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Experimental Study of a Mechanical Ventilation System in a Greenhouse

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Greenhouse cultivation is one of the most energy intensive activities in agriculture. This is especially true in cold climate zone. Generally heating systems involves boilers fed with fossil fuels. This means low yields of the heat generator and high pollutant emissions. Moreover, the increase of annual crop yield in greenhouses is possible only through a very close control of the internal conditions. Ventilation systems could allow proper control of temperature, relative humidity and CO_2 rate. For this purpose a prototype of a mechanical ventilation unit was installed at service of a mini-tunnel greenhouse. The recovery unit is equipped with a heat pump and is able to increase the thermal energy recovered, by the flow of exhaust air, through a high efficiency heat exchanger. A first study was carried out to evaluate the thermophysical and energy performances of the system during the heating season. The experimental apparatus consists of mechanical ventilation system, a perforated duct for air distribution, a fog system to adjust humidity and a supervision system to acquire the field data. Another dedicated supervision system allows to measure and collect all the parameters of the prototype, such as thermophysical parameter of the air flow, thermophysical parameter of the refrigerant circuit of the heat pump, status and alarms of the unit. To characterize the whole system under investigation the main data measured are temperature, relative humidity and carbon dioxide inside the greenhouse and temperature in all section of the prototype. Other two mini-tunnel greenhouses are monitored as references. One is heated with radiant tubes placed on the bench and humidified with a fog system, the other is completely passively heated (without heating system) and humidified with the same fog system. A First test was performed to evaluate the ability of the system to regulate the indoor temperature of the greenhouse with a set point of 27 °C. By using a temperature probe installed on the return side of the machine, the results shown an appropriate temperature regulation.

1. Introduction

Nowadays energy saving is one of the most important challenges to overcome. This is particularly true when related to the conditioning of greenhouses to manage their internal climate. Environmental control of greenhouses involves the managing of temperature, humidity and carbon dioxide of the indoor air. To this purpose several systems were studied. Sethi and Sharma (2008) have classified these systems as heating system, cooling system and composite system:

- Heating system: water storage, rock bed storage, PCM's (Phase Change Materials) storage, movable insulation, ground air collector and north wall.
- Cooling system: natural and forced ventilation, shading and evaporative cooling (fan-pad, mist/fog and roof cooling).
- Composite system: EAHES (Earth-to-Air Heat Exchanger System) and ACCFHES (Aquifer Coupled Cavity Flow Heat Exchanger System).

With particular attention to ventilation, only in recent years mechanical ventilation was proposed as an alternative to natural ventilation. Commonly, both indoor temperature and humidity are controlled by opening, manually or automatically, the windows alongside the greenhouse or on his rooftop. In this way the indoor air

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is replaced with the outdoor one which has a lesser content of moisture and a lesser temperature value. Also the adjustment of CO_2 happens in the same way. Generally the outdoor carbon dioxide level is higher than that of the indoor due to its consumption in the photosynthesis.
Natural ventilation is based on the pressure difference between the indoor of the greenhouse and the external environment. Consequently, its efficiency is closely linked to the climatic zone in which the greenhouse is located. In fact, the effectiveness of mass and energy exchange is related to the outside wind and internal and external temperature. Moreover, natural ventilation efficiency is function of the design characteristic of the greenhouse (e.g. size, shape and position of the openings). When only natural ventilation is used to control the climate condition the greenhouse is considered an “open-system”.
In the recent year, also mechanical ventilation was considered to maintain the internal condition. The presence of fans shows a lesser dependence from the external condition and internal buoyancy forces than natural ventilation (Fuchs et al., 2006). Thus mechanical ventilation reduces internal air stratification and vertical temperature gradients in summer. Furthermore, this system allows to treat the air flow rate before its inlet in the greenhouse (air flow mixing, heat recovery, pre-heating, etc.). If only mechanical ventilation is used the greenhouse is a “closed-system”.
From a literature search of recent studies on mechanical ventilation systems appears that only few works deal with this topic. In addition it is usually accompanied by natural ventilation. As a result you have a “semi-closed” system. In these systems, generally, mechanical ventilation is used as the primary means, limiting the use of natural ventilation at times in which is energetically and economically viable.

