Energy-optimal ventilation strategy outside of the operating time for passive house office buildings in cold climates

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Abstract

The GK environmental house is the first office building in Norway built according to the passive house concept. In such buildings, it is crucial to develop a ventilation strategy to reduce the energy use outside of the operating time. An optimal operating strategy has been developed for cold days, when the outdoor temperature falls well below 0 °C, which is presented in this paper. Indeed, these conditions correspond to the largest heat loss.

The building is mainly heated with warm air supplied through the ventilation systems, with power poles down in each area for peak load. The air handling units(AHU) can be turned into a recirculation of the indoor air mode by night, when there is no need for fresh air since there are no person presents. Data from the active supply air diffusers and AHU's are logged in a central control and monitoring system.

The approach followed in this paper, was to develop different models for running the AHU by night in the building. Energy consumption for the AHU are then downloaded from the central control and monitoring system after each test. Tests at Environmental house GK is then used as foundation for verifying calculations, by comparing the logged data and calculations.

Room temperature data from the supply air diffusers, were used to calculate the building time constant. The latter describes the thermal inertia of the building, and represents the relationship between the heat storage and heat loss capacity. The NS 3031 standard ("Calculation of energy performance of buildings – Method and data") was used as a foundation to create a dynamic model for the building. This model enabled to see the temperature development in the building and find the time constant corresponding to the measurements.

The tests are showing that turning the AHUs in recycling mode by night, enables to easily maintain the temperature throughout the night and also save energy. The results show that the studied building with very low heating demand has a long time constant compared with conventional buildings. Therefore, even for low outside temperatures, the drop in inside temperatures is slow. This makes it possible for intermittent operation without compensating for the heat loss in the off mode.

The developed strategy provides a good example of how to reduce the energy use in in office buildings with very low heating demand in a cold climate.

Keywords: Thermal inertia, cold climate, heating by ventilation, office building, low heat demand

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1. Introduction

This paper is part of a bigger scientific research project by name “For Klima”(Forklima, 2012). That addresses “Simplified demand controlled air conditioning of office buildings with very low heating demand”. The project is implemented by GK Norway and GK environmental house is made available as case. SINTEF building and infrastructure is project manager and will conduct field / lab studies, which will help develop and disseminate knowledge.

The overall idea of this research project is that “future well-insulated building shells will have a very low heating demand. With sufficiently low heating requirements, it is possible to simplify the current air conditioning solutions and achieve good indoor air quality with lower investment and operating costs”

As of 2015, the public policy in Norway is that all future buildings will be constructed according to the Passive House Standard NS 3701. These are buildings that use passive measures in building construction, which lowers heating demand and thus gives energy efficiency buildings(Government Stoltenberg II, 2013).

By carrying out calculations and experiments in Environmental house GK outside of the operating time, by making use of the supply air temperature of the coldest days of the year. Would it be possible to develop optimal solutions for the operation of the office buildings in the future, which maintain a good thermal comfort, good indoor air quality and lowers the energy demand.

This will provide documentation that the buildings built by the passive standard, has no need for traditional heating system such as radiators. This is also shown in other papers(Feist & Schnieders, 2009) (Feist, Schnieders, Dorer, & Haas, 2005). This will simplify air conditioning solutions in the future, lead to more sustainable buildings, simpler design and leading to lower investment and operating costs. In particular, low investment and operating costs for the building, should make this an affordable option for building owners and provide a competitive edge on other types of buildings. By utilizing the building construction and internal loads in the premises, would the energy demand for heating be lowered further. This is also documented in other works(Lehmann et al., 2010) (Karlsson, Wadso, & Oberg, 2013).

The purpose of this paper is to create “Energy-optimal ventilation strategy outside of the operating time for passive house office buildings in cold climates”. This means that the heating demand in GK environmental house, must be covered by an over temperature supply air flow from ventilation units outside the operating time without use of traditional heating.

The hypothesis is therefore whether the ventilation air with the over temperature can contribute to good indoor air quality if the heating demand is sufficiently low.

The approach is therefor:

1. Can supply air from the AHU warm up the building outside of the operating time and satisfy the heating demand at low outdoor temperatures and how is this effecting the energy consumption?
2. Can recirculation of air outside of the operating time be used to keep the temperature steady in the building?
3. Under what conditions is this okay?

