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**CONTROL STRATEGIES FOR HYBRID VENTILATION
DEVELOPEMENT OF AN EXPERIMENTAL DEVICE**

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ABSTRACT

This paper summarizes part of the work held at ENTPE within the framework of the IEA Annex 35 project. The aim of the work is to develop and experimentally evaluate control strategies for hybrid ventilation systems to provide comfortable indoor environment and good air quality by combining the best aspect of natural and mechanical ventilation. To reach this target and assess the physical model elaborated in this project, a test cell "HYBCELL" has been designed within the laboratory.

In order to represent a large office or a meeting room, HYBCELL has been created by totally retrofitting an old local within a large hall whose temperature can be controlled to create an artificial climate around the test cell. The front of the cell is a sloped wall (70°) which communicates with the outdoor climate through six sash windows. The test cell is 5.1m long by 3.5m wide and it is 2.9m high. Except the floor, the false ceiling and all walls are made with office building materials.

The hall is equipped with a HVAC system creating an artificial climate around the test cell. The temperature can be controlled between 5 and 20°C in winter and 15 up to 35°C in summer. In order to air-condition and ventilate the test cell, we consider linking it to the hall HVAC network and equip it with a blower. To simulate the occupancy, CO₂ and sensible heat will be injected in the test cell. Various sensors (Temperature, Relative humidity, CO₂ concentration, COV, Pressure) have been installed in the large hall, in the test cell and outdoor. In addition, wind velocity, wind direction and solar radiation can be collected from the meteo station located near the cell. The data acquisition system is based on a DAQ card and the whole experimental device is connected to a Personal Computer.

The experimental device will be used to adjust the physical model, characterize the openings (determination of the pressure coefficients (CP) and discharge coefficients (Cd)) and carry out several control strategies for hybrid ventilation. On-off and PID Controllers based on temperature, CO₂, and PMV control will be the first approach to the problem. Then elaborated controllers based on multicriteria approach will be tested and optimised.

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1 INTRODUCTION

The basic principal of Hybrid Ventilation system is to combine the best features of the natural and mechanical ventilation in order to provide the best thermal comfort. The philosophy of this system is to use as long as possible a free and safe energy and avoid the coast and the environmental damages.

The ENTP-LASH is one of the twenty participants to the 35 Annex of the IEA. The role of the laboratory within this annex is to develop control strategies for hybrid ventilation systems for new build and retrofitted of office and educational buildings. To reach this target and asses the physical model elaborated in this Annex, a test cell “HYBCELL” has been created within the laboratory.

The HYBCELL cell test is located within a large hall (figure: 1) at the laboratory and was first used to adjust thermal models. In it’s primary state (figure: 2 and 3), HYBCELL was 5.3m long by 3.5m wide and it was 3.35m height. The cell is surrounded by a large hall whose temperature can be controlled in order to create artificial climate around the test cell. The front of the cell was a completely glazed façade (11 m²) and oriented East-North.

