HOW TO SAVE ENERGY IN VENTILATION SYSTEMS THROUGH DISTRIBUTED FANS

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SUMMARY

Fans are essential to ensure proper ventilation in increasingly airtight buildings, whereby the energy consumption is immense. In order to adapt the volume flow to the demand, the centrally built-up pressure is usually throttled in volume flow controllers, thereby dissipating energy. Alternatively, energy can be supplied through distributed fans in order to reduce the overall energy consumption. We show the potential of the approach in several generic examples and give a calculation rule for the savings. Finally, we show a real case study and analyse the trade-off between number of distributed fans and energy savings.

INTRODUCTION

In the European Union, 12.3 % of the electrical energy demand is caused by fans only [1]. Mechanical ventilation systems, i.e. the ventilation of buildings supported by fans, can nevertheless reduce the absolute energy consumption through heat recovery in combination with highly insulated buildings - provided that the fans have a low power demand [2].

The electrical power demand of a system can in general be calculated by $P_{\mathrm{el}} = P_{\mathrm{hydr}}/\eta$. In this contribution we do not want to look at the efficiency η, but at the demand for hydraulic power P_{hydr}. First, we want to clarify where the need for hydraulic power originates. The total power provided by the ventilation system is given by the sum of all fans F:

$$P_{\mathrm{hydr}} = \sum_{f\in F} Q_f \cdot \Delta p_f \qquad (1)$$

Thus, the power demand can now be reduced by decreasing (i) the volume flow Q or (ii) the pressure increase Δp. The volume flow (i) can only be reduced to a minimum level, since the fundamental function of the ventilation system is to provide a volume flow: Depending on the room type and occupancy, a certain volume flow is required in the individual rooms. By means of a volume flow control, this demand can be exactly fulfilled and the required energy can be reduced by avoiding overfulfillment. A first measure is therefore the implementation of a Variable Volume flow System (VVS). This is usually realized via volume flow controllers in the rooms, i.e. energy is specifically dissipated. In this case, the required pressure difference of the fans is not necessarily reduced.

The pressure increase by the fans is needed to overcome friction losses in the duct network, additional built-in elements and the volume flow controllers. While the friction in the duct network or additional built-in elements cannot be changed from the perspective of the control system, the pressure losses in the volume flow controllers can be influenced. In addition to system-wide tuning, the concept of distributed fans is particularly promising: Instead of volume flow controllers, distributed fans are used at the individual rooms. These specifically add energy instead of dissipating energy. As a result, the hydraulic power of the centrally installed fans can be reduced and thus the total energy consumption. Figure 1 shows the central system and the distributed system with an additional fan.

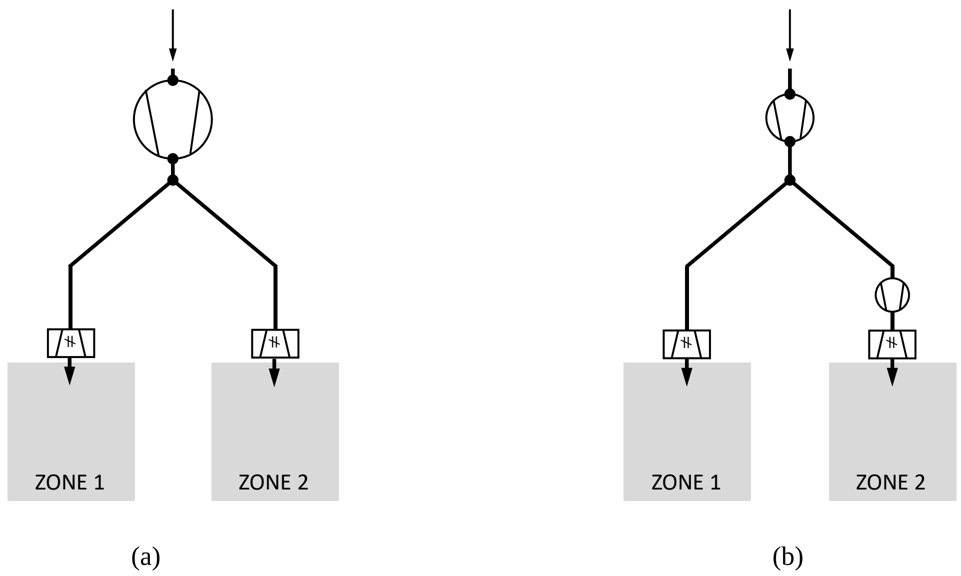


Figure 1: comparison of system designs with a) central and b) distributed topology.
The central topology consists of a central fan and volume flow controllers in front of all rooms.
In the distributed topology additional fans are placed in front of the volume flow controllers.
For simplicity, silencers, fire prevention valves and other components are omitted.