This with earlier works, will help to contribute to the documentation of the function and the conditions that must be the basis for future dimensions projections of passive houses. It will also prove due. stricter energy requirements, will open for ventilation solutions that provide good thermal comfort without using other heating systems.

2. Theory

In the following sections is the current theory that explains the features of the building and systems closer.

2.1 Environmental house GK

Figure 1: Environmental hlouse GK

Environmental house GK is an office building located at Ryen in Oslo. The building was opened on 23. August and was then the first office building in Norway built after the passive house standard NS 3701.

Environmental house GK is divided into 3 parts, where it's 2 balanced ventilation systems in each section that distributes air to the premises. The systems are built on the principle DCV (Demand Controlled Ventilation) and needs are controlled by temperature and the presence. In the premises the air are distributed through active supply diffusers, which may vary the slot height in the blowout sone so that the speed of the valve is kept constant regardless of the airflow.

The heating of the building occurs through heated air through ventilation systems using heat batteries installed the AHU's. Heating coils in the heating batteries is designed for a temperature of 35,0/27,9 ˚C, with a maximum capacity of 103.56 kW at 20,000 m3/h. The energy distributed through the heating coils is supplied by 2 pcs. reversible air / water heat pumps.

Since not all of Environmental House GK is implemented yet, will building C be the focus for further work. Building C is the southeastern part. Building C has a total floor area of 3687.4 m2. Ventilation systems are divided into a southern and northern part. Data from the active supply air diffusers and AHU's are logged in a central control and monitoring system.

2.2 Heat storage and heat loss

Since modern buildings gets better and better insulated, the heat loss will be greatly reduced. In passive houses heat losses are so low that much of the heating demand could be covered by internal loads within the operating time even at low outdoor temperatures.

Different materials have different properties, when it comes to heat storage C (J/m^{2}K). This tells us how much energy is required to raise the temperature by 1 K. If a material is covered by something, usually the heat storage capacity for the material is greatly reduced.

With the heat storing properties as base in combination with heat loss to the building, the temperature development of a room can be determined. This can be calculated from the building time constant, which is a term for the building's internal thermal inertia.

2.3 Demand controlled ventilation

Demand controlled ventilation is ventilation systems where airflow needs are controlled automatically based on measured demand at room level. The system is a variation of VAV (Variable Air Volume) where there is a variable air volume system over the operating time.

DCV include ventilation systems where supplied ventilation air flow is controlled automatically and in real time by measured needs at room level. That is DCV must have a room sensor, which provides a target / signal on the room air quality, and this signal is used to control the flow in direct relation to the required quality standards(Mysen & Shcild, 2013).

3. Method

Experiments are conducted on nights when the outdoor temperature has dropped well below 0. Operating personnel at Environmental House GK is contacted to implement the desired strategy.

The paper looks at 3 different air volumes that have organized after the amount of air in each flow, V’min, V’HygMin and V’Max. V'min has an airflow of 2,5 m^3/hm^2, representing the minimum airflow by NS 15251 without present(Standard Norge, 2007a). V’HygMin are with presence, with an airflow of 4,2 m^3/hm^2. V’Max are the maximum airflow for the AHU’s, with an total airflow of 10,8 m^3/hm^2. This corresponds to an airflow at 40.000 m^3/h.

Tests at Environmental house GK is then used as the basis for verifying calculations. Basic equations for heat loss by NS 3031 are as follows(Standard Norge, 2007b):

Transmissions losses (eq.1) are the heat loss caused by heat transfer through the building envelope like floor, walls, windows and roof. U represents the u-value of the relevant building part, while A is the area of heat transfer area. Ψ is the thermal bridge constant and *l* is the length of the thermal bridge part.

$$H_{Tra} = \Sigma U_i \cdot A_i + \Sigma \Psi_k \cdot l_k \ (W/K) \tag{1}$$

Ventilation losses (eq.2) are heat loss due to AHU’s that extracts air from the building. V is the ventilation air rate and Ƞ is the degree of recuperation in the rotating recuperator. By recirculating the air in the AHU’s, the recuperation rate will be 100%, this means that the ventilation heat loss will be 0 W/K. This would also be accomplished by turning off the AHU’s. Factor 0.33 is the air heat capacity (Wh/m^3K)

$$H_V = 0,33 \cdot \bar{V} \cdot (1 - \eta_{recuperator}) (W/K) \tag{2}$$

Infiltrasion losses (eq.3) are heat loss caused by leaks in the building envelope. n_{50} is leakage number at 50 Pa, and V is the heated air volume.