2. State of art

Van de Bulck et al. (2013) studied an innovative ventilation concept based on intensive screening and controlled ventilation through combined mechanical and natural ventilation. The experimental apparatus was installed in a warm temperate humid climate zone. The ventilated greenhouse was insulated with two thermal screens. A first screen guarantees a high thermal insulation (67 %) but a low optical transmission (25 % in sunlight and 24 % when overcast). Thus it was used only during night-time. The second screen was a movable AC foil (anti-condensation foil) with high optical transmission (90 % in sunlight and 90 % when overcast). The purpose of this experimental apparatus was that of postpone the need of natural ventilation through mechanical dehumidification. The mechanical ventilation system was equipped with three intake ducts for the adjustment of the supply air. One duct is located external to the greenhouse and is committed to carry within the compartment the outdoor air. The other two intake ducts was installed at the inner side of the greenhouse. Particularly, one is placed above the screens the other below them. The latter is used for recirculation of internal air while the upper intake can provide drier air for dehumidification. The air mixing required at the inlet of the compartment was adjusted by controlling the valves installed on the intake ducts. The supply air is blown below the growing gutters through a perforated air duct. Finally, the air before entering the greenhouse pass through a low temperature heat exchanger. The main heating system of the compartment was done by two tube rails and two growing tubes for each growing gutter.
A central Building Monitoring System (BMS) allowed managing all field devices and to acquire all the data measured on a minute basis and averaged every five minutes. The mechanical ventilation system has shown an energy saving up to 12 % if compared with a reference greenhouses equipped only with natural ventilation system. Moreover, it can be argued that mechanical ventilation improves homogeneity of the indoor climate and stimulates plant activity.
Coomans et al. (2013) have conducted an almost identical experiment to that above described, except for the presence of an air-to air heat exchanger. Furthermore, this system has only two intake ducts. The first one positioned in the inner side of the greenhouse under the thermal screens, while the second one is located at the exterior providing outdoor air supply. In this concept a first screen has high thermal performance and low optical transmission (72 % thermal insulation, 18 % direct light transmission and 17 % diffuse light transmission) and a second screen has mediocre thermal performance and high optical transmission (45 % thermal insulation, 84 % direct light transmission and 75 % diffuse light transmission).
The presence of the heat recuperation reduces energy loss when ventilating with cold outside air. Heat exchanger extracts heat from the exhaust air outgoing the greenhouse to pre-heat the cold incoming airflow from the outside. Thus, heat loss can be reduced when mechanical ventilation was used for dehumidification. In this application totally heat recuperation of 30 kWh/m2, which correspond to 12 % of the ventilated greenhouse’s energy consumption, was obtained. Measurements have shown that an average efficiency of 25 – 40 %. The data acquired showed that efficiency has a strong dependence on air flow rate (the efficiency increases when the ventilator is at maximum capacity and the outside intake is opened at 100%). Moreover, when natural ventilation is used combined with mechanical one the efficiency decrease further. This is easily explained by the fact that indoor air parameters conform to the outside conditions by resulting in a reduction of

heat potentially available for recuperation. The new mechanical ventilation system has shown an energy saving of 28% respect to the reference greenhouse in which only natural ventilation is used. Indeed, in the same period the reference greenhouses needed more heat to compensate the heat loss due to the frequent use of natural ventilation for dehumidification.
It is finally important to note that the presence of a low temperature pre-heater has reduced the need for tube rail heating in both cases of study above mentioned and has completely replaced the growing tube network in the second case. Since the use of a low temperature heater is advantageous for energy performance of the system, it is important to evaluate the possibility of using more efficient heat source than boiler.
In the recent years an innovative mechanical ventilation system equipped with an air-to-air heat exchanger and integrated with a heat pump (SIVeMeC: SIstema di Ventilazione Meccanica Controllata: Integrated System for Controlled Mechanical Ventilation) was realized and tested (Fucci et al., 2016). This new concept of heat recovery was optimized and installed at service of a mini-tunnel greenhouse. The main differences with the cases of study aforementioned (in particular with the second study) are a higher efficiency of the heat exchanger and a heat pump with BLDC compressor driven by an inverter as a heat source for the pre-heating of the supply air flow rate. This means very high energy performances.
The present work focused on the new experimental apparatus installed at Vivaio Verde Molise, Termoli – Italy. A description of the main components of the system and a first evaluation on the internal distribution of temperature by using SIVeMeC are outlined in sections 3 and 4.

3. Materials and Methods

The experimental apparatus is composed of the mechanical ventilation system SIVeMeC, a distribution system and a Building Monitoring System (BMS).
SIVeMeC is the realized prototype, equipped with a static heat exchanger and integrated with a reverse-cycle heat pump machine. Its main components are:

- a high efficiency counter-current heat exchanger able to ensure the highest possible static recovery;
- a high efficiency electronic fans which speed is modulated by an inverter;
- a rotary compressor BLDC (Brushless Direct Current) for modulation of the thermal load;
- an electronic expansion valve for superheating management;
- a programmable control unit to control the summer and winter configurations.

