When the EPR hits the fan, or…the killing of the fan energy

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ABSTRACT

The last decades big steps have been made on the road to develop and design energy neutral buildings. Despite the large list of developments and improvements of all kind of energy saving technologies we see specifically for the larger non-residential buildings that the electric energy use for fans hardly show any reduction and becomes a dominant factor in the total energy use of these buildings. The fan energy currently counts already for approximately 15-20% of the total building related energy and becomes increasingly important.
Among other developments, the work of IEA Annex 35 "Hybrid ventilation in new and retrofitted office buildings" and IEA Annex 62 "Ventilative cooling" revealed new directions in the design of ventilation systems. However, in daily practice the HVAC designers and installers do not seriously pick up the (new) knowledge and keep on going the well-known traditional way: designing and realizing mechanical ventilation systems with a total pressure drop of over 800 Pa. The reason not to do so, does not only lie in financial arguments, but is based in a much broader range of barriers. Of course, the unfamiliarity and knowledge gap of how to design low-pressure systems is a relevant stumbling block, but also the "wish to control" the air flow, the IAQ and the comfort conditions results in installations that are fully equipped. All kind of provisions are foreseen that filter, heat, cool, humidify, recover the heat and control the air. And this ends up in the well-known high-pressure system, that needs to be equipped with big fans to provide the air in the right places. To come to a serious reduction in fan energy for ventilation, the above described circle has to be broken.

KEYWORDS

Fan energy, low pressure ventilation systems, non-residential buildings, system design, low pressure components

1 INTRODUCTION

The development in the energy performance of buildings has made significant progress in the last decades. As a logical result of the increased energy performance requirements (EPR) all kind of energy saving technologies have been developed and implemented in the design and construction of new buildings. The list of developments that are relatively new is long and ranges from improved insolation materials and high performance glazing to LED lighting, all kind of heat recovery systems and improved heat and cold generation appliances. Also in the field of ventilation substantial progress has been made compared to the situation a couple of decades ago. I.e. the improved air tightness of buildings and systems, the development of heat recovery systems for ventilation and the development of demand controlled ventilation (based on sensor technologies) has led to a substantial energy reduction. Despite the large list of developments and improvements we see specifically for the larger non-residential buildings that the electric energy use for fans hardly shows any reduction and becomes a dominant factor in the total energy use of these buildings. The fan energy currently counts already for approximately 15-20% of the total building related energy and becomes increasingly important.

The background for this relative high amount of fan energy is that ventilation systems in larger non-residential buildings are regularly designed for a total static pressure difference of approximately 800-1600 Pa and even higher. The reason lies in practical issues as space requirements and system optimization for (short term) financial arguments. By optimizing the size of the air distribution system until the limit the material costs and the use of space are reduced. The operational costs (long term costing) however increase as a result of higher fan energy. The fundamental reason to do so is not only the wish for cost optimization, but lies in a much broader range of barriers. Of course, the unfamiliarity and knowledge gap of how to design low-pressure systems is a relevant stumbling block, but also the “wish to control” the air flow, the IAQ and the comfort conditions results in installations that are fully equipped. All kind of (in a lot of occasions and situations not functional) provisions are foreseen that filter, heat, cool, humidify, recover the heat and control the air. And this ends up in the well-known high-pressure system, that needs to be equipped with big fans with a high energy use to get the air on the right place.

2 COMPLETED RESEARCH PROJECTS

A couple of completed IEA EBC projects have dealt with the challenges to come to low pressure ventilation systems from different perspectives.
From 1997 – 2002 “Annex 35 Hybrid Ventilation in new and retrofitted office buildings” was carried out with the objective to considerably reduce the energy use for ventilation and cooling by combining the advantages of natural and mechanical ventilation in a new hybrid ventilation system. One of the outcomes was examples of ventilation systems with an ultra-low pressure loss for the total system (often below 50 Pa) ranging between natural ventilation systems boosted by fan-power to mechanical systems, where fans were supported by natural driving forces. Although the requirements to buildings, their indoor environmental quality and energy use has developed considerably in the last 20 years many of the ideas, concepts and lessons learned are still applicable today. However, off the shelve efficient and affordable solutions to the challenges and application barriers that was identified in the project are still not developed today and is still a major barrier for application. These include among other solutions for low-pressure filtration, heat recovery as well as sound insulation and fire protection of openings in envelopes and internal constructions.
From 2012 – 2017 “Annex 62 Ventilative Cooling” was carried out with the objective to develop energy efficient ventilation systems for cooling of buildings utilizing the cooling potential of outdoor air. The design of energy neutral building has increased the need for cooling, but the high energy use for air transport in traditional ventilation systems reduces the benefit of utilizing the “free cooling” potential of outdoor air considerably. Due to thermal comfort issues and the risk of draught limited temperature differences between supply air and room can be utilized making heat recovery or air preheating necessary. The result of this is a cooling capacity reduction and an increased airflow rate - sometimes with a factor of more than five. In mechanical ventilation systems, this leads to an increase in energy use for air distribution and an increased investment in equipment. As a result, the energy and cost advantage of utilizing the “free cooling” potential of the outdoor air in a mechanical ventilation system compared to a mechanical cooling solution might become very limited. These limitations do not apply to the same extent when the outdoor air cooling potential is

