An argument for a reality check in the ventilation industry: We still have an energy crisis, in practice, and are not generally, in practice, achieving better indoor climate

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ABSTRACT

In 2017 the Danish Building and Property Agency started a project titled **"Avoiding energy waste in ventilation systems"** by tracking the actual energy use in a sample of their 4 million m^2 portfolio of buildings through on-line energy management tools. The project is not complete, but the key preliminary findings described in this paper are:

1. The energy consumption of ventilation systems is a much higher **proportion** of the total energy consumption of the buildings than expected.

2. The ventilation system **components** are generally well maintained, but the ventilation **systems** as a whole are not well maintained, which results in poor indoor climates in buildings, despite the high energy costs.

3. Although a component was possibly checked, it was found that an important distinction between component function and component quality caused operational problems if the component was not **calibrated,** or its real function was not **tested**.

4. Original design or installation **mistakes** not discovered at the time, often complicated by changes to the systems over time, led to additional ad-hoc attempts at system repairs over many years, which often did not address or correct the original faults.

5. The **control** systems are extensive and have developed - or mutated - over many years into webs of complexity that are difficult to analyse, understand or operate effectively, so that user complaints often lead to systems being "adjusted" inappropriately.

6. A growing tendency is the apparent abandonment of faith in existing ventilation systems and investment in several small **decentral** cooling or ventilation systems, often installed in the same areas served by the central ventilation systems, thus adding to the energy burden and also adding to the complexity of the indoor climate control systems.

7. Re-creating ventilation system **documentation** and design information combined with installing indoor climate data loggers allowed **analysis** of system performance, and thus revealed possibilities for simple indoor climate **improvement** as well as energy **savings**.

8. The overall results appear to confirm that the old saying **"Keep it simple"** is still true, and that the use of intelligent user-friendly data monitoring tools should be combined with simpler user-friendly control tools so that Facility managers and other operators can achieve a better correlation between energy use and indoor climate.

9. The overall **conclusion** of this study is that our ventilation industry is still too focused on theoretical project design and construction delivery, with an overall belief in complex controls. Combined with a lack of attention

to durability and operational performance, most ventilation systems degenerate within a short period of time into systems with high energy costs providing low indoor climatic quality.

10. The overall **recommendation** of this article is that our ventilation industry reduces its attachment to traditional business goals of growth and turnover and instead focuses on **quality** of the delivered product through simplification and durability.

KEYWORDS

Ventilation, Maintenance, Operation, Sustainability, Energy

1. INTRODUCTION

1.1. "From energy crisis to sustainable indoor climate"?

This conference title *"From energy crisis to sustainable indoor climate"* reflects the complacency, or possibly, some may say, the cynical marketing strategy, of our ventilation industry. Most engineers involved in the practical side of the industry, working with real systems in real buildings with real people, will probably smile at the title too. Don't we have **more** of an "energy crisis" now than ever before? What exactly is meant by "sustainable indoor climate"?

1.2. Time for real change in our industry?

From my previous work at the Danish Energy Authority, and now as a Consulting Engineer currently working on numerous building projects for the Danish Building and Property Agency, it does not seem that we in the ventilation industry produce much sustainability at all, and we certainly seem to be adding to the weight of the energy burden, not lightening it. One of the problems is that there seems to be a lack of real support from the ventilation industry for real change towards sustainability. As Fanger (Reference 7) once said of our ventilation industry's design methodology: **"What a waste!"**. That was in 2003.

1.3 Do the results match the image?

All this should be viewed within the framework of the image, expectations and ambitions of consecutive Danish Governments towards energy effectiveness and climate goals. Denmark prides itself on sustainable energy systems, and its advances in renewable energy **supply** systems, such as offshore wind power, have been a model for many nations. However, the net energy **consumption** in commercial and domestic buildings has not matched the transformation of the energy supply systems. In the period 1980 to 1990 energy consumption did fall, in all buildings, but since 1990, energy consumption has risen, and our ventilation industry is a major contributor to this problem. This problem is reflected throughout the EU, and indeed the world. See Figure 1.