The system was optimized for greenhouse application. While, when applied at the civil sector, a mechanical ventilation system should provide the only amount of outdoor air for the indoor air quality, in greenhouse application also a quantity of recirculating air could be considered.
The existing internal partitions combined with the internal by-pass ducts allows to operate according different arrangements:

- passive plus active recovery, when by-pass ducts are closed and the compressor is active;
- only passive recovery, when by-pass ducts are closed and the compressor is disabled;
- only active recovery (thermodynamic recovery), when by-pass ducts are open and the compressor is active;
- freecooling/freeheating, when by-pass ducts are open and the compressor is disabled.

To add the possibility of recirculating the internal air will be realized (not yet installed) a duct which connects the recovery side with the supply one. A regulation damper will be managed by SIVeMeC to adjust the air flow rates as a function of the damper degree of opening. To date the operating logics in SIVeMeC to control the damper are implemented. However, a strong recirculation of indoor air means an additional strain for greenhouse dehumidification and consequently an increase in energy consumption. Hence the decision to delay the installation of recirculating duct. Nevertheless, a future installation of this system is possible since the application software for damper regulation is already installed.
Another optimization of mechanical ventilation system for greenhouse application involves the approach of the unit about the management of the level of carbon dioxide. As opposed to the civil sector, where the supply air flow rate increase linearly with the CO_2 concentration, in greenhouse application there is a CO_2 depletion. So a variation in operating logics related the indoor air level of carbon dioxide was made. The control of the air flow rates was done primarily as a function of temperature and relative humidity. Thus, in contrast with previous application the air flow rate never decreases when CO_2 level increases.
For a suitable distribution of the supply air a perforated duct was designed and realized. A stainless steel tube of diameter 250 mm, with 5 holes each side of 10 mm and with a distance of 40 mm, was installed in the ridge of the greenhouse. It was connected with the supply side of the unit through an insulate hose. The perforations were designed to guarantee homogeneity of distributions and to avoid high values of air speed near the plants. The recovery side was connected to the mechanical ventilation system through a hose and a plenum. The aspiration and discharge duct are galvanized steel tubes of diameter 250 mm.

Figure 1 shows the experimental apparatus. It consists of three mini-tunnel greenhouses type (A, B, C) of 1.8 x 10 m and 1.3 m high: A is the reference one, B is heated by a flat plate collector placed on the bench and C is air-conditioned with SIVeMeC and if necessary with the flat plate collector.
SIVeMeC allows to balance the thermal load of the greenhouse C by adjusting the supply air temperature. In this way the internal temperature should be kept constant. Instead in the greenhouse B temperature was not controlled because the collector on the bench are always supplied with water at 22 ± 2 °C. Thus, the internal air temperature was influenced by the external conditions (increases in mild days and decreases in cold days). In the reference greenhouse A, the flat plate collector is closed with a gate valve. Only relative humidity is controlled by introducing water through misting nozzles. The relative humidity set point was set at RU 80 ± 5 %. The same system and regulation of humidity was used in the greenhouse B. To regulate relative humidity in greenhouse object of study (C) a separate line of water supply was installed. The supervisor reads the internal value of relative humidity and manages the solenoid valve opening. This new line is necessary since the presence of mechanical ventilation system produces a higher level of dehumidification than reference case.
Finally, CO_2 reads by two probes inside the greenhouse acts on the managing of the electronic fans which regulates the air flow rate to maintain a proper internal carbon dioxide level.

Figure 1: Experimental apparatus installed at Vivaio Verde Molise, Termoli - Italy

The main action for the optimization of a compact mechanical ventilation system at service of greenhouse was the control panel (Figure 2). A BMS system was used to acquire and control all the field parameters. In this way, the complete system (SIVeMeC and control panel) allows to regulate the internal conditions.
The BMS system was a supervisor able to communicate with field devices through Modbus protocol. A I/O module and three parametric controllers (DN33) was configured on a bus line. I/O module allows to collect temperature values along the greenhouse (4 NTC probes), while the DN33 controllers allow to acquire values of relative humidity (2 RU probes), CO_2 concentration (2 CO_2 probes) and air speed (2 ILV probes). Particularly, the DN33 at which was connected relative humidity probes permits also the activation of a solenoid valve to manage the activations of a fog system (Figure 2).
Also an energy meter was installed on a second Modbus line (because of a different speed of communication: 9600 baud/s). In this way is possible to evaluate the coefficient of performance of the SIVeMeC because the energy meter was inserted on the power line of the ventilation unit.
A second supervisor installed on a PC allows to manage and acquire all the parameters of SIVeMeC (including alarms and status).
A first test was performed to evaluate the ability of SIVeMeC to regulate the internal greenhouse temperature. The mechanical ventilation systems read the exhaust air temperature T_e, through a probe on the recovery side, and regulates the supply air temperature T_s to keep the indoor air temperature to the set-point.

