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Reduced energy use in Educational buildings with robust Demand Controlled Ventilation

Summary:
Several studies have shown that the energy use due to ventilation of classrooms can be reduced with 50 to 60 % with well designed demand controlled ventilation (DCV) compared with constant air volume (CAV), presupposed traditional classroom based education. However, the use of the school areas has changed radically the last decade, and the energy saving potential in modern schools needs to be reanalyzed. In addition, technology advances with sensors, communication and control systems open up new opportunities for more robust and energy efficient DCV-systems. Furthermore, the decision makers will probably not aim to utilize the potential to reduce energy use with demand controlled ventilation if they do not have sufficient knowledge about the energy saving potential. This project aims to develope and disseminate more accurate knowledge about the energy saving potential with DCV in educational buildings and produce tools for simplified documentation of DCV-systems according to the Norwegian building regulations. The tools will give input data for design, management and maintenance and thereby reduce the risk for unnecessary increase in energy use and running costs throughout the operational life of the DCV-system.

This project focus on educational buildings, but the results will be applicable for other type of buildings.

Users:
The organization NVEF with more than 30 members, mainly ventilation entrepreneurs and producers/agents of ventilation equipment, Skanska, Undervisningbygg Oslo KF and Optosense.

Research partners:
SINTEF, Norwegian University of Science and Technology, Oslo University College and International Centre for Indoor Environment at the Technical University of Denmark and Energy

Project description

PART 1: The KMB project

1. **Objectives**

   Principal goal:

   Help the Norwegian construction sector to utilize the potential to reduce energy use with demand controlled ventilation in educational buildings by developing knowledge and by dissemination of guidelines supplementing the Norwegian building code and building standard NS3031.

   Sub-goals:

   1. Establish knowledge about the energy saving potential with demand controlled ventilation in schools without compromising the indoor air quality.

- Perform a rough review of previous research on ventilation rates and health effects, well-being and risk of building construction damage in schools.
- Perform a critical review of previous research on occupancy factors and corresponding ventilation air flow rates and energy use in schools.
- In field studies of the use of indoor school areas like density (people/m^2), time of use, operation time of air-handling-units, ventilation system and energy saving potential
- Establish a tool for simulation of the energy saving potential in schools that will serve as appropriate documentation according to NS 3031 and give the necessary input data for design, management and maintenance.
- Validate the tool in pilot studies and field measurements.

2. Establish knowledge about how this energy saving potential can be reach throughout the lifetime of the ventilation system with optimal combination of control parameters and sufficient sensor- and system quality.
    - Perform a critical review of demand controlled ventilation system including sensor technology and internal communication technology
    - Evaluate optimal control parameters and combination of control parameters in schools.
    - Evaluate optimal localization of sensors, air inlet and air outlet in relation to ventilation efficiency and use of the room
    - Make guidelines for design, management and maintenance of demand controlled ventilation in schools
3. Enlighten decision-makers in building projects about demand controlled ventilation in relation to cost and benefits.
    - Perform cost – benefit analyses of demand controlled ventilation in schools and office building and establish key profitability data and make the results easy accessible for the decision makers and applicable for early stage evaluation.

2. Frontiers of knowledge and technology

There are many possibilities for the application of DCV and new knowledge about the importance of outdoor air supply, because of awareness of its positive effect on sick leave and productivity (Eriksson 2008, Wargocki et al 2000) should lead to a wish to increase the outdoor air supply in comfort ventilation applications. This will further increase the necessity and profitability of DCV-systems.

Demand controlled ventilation (DCV) considerably reduces the ventilation airflow rates and energy use compared to constant air volume (CAV) ventilation system. This conclusion is based on an inspection of 157 classrooms in primary schools (Mysen et al 2005). In average 74% of the design capacity is utilized when the classroom is in use, in terms of number of occupants. The classrooms are typically used for four hours during days with normal school activity. CO_2-sensor based DCV reduces the ventilation air volume in the average classroom to about 43% of the corresponding air volume for a CAV-system operating with full airflow from 7 AM to 5 PM. The energy use for ventilation purposes is reduced to about 38% of the corresponding energy use for a CAV-system. Comparison of perceived indoor climate in schools with CAV-systems and DCV-systems does not indicate that CAV-systems add extra quality to the indoor climate. (Mysen Doctoral Theses 2005). The studies of Wachenfelt (Wachenfelt et al 2007) supports this conclusion. The purpose of extra ventilation with CAV-systems is therefore questionable as it leads to additional energy use.