$$H_{Inf} = 0,33 \cdot n_{50} \cdot V \ (W/K) \tag{3}$$

The overall heat loss is then presented in equation 4. Where heat loss figures are summed and divided by the floor area.

$$H" = \frac{H_{Tra}+H_V+H_{Inf}}{A_{Floor}} \; (W/_{m^2K}) \tag{4}$$

When calculating the optimal supply air temperature and heating demand for the building, is the heat balance by NS 3031 for heat gains and heat losses used (eq.5).

$$q"_{heat} + q"_{int} + q"_{sun} - q"_{loss} - q"_{vent} = C"\frac{\delta\theta_i}{\delta t} \tag{5}$$

The cumulative capacity C", refers to the accumulating layers in the building. A is the area of the material that accumulate heat, and C is the accumulating ability for the material.

$$C" = \frac{\Sigma(A_{material} \cdot C_{material})}{A_{bra}} \; (Wh/_{m^2K}) \tag{6}$$

According to NS 3031, the time constant is defined as

$$\tau = \frac{C"}{H"} \; (h) \tag{7}$$

4. Results

Logged indoor temperature in Environmental house GK is illustrated in Figure 2. This is a test from the night of January 24, where internal loads and the AHU's was shut down in 5 hours and the outside temperature was -8,14 ˚C. Results show that the temperature drop during 5 hours is minimal. The average temperature in the building falls with a total of 0,273 °C in the southern part and 0,245 °C in the northern part. Calculated average temperature drop in Environmental house is presented by the red graph. The calculated temperature drop is almost identical to the logged temperature drop in part north and south of building C. Over a period of 5 hours, the difference between the calculated and logged temperature was 0.10 °C. The calculated temperature drop is based on heat loss and heat storage capacity of the building.

Internal loads are valued at 1 W/m^2, due. an assessment of the operational scenario. After Project Report 42 from SINTEF, the internal loads for lighting, equipment and people have a load of respectively 5, 6 and 4 W/m2 in low energy buildings - non-residential in the operating time(Dokka, Klinski, Haase, & Mysen, 2009). Outside life will lighting and personal burden be eliminated, the loads will be approximately 0. It is therefore estimated that the internal loads is 1 W/m^2, since there will always be some equipment that can affect the temperature in the building. Since the temperature drop is almost identical to the real case, input in calculations are approved.

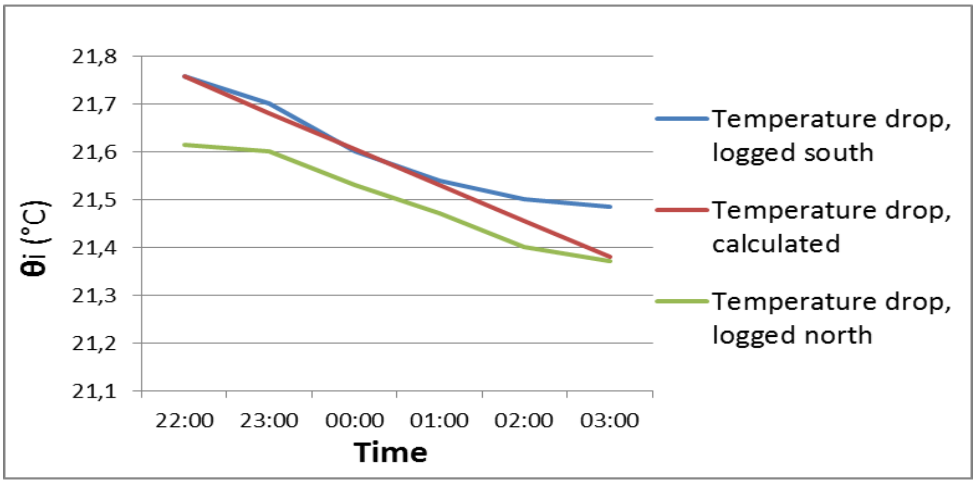

Figure 2: Logged and calculated temperature drop in Environmental house GK, building C, at an outdoor temperature of -8.14 ˚C.

Heat loss figure for Environmental house GK is stated to be 0.36 on their website(GK Norge AS). Table 1 shows heat loss figures for operation without recirculation mode for different airflows in night mode during winter. It shows that the heat loss increases with increasing air flow, which will have a negative impact on the heating demand.

Table 1: Heat loss figures without recirculation of air.