The distributed fan approach is gaining more and more attention. Extensive research has been carried out at the University of Kassel [3], demonstrating the potential [4] and showing the practical feasibility and planing guidelines [5]. It turns out that the complexity of planning is increased because many different positions have to be considered, different fans are necessary and a complex interaction has to be taken into account. The planning therefore includes the question of where fans should be placed and which fans should be used. Already the question of which fans to use is complex, which is why algorithmic planning methods are useful [6], [7].

For the analysis of the first question we will give a procedure and calculation. In addition, we show the potential in generic examples and a case study. In particular, we investigate the influence of the number of distributed fans on the energy savings.

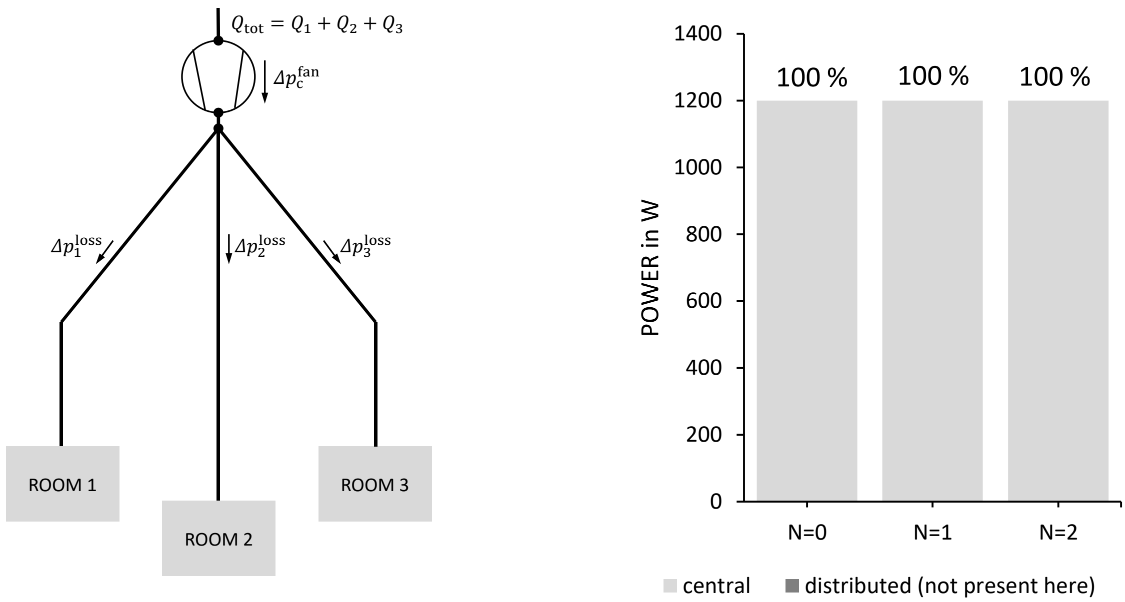
POTENTIAL OF DISTRIBUTED SYSTEMS

In the following, different ventilation systems are presented and the potential of the distribution is illustrated using four different cases.

In all four cases, three rooms are supplied. A central ventilation system is always used for this purpose, which is supported by an additional fan in the distributed topology. Only the fresh air is considered here, but the return air can be considered equivalently, which would result in twice the cost.