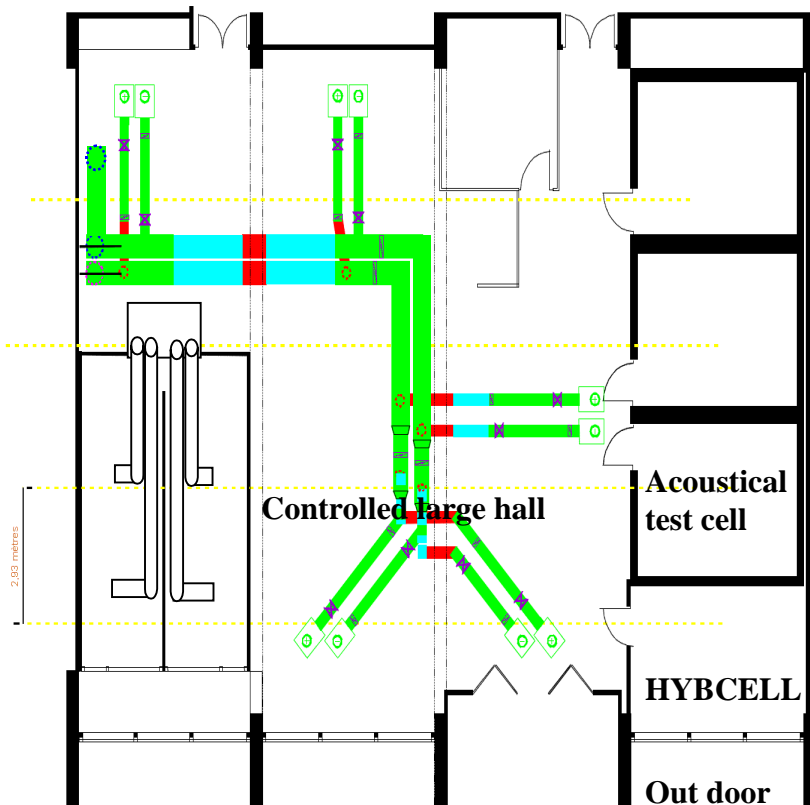


Figure 1 : Location of the test cell in the laboratory hall



Figure 2 : External view of the former test cell



Figure 3 : Internal view of the former test cell

2 ARCHITECTURE OF THE RETROFIED TEST CELL

The architecture of the test cell has been modified. The aim of the modifications is to represent a large office or a meeting room. In order to reduce the height of the cell and avoid the thermal stratification, a false ceiling and a technical floor were installed. The front of the test cell has been completely modified to improve the airtightness and reduce the large glazed area. For this, six windows were realised in the façade. In such a way to take account of the masks and study the relationship between the air flow through openings and their dimensions or their position on the façade, the six windows have different area and different places.

Actually the test cell (figure: 4, 5 and 6) is 5.1m long by 3.5 wide and 2.9m high. It is built on a technical floor above the mean floor level. The windows are symmetrically disposed on the façade:

- Two windows (1.4 m × 0.2 m) on the top of the front
- Two windows (1.4 m × 0.9 m) on the middle of the front
- Two windows (0.6 m × 0.2 m) on the base of the front

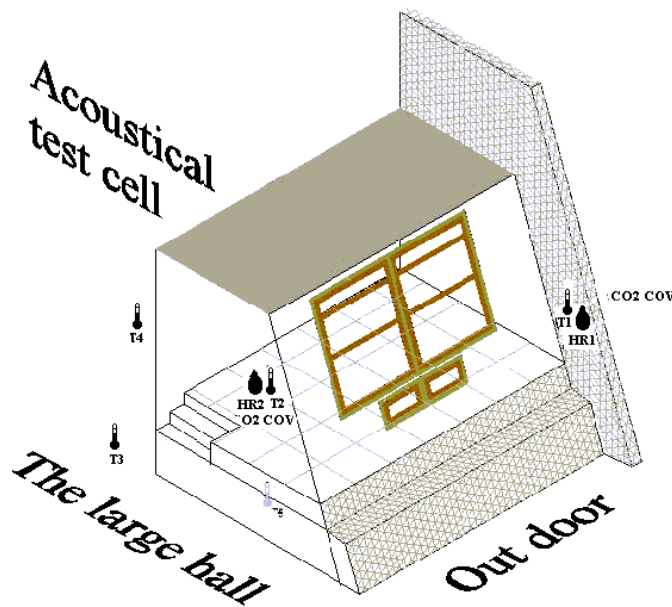


Figure 4 : The architecture of HYBCELL



Figure 5 : Internal view of HYBCELL



Figure 6 : Internal view of HYBCELL

3 TEST CELL MATERIALS

The walls, false ceiling and the floor are not built with the same materials. Except the front, all the other walls are made of office building materials. The materials are similar for the Southern, Northern and Western walls, the frontage is entirely made out of wood. The false ceiling is made of plaster panels (0.6m × 0.6 m) with glass wools. The floor is made from paves (0.6 × 0.6) provided with six pass-cables.

3.1 Walls

The Southern, Northern and Western walls are of very light construction, representative of office partitions. They are composed of two thin steel plates on each side (internal and external) with rock wool in between.

The cell walls surfaces are as follows:

Frontage wall : 16.06 m²

Northern wall (adjacent to Southern test cell): 8.30 m²

Southern wall: 8.30 m²

Western wall : 15.07 m²

The thermal characteristics of all materials have been estimated as follows for all walls except Eastern walls:

Element	Thickness (m)	Thermal conductivity W/m.K	Specific heat J/kg.K	Density (kg/m ³)
Steel	0,001	54	1830	7850
Rock wool	0,06	0,144	1000	450
Steel	0,001	54	1830	7850

Concerning the Eastern wall (frontage), thermal characteristics are as follows :

Element	Thickness (m)	Thermal conductivity W/m.K	Specific heat J/kg.K	Density (kg/m ³)
Wood	0.023	0.13	2000	900
Polystyrene	0.016	0.03	1000	25
Wood	0.005	0.13	2000	900

3.2 Floor

The floor surface is 17.11m² .