Infrared occupancy sensors are a cheap alternative to CO_2-monitoring for controlling the ventilation rate. This strategy is bimodal: The ventilation rate is reduced to a minimum when the room is unoccupied, and is increased to the design ventilation rate whenever the room is occupied. The occupancy sensor can also control artificial lighting and solar shading. IR-sensor based demand-controlled ventilation reduces the energy use for ventilation purposes in the average classroom to about 51% of the corresponding air volume for a CAV system operating with full airflow from 7 AM to 5 PM (Mysen et al 2005).

The decision as to which of IR-sensor based DCV, or CO_2-sensor based DCV, is the most profitable depends on absenteeism and utilization of class capacity together with the operation time. Information about use is therefore crucial for optimal design of DCV-systems. (Mysen et al 2003, Sørensen 2002).

The actual CO_2-production rate has a strong influence on the air flow rates and energy use with DCV-CO_2. All calculations are based on a CO_2-production of 9 mg/s per person (Fisk, Almeida 1998). This production rate is valid for adults. Children in primary school with normal activity (1.2 MET) will have a CO_2-production of about 7 mg/s per person (Diem, Lentner 1975). DCV-CO_2 with this CO_2-production rate can theoretically reduce the energy use for ventilation purposes to roughly 31% relative to CAV with 10 hours operation period. *Since CO_2 is only an indicator for the pollution load caused by occupants, it is an open question whether the actual ventilation rate should depend on the CO_2-production of the occupants, or the number of occupants. If the latter is true, then the CO_2-target for ventilation control should be harmonized with pupil's age and expected activity and reduced in primary school classrooms. This will be evaluated in this project.*

Several studies have shown that DCV is a cost- and energy-efficient alternative to CAV (Fisk, Almeida 1998). Case studies in Swedish schools have shown that IR-sensor based DCV can reduce the ventilation energy requirements by approximately 50% (IEA Mannson (Ed), 1993). Persily (Persily et al. 2003) has found that DCV-CO_2 can reduce the energy use for ventilation purposes from about 50 to 75% in a lecture hall. Both of these results are in good agreement with the results of Mysen (Mysen et al 2005).

Sørensen (Sørensen 2002) has estimated the energy savings to be between 30 and 55% with DCV relative to a comparable CAV-system without being specific about the type of building. Drangsholt (Drangsholt 1992) found that the average occupant load in a university auditorium during the working period was about 36% of maximum allowed occupancy load.

The results from Mysen (Mysen et al 2005) is based on a class and classroom based education principle. The schools have changed to more open indoor solutions with individual and group based education since the input data for the study of Mysen were collected. *We need knowledge about the use of modern indoor school areas to decide important parameters like density (people/m^2), time of use, operation time of air-handling-units, ventilation system and energy saving potential optimal sensor choice and ventilation system design.*

Mysen (Mysen et al. 2004) evaluated a simplified ventilation system with direct air supply through the façade in a school in a cold climate. The school had problems with draughtiness and too low temperatures that hopefully could be mitigated with better tuning of the control system. Use of a combined CO_2- and temperature target seems more appropriate for such ventilation concepts. This is supported by the fact that perceived air quality (PAQ) in the school is better in January than June, which we can assume is mainly caused by a lower indoor air temperature in the breathing zone. Figure 1 shows examples of different control strategies. The figure illustrates our suggested improved control strategy with temperature compensation of the CO_2 set-point. The control can be either linear or stepwise. Both are illustrated.