Four different cases of that system are investigated:

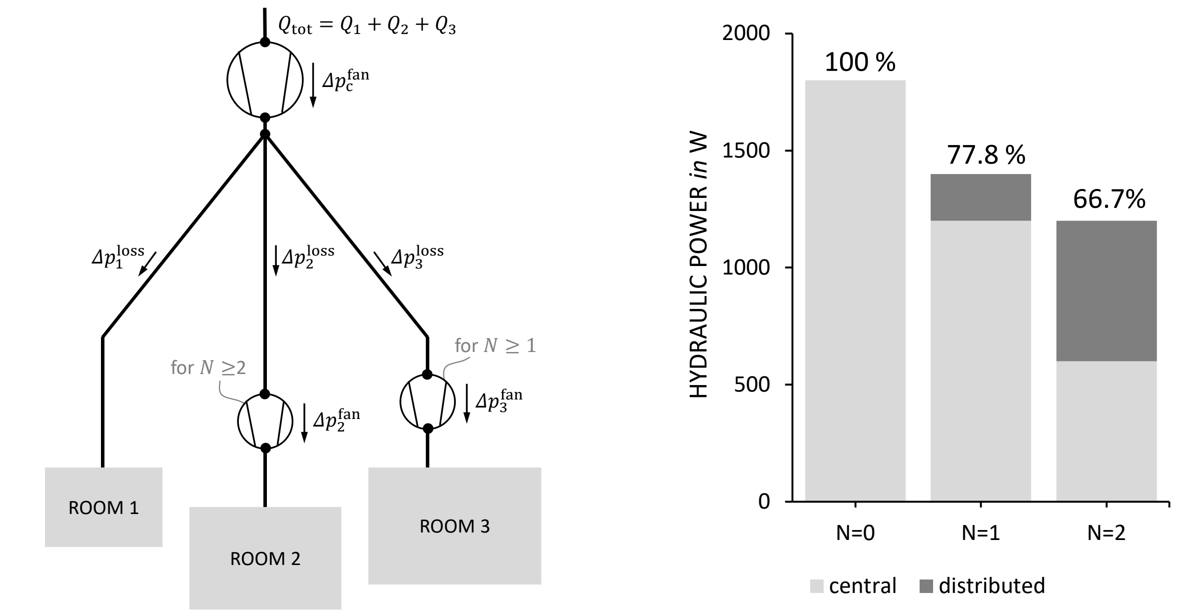
i. same distribution of volume flow demand and same pressure loss in all rooms
ii. different volume flow demands but same pressure loss
iii. same volume flow demands but different pressure loss
iv. one room with low demand but increased pressure drop (bottleneck)



(a) (b)

Figure 2: (a) shows the ventilation system for case (i). The black lines represent the duct network, connecting the central fan with the three rooms. The size of the rooms corresponds to their volume flow demand. N is the number of distributed fans. In case (i), due to the symmetrical distribution, distributed fans do not offer any improvement by lowering the hydraulic power and are therefore not implemented. Generally, the distributed fans are only present in the distributed variants, thus, the volume flow controllers are not shown here. In (b) light-grey bars account for the hydraulic power demand of the central fan, while the bars colored dark-grey would account for the power demand of the distributed fan.