Element	Thickness (m)	Thermal conductivity W/m.K	Specific heat J/kg.K	Density (kg/m ³)
Covering	0,003	0,2	1000	600
Rock wool	0,04	0,144	1000	450
Covering	0,003	0,2	1000	600

Figure 7 : HYBCELL floor

3.3 Ceiling

The ceiling surface is 11.65 m



Element	Thickness (m)	Thermal conductivity W/m.K	Specific heat J/kg.K	Density (kg/m ³)
Plaster	0.015	0.054	800	250
Rock wool	0.06	0.1	1000	300

Figure 8 : HYBCELL ceiling

3.4 Windows

The test cell have six such windows and the total surface area for the window is 3.5 m² in each test cell. They are oriented east (azimuth is -70°) from South.

Element	Characteristics	Solar transmittance (at 90°) g-value	Absorptance (without blind)	Reflectance
Double glazing	4 mm - 12 mm - 4 mm	0,70	0,05	0,15

3.5 Mass adding

To achieve good indoor comfort in summer, passives control strategies (Intensive night ventilation) will be tested by cooling down the internal masse of the test cell with cold external air. In order to study the thermal masse effect on the behaviour of the test cell, removable concrete paves (figure 9) with different thickness will be added to the floor.



Figure 9 : Views of removable concrete paves

4 DATA ACQUISITION AND SANSORS

The data acquisition system provide information on the parameters used to define the control strategies (temperature, humidity, CO₂, VOC, Wind speed, Wind direction, Occupancy). Those parameters will be take in account when applying the control rules.

4.1 Temperature and relative humidity

In order to measure the different temperatures (external and internal), various sensors are installed in and around the test cell (Air temperature, Mean Radiant temperature, relative humidity). Several precautions have been taken when placing the sensors. They are placed far from corners, solar irradiance and heat sources. The table bellow shows the characteristics of the sensors used.

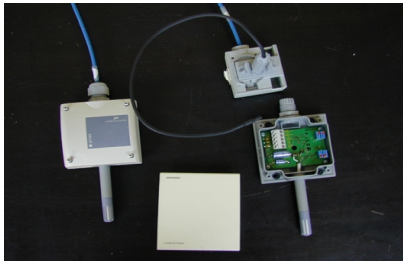


Figure 10 : Views of the sensors used in the test cell

Parameter	Manufacturer and product type	Data range	Accuracy (of full scale or measured value)	Response time	Additional information
temperature and humidity	Landis and Staefa QFM66	T : 0-50°C RH : 0-100%	T : $\pm 0,5^{\circ}\text{C}$ RH : $\pm 3\%$ RH	20 s	0-10V
Air temperature and Relative humidity	Landis and Staefa QFA 66	T : 0 - 50°C RH : 0 - 100%	T : $\pm 0,5^{\circ}\text{C}$ RH : $\pm 3\%$ RH	20 s	0-10V
Air temperature	Landis and Staefa QAE22	-30 +130°C		20 s	NI1000 Ω converted to 0-10 V signal
Radiant temperature sensor	Engelhardt	-30 - +80°C			Pt 100 placed in black sphere (D = 12 cm)

4.2 CO₂ and VOC sensors

CO₂ and VOC sensors are used for sensing indoor air quality in the test cell. They are microprocessor-based units consisting of a selective photo CO₂ sensor and VOC sensor with a heated stannic dioxide semiconductor. Those sensors acquire the CO₂ and VOC concentrations in the test cell and outdoor. The output signal delivered by the CO₂ sensor is proportional to the CO₂ concentration in ppm of the ambient air.