applied to a free-running building (naturally ventilated building) and thus the appropriate use of ventilative cooling in connection with natural ventilation in non-residential buildings could contribute significantly to a reduction of the energy consumption. However, a major barrier for application of such a solution is that energy performance calculations in many countries do not explicitly consider ventilative cooling. Therefore, available tools used for energy performance calculations might not be well suited to model the impact of ventilative cooling, especially in annual and monthly calculations and driven by natural ventilation.

3 AIVC TECHNICAL NOTE 65 AND ASSESSMENT OF THE CHALLENGES

In 2009 AIVC has published the AIVC Technical note 65 “Recommendations on Specific Fan Power and Fan System Efficiency. In this publication a rather extensive and complete overview is given about the aspects concerning the fan energy in buildings. The first page already addresses the relative contribution of the fan energy to the total energy use in a Nordic office building as given in figure 1, which counts (in 2009) for 17%. This relative contribution has since then grown to 20-25% and will even become bigger.

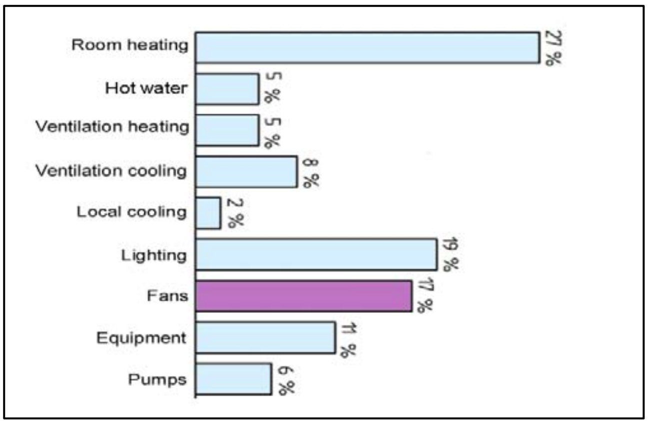

Figure 1: Approximate breakdown of typical energy use in a Nordic office [Fig. @Sintef]

The AIVC Technical note describes various methods to bring down the fan energy by a series of actions as:

- Optimisation of fan system efficiency
- Aerodynamic inefficiencies of fan inlets and outlets and improvements
- The improvement of fan system components as ductwork, silencers and exhausts

Table 6 of the Technote (given below as figure 2) illustrates the overall pressure drop for a typical ventilation system in a large building and makes a distinction between the pressure losses over the distribution system and the pressure losses over the air handling unit (AHU). The conclusion is that the pressure drop over the distribution system and the pressure drop over the AHU are nearly equal as big.