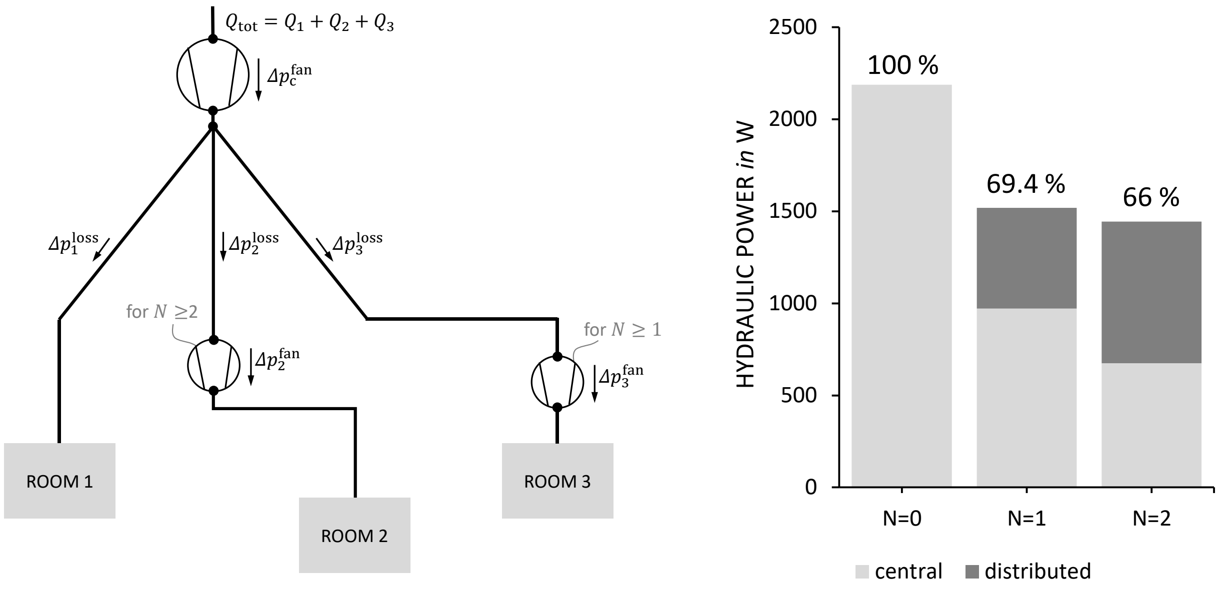
Case (i) is completely symmetrical in the distribution of volume flow demands and the duct network. For the pressure loss and volume flow demand for each room in each case refer to the appendix. In this case, all volume flow controllers can be completely open. The demand can be adjusted via the speed of the central ventilation unit as long as the required volume flow remains the same in all rooms. In this case, the distributed system has no advantage because there are no throttling losses.



(a) (b)

Figure 3: (a) Ventilation system for case (ii) with distributed fans for $N = 1$ and $N = 2$, respectively. (b) Influence of distributed fans on the system's power demand.

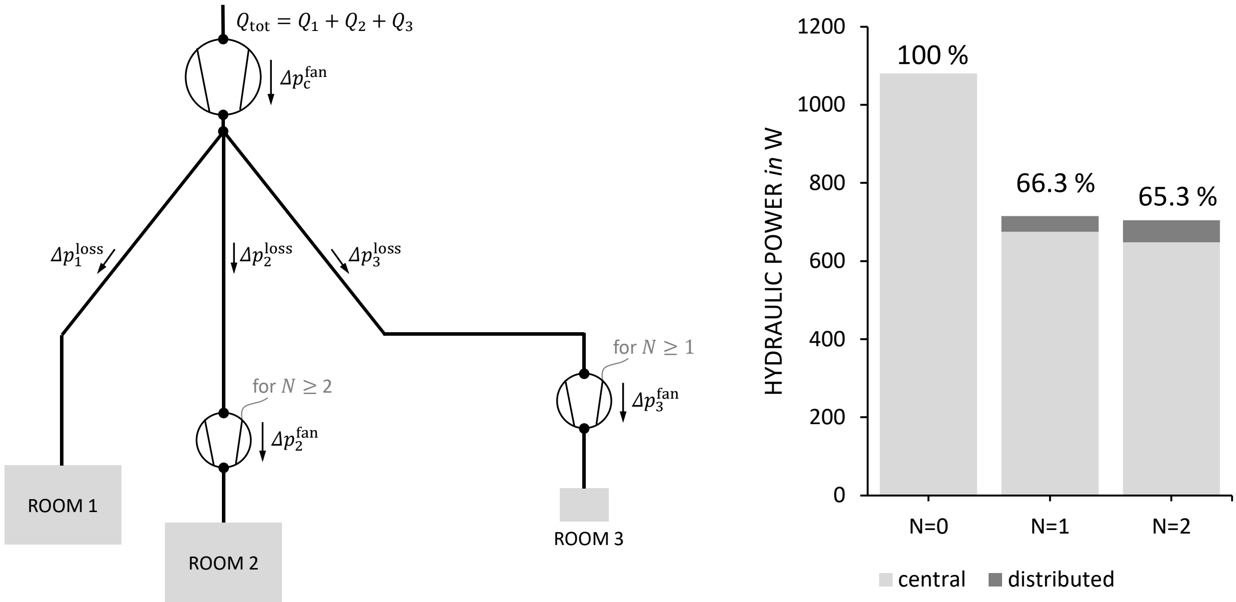
In case (ii) we assume the same duct network, but now the demand is distributed differently between the rooms. This means that in case of $N = 0$ for the rooms with lower than maximum demand, the volume flow must be throttled, which leads to energy dissipation. By using the first distributed fan, these losses are significantly reduced and the total hydraulic power demand is lowered to less than 80 %. Using the second distributed fan again reduces the total hydraulic power demand to a total of 2/3 of the central case. The installation of a third distributed fan for room 1 would not yield any improvement in terms of the total hydraulic power demand, as then the central fan would become obsolete.