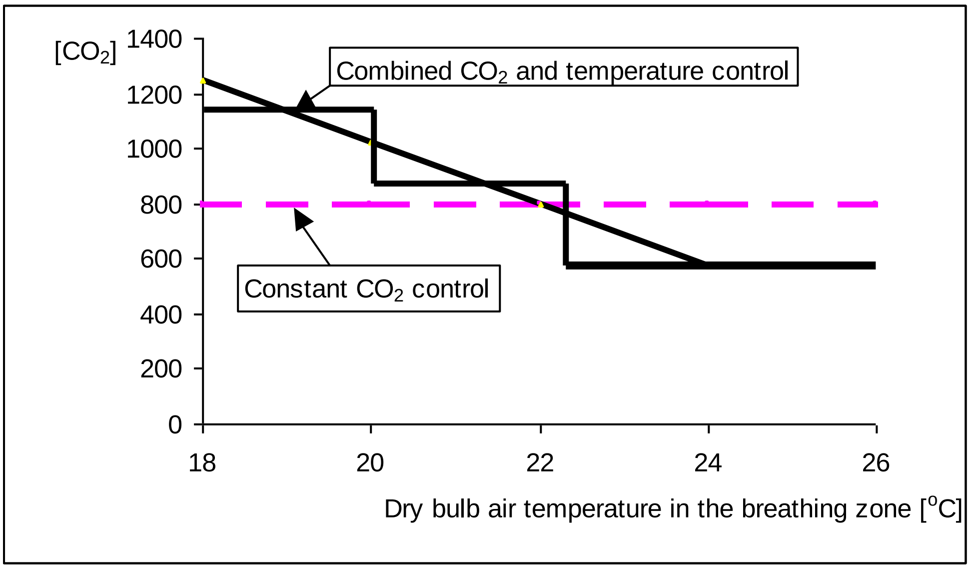

Figure 1. Three different control strategies for DCV. The conventional constant CO_2 control and the suggested improved control strategy with linear or stepwise temperature compensated CO_2 set-point.

Implementing such a control strategy could improve thermal comfort and reduce energy use for heating without compromising PAQ during cold weather. In addition it could improve indoor air quality (IAQ) during warm weather with only a slight increase in energy use.

The studies of Fang et al. (Fang et al. 2004) support this assumption. They studied PAQ, SBS-symptoms and performance of office work at three levels of air temperature and humidity and two levels of ventilation rate (20°C/50% RH, 23°C/50% RH, 26°C/60% RH at 10 ℓ/s per person outside air, and 20°C/40% RH at 3.5 ℓ/s per person outside air). This study shows that the impact of PAQ of decreasing the ventilation rate from 10 to 3.5 ℓ/s per person could be counteracted by a decrement of temperature and humidity from 23°C/50% RH to 20°C/40% RH. Several SBS symptoms were alleviated at low levels of temperature and humidity despite a coincident reduction of ventilation rates. This is consistent with several other studies starting with Wyon (Wyon et al. 1975) demonstrating that that warm humid air is perceived as less fresh and less acceptable, and that SBS symptoms such as fatigue and headache may be caused by exposure to air at slightly raised temperature and humidity.

Such a strategy might lead to negative consequences for IAQ related symptoms if the pollution load is considerably influenced by factors such as cleaning standard, emissions from building materials and pollution caused by moisture problems. DCV with CO_2- or temperature-compensated CO_2 control, presuppose that the total pollution load is always dominated by pollution from the occupants, or that the indoor environment is controlled by multisensors. Nano- and microtechnology and industrial production methods have made it possible to produce cheap and robust mulitisensors (Drysdale et al 2004). *The use of temperature-compensated CO_2 control and other intelligent parameter combinations should be investigated further*.

Another interesting reflection is that the ventilation rates prescribed in existing ventilation standards do not include the impact of air temperature (NS-EN 15251:2007, ASHRAE 2001). These standards can be a barrier towards a possible more optimal ventilation control with temperature-compensated CO_2-set point and the rational basis for this seems dubious. *This should be investigated further because it might lead to an unnecessary use of energy during cold weather*.