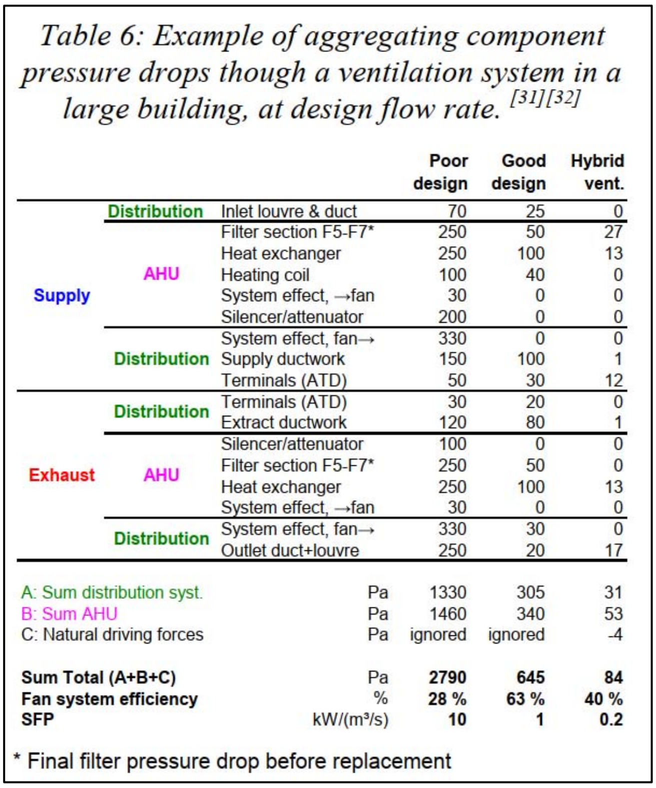

Table 6: Example of aggregating component pressure drops though a ventilation system in a large building, at design flow rate. [31][32]

			Poor design	Good design	Hybrid vent.
Supply	Distribution	Inlet louvre & duct	70	25	0
	AHU	Filter section F5-F7*	250	50	27
		Heat exchanger	250	100	13
		Heating coil	100	40	0
		System effect, →fan	30	0	0
		Silencer/attenuator	200	0	0
	Distribution	System effect, fan→	330	0	0
		Supply ductwork	150	100	1
		Terminals (ATD)	50	30	12
Exhaust	Distribution	Terminals (ATD)	30	20	0
		Extract ductwork	120	80	1
	AHU	Silencer/attenuator	100	0	0
		Filter section F5-F7*	250	50	0
		Heat exchanger	250	100	13
		System effect, →fan	30	0	0
	Distribution	System effect, fan→	330	30	0
		Outlet duct+louvre	250	20	17

		Poor design	Good design	Hybrid vent.
A: Sum distribution syst.	Pa	1330	305	31
B: Sum AHU	Pa	1460	340	53
C: Natural driving forces	Pa	ignored	ignored	-4
Sum Total (A+B+C)	Pa	**2790**	**645**	**84**
Fan system efficiency	%	**28 %**	**63 %**	**40 %**
SFP	kW/(m³/s)	**10**	**1**	**0.2**

* Final filter pressure drop before replacement

Figure 2: Table 6 of AIVC Technical note 65, typical pressure drop for various designs for a large building

The conclusion of the authors of this paper is that the optimisation of the fan system efficiency and the improvement of the aerodynamic inefficiency of the fan inlets and outlets is important, but does not bring the needed reduction. But, a fragmented and detailed approach will not lead to the big step that has to be made. Therefore, we need a holistic approach in which we look in the direction of the design fundamentals as well as in the direction of the system and component improvements. In the last chapter of the Technical note the various stakeholders are addressed and pointed on their role and responsibility in the process to come to better and more energy efficient ventilation systems.

4 CURRENT LOW PRESSURE SYSTEM DESIGN PRACTICE AND EXAMPLES

The current design practice is confronted with the increasing requirements on the developments of low energy buildings. Not only the mandatory building regulations give (increasingly) strict requirements for the energy performance of buildings, but also from the side of the clients the demand for energy friendly, energy neutral and even energy delivering buildings is the new reality. To reach this level of building energy performance all energy saving options and resources have to be deployed in a systematic way and needs to be on the agenda of the design team from the very first beginning. This also counts for the issue of reducing the fan energy, as this can only be substantially reduced if it is incorporated in the building design strategy.

The ventilation system performance is after all directly related and interacts directly with the building shape, height, floor plans, corridors, façade layout, etc. Two examples of buildings in which these design considerations have played a role are illustrated in the next chapters.

4.1 A large office building with 2 atriums and a diffuse ceiling

In a design competition the target was to develop a new Office building of 70.000 m^2 in the centre one of the major capitals in Europe. The building had to be energy neutral with a high level of sustainability and circularity. For a number of reasons (light weight, constructability, circularity and sustainability) the building structure was foreseen to be made in CLT wood.

The 10 storey building floorplan was designed in the form of a H-shape, where two atriums were constructed, one north orientated and one south. From a conceptual level four principle concepts were discussed in the design team, ranging from conventional to more advanced in which one or two atriums were used as inlet and exhaust. In figure 3 the various variants are schematically illustrated.