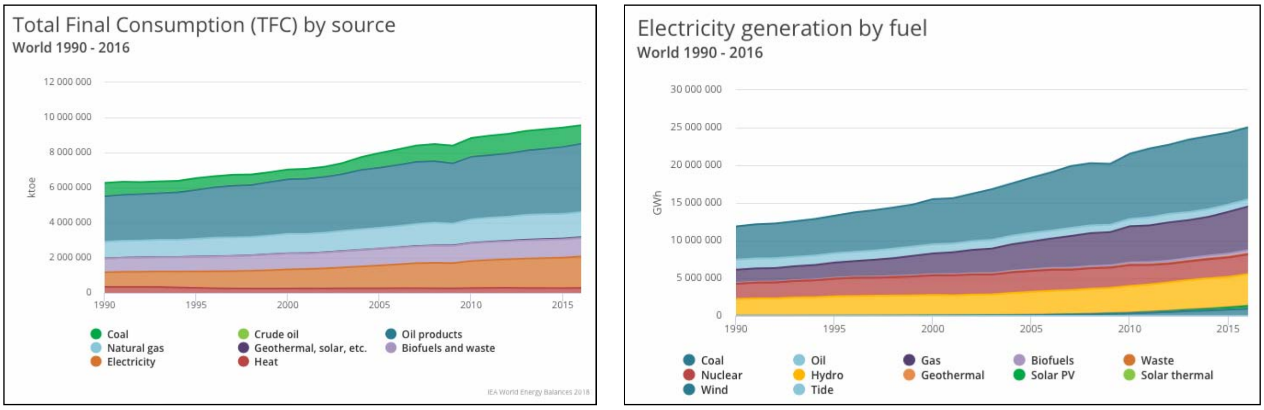


Figure 1: World Energy Consumption, IEA data. Electricity is one of the highest rising energy "sources".
https://www.iea.org/statistics/?country=WORLD&year=2016&category=Energy%20consumption&indicator=TFCbySource&mode=chart&dataTable=BALANCES

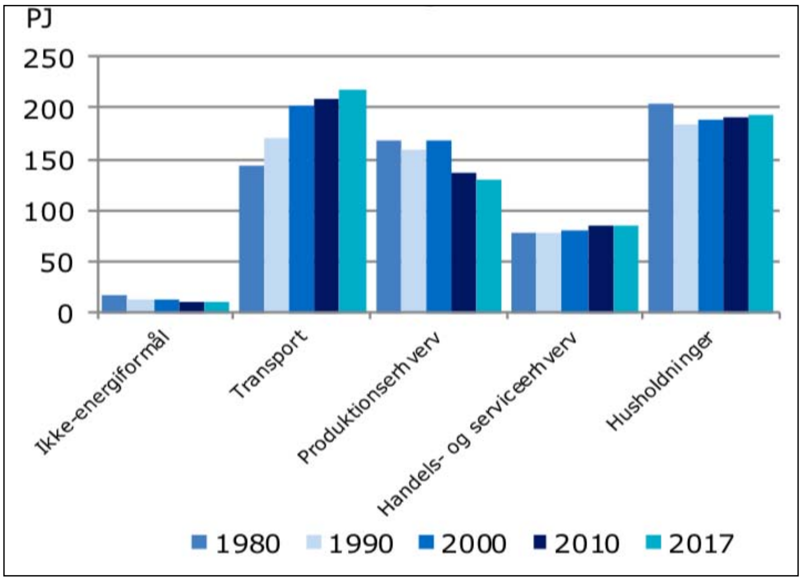
1.4 Our industry can do a lot better!

The hope with this paper is that it can contribute towards a "reality check" within the ventilation industry so that the very real challenges of climate change can be addressed seriously. Our children and grandchildren deserve more from us. Our industry can do a lot better, and we know it.

2. STATISTICS

2.1 National energy consumption data (Denmark)

It can be seen, with hard-core energy statistics, that most good intentions regarding energy savings do not seem to give results. See Figure 2 (from Reference 1). Energy consumption in all Danish buildings fell from 1980 to 1990, but has since been rising steadily, despite national and EU legislation and other initiatives.



This figure from the Danish Energy Authority is only officially available in the Danish language.

The areas of interest for the ventilation industry are the two sets of columns on the right:

"Handels- og serviceerhverv" is ***"Commercial and Public Services"*** *and "Husholdninger" is* ***"Households"***

Figure 2: The **development in energy consumption** in Denmark from 1980 to the latest available statistics (2017) showing a rise in energy consumption in buildings for the past 30 years. (Reference 1).

2.2 Increase in energy consumption in buildings

Specifically, the percentage changes in the markets most served by the ventilation industry show very high energy consumption **increases** in the very period when energy saving initiatives were supposed to be taking effect. See Figure 3 (Reference 2). In particular, despite all the very real warnings about climate change, there are also increases in all categories in the latest statistical period 2016-2017. The EUs "Energy Performance of Buildings" Directive (Reference 3), has been in force for many years, but the message does not seem to have filtered down to the people actually responsible for running and using ventilation systems.