(a) (b)

Figure 4: (a) Ventilation system for case (iii) with distributed fans for $N = 1$ and $N = 2$, respectively. (b) Influence of distributed fans on the system's power demand.

The assumptions change in case (iii): here the same volume flow demand for all rooms is assumed, but the duct network is not uniformly configured (e.g. cross-section, lengths, additional installations), which results in different pressure losses. Here, for $N = 0$ the flow has to be throttled in the rooms with lower than maximum pressure losses in the according duct network (e.g. the closer rooms). The rotational speed of the central ventilation unit still has to be high enough to supply also the most distant rooms.



(a) (b)

Figure 5: (a) Ventilation system for case (iv) with distributed fans for $N = 1$ and $N = 2$, respectively. (b) Influence of distributed fans on the system's power demand.

In case (iv) there are two rooms having almost the same demand and pressure loss in the duct network. In addition, there is a third room with a very low volume flow demand but a high pressure loss. This could be a small room located far away. This acts as a bottleneck, as the central ventilation unit has to provide a high pressure only for this room. However, most of the introduced hydraulic power is dissipated in the volume flow controllers of the other rooms. By placing a distributed fan for the bottleneck, the total power can be reduced by 1/3, as the speed of the central ventilation unit can be decreased. It is particularly remarkable that this fan does not require a large amount of power and can therefore be small. The installed hydraulic power is only 6% compared to the central unit.

These examples show the high potential of distributed ventilation. This is always given when the pressure losses in the supply ducts of the individual rooms or zones vary. In these cases, the throttling losses in the volume flow controllers can be reduced. Alternatively, decentralised ventilation units can be used for the rooms of the bottleneck, which directly ventilate independently of the duct network to the exterior.

By good planning, different pressure losses can be avoided in some cases. However, this is not always possible: on the one hand, because the conditions of the building do not allow it and, on the other hand, because there might occur strongly fluctuating demands.

An installation is particularly worthwhile if there are bottlenecks that have significantly higher pressure losses but small volume flows. In general, it can be stated that not only energy can be saved through the reduced need for hydraulic power, but also smaller ventilation units can be used. This has a positive effect on installation and maintenance costs, which can compensate for the possible expense of additional fans.

PLANING METHOD

The design task is to place, select and operate distributed fans. For the purpose of this contribution, we will only consider the placement of distributed fans. The question is: Where should up to N distributed fans be placed to minimise the required hydraulic power?

For this purpose, it is necessary to minimise the power that is dissipated in volume flow controllers by adding a distributed fan. For this, a fan has to be placed in the branch with the highest pressure loss, the critical branch. Then, the central ventilation unit can reduce the speed so that the second critical branch is just supplied sufficiently. This allows to open the volume flow controllers in all rooms. In the new critical branch even up to the maximum open position. Then the new critical branch is identified and a fan is placed there. In the following, we focus only on one volume flow demand per zone. If multiple scenarios of volume flow demands per zone are considered, the critical branch may change and the procedure is getting more complicated. For this purpose, optimisation methods may be used as shown by Müller et al. [8].

The required hydraulic power depending on the number of distributed fans can be calculated using the following procedure.

For each supply zone $i \in \{1,2,\dots,M\}$ the pressure loss in their supply duct Δp_i is determined, where M is the number of different supply zones. The assignment of the zones is done in such a way that the pressure losses are decreasingly ordered, i.e. $\Delta p_1 \geq \Delta p_2 \geq \cdots \geq \Delta p_M$. Furthermore, it is assumed that the provided volume flow Q_i is known for each zone.