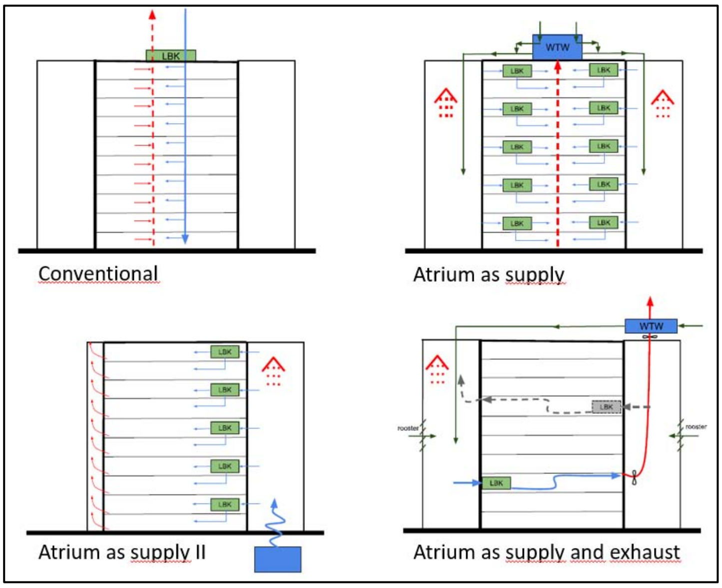

Figure 3: Schematic overview of ventilation concepts

Based on a discussion in the design team the variant in which both atriums are being used for the supply and exhaust was further investigated as the preferred solution. The south orientated atrium was used as a space to precondition the air to a certain level and distribute the supply air to the various floors. The north atrium acted as a collector for the return air. As the building was planned to construct in wood the idea was to use the hollow spaces in the floor for distributing the air over the floors to the individual office spaces. The supply of air to the rooms was based on a diffuse ceiling principle, assisted with locally placed DC-fans per room, controlled by CO$_2$-sensors. The return air from the rooms was extracted via an overflow damper to the central corridors and to the exhaust atrium. Figure 4 illustrates the schematic principles of the building set up and the floor construction. Figure 5 gives some first results of the CFD feasibility analyses of the air flows.

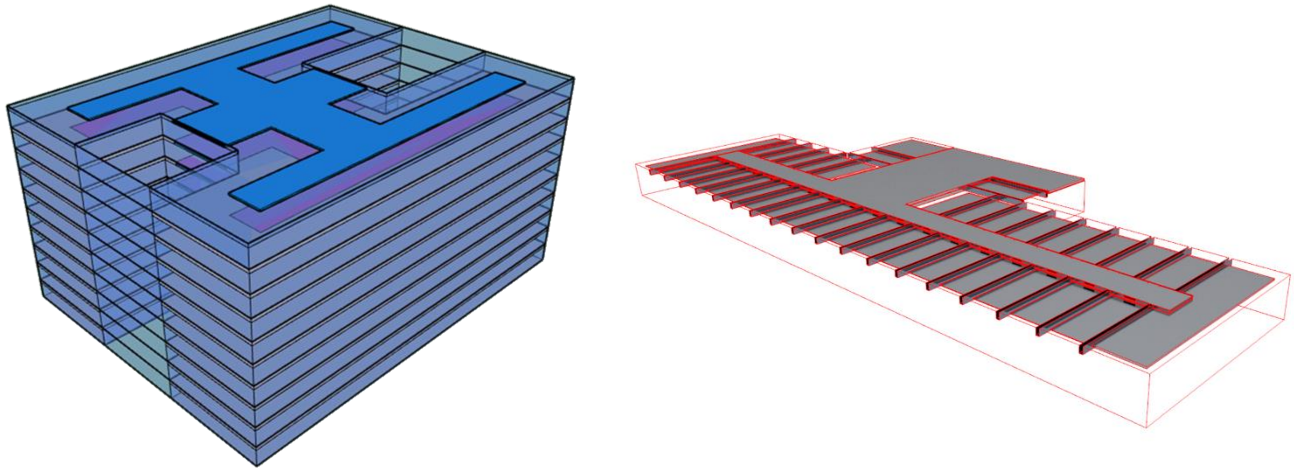

Figure 4. Schematic principles of building set up and floor construction.