	Change %	
1980-2017	1990-2017	2016-2017
50,5	-0,6	2,4
57,7	14,7	0,1
115,0	53,2	8,1
47,5	14,9	2,4

Electrical energy consumption changes in the following categories:

Wholesale.

Retail trade.

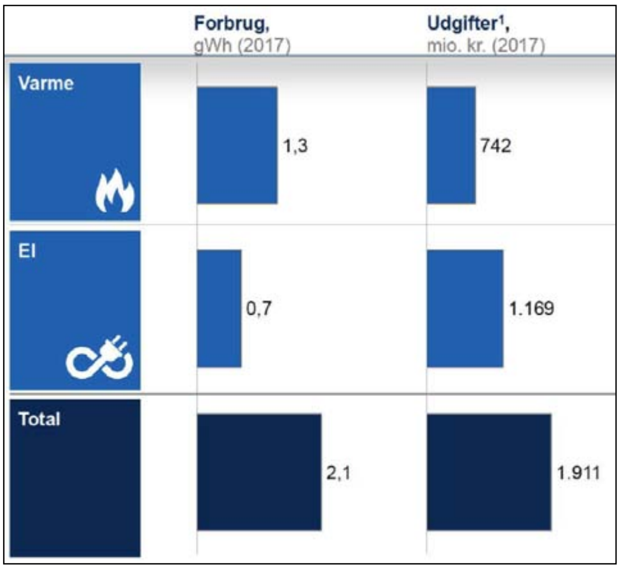
Private Service.

Public Service.

Figure 3: A detailed statistic from Figure 2, with numbers. The **percentage increase** in development in electrical energy consumption in commercial and public buildings in Denmark from 1980. (Reference 2).

2.3 Cost of energy in buildings run by the Danish Building and Property Agency

Getting away from statistics and moving into the area that most building Facility Managers are concerned with, that is, actual costs of providing (good) indoor climates, one can see in Figure 4 that electrical energy costs are the highest, and as we saw from Figure 3, are also rising at the highest rate. Our ventilation industry, including cooling and related components such as pumps etc., are one of the main reasons for this electrical energy consumption in buildings.



Heating ("Varme") is the highest consumption at 1.3 GWh, but electricity is the highest cost at 1,169 million kroner per year (157 million €/year (2017)).

Figure 4: A further breakdown from statistics, the heating and electricity consumption data and costs for the 4,1 million m^2 portfolio of the Danish Building and Property Agency (Reference 4).

3. ANALYSIS

3.1 The project "Avoiding energy waste in ventilation systems"

In 2017 the Danish Building and Property Agency started a project titled "Avoiding energy waste in ventilation systems". The Agency had for some years been tracking the actual energy use in their portfolio of buildings through on-line energy management tools such as "EnergyKey" and "WebTools". Although there was no clear quantifiable data about the extent of this ventilation system energy "waste", if in fact there was any, the hypothesis from the experienced Project Managers in the Agency was, that there was "something wrong".

3.2 First results: Phase 1 energy savings by simulated demand control.

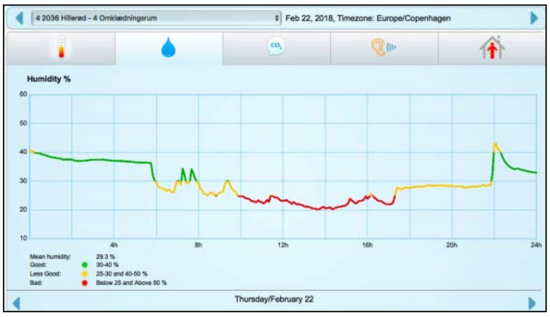
After two years of investigations and tests, including pilot projects, there are clear indications that there is indeed "something wrong", and that customers, the users of the buildings, are not really getting what they pay for. In 2017 indoor climate dataloggers were set up in properties 3 and 8 in Figure 5, and after analysis of the actual use (CO2 levels and acoustic data) simple software changes to the control system to simulated demand controlled ventilation for one

ventilation system at each location gave measured energy savings of 9 %.