The acquired VOC concentration is also passed on to a sensor output. The output signal provided is inversely proportional to the concentration of oxidizable gases, such as tobacco smoke, CO, alcohol and body odours

Parameter	Manufacturer and product type	Data range	Accuracy (of full scale or measured value)	Response time	Additional information
CO ₂ concentration	Landis and Staefa QPA 62	0-2000ppm	3% MV	2 minutes	0-10V
CO ₂ concentration	Landis and Staefa QPA 63.1	Quality Poor – best	3% MV	2 minutes	0-10V

4.3 The ENTPE meteo station

Every five minutes, the ENTPE meteo station provides information concerning wind direction, wind speed, the solar irradiation, external temperature and external relative humidity. The file returned by the station is formatted as bellow:

Date	mm/dd/yyyy
Hour	hh/mm
Temperature	°C
Global irradiance	W/m ²
Diffuse irradiance	W/m ²
Wind	
Direction	Clockwise from north
Speed	m/s

5 ACTUATION

5.1 Windows driving

When designing the mechanism controlling the openings, we first considered a system of endless screw coupled with a belt notched to automatically open and close the windows. This solution was isolated. Indeed, a failure on the level of the parallelism of the endless screws could involve the blocking of the windows. Finally the solution is to use a system of toothed racks and pinion coupled with a step by step engine. The engines used are step by step engines with brake and encoder in order to determine the position of the opening at any time. The minimum engine step is about 5 mm and the total opening of the heaviest windows (40 cm) takes 8s.

The system consists in fixing two toothed racks on each opening, these toothed racks will be connected to a shaft containing two pinions fixed on the window frame by two bearings. The shaft is then connected to the step by step engine. The rotation of the drive pinions involves a translation of the two toothed racks and consequently the opening and the closing of the sash window.



Figure 11 : View of the shaft, toothed rack and pinions



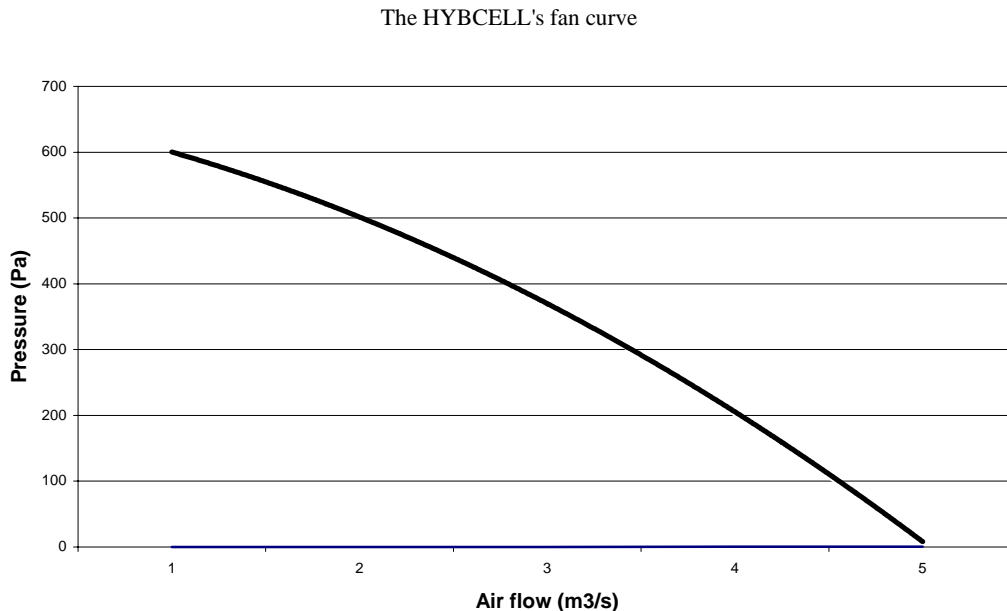
Figure 12 : View of the step by step engines



Figure 13 : View of the driving system

5.2 The fan

The mechanical ventilation is ensured by a centrifugal fan for circular ducts installed in top of the test cell. The speed of the ventilator can be controlled from 0 to 100% by varying the power supply. The curve “flow – pressure” of the fan is shown in the following graphic



5.3 Occupancy patterns – CO₂ and sensible heat injection

In order to take in account the thermal behaviour of the occupants and their impact on Indoor Air Quality, occupants will be invited to participate to the tests. Moreover, the occupancy will be simulated by injecting CO₂ concentration and sensible heat (figure 14).



Figure 14 : Views of CO₂ injector

6 THE DATA PROCESSING AND CONTROL

The test cell is controlled by a microcomputer (Pentium II, 333 MHz) which allows the acquisition, the processing and the data recording. The data acquisition system is composed of a DAQ card from National Instrument (AT-MIO16H9) as well as a chassis (SCXI 1000) equipped with various data acquisition or control module. These modules are :

- 1 SCXI 1100 modules allowing to connect up to 31 sensors with 0-10V output
- 1 SCXI 1124 : with 6 analogue outputs (voltage or current).

