a genuine item to verify and monitor.

However flow being the basic mechanism of protection can not be directly measured as such. Pressure however can be very easily be measured and monitored. So designing for flow but sizing for pressure drop along overflow devices, provides the possibility to monitor the designed functionality.

This requires the measurement not to be on absolute pressure against a common reference line but to be a measurement relative to the surrounding area (figure 4). The importance can be illustrated as shown in figure 5 Here the pressure difference of a typical pharmaceutical clean rooms against a central reference system is shown.

The fluctuations are exceeding the established limits. The company got a deviation warning and had to put effort in a project to correct the situation.

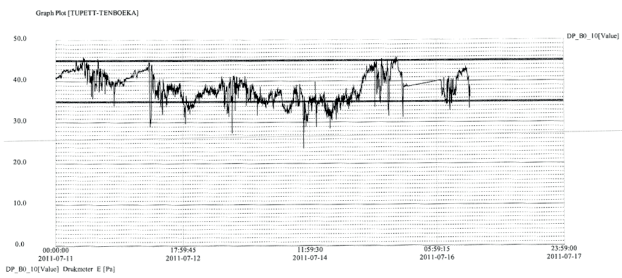

Figure 5 .Individual room pressure against a reference line showing out of specification data. .

At closer look, reviewing more pressure monitoring data is became clear that roughly all the rooms fluctuated in comparable direction and magnitude.

Reviewing the data and comparing the room pressure values for adjacent rooms (figure 6) it became clear that rooms with a higher classification and higher room pressure always demonstrated an overpressure of minimal 5 Pa despite all fluctuations.

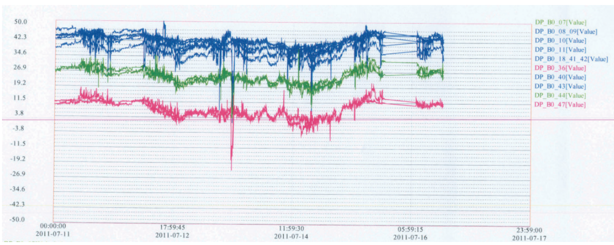

Figure 6 .Individual room pressure against a reference compared to adjacent room pressure in the cascade showing >5 Pa difference.

So – although the documented pressures exceeded the formal established limits – from contamination control perspective there was not a serious problem. The only problem seemed to be the approach to monitoring the pressure regime and, as turned out later, the use of an unstable and erroneous central reference system.

5. The pressure reference issue

Defining a room pressure cascade requires the conceptual definition of a "zero" reference. This gives rise to a lot of confusion. One of the great errors is considering overpressure against a defined "zero" pressure reference to be enough to protect a clean room against infiltration. This might be the case but is depending of the total concept of the enveloping building. It should be noted that the pressure directly surrounding the clean room itself

is the major factor to protect the inner conditions against the surrounding contamination. When the "zero" reference is not identical as the direct surrounding static pressure, a false conclusion can be drawn that the clean room is in overpressure while it is not.
In line with the resolution of the wind attack challenge, a greater building envelop containing the clean rooms, will provide the optimal solution for the reference pressure. The reference pressure is all around within the building envelop. When a building is more confined and segregated an enveloping reference is more difficult to achieve. Various examples of reference pressure lines with non zero reading compared to the surrounding envelop have been encountered in practice.
Misreading in the order of magnitude of 10th of Pascal's can be the result.

6. Cost and Efficiency gain

Utilizing high quality supply air twice or thrice in a pressure cascade with overflow has various additional benefits. It reduces the amount of recirculating air. In the example of fig 1 this added up to a 15% reduction in designed air volume. Based continues operation, this could save substantial amounts of energy and associated costs. As the air volume is reduced, the installation costs are reduced as well. Further more a reduction in control equipment and software can be made as an overflow concept is self stabilizing by nature when designed and sized properly. These initial costs savings can ad up to at least to 5 – 10% of the installation costs. When, as in some projects has been designed, airlocks can be left out, using segregation based on ≥0,2 m/s overflow (ISO14644-4-2001 A.5.2 Displacement concept (low pressure differential, high airflow)) also clean room construction and floor space can be saved.

6. Conclusions

Room pressurization of modern leak tight clean rooms, especially small ones becomes a significant design and commissioning challenge as the required accuracy, resolution and reaction time of utilized controls need to increase significantly.
The pressure/flow cascade concept offers a stable energy, and cost efficient alternative that offers the additional benefit to have a better protection when doors are open.

A box in box approach is useful to counter wind attack and as a relevant pressure reference.

References

Eudralex: The Rules Governing medicinal Products in the European Union, Volume 4 EU Guidelines to Good Manufacturing Practice Medical Products for Human and Veterinary Use, Annex 1 Manufacture of Sterile Medicinal Products (2008)

Van den Brink A.H.T.M and Van Schijndel A.W.M.. (2012) "Improved control of the pressure in a cleanroom environment". Build Simul (2012) 5:61 - 72.

ISO 14644-4 (2001), Cleanrooms and associated controlled environments Part 4 Design-construction and start-up, International Standardization Organization