CONTROL STRATEGIES FOR HYBRID VENTILATION SIMULATIONS

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ABSTRACT

This paper describes the results of a collaboration study between ENTPE-LASH and LEPTAB within the framework of the IEA Annex 35 “Hybrid Ventilation in New and Retrofitted Buildings”. The aim of the work is to carry out a cross-simulation study and identify optimal control strategies for Hybrid Ventilation systems in order to maintain comfortable indoor environments and good air quality with energy efficiency.

Models developed by ENTPE-LASH and LEPTAB in order to carry out Hybrid System simulations taking heat transfers into account, CO2 concentrations and air flows. ENTPE-LASH’s model uses finite differences to calculate conductive heat through the walls when LEPTAB’s model uses a (2R3C) model and both the models are using pressure difference power lows to calculate the air flow rate. Several control strategies for Hybrid Ventilation based on CO2, temperature and occupation pattern were implemented to the models.

A Danish classroom was selected to test and evaluate several control strategies. This room, 9m long by 6m wide and 3m high, is a single zone on the middle floor of a three storey building. It has large glazed facade and equipped with natural (inlet grille and exhaust chimney) and mechanical (fan with heat recovery) ventilation. The control strategies are based on CO2 concentration, indoor air temperature, solar radiation and occupancy pattern.

KEYWORDS

Hybrid ventilation, Control strategies, Comfort, Energy efficiency

INTRODUCTION

Nowadays, there is a growing interest in taking the ventilation into account at the early design stage of a building. Designers are interested in more ventilation features in addition to the indoor air quality (thermal comfort and energy consumption), Annex 35 (1999), and design tools are needed to generate guidelines on control strategies.

This paper describes the work done in the context of a collaboration between the ENTPE/LASH laboratory and the LEPTAB laboratory. The main objective of the work is to identify optimal control strategies for hybrid ventilation systems in a simple school building in Denmark. Two mechanical ventilation systems were compared with a hybrid ventilation system during three seasons. Two simulation models (HYBCELL and SPARK) using coupled air-flow and thermal model were used. Tools also predict indoor air quality in terms of CO_2 concentrations and relative humidity.

This work also reveals how the used tools agreed in modelling hybrid ventilation systems and how they conclude about the relative performance of control strategies.

THE TOOLS USED IN THE SIMULATIONS

HYBCELL

HYBCELL has been developed at the LASH/ENTPE (France) laboratory within the frame work of the IEA Annex 35. Simulations are carried out by coupling a thermal model based on finite differences and a pressure air flow model using the onion approach. This tool has been developed under the mathworks MATLAB/SIMULINK environment. Several control strategies for Hybrid Ventilation based on CO_2, temperature, time and occupation pattern were implemented in the model.

Indoor air temperature is calculated using various heat flows such as the heat flow through the walls and other enclosure structures, air infiltration, ventilation, internal heat gain and auxiliary heating or cooling . A finite difference method has been used to calculate the wall surface temperature. Each surface is considered as a one dimensional transient heat conduction problem and is divided into sub-layers of equal thickness, the temperatures of which are calculated for each time step. This model takes the short-wave radiation penetrating through openings and internal and external long-wave radiation exchange into account. The ventilation model has been built according to the concept of airflow network modelling. The airflow rate through the building is directly related to pressure drop across the openings. HYBCELL1.0 also include a module for CO_2 concentrations, relative humidity and PMV calculation

SPARK

This model has been developed at the LEPTAB (France) and uses the object oriented solver SPARK to compute the entire problem with differential and non linear equations. All the equations have been implemented in SPARK, so the model used ones based in part on a previous study done for the IEA Annex 35, Cron et al, (2002).

The conductive heat transfer was described by an electrical 2R-3C model. The direct short-wave radiation that was transmitted through the window was supposed to be entirely incident on the floor surface. One part was absorbed and the other part was supposed to be reflected in a diffuse way. Internal and external long-wave radiation exchanges were also taken into account. The ventilation model used by SPARK is the same as in HYBCELL1.0.

Experiments results provided by a test cell, called HYBCELL, EL MANKIBI et al (2001), designed at the ENTPE-LASH Laboratory has been used to adjust the physical models. HYBCELL is 5.1m long by 3.5m wide and it is 2.9m high equipped with hybrid ventilation system (fan and motorized openings), sensors (temperature, CO2, relative humidity, VOC), occupancy simulation (heat and CO_2 supplies).

THE TEST ROOM

Description and fabric

The selected test room is a Danish classroom in Copenhagen. It is a single zone, 9m long by 6m wide and 3m high, on the middle floor of a three storey building, has a large glazed facade and equipped with natural (inlet grill and exhaust chimney) and mechanical (fan with heat recovery) ventilation. The control strategies are based on CO2 concentration, indoor air temperature, solar radiation and occupancy pattern.