A software has been developed using Labview version 5.0.1 to get the data and control the parameters. It allows the user to analysis the data provided by the sensors, define and apply the control rules.

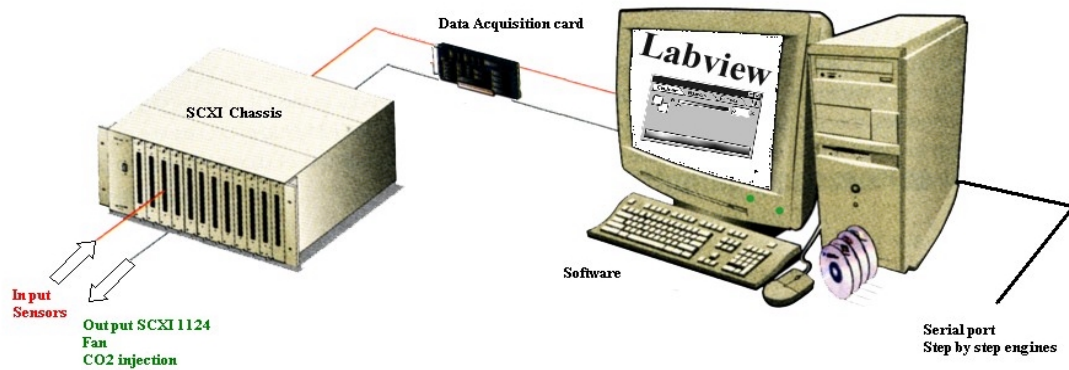


Figure 15 : The data processing and control

The SCXI 1100 module receive and conditions the signals returned by the various sensors. Then it transmit them to the data acquisition card witch allows the processing of these signals using the software. The instructions of intervention returned by the application are transmitted to the data acquisition card then to module SCXI 1124 in term of 0..10V tensions intended for the various actuators (driving step by step, variable speed transmissions for the ventilator, CO2 injector,..).

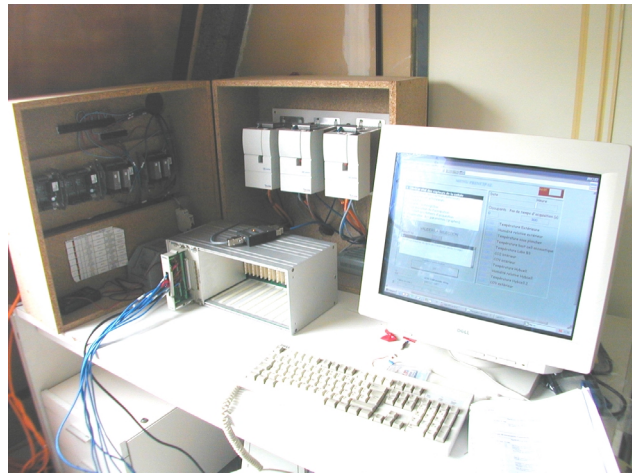


Figure 16 : Views of pilot system of the test cell

7 THE LARGE HALL HVAC EQUIPMENTS

An artificial climate can be created around the test cell thanks to an HVAC system (figure 17 and 18) comprising a duct network as well as an heat pump and a chiller placed on the roof . Temperature can be controlled between 5 and 20°C in winter and 15 up to 35°C in summer. The main technical characteristics of these equipments are as follows :

- Maximum pressure drop in supply and exhaust network : about 390 Pa.
- Maximum air flow rate : 6000 m³/h (both exhaust and supply)
- Minimum supply temperature : 5°C
- Maximum supply temperature : 50°C
- Cooling power from chiller : 25 kW. Cooling power delivered to supply air fully controlled through 3-way valve.
- Heating power from HeatPump : 25 kW (reversible heat pump, possibly converted to Chiller with 20 kW maximum power). Heating power delivered to supply air fully controlled through 3-way valve.
- Additional electric heating coil : 20 kW
- Heat recovery unit

No humidifier is currently being installed, though there is provision for it in the supply air handling unit.