V''	V'' (m^3/hm^2)	η_{rec}	H'' (W/m^2K)
V'Min	2,52	0,88	0,33
V'HygMin	4,2	0,88	0,40
V'Max	10,8	0,88	0,66

Table 2: Heat loss figures with recirculation of air.

H_{tra} (W/K)	H_{inf} (W/K)	H_{vent} (W/K)	H (W/K)	H'' (W/m^2K)
793,19	51,23	0	844,42	0,23

Table 2 shows AHU's in recycling mode, it will ensure that the heat loss from ventilation will be zero. Heating will therefore only consist of transmission and infiltration. This would also be accomplished by turning off the AHU's. The overall heat loss for the building falls to 0,23 W/m^2K.

The specific power requirements at different air flows based on the heat loss figures, are shown in Figure 3. V'Min, V'HygMin and V'Max are air flows without recirculation with an efficiency for the recuperator at 88 %. Since the heat loss is unaffected by the air flow in resirculation, is this constant and only presented with a purple graph. The figure shows that the power requirement for heating increases with increasing air flow when it's not recirculation.

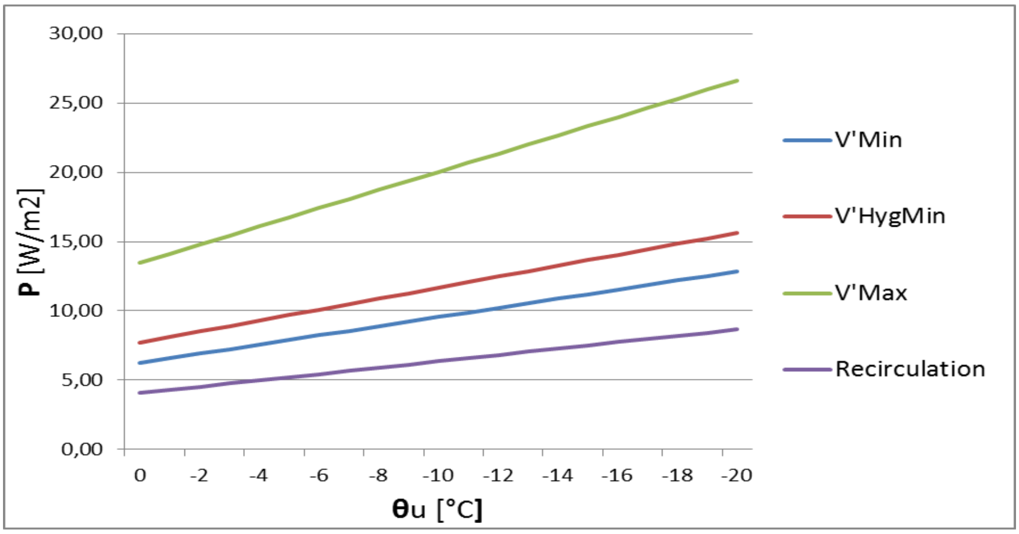

Figure 3: Power requirement by various air flow without recirculation of air and power requirement in recirculation mode.

Based on the power needed to meet the heating requirements, that is presented in Figure 3. Will this give a total power requirement at an outdoor temperature of -20 ˚C for building C on 32-, 47-, 57- and 98 kW respectively for recirculation, V'Min, V'HygMin and V'Max.

Optimal supply air temperature to keep an indoor temperature at 22 ˚C, is presented in Figure 4. Set-point temperature of the supply air will have a maximum value at an outdoor temperature of -20 ˚C, on 24,4-, 28,2- and 32,4 ˚C respectively for V'Max, V'HygMin and V'Min. With lower air flows the higher temperature of the supply air is required to meet the heating demand.