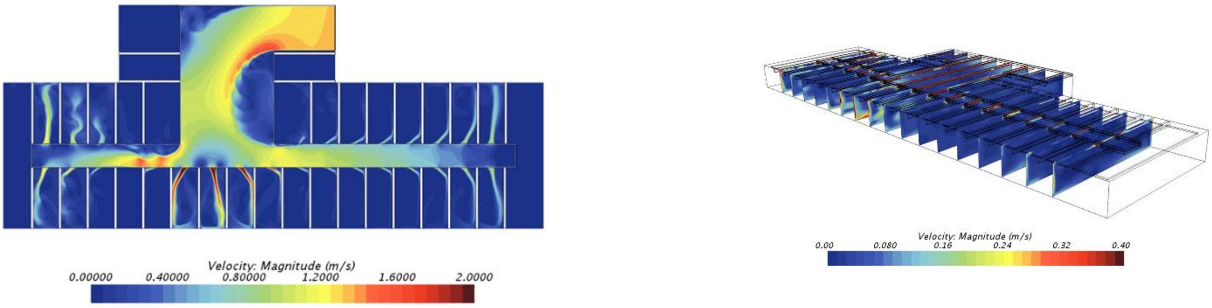

Figure 5. Results of CFD feasibility analyses of air flows

The original ideas were further incorporated concretized in the design and at the end of the preliminary design phase presented to the client. In general the reaction was interest and willingness to further investigate the proposal.

For the final design phase a contractor was selected to join the team. Some critical questions were raised about the concept, but after several industrial partners were brought in the original skepticism changed into enthusiasm on the opportunities that came with the proposed concept. A technical team, hired by the client, reviewed the proposal and came up with a number of points of concern:

- The designers propose a diffuse ceiling principle in combination with a thermally activated ceiling. Can this be explained further and be guaranteed in relation to the IAQ requirements and comfort conditions?
- The supply and exhaust of fresh air is at ceiling level. Is the air evenly distributed over the total ceiling? What does this mean for the efficiency of the ventilation in the room?
- How are the air flows controlled and guaranteed?
- The demanded IAQ imply the application of 2 filters on the inlet air of F7 and F9. How will these filters be applied?
- You propose a hybrid ventilation with heat recovery. Can you give examples of realized projects?

- You propose to use the wooden structure and the corridors for distribution of air. How do you cover the risk for condensation and mold growth and dust collection in the system?

The questions raised by the review team are valid and relevant, but on the other hand are based on unfamiliarity and avoidance of uncertainty. To further substantiate the proper functioning of the concept detailed multizone ventilation calculations were conducted with Comis. In Figure 6 and 7 an impression of the results are given, that proved that a stable ventilation system could be achieved. The maximum pressure difference for the local fans was calculated to be 30 Pa.

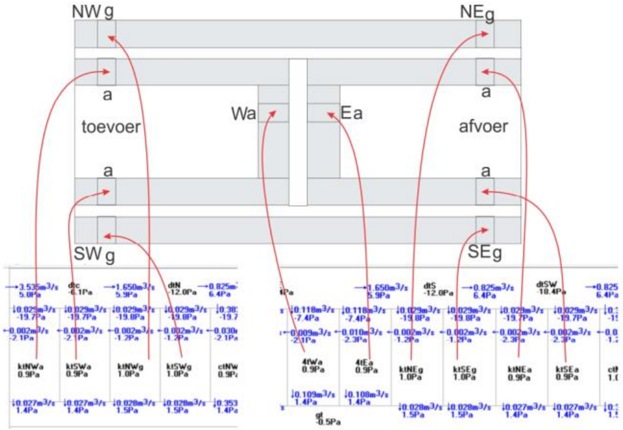

Figure 6. Results of Comis simulations of the low pressure ventilation system

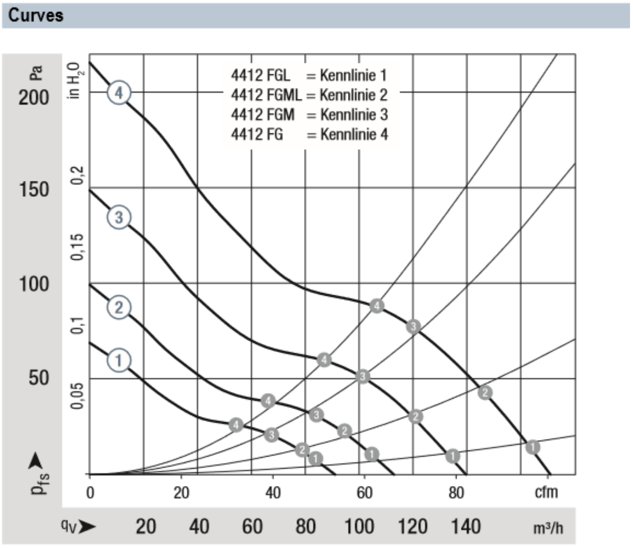

Figure 7 A possible fan characteristic for the air flow control to an office room