Figure 17 : Views of the duct network of the large hall



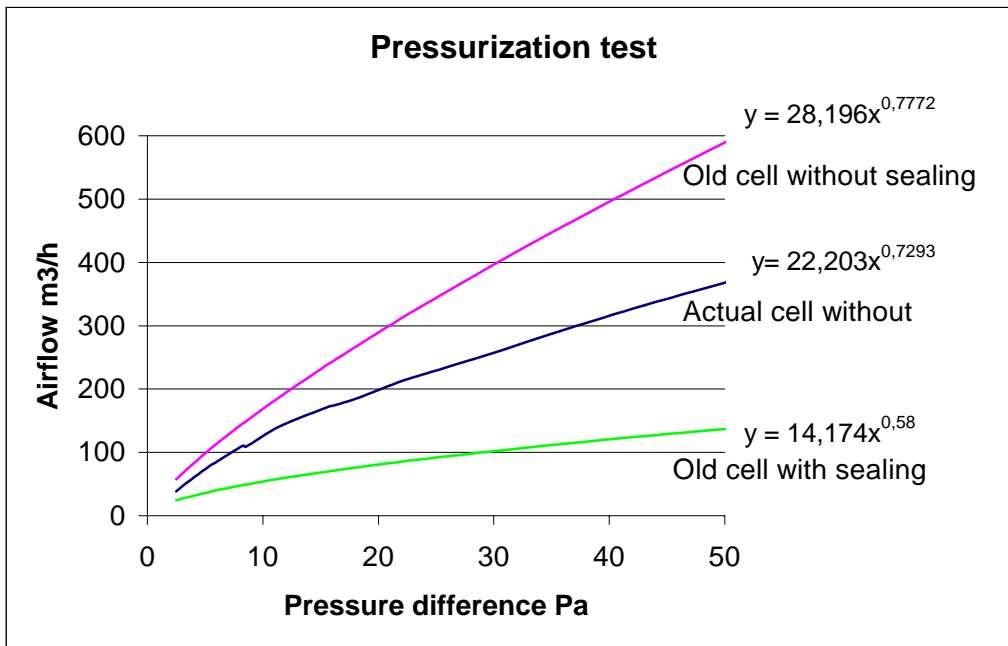
Figure 18 : View of heat pump (left) and three-way valve for heating power control (right)

8 THE EXPERIMENTAL TEST CARRIED OUT

Experimental tests were carried out in order to determine the thermal and aerodynamics parameters of the test cell and asses the physical model.

8.1 HYBCELL's pressurization test

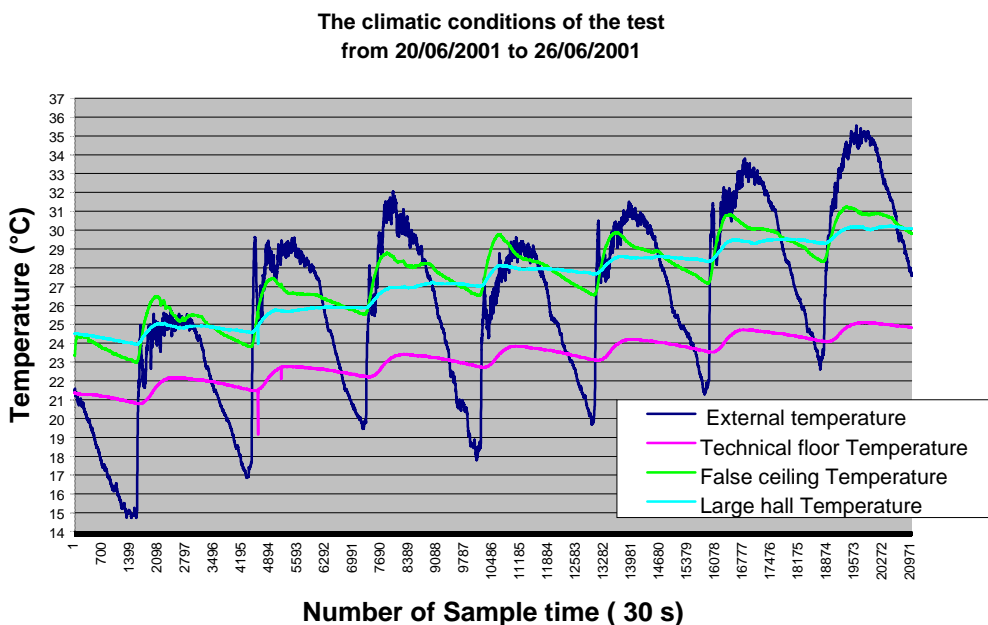
The aim of this test is to characterize the infiltrations due to the pressure difference between the test cell and outdoor. Pressurization test was carried out without sealing the test cell. The following curve represents the results obtained:



The comparison of the results of the pressurization tests shows that the leak-flow decreased and that one can especially decrease more this flow by sealing the test cell cracks.