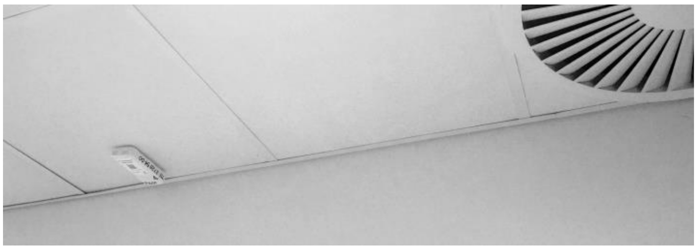
Figure 5: A detailed analysis of the energy consumption statistics: The electricity consumption data and pilot project results for the 10 buildings in the 2017-2019 project "Avoiding energy waste in ventilation systems" of the Danish Building and Property Agency (References 5 and 6).

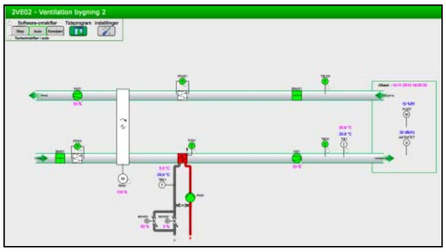
3.3 Phase 2: Energy savings by wireless demand control.

In 2018 real demand controlled ventilation was installed for property nr. 10 for one ventilation system (out of five at the property) and gave 33 % measured savings (Figure 5). This was a surprisingly high result and indicated that the proportion of energy in total going to the ventilation systems was much higher, based on a rough analysis of the before and after performance (Figures 6 and 7). A programme of measuring the specific electrical consumption of the ventilation systems alone has now been implemented, with results expected in 2020.



Figures 6 and 7: At the left, Fig. 6, showing the actual moisture levels in Property nr. 10 (Figure 5) before any changes (February 2018), with the ventilation system running at full power from 5.30 am to 5.30 pm. User complaints of "sauna-like" conditions were received sporadically, and confirmed by service personnel. One year later, January 2019, the system is performing according to demand - BMS trend-diagram at the right, Figure 7.





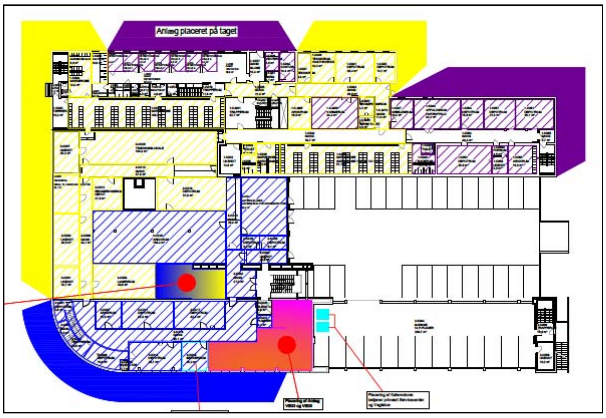
Figures 8 and 9: At the left, Fig. 8, showing the indoor climate data logger providing the wireless signal for the control of fan speed. System diagram from the BMS showing control parameters at the right, Figure 9.

3.4 Phase 2 challenges: System imbalance and blockages.

However, the physical ventilation system required an overhaul before any intelligent control system could be effective. The system had last been commissioned in 1994 and although checks of total air quantities were made at yearly service intervals, there was no control of where the air actually went to, or, more importantly, where it did not go. There had been many physical building changes since 1994, without corresponding adjustments to the ventilation system (Figure 10), and accumulated dirt (Figure 11) had also reduced air quantities, so that system cleaning, physical duct checking, measurements, and re-commissioning were required.

3.5 Phase 2 results and consequences of the hidden extra expenses.

However, despite the extra expenses, the simple payback time for Phase 2 was under 3 years (Reference 6) and the users achieved a better indoor climate (Figure 7). This problem with hidden expenses related to basic system performance was both a benefit and a concern moving into Phase 3. An advantage was that an apparent lack of ventilation could often be related to system defects that could be relatively easily remedied, although sometimes difficult to identify, instead of requiring "new systems". The disadvantage of course is that costs of intelligent improvements such as wireless demand control could not be estimated owing to the uncertainty about basic system assumptions, such as design air volumes.