4.2 A laboratory building with a ring ducting system

At the design of laboratory buildings safety goes first. For chemical laboratories this safety requirements go hand in hand with large amounts of ventilation air. But also for these type of buildings the present energy related requirements are strict.

The question in this case was to design a new educational and research laboratory building of 35.000 m^2 with a high level of flexibility. These 35.000 m^2 form the second phase of a 100.000 m^2 building. In the first phase the client was “designed and sold” a ventilation installation with a conventional (“optimized”) branched ductwork. At the first startup of the ventilation installations it showed up that the pressure losses in combination with the flow rate demands were much higher than calculated and that the AHU's were not able to come to a stable situation. This led to a number of necessary adjustments from reducing the flow rates over the safety cabinets to modifications in the exhaust chimneys to reduce the pressure losses. The end result was a critical working ventilation installation of 210.000 m^3/h with a pressure difference over the fans of 1.800 Pa. There was clearly room for improvement in the next phase!

To come to a robust, safe, energy friendly and flexible installation the idea was to design concept with a low pressure ring based ductwork infrastructure for the building. Figure 8 gives an impression of the first design sketches.

Figure 8. Illustration of first design sketches of low pressure ring system

The design concept of a low pressure ring based system has a number of advantages over a traditional branched ductwork:

- The uniformity in size of the ducts and branches makes it more easy to produce and install;
- The more or less uniform pressure differences over the system makes it easy to adjust and control;
- The system can be designed as a low pressure system with less fan energy;
- The system has a high level of flexibility as long as the total air volume for the whole building is not exceeded.

The system has some disadvantages compared with a conventional branched system:

- The construction needs more ductwork. This drawback should be compensated by the reduced production and installation costs;
- The system requires more space in the building which can lead to somewhat bigger floor heights;
- The system requires a clear structure and needs to be implemented in the first design phase, as the ductwork is not "as flexible" as usually presumed by the architect;
- For the design calculations there are no well described standard guidelines, procedures and software programs. In figure 9 a number of figures are given from the CFD-design optimization that have been conducted.

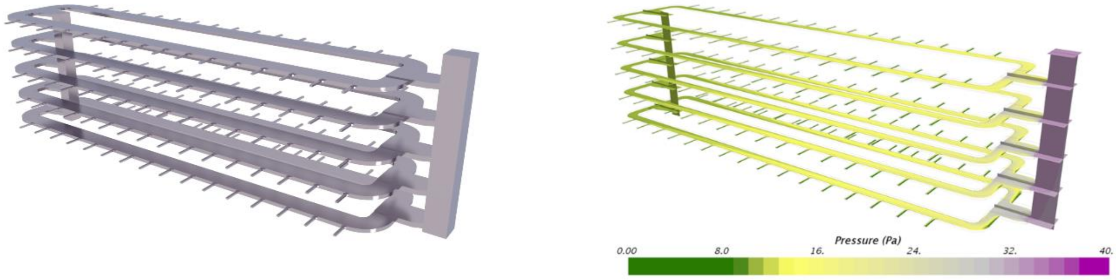

Figure 9. CFD-design calculations of a low pressure ring ductwork system

The building and system design is at this moment in the final design stage. During the previous design stages the experiences of the designers are similar with those issues described in the first example. There is a lack of knowledge, a lack of practical applicable tools, there is a lot of hesitation at the side of the other team design team members (architect, client) and the contractor and the installer are not yet involved, but will probably also have their doubts and objections and likely plea for going back to conventional.

4.3 Conclusions and lessons learned from the practical examples

The above given examples from practice illustrate a number of issues and questions that arise when low pressure systems are applied. These issues range from questions for realized and proven projects and ask for long term experience with the new technology. But also address more fundamental questions about the need for i.e. filtering and heat recovery and procedures for design, calculations and dimensioning of these types of (new) solutions.