The window is a line of 3/12/4 Argon-filled low-e double glazing (U-value 1.5 $W.m^{-2}\ K^{-1}$) along the whole facade. Bottom of glazing is 1 m above floor. The overall transmittance and absorbtance for each pane is a function of angle of incidence of short-wave solar radiation. Table below summarises the materials used in the test room fabric.

	Material form inside	Thickness (m)	Conductivity ($W.k^{-1}.m^{-1}$)	Density ($kg.m^{-3}$)	Specific heat ($J.kg^{-1}\ K^{-1}$)	Absorbtance (-)	Emissivity (-)
Floor and ceiling	PVC	0.005	0.35	1300	960	0.5	0.9
	Massive concrete	0.15	1.7	2300	920	0.5	0.9
External wall	Massive concrete	0.1	1.7	2300	920	0.5	0.9
	Mineral wool	0.15	0.04	30	840	-	-
	Brick	0.11	0.8	180	840	0.7	0.9
Partition walls	Plaster board	0.013	0.2	800	1100	0.5	0.9
	Mineral wool	0.05	0.04	30	840	-	-
	Plaster board	0.013	0.2	800	1100	0.5	0.9

The classroom is occupied by 24 children and a teacher from Monday to Friday between 8:00 and 12:00 and from 13:00 to 15:00. On Tuesday between 10:00 and 11:00 50% of the children are out and on Tuesday from 14:00 to 15:00 everybody is out. On Wednesday afternoon all occupants are out.

Ventilation system and strategies

Two reference mechanical systems and a hybrid ventilation system were considered. The classroom is provided with two natural inlet grills and a fan-assisted natural exhaust chimney. The grills are positioned under the windows 0.5 m above floor level.
Each grille is 1.8 m wide and is closed outside normal school hours except when night cooling is on. The exhaust chimney (4.0 m long) is just a simple duct and a low pressure fan. The top of the stack is 10 m above ground.

Reference ventilation system 1: mechanical exhaust

A constant supplied airflow rate of 150 $dm^3.s^{-1}$ is provided during all normal school hours (8:00 to 15:00). The low power consumption fan is 1 w per $dm^{-3}.s^{-1}$. The supplied air is preheated in winter and spring when the external temperature is bellow 18 °C.

Reference ventilation system 2: balanced mechanical ventilation

The mechanical supply and exhaust flows is 150 $dm^3.s^{-1}$. a heat recovery with 60 % temperature efficiency is added in spring and winter. The supply air is preheated to 18 °C by the heat recovery and a heating coil. The heat recovery is continuously controlled to get 18 °C supply air temperature and stops at higher external temperature. In operation during all normal school hours. The power is 2.5 W per $dm^3.s^{-1}$.

Hybrid ventilation system

The hybrid system tested is a fan-assisted stack exhaust with pre-heating of supplied air. The inlet grilles and exhaust chimney are the same as in reference ventilation system 1.

CO_2 Control

The mechanical systems operate with fixed flow rates during normal school hours and don't depend on the CO_2 Concentration. For the hybrid system, the control tested is an on-off based on CO_2 concentration only:

- The first inlet grille opens if the CO_2 is higher than 800 ppm
- The second inlet grille opens if the CO_2 is higher than 1000 ppm
- The fan in the exhaust chimney is switched on if the CO_2 is higher than 1200 ppm
- The fan stops and the grilles close in the opposite order at 100 ppm lower set points

Temperature Control

The window is open when the internal temperature is higher than 23 °C and external temperature is above 12 °C and stops when internal temperature is below 21 °C. The air change rate when window is open doesn't depend on external conditions, it is fixed to 4 air changes per hour and additional to ventilation system rate. The Temperature is also controlled heating in winter and spring. Heating hours are 7.00-15.00, Monday-Friday. The controller used is a proportional controller based on temperature with two set points:

- Heating hours: 21°C.
- Non-heating hours: 18°C.
- Maximum power 5 kW.

Night cooling

Night cooling is actuated only in summer between 22:00 and 07:00. It is On if the internal temperature is higher than 24°C and the temperature difference between indoor and outdoor is higher than 2 °C and off when internal temperature is bellow 18 °C.

RESULTS AND DISCUSSION

Three periods (spring, summer and winter) of three weeks long were simulated. The results returned by SPARK and HYBCELL show that the degree of agreement in predicting the relative performance of the three systems depends on the weather while the agreement in predicting the indoor temperature, CO_2 concentration and energy consumption is ventilation system dependent.