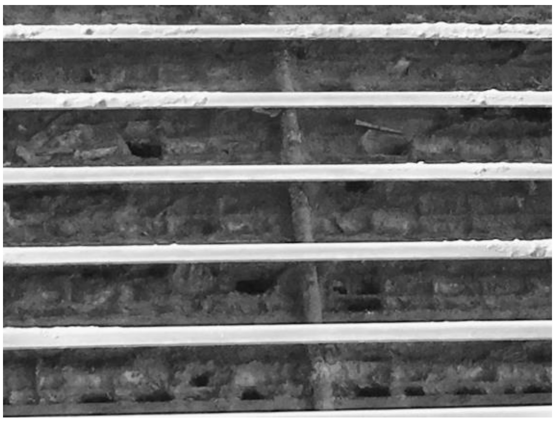
Figures 10 and 11: At the left, Fig. 10, showing an example of the ventilation system mapping that was necessary to determine which areas were served by which systems. At the first location studied in 2018 it was discovered that the Facility Manager was having IAQ issues with some offices, but he was adjusting the wrong ventilation system, because there were no drawings, and the assumptions about ventilation zones used in the BMS control software turned out to be incorrect.
On the right, Fig. 11, a well known issue with duct cleanliness. In this particular case, air volume was down to 35 % of design volume and simply cleaning the system gave considerably improved IAQ.

3.6 Hidden expenses: Ventilation system anarchy

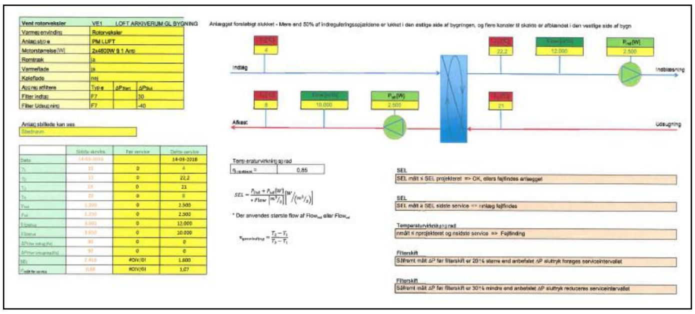
The project goal of simplifying existing ventilation system control with intelligent wireless demand control systems had met some challenges, as mentioned above, but as the project proceeded the extent of these hidden expenses began to mount, revealing, on the one hand, simple possibilities for energy saving and indoor climate improvement, but on the other hand, delaying the project considerably. In almost all cases the standard response from the Service companies involved was a recommendation to completely renew the systems, which of course is a possibility, but an expensive option, and one which does not address the reason that the original systems got into such a bad state in the first place, or provide an answer to the question of why it will not just happen again.

4. EXAMPLES FROM THE CURRENT PROJECT PHASE 3

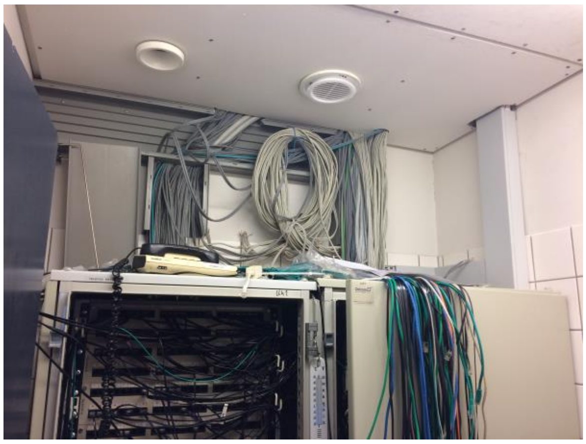
The following figures illustrate the real life challenges met during Phase 3 here in 2019, which partly provided the motivation for this article, since they show that, despite good intentions on the side of politicians and academics, our industry is just not meeting modern requirements for sustainability, neither energy savings, durability, or good indoor climates.
Figures 12 and 13: Fresh air intake problems. On the left, Fig. 12, an example of a blocked fresh air inlet grille.



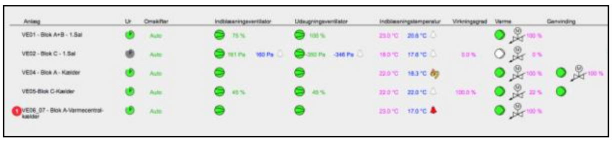
Both the ventilation service company and the cleaning contractor “assumed” that the other party had responsibility for these grilles.
On the right, Fig. 13, a fresh air intake box right next to the air exhaust box, both with horizontal louvres, such that there is considerable mixing of the two airstreams, depending on wind directions.