5 FURTHER WORK AND RESEARCH ISSUES

The issues addressed in the previous chapter raise a number of questions for research, the development of guidelines and knowledge dissemination. A number of more fundamental questions need to be investigated and answered.

Improvement of air distribution systems in buildings

Large non-residential buildings have often a comprehensive ductwork installation including a central air handling unit to take care that the air is coming at almost constant flow level on the right place in the building. The ductwork but also the air handling unit itself consume a lot of pressure and so energy. For the transportation of air, for instance for a flow rate of 1 m^3/s just about 2 W is really necessary. In common practice about 500 W is used for transportation of 1 m^3/s of air through the ductwork including supply and exhaust grilles. The air distribution is in most cases not optimized. Another 200 to 400 W is used for air transport through the components in the air handling unit itself, such as filters, flow stabilizers, heating and cooling coils.

For a well-designed modern building, ductwork can be minimized because atria and corridors may act as ducts for air distribution. The highest resistances to control air transport are the negative effect of thermal- or buoyancy- and wind-forces. These forces in Western European buildings up to 40 m high can go up to about 30 – 50 Pa. Hence fans for air transportation of 1 m^3/s in buildings should not ask more than 35 to 55 W. (see figure 7). It is a challenge for designers to go in this direction of Nearly Zero Pressure buildings. The question is how?

Grilles and valves

Grilles and valves are normally applied to throttle and control the air flow because in most cases the pressure in the ductwork is too high. Low pressure grilles and valves can be applied when the design has been focused on low pressure systems. In most cases the grilles are not much more than visual esthetic covers of the duct. The question is are those appliances needed and if so, how do low pressure appliances to be sized and selected?

Filtering of air

Filtering is not always necessary. It is to protect people against health effects. Filtering large particles is not necessary. In case fine particles plays a role, the ventilation system should not take care but local air cleaning or local filtering can be applied. In case there is a need to include filtering in the ventilation system, low pressure filtering such as electrostatic filtering should be considered. The question is under which conditions filtering is needed and when can filtering been left out and if so how can filtering been realized with a minimum pressure loss?

(Pre-)conditioning of air

(Pre-)conditioning of air is sometimes a necessity but can also be minimized or avoided i.e. with the applications of diffuse ceilings. The research question is to come up with solutions to minimize the need for preconditioning of air or to develop solutions for preconditions with a minimum of pressure loss.

Heat recovery

The real performance of heat recovery systems is most of the time (much) lower than expected from the test specifications from the suppliers. *[Roulet et al, 2001].* A question that needs to be answered is, if heat recovery is always necessary and logical and what the decision criteria are to apply heat recovery. Furthermore, if heat recovery is applied there are several solutions for low pressure applications that could be further developed.

Next to this there is definitely a need for knowledge transfer. It seems to be that there is a big gap between the daily design and construction practice and the research world. But there is also a lack of practical applicable tools for sizing and dimensioning low pressure systems. The daily practitioners in the HVAC industry are not aware of the possibilities, but also do not have the right information and tools to design these type of systems in a proper way. But also the architects, contractors and the clients have their hesitations to leave the well known traditional path and follow a new direction.

6 CONCLUSIONS

It has become obvious that there is need for reduction of the fan energy in large non-residential buildings as an outcome of the increasing energy requirements. In daily practice the knowledge and tools how to come to a significant reduction in fan energy is lacking. Further more there is a lot of hesitation in the market to leave the traditional approach of designing and installing the well-known high pressure ventilation systems. Previous research work i.e. IEA Annex 35 “Hybrid ventilation” and IEA Annex 62 “Ventilative cooling” have already addressed the opportunities for low pressure ventilation systems. However, there is still a world to discover and answer, as well as there is an obligation for knowledge distribution and transfer to the market. In this paper a number of scientific questions have been addressed that have to be solved. But also questions from the daily practitioners in the HVAC industry, the architects and the clients have been described that are waiting for answers.

7 REFERENCES

Heiselberg, P (2002). *Principles of hybrid ventilation*

Roulet, C.A. (2001). *Real Heat Recovery with Air Handling Units.*

Schild, P.G. (2009). *AIVC Technical note 65 "Recommendations on Specific Fan Power and Fan System Efficiency.*

TIPVENT EU-Joule IV project (2001) *Towards improved performances of mechanical ventilation systems*