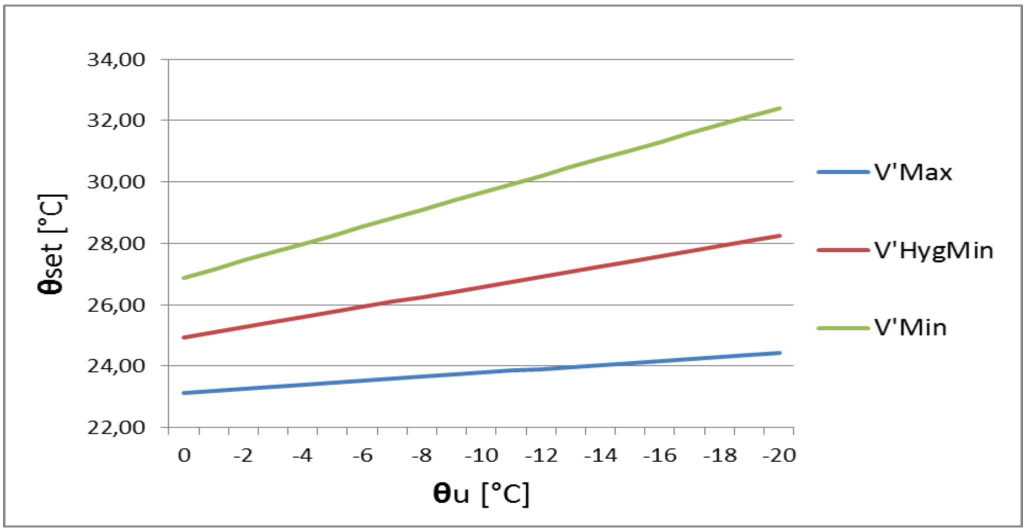

Figure 4: Optimal supply air temperature at different airflows.

Heating coils in the heating batteries is designed for a temperature of 35,0/27,9 ˚C, with a maximum capacity of 103.56 kW at 20,000 m3/h per piece. Maximum heating demand is 98 kW for the airflow V'Max, the largest optimal supply air temperature is 32,4 ˚C for V'Min. This proves that Environmental house GK covers the heating demand, by only using over tempered air from the AHU's. Since the heating demand and optimal supply air temperature is under the batteries capacity. By making use of recirculation in the AHU's, the heating demand to Environmental house GK will be reduced, compared with fresh air strategies. Recirculation would therefore be a beneficial strategy to maintain a constant temperature in the building and to reduce energy requirements for heating even further outside of the operation time. It was not chosen to look at lower airflows, since optimal supply air temperature will pass the trip temperature in the heating coil

The time constant that was calculated for Environmental house GK night of January 24, is shown in Table 3 is an average of the southern and northern part of building C. The mean time constant tau that appears in the table is 285.43 hours. It is important to emphasize that this is with turned off AHU's and heating elements in the electric poles.

Table 3: Time constant for logged attempts for an average of part south and north.

Date	t_{off} (h)	$t_{calculation}$ (h)	South, τ (h)	North, τ (h)	$τ_{average}$ (h)
Night of Jan 24	5	4	291,0	279,9	285,4

Table 4: Time constant for dynamic calculations.

V"	V" (m^3/hm^2)	C" (Wh/m^2K)	H" dynamic (W/m^2K)	τ (h)
V'Off	0	76,9	0,2	335,6
V'Min	2,5	76,9	1,1	72,5
V'HygMin	4,2	76,9	1,6	47,6
V'Max	10,8	76,9	3,8	20,3

By turning off the AHU's shows the dynamic calculations for the building that the building time constant is approximately around 335.63 hours (Table 4). The difference is approximately 50 hours between dynamic calculations and calculated from the logged data. Reading error could occur for the recorded temperature profile for the building, since this is presented in a graph. When the time constant achieves this size, decimals will affect the outcome of the final result in a big scale. The difference is therefore accepted, since a small change for the read temperature profile, would make logged time constant passing the dynamic calculated time constant.

Table 4 also shows that the result around the time constant of the premises is heavily dependent on how much air flow being pulled out of the premises. V'Min V'min will have a time constant of 3 days, V'HygMin 2 days and V'Max about 1 day. This means that it requires very large volumes of air to achieve a temperature change in the building, but it will also mean that the temperature remains stable at low flows and turned off AHU's. This is due to good heat storage capacity and low heat loss figures. With such a large time constant in the off mode, will it confirm the potential for intermittent operations outside the operating time.

Figure 5 shows that the temperature drop for an outdoor temperature of -20 °C, will be approximately 0.33 °C for a time interval of 3 hours a night where the AHU's and the heating elements in the power poles is turned off. The temperature drop will only be 0.16 °C for a temperature of 0 °C. To exploit Environmental house GK's thermal inertia and low temperature drops, will be ideal to make use of intermittent operations. If one allows that the temperature in the premises to fall outside the operating time and let internal loads heat up construction during the work day, would this be an ideal solution for saving energy.