Winter

Tools return the same results in term of temperature and CO_2 Concentrations. However we noticed that there is disagreement in pre-heating and heating consumption. Both HYBCELL and SPART agree that HV system has higher room heating and preheating. The best results in terms of energy consumption was the reference system 2

Model	Heating (kwh/week)			Pre-heating (kwh/week)			Fan power (kwh/week)			Temperature (°C)		CO_2 (ppm)	
	Ref 1	Ref 2	HV	Ref 1	Ref 2	HV	Ref 1	Ref 2	HV	max	mean	max	mean
SPARK	21,39	21,39	21,43	119,00	34,85	125,69	5,26	13,16	0,00	22,30	21,30	1062	958
HYBCELL	32,64	32,64	34,22	128,69	37,11	185,00	5,25	13,12	0,00	23,66	21,35	1048	902

Spring

The difference between tools are not very significant, this is due to the lower heating energy. The pre-heating and fun consumption behaviours are the same as winter. Lower maximum CO_2 was predicted for the hybrid system.

Model	Heating (kwh/week)			Pre-heating (kwh/week)			Fan power (kwh/week)			Temperature (°C)		CO_2 (ppm)	
	Ref 1	Ref 2	HV	Ref 1	Ref 2	HV	Ref 1	Ref 2	HV	max	mean	max	mean
SPARK	8,57	8,57	6,03	58,21	8,21	61,23	5,26	13,16	0,00	23,00	21,80	1148	975
HYBCELL	6,70	6,70	8,45	60,92	8,59	94,24	5,25	13,12	0,00	22,81	21,70	1053	884

Summer

Since there is no heating nor pre-heating energy, the results of this period show that hybrid systems are more interesting than reference systems.

Model	Heating (kwh/week)			Pre-heating (kwh/week)			Fan power (kwh/week)			Temperature (°C)		CO_2 (ppm)	
	Ref 1	Ref 2	HV	Ref 1	Ref 2	HV	Ref 1	Ref 2	HV	max	mean	max	mean
SPARK	0	0	0	0	0	0	6,70	16,76	0,36	27,10	25,10	925	842
HYBCELL	0	0	0	0	0	0	9,30	23,24	0,79	26,88	24,54	1081	811

The figure below shows the time series comparison of temperature of the hybrid system in summer and reveals how HYBCELL and SPARK agree. We noticed that tools agree well on the effect of night cooling except in day 6 because the temperature of HYBCELL is not high enough to invoke the night cooling.