There is a considerable potential of reduction of energy use with DCV and the cost of technological equipment to realize this potential is rapidly decreasing (Drysdale et al 2004), making DCV increasingly profitable (Mysen et al 2003). However, lack of knowledge among decision makers is probably a major barrier. The energy use in new building must be substantiated according to NS 3031 saying that average air flow rate can be reduced with 20% with a DCV-system if not project specific analyses are done. *It is necessary to establish a tool for simulation of the energy saving potential in schools that will serve as appropriate documentation according to NS 3031 and give the necessary input data for design, management and maintenance.*

3. Research tasks (Forskningsoppgaver)

Help the Norwegian construction sector to utilize the potential to reduce energy use with demand controlled ventilation in schools by dissemination of guidelines supplementing the Norwegian building code and building standard NS3031.

- Perform a rough review of previous research on ventilation rates and health effects, well-being and risk of building construction damage in schools.
- Perform a critical review of previous research on occupancy factors and corresponding ventilation air flow rates and energy use in schools.
- Establish knowledge about the use of modern indoor school areas to decide important parameters like density (people/m^2), time of use, operation time of air-handling-units, ventilation system and energy saving potential optimal sensor choice and ventilation system design.
- Establish a validated tool for simulation of the energy saving potential in schools, based on the methods described of Mysen (Mysen et al. 2003, Mysen et al 2005) that will serve as appropriate documentation according to NS 3031.
- Evaluate a strategy for controlling the ventilating airflow rate with an indoor temperature-compensated CO_2 set point is suggested.
- Evaluate other possible control-parameter combinations
- Identify barriers towards DVC in general and indoor temperature-compensated CO_2 set point in particular.
- Perform a critical review of demand controlled ventilation system including sensor technology and internal communication technology
- Make guidelines for well-functioning and lifetime robust demand controlled ventilation in schools with optimal use of control parameters, sensor localization.

- Perform cost - benefit analyses of demand controlled ventilation in schools and office building and establish key profitability data and make the results easy accessible for the decision makers and applicable for early stage evaluation.

The project is interdisciplinary and will contribute to more energy efficient ventilation system technology, indoor environment knowledge, and sensor and communication technology. The project will fund a PhD or a Post Doc.

4. **Research approach, methods**

Literature reviews and focus groups
Critical review will be conducted in the initial stage of the project. If necessary, interviews of focus groups will be carried out.

Field studies
Gain relevant knowledge about the use of modern school as basis for evaluate the potential of energy use reduction with DCV.

Analyses
The results of the field study will be analyzed with statistical tools leading to relevant input data for calculation of energy saving potential controlled for not relevant parameters. The need for sensibility analyses will be continuously considered and, if necessary performed.

The energy saving potential will be analyzed base on the field study results. The variation of the energy potential including relevant uncertainty will be analyzed with statistical tools.

Compose tools
Establish a validated excel based tool for simulation of the energy saving potential in schools, based on the methods described of Mysen (Mysen et al. 2003, Mysen et al 2005) that will serve as appropriate documentation according to NS 3031. The tool should give necessary input data for design, management and maintenance of the DCV system.

Establish guidelines and a excel based cost-benefit tool for decision makers applicable in the early stage of a project.

Validation in field and laboratory
Validate the calculation tools through pilot studies and field and laboratory measurements.

5. **Project organization and management**

The project consortium includes specialist in the field of indoor environment, demand controlled ventilation, product and system development, sensor technology, marketing, management and maintenance. In addition, scientific partners from the higly reputable Indoor Environment International Centre for Indoor Environment and Energy will contribute to the quality of the study and make the project relevant for other than the Norwegian context. Research partners in the project are:

SINTEF
    Research Manager Mads Mysen (Project Manager), Professor Hans Martin Mathisen and Researcher Niels Peter Østbøe

Norwegian University of Science and Technology

Professor Vojislav Novakovich

- Competence: Ventilation control systems and commissioning

Oslo University College

Professor Oddbjørn Sjøvold

- Competence: Indoor Air quality, Ventilation hygiene

International Centre for Indoor Environment and Energy at the Technical University of Denmark

Professor Jørn Toftum

- Competence: Thermal indoor environment and human comfort and health

The project is partly funded and supported by the users. The partners will form a reference group who will meet regularly during the duration of the project. The reference group will assist in developing relevant research goals, comment quality and progress and play a role in the dissemination of results from the project.

6. International co-operation

International Centre for Indoor Environment and Energy at the Technical University of Denmark is a research partner in the project.