In the central case, the central ventilation unit must provide the maximum pressure loss Δp_1 and supply the total volume flow $Q_{\text{tot}} = \sum_{i \in \{1,2,\dots,M\}} Q_i$. This results in the necessary hydraulic power in the central case:

$$\mathrm{P_{hyd,C}} = \mathrm{Q_{tot}}\,\Delta \mathrm{p_1}. \tag{2}$$

If distributed fans are installed in $N \leq M$ rooms, the required pressure increase of the central ventilation unit is reduced to Δp_{N+1}. In addition, however, the differences of the required Δp_i and the centrally applied Δp_{N+1} pressure differences must be provided in the N distributed ventilation units. Overall, this results in the following hydraulic power demand:

$$\mathrm{P_{hyd,N}} = \mathrm{Q_{tot}}\,\Delta \mathrm{p_{N+1}} + \sum_{\mathrm{i=1}}^{\mathrm{N}} (\Delta \mathrm{p_i} - \Delta \mathrm{p_{N+1}})\,\mathrm{Q_i}. \tag{3}$$

In this way, for any number of distributed fans, the necessary hydraulic power and thus the energy saving potential can be determined.

CASE STUDY

The procedure and potential are demonstrated based on a real-world case study. For this purpose, the ventilation system of a building at the Technical University of Darmstadt, which is shown in Figure 6, is considered. For simplification, only the case with the highest volume flow demand is taken into account, which is shown in Table 1.

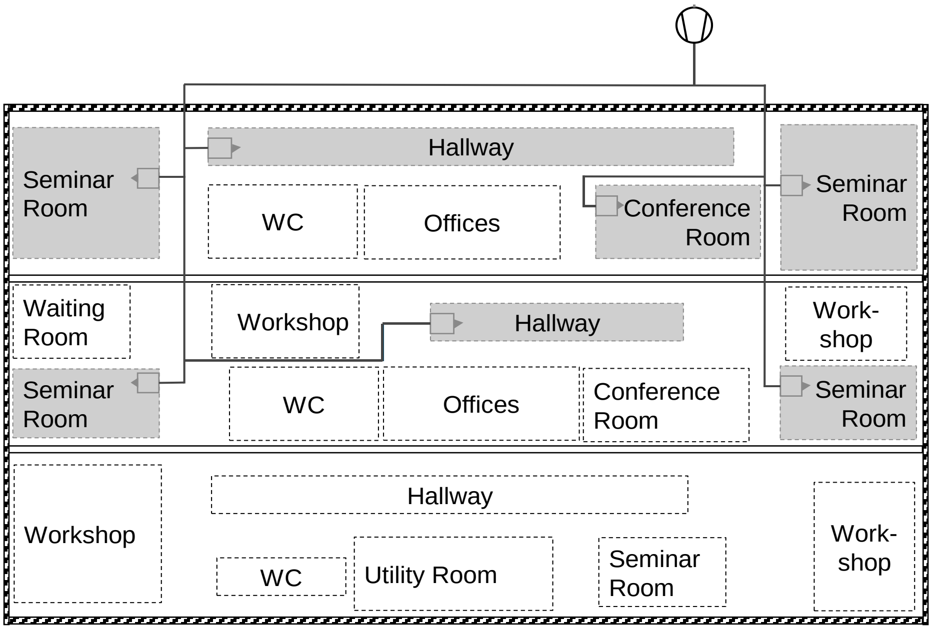


Figure 6: ventilation system of the case study. Only the highlighted grey rooms are considered. Here, distributed fans can be placed. For simplicity, only the supply air system is shown as it is similar to the outlet air system.

Table 1: volume flow demand and associated pressure losses for the different rooms of the case study

ROOM NUMBER	VOLUME FLOW DEMAND *in* m^3/s	PRESSURE LOSS *in* Pa
1	0.67	944
2	0.68	675
3	0.29	523
4	0.12	445
5	0.1	442
6	0.29	241
7	0.05	145

If the procedure described above is applied, the hydraulic power demand as shown in Figure 7 depends on the number of distributed fans. It is noticeable that especially the first distributed fan yields high savings of 20 %. This is due to the high difference in pressure loss between the first and second room. The other savings are lower and in total up to approximate 33 % can be saved.