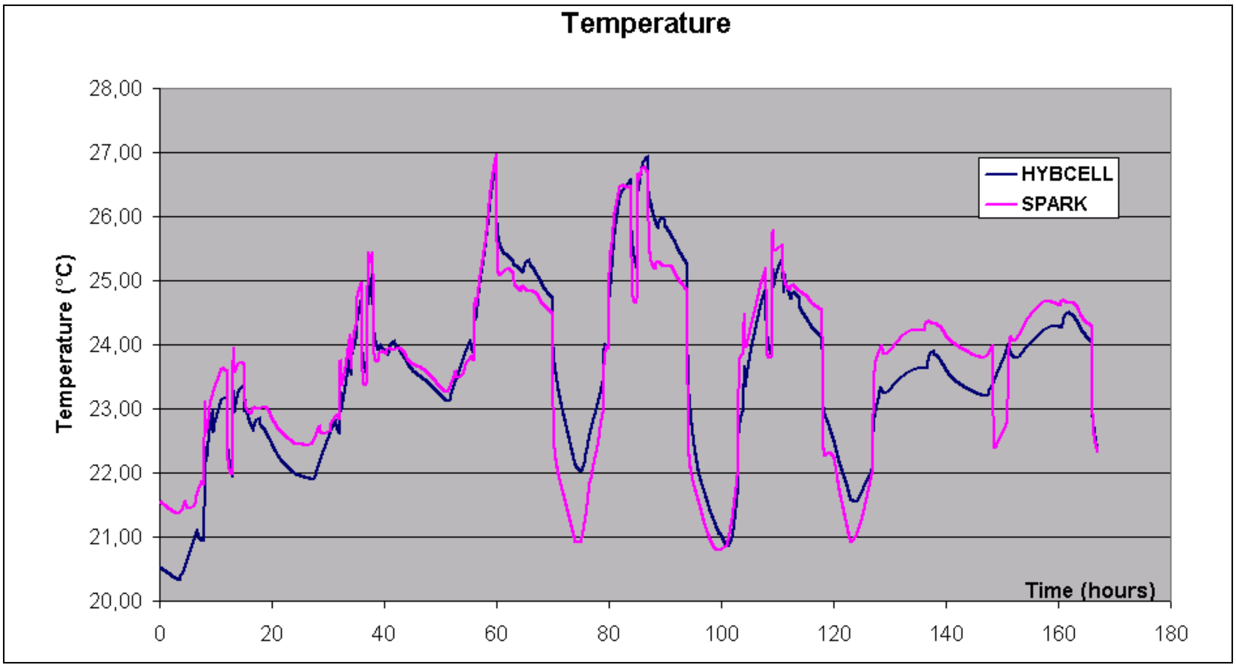

Figure 1. Room temperature for Hybrid System in summer

The graph below shows the time series comparison of CO_2 concentrations of hybrid system in summer.

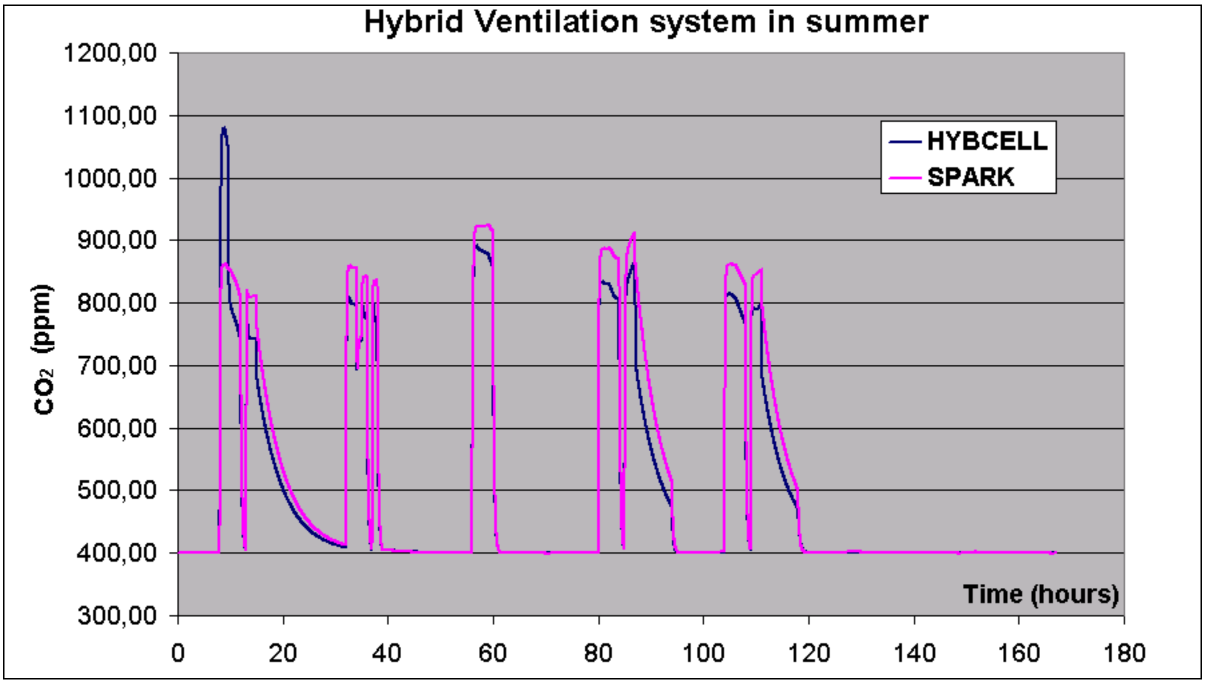

Figure 2. Room temperature for Hybrid System in summer

The tools agree well in predicting the indoor air quality. During the first day we noticed that the CO2 concentration returned by HYBCELL are higher. This is due to the window opening strategy (window is open when indoor air temperature is over 23 °C).

CONCLUSIONS

The disagreement noticed in energy performance is due to the fact that tools modelled heating in different ways. In addition, a number of simulation parameters like coefficient of convection were not integrated in models in the same way. Errors of interpretation of the study specifications, difference between airflow models can also lead to such disagreement. Great efforts were necessary to eliminate this errors. On the other hand, tools were in agreement regarding the CO_2 concentration and temperature performance and the relative performance of the systems. The simulation results show that:

- in winter and spring hybrid ventilation system has higher energy consumption but has similar indoor air quality and thermal performance.
- in summer hybrid ventilation energy consumption is lower than those of reference systems but the CO_2 concentrations are higher.

According to this study results and to agreement noticed and knowing that the on-off can lead to differences between tools, the use of other control strategies (PID or fuzzy controller) can improve the agreement of tools

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