The project will generate knowledge that will be relevant for several on-going projects with SINTEF involvement like.

- EU-project IntUBE (Intelligent Use of Buildings' Energy Information)
- EU-project ASIEPI (Assessment & Improvement of EPBD Impact)

7. Progress plan - milestones – rev 15.06.2010

Milestones		**2010**				**2011**				**2012**				**2013**			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	Reviews – • ventilation rates • occupancy, DCV and energy use • DCV system solution and sensor technology	x	x														
2	Field studies – use of modern schools	x	x	x	x												
3	Simulation tool – DCV energy saving			x	x	x	x	x	x								
4	Simulation tool validation					x	x	x	x	x							
5	Evaluate optimal control parameters and localization					x	x	x	x	x	x						
6	Guidelines – Design, Management and Maintenance of robust DCV									x	x	x	x				
7	Guidelines/tool – Decision Makers										x	x	x	x	x		
8	Dissemination of results											x	x	x	x	x	x

8. Costs incurred by each research performing partner, rev 15.10.2010

	2009	**2010**	**2011**	**2012**	**2013**	***Total***

Personnel cost						
SINTEF	100.000	350.000	350.000	350.000	350.000	*1.500.000*
Post Doc		320.000	480.000	480.000	480.000	*1.760.000*
Norwegian University of Science and Technology (NTNU)		20.000	20.000	20.000	20.000	*80.000*
Oslo University College		20.000	20.000	20.000	20.000	*80.000*
International Centre for Indoor Environment at the Technical University of Denmark and Energy		20.000	20.000	20.000	20.000	*80.000*
Operating costs						*0*
Surveys and experiments		50.000	50.000	50.000	18.000	*168.000*
Services purchased/travel costs		58.000	58.000	58.000	58.000	*232.000*
Dissemination and workshops				50.000	50.000	*100.000*
Total	*100.000*	*838.000*	*998.000*	*1.048.000*	*1.016.000*	*4.000.000*

9. **Financial contribution by partner, rev 15.10.2010**

The project is funded by contributions from industry partners (20%) and public funding from the Norwegian Research Council (80%).

	2009	**2010**	**2011**	**2012**	**2013**	***Total***
Norwegian research council	80.000	670.400	798.400	838.400	812.800	*3.200.000*
NVEF	10.000	83.800	99.800	104.800	101.600	*400.000*
Skanska	3.330	27.905	33.233	34.898	33.833	*133.200*
Oslo Undervisningsbygg KF	3.330	27.905	33.233	34.898	33.833	*133.200*
Optosense AS	3.330	27.905	33.233	34.898	33.833	*133.200*
Total	*100.000*	*838.000*	*998.000*	*1.048.000*	*1.016.000*	*4 000 000*

PART 2: Exploitation of results

10. **Relevance for knowledge-building areas**

The project is relevant for three knowledge-building areas: Informasjons- og kommunikasjonsteknologi, Energi og petroleum and Bygg- og Miljøteknikk. The project will especially develop expertise necessary to reduce the energy use in the educational building stock, but the results will also be applicable for other type of building. In addition knowledge about maintenance and management will be developed in the project to reduce the risk of increased energy use and reduced indoor air quality throughout the operational time of the ventilation system.

11. **Importance to Norwegian industry**

There is a growing interest in more environmentally favorable technical equipment. Building installations that contribute to a better environment as well as increased profitability, due to reduced energy use and increased productivity, will probably have a bright future. DCV contributes to a high quality of Indoor Climat with a reduced energy demand.
Within DCV there is a rapid technological development towards reliable equipment and installations communicating with a building management system . This development will probably make DCV a more attractive option in the near future.

This challenge:

- the building owners and builders to require optimal quality
- the contractors and constructors to deliver well-functioning integrated system solutions
- the manufactures to develop technology and equipment that provides profitability for the building owners when completely installed and in operation.

NVEF *(The Norwegian Association for Ventilation and Energy Technology)*
The association NVEF has more than 30 qualified member companies, representing manufacturers/sales agents of ventilation products, contractors and service companies who employ 1400 people. The total turnover is about 3 800 MNOK.