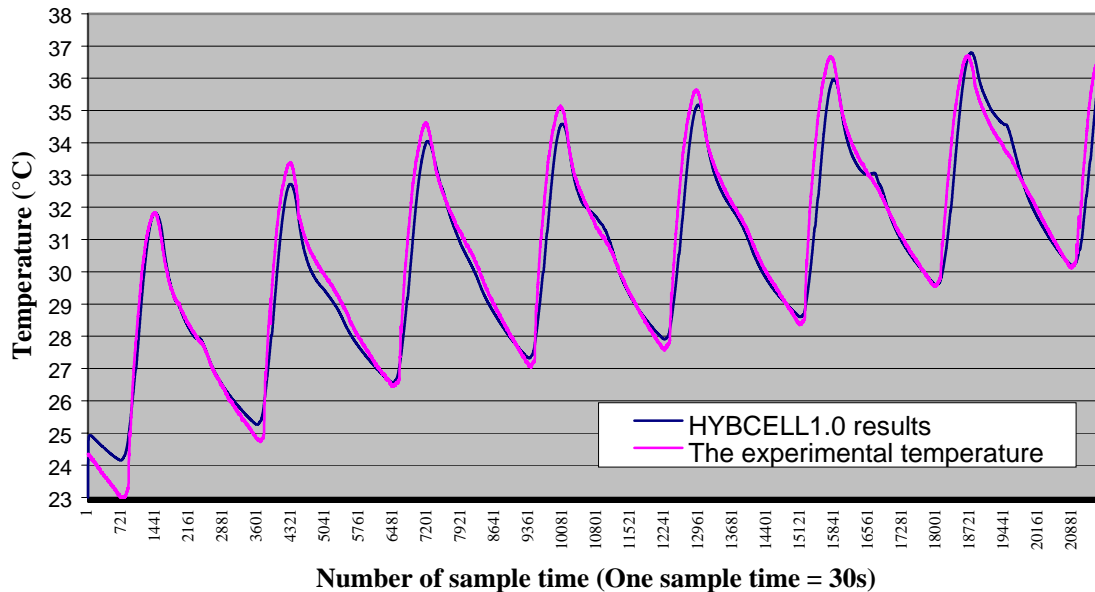
8.2 The calibration of the physical model

A software (**HYBCELL1.0**) has been developed using MATLAB/SIMULINK to simulate the behaviour of the test cell when applying the control strategies for Hybrid Ventilation. In order to adjust this physical model, experimental testing has been carried out during June 2001. The climatic conditions of the test are shown in the following graphics:



The simulation results are shown in the graphic below.

HYBCELL1.0 adjust test results
From 20/06/2001 to 26/06/2001



8.3 The Pressure Coefficients

The pressure coefficients values have to be correctly evaluated when simulating the air flow throughout the openings. In the case of the HYBCELL test cell those coefficients are influenced by the lateral masks, the sloped façade (figure 4) and the surrounding environment (trees and buildings). Experimental tests have been carried to estimate the pressure coefficients. Each window is equipped with a differential pressure sensor measuring (each 15 s) the dynamic pressure of the wind. The information on wind speed and wind direction are given by the ENTPE meteo station

9 CONCLUSION AND OUTLOOK

The HYBCELL experimental device has been created by totally retrofitting an old test cell. The aim is to develop and experimentally evaluate control strategies for hybrid ventilation systems. The test cell was first used (in June 2001) to adjust a thermal model and characterize the air flow throughout openings (determination the pressure coefficients (CP) and discharge coefficients (Cd)).

Several control strategies for hybrid ventilation system will be tested using the HYBCELL test. In a first time, basic control strategies will be tested:

- Control strategies based on only one control parameter: On-off and PID Controllers based on temperature, CO₂, and PMV control
- Control strategies based on time: night ventilation

Other and more elaborated control strategies based on multicriteria approach will be tested and optimized.