Figures 14 and 15: Ventilation system non-alteration problems. On the left, Fig. 14, the service chart for the ventilation system serving a five story office building. The original system supplied 12.000 m^3/h air to all offices in the building. Over the course of 30 years the ventilation unit itself has been upgraded several times, and the areas served have been modified considerably. On the right, Fig. 15, can be seen a photo of the blocked off vertical ducts from the ventilation unit that used to supply offices. The delivered capacity is in 2018 down to



approx. 4.000 m^3/h, but no-one was sure which areas in the building were actually supplied by this system.
Figures 16 and 17: Consequences of alteration problems: Some offices that are no longer supplied with air from the ventilation unit (Fig. 14 and 15) are overheating, but because the tenants just think that the ventilation system is inadequate (instead of just not being connected) they install split air conditioners (Fig. 16, left photo) adding to the energy burden, at the same time as the ventilation system is running inefficiently and is underused. The photo on the right, Fig. 17, shows a small server room with ventilation connected to the system shown in figure 14. It needs ventilation constantly, 150 m^3/h 168 hours/week, but it is connected to the same system supplying



offices that only need ventilation 40 hours/week, so that the the ventilation unit designed for 12.000 m^3/h runs inefficiently and constantly at 4.000 m^3/h just to supply one room with 150 m^3/h.
Figure 18: The project group is currently (summer 2019) having to check just about everything. At a separate location with five ventilation systems (CTS picture above) we have found that several of the temperature detectors are measuring incorrectly, the outdoor temperature detector is defect, the rotary heat recovery units are running manually, there is only 30 % of design air quantity available, the night-cooling function was disabled, and there were very high pressure drops in the system.

Figure 19 on the right shows an example of the physical investigations. The ventilation unit and ductwork has been replaced at some time, but apparently without knowledge of system design conditions. The open duct in the photo is attached (incorrectly) to the side of the sound attenuator and has an air velocity of 26 m/s and a pressure drop of 250 Pa. Once found, resizing and reconnecting (correctly) the duct reduced system pressure considerably, giving an electrical energy saving of approx. 2.000 €/year and delivering twice as much air to the users. Energy savings and IAQ improvements for very little work - once the problem was found.

5. CONCLUSIONS

"We need a paradigm shift" wrote P. Ole Fanger in 2003 (Reference 7). He was writing in terms of increasing the quality of air *"while maintaining the same or even a lower ventilation rate and energy consumption"*, as he concludes in his paper.

This 2019 paper ***"An argument for a reality check"*** illustrates the current poor state of our ventilation industry, in practice, at the level of users and service personnel, with all manner of small problems, accumulated over many years, resulting in low IAQ and high energy consumption. Exactly the opposite of what Fanger wrote about 16 years ago.

In fact, the project ***"Avoiding energy waste in ventilation systems"*** indicates that our ventilation industry is responsible for a much higher proportion of the rising electricity use in buildings than is usually expected, and this hypothesis is currently the subject of analysis in Phase 4 of the current project.

One of the main problems seems to be the extremely **low durability and weak robustness of our ventilation systems**. Ventilation systems seem to "mutate" and degenerate, very soon after the project team has left, into "monsters" that Facility Managers, Service Personnel and users have no control over, often leading to the bizarre situations described above.

The **examples** of many problems can easily be dismissed as exceptions, but unfortunately, the exception seems to be the opposite, as existing ventilation systems that meet good industry standards are very rare in the current project with a sample size of 10 buildings. The current Phase 4 of this project is starting to systematically collect data so that we can statistically identify the extent of each problem, but one can ask if this is not something our industry should be doing themselves for our own reputation's sake?

Well meaning academics, altruists and civil servants have for many years been trying to improve our ventilation industry with **top-down measures** that seem to have very little effect at on-site level. At the on-site level consultants, producers and contractors seem to be getting away with, at worst bad-practice. and at best systems with extremely low practical durability.

There is still a need for a paradigm shift, but it would seem that this shift can start at a very low level, just by simplifying the complex mess that our industry has been selling for decades, and getting back to basics: selling the customer something she can use, and not selling her all manner of stuff that she does not really need, and that does not really work.

"Keep it simple", as well as **"keep it durable"**, even if this means not so much turnover, is the message of this paper. Quality, not quantity. And as an industry we should be much more honest with our customers about the realities of what we are selling. I am sure that many of the examples shown above will not surprise the practical people in our industry, and perhaps it is time that the practical people starting leading the industry again?

6. ACKNOWLEDGEMENTS

Mr. Bjarne Dalgaard of the Danish Building and Property Agency, Project Manager for the project: "Avoiding energy waste in Ventilation Systems".

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