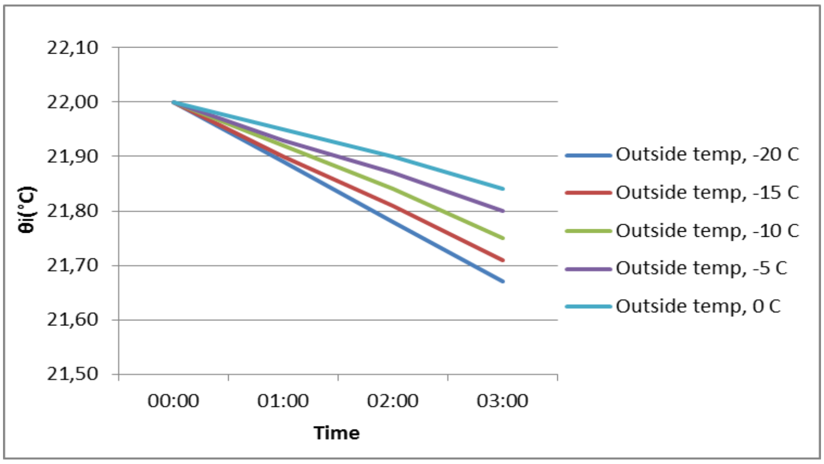

Figure 5: Average temperature drop in Environmental house GK, building C, based on calculations.

Table 5 shows the energy savings for heating, during a normal winter for Oslo. A normal winter is considered the months of December, January and February with normal outdoor temperatures. Recirculation will have a energy consumption on 13,095.34 kWh/winter, and have the lowest energy consumption compared with strategies with outdoor air. Without recirculation would the energy consumption be at 19,929.27 -, 24472.99 - 42403.95 and kWh/month at airflows V'Min, V'HygMin and V'Max.

Table 5: Energy demand for a normal winter and the difference between air flows and recirculation mode.

V''	V'' (m^3/hm^2)	$E_{Heating}$ (kWh/night)	$E_{Heating}$ (kWh/winter)	E_{diff} (kWh/winter)
V'Min	2,5	221,5	19929,4	6834,0
V'HygMin	4,2	272,0	24473,0	11377,6
V'Max	10,8	471,3	42403,9	29308,6
Reciculation	-	145,5	13095,3	0,0

Table 6 presents the potential saved energy for a deactivated AHU's, for a time interval of 3 hours a night for a winter. GK has stated on their website, they have a total heating demand on 9 kWh/m^{2}year in Environmental house GK. With the potential of intermittent operation, this could be lowered to 7.7 kWh/m^{2}year.

Table 6: Total heating demand due to intermittent operation.

Heating demand (kWh/m^{2}year)	Heating demand (kWh/year)	Intermittent savings (kWh/vinter)	New heating demand (kWh)	New heating demand (kWh/m^{2}year)
9,0	33183,9	4910,8	28273,1	7,7

5. Conclusion

Results from the paper will thus provide evidence that the office building built by the passive house standard NS 3701, are able to meet their heating demand just by making use of the supply air temperature even at outdoor temperatures down to -20 °C. This relates to office buildings with the same or better heat loss figures, or in warmer climates. It is necessary in this type of heating, that warm air will have the opportunity to flow into the room without heating or with greater heat loss.

Average heat loss figures for Environmental house GK is given to be 0.36 W/m^{2}K on their webpage. By using recirculation in the AHU's ensures however that the heat loss figure drops to 0.23 W/m2K, which is almost a halving of the declared value. This would also be achieved by turning off the AHU's. This is due to the heat loss of ventilation will be eliminated and will only consist of transmission and infiltration at this strategy. By running with recirculation outside operation time, will therefore ensure energy saving compared with heating with fresh air and be ideal strategy. A good recirculating solution would also even out temperature differences in the building.

The paper reveals that the future office buildings with low heating demand, could use intermittent operation as a strategy in combination with recycling mode. Due to the buildings' low heat loss figures in combination with high heat storage capacity, will cause a large time constant that makes the buildings thermal slow and causes low temperature drops. By allowing the construction dissipate heat outside the operating time by declined ventilation, will provide minimal temperature drop in the premises during the night. It is important that the AHU's do not compensate for heat loss that has occurred in off mode at a later stage, but let internal loads during the work day compensate for the heat loss during the night in the off mode.

Questionnaires related to indoor climate in the occupied open plan offices during the working day are ongoing, and will be presented in completed study. If interested, see http://www.sintef.no/Projectweb/For-Klima/ for more information.

6. Acknowledge

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