Three associations:

- Kulde- og varmepumpeentreprenørenes Landsforening (KELF)
- Ventilasjons- og Rørentreprenørenes Forening (VRF)
- Norsk Ventilasjon og Energiteknisk Forening (NVEF)

are now merging to one:
VKE - Foreningen for ventilasjon, kjøling og energi.
Norwegian HVAC association.
Members of VKE will employ approx. 2400 people with a total turnover of approx.
6 000 MNOK.
Increased focus on Indoor Climat and Energieffciency has lead to an increased demand for DCV and increased investments in ventilation systems. The profitability of this extra investment for the building owners is challenged because of lower energy costs.
Many members of NVEF have met this business opportunity with product- and system development, marketing and deliverance of DCV-solutions. However, teething problem with such “new” solution results in cases of system failure, wasted energy and bad reputation for DCV-systems. This, together with lack of accurate and convincing knowledge about the real energy saving potential, motivates decision makers to go for traditional CAV-solutions, or not optimal low-technology DCV solutions. The members of NVEF will gain from the project because of increased volume in the market and less unexpected costs because of complaints/unsatisfied customers.

Skanska:
Skanska is a major construction entrepreneur operating in the Nordic countries. Skanska will benefit of more robust solution and Skanska look at DCV knowledge as business advantage. More information at: http://www.skanska.no/ or look at enclosed letter of intent.

Undervisningsbygg Oslo KF:
Undervisningsbygg develop 1.3 million m2 of educational areas. Undervisningsbygg is in a continuous process to increase cost efficiency. Robust and optimal designed DCV could

reduce the energy cost for Undervisningsbygg considerably and release means for other purposes, or counteract growing energy costs in general. Visit Undervisningsbygg for more information at: http://www.undervisningsbygg.oslo.kommune.no/

OptoSense AS:

OptoSense develops and sells micro-optical sensors for demanding gas detection and measurement applications. The company's first products are a family of CO2 sensor to be released the summer of 2008. Compared to existing sensors OptoSense offers better long term stability and higher accuracy, giving excellent indoor air quality without over-ventilation that result in heating or cooling of excessive air. The sensor comes with temperature measurement other options like humidity measurement and room controller functions.

The patented HoloChip technology gives unparalleled accuracy and stability and multi-gas measurements at same cost. OptoSense is a seed-venture funded Norwegian startup company with high ambitions. Visit OptoSense for more information at: www.optosense.com

12. Relevance for call for proposals and programmes

The project corresponds with the stated research priorities within the topic Energy use in the RENERGIcall: Low energy solutions and More efficient energy use

13. Environmental impact

Environmental threats such as climate change and severe inequalities in wealth and resource use are grave global challenges (World watch institute 2006). Mankind must strive towards a more energy efficient and sustainable built environment since building and construction activities account for about one third of global resource consumption (Scmidt 2003). DCV can contribute to a substantial reduction of energy use in building and thereby contribute to a sustainable built environment in the future.

Buildings in Norway account for 40% of the total annual energy use and about 50% of the electrical energy use (BNL, 2002). The use of electricity has increased with 1.5% per year during the 1990s (Myhre and Pettersen, 2003). Showing a substantial need to improve the energy efficiency of buildings. One step forward is to utilize the potential of DCV to reduce the energy use for ventilation purposes without compromising the indoor environment. DCV can lead to both a substantial reduction of electrical energy for operating fans and a substantial reduction of thermal energy for heating and cooling.

14. Information and dissemination of results

- The project will generate at least 3 Peer Review papers and additionally at least 3 Peer Review papers in peer reviewed conference proceedings
- There will be national dissemination through “Byggforskserien” (Regular published building detail sheets with about 14.000 users in Norway)
- Developed tools will be accessible at www.sintef.no
- Guidelines for planning, execution, management and maintenance of demand controlled ventilation in schools will be developed and accessible at www.sintef.no
- Results cost – benefit analyses of demand controlled ventilation in schools and key profitability data will be made accessible for the decision makers for educational buildings at www.sintef.no and through “Byggforserien”. Information will be given in a national workshop.
- Status report at regular partner meetings.

- Inform Standard Norge about results and, if relevant, suggest standard improvement

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