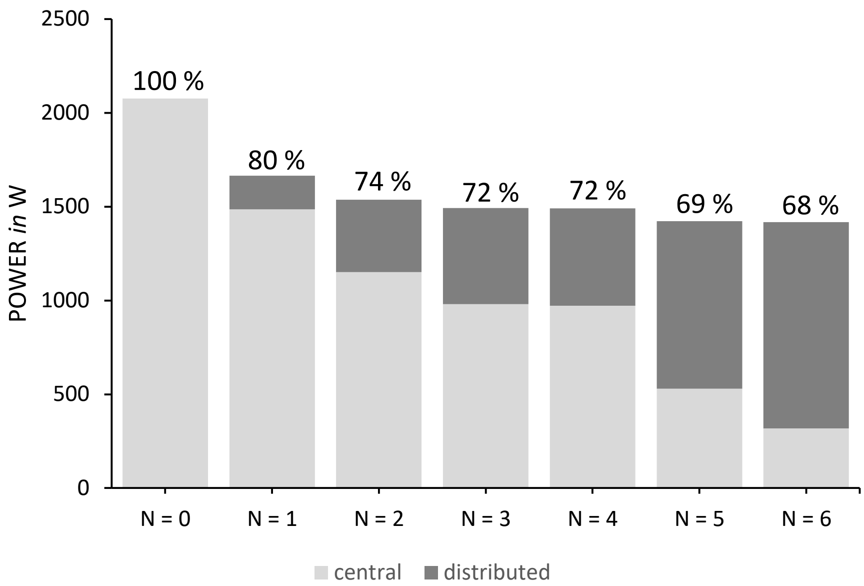


Figure 7: total hydraulic power demand for the fans used in case study. N is the number of distributed fans.

DISCUSSION AND CONCLUSION

The results show that significant savings are possible due to the distributed approach. This differs depending on the system design and demand, as the four different examples showed. The differences in the pressure losses and the volume flows of individual zones are decisive: if there are rooms with significantly higher losses, there is potential for savings, especially if these have a low volume flow demand. As shown in the case study, this is certainly relevant for real-world systems and up to a third of the hydraulic power can be saved.

The presented calculations allow a first estimation of the potential savings. This can be refined by considering all different volume flow scenarios. In this case, the accurate procedure is more complex, as the rooms with maximum pressure loss can change. This can be considered as in Müller et al. by means of a mixed-integer quadratic optimisation problem [8]. Thus, the globally optimal configuration regarding the hydraulic power for varying load in relation to the number of distributed fans can be found.

Subsequently, the life cycle costs should be included in the estimation. For this purpose, the limited efficiency in the form of characteristic curves of the fans, the volume demand profile and the purchase and maintenance costs must be taken into account. One disadvantage of using distributed and thus smaller fans is that smaller fans usually have lower efficiency. This should be considered when considering life cycle costs. In addition, a final assessment must be made with regard to the complexity of the resulting system. Here, for example, an increased maintenance effort must be considered or the fact, that in some cases negative pressure areas can arise in the supply ducts or positive pressure areas in the exhaust ducts [5].

The evaluation of life cycle costs and the selection of specific fans further increases the solution space, which is why algorithmically supported approaches, e.g., from the field of discrete optimisation, are crucial.

New challenges are also arising for fan manufacturers: There are changed installation situations, increased noise requirements and different operating points that have to be covered.

APPENDIX

Table 2: pressure loss and volume flow demand of each room for the four different cases.

room	case (i) Δp^{Loss} in Pa	case (i) Q in $\mathrm{m^3/h}$	case (ii) Δp^{Loss} in Pa	case (ii) Q in $\mathrm{m^3/h}$	case (iii) Δp^{Loss} in Pa	case (iii) Q in $\mathrm{m^3/h}$	case (iv) Δp^{Loss} in Pa	case (iv) Q in $\mathrm{m^3/h}$
1	400	1	225	0.75	200	1	1.2	216
2	400	1	324	0.9	400	1	1.5	225
3	400	1	729	1.35	600	1	0.3	360

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