The data logged with the supervisor on the PC were collected with a sampling time of 1 second, while the data recorded by the BMS system every 30 seconds.

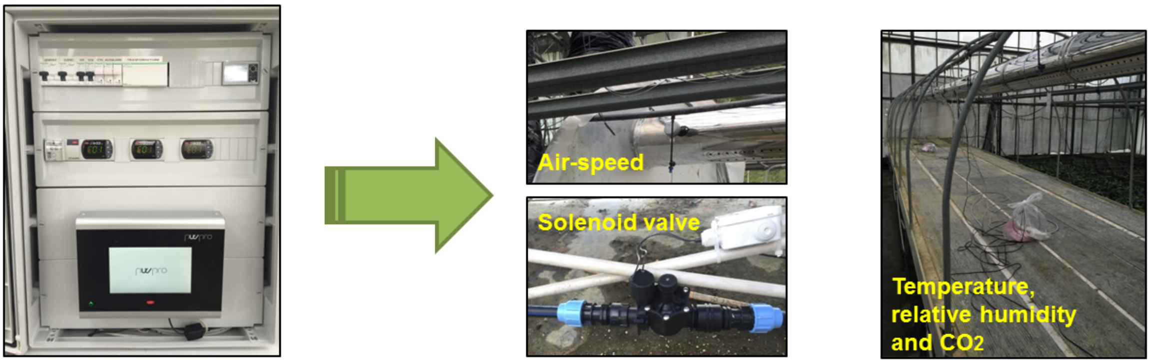

Figure 2: Control panel with a I/O module, 3 parametric controllers and an energy meter

4. Results and discussion

A first evaluation of internal air temperature managing in greenhouse application was made. Figure 3 shows the exhaust air temperature T_e and supply air temperature trends T_s as the outdoor air temperature T_o changes. The test was carried out with a set point of internal air temperature of 27°C. The probe for the regulation of SIVeMeC was installed on the recovery side of the unit (on board).

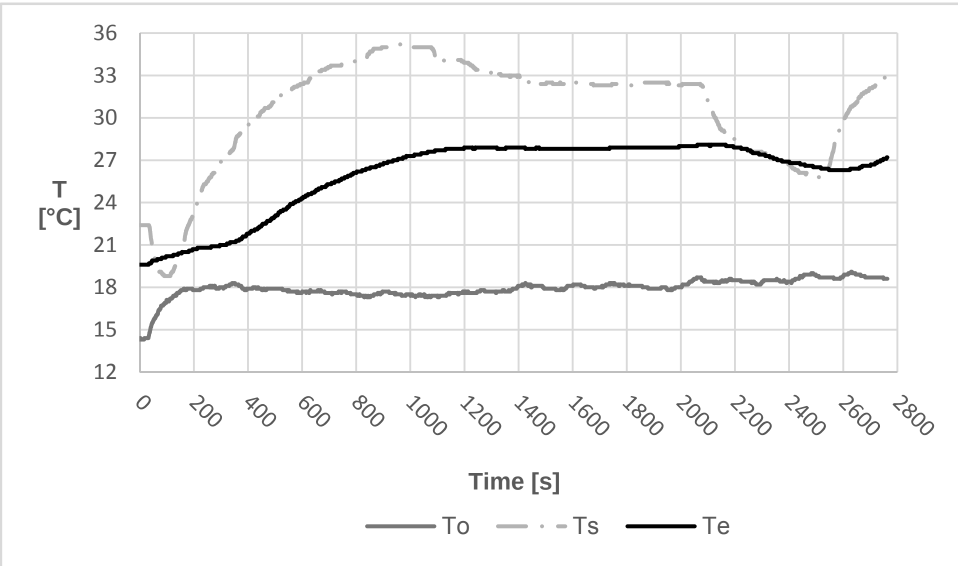

Figure 3: Exhaust air temperature (Te) and supply air temperature (Ts) as a function of outdoor air temperature (To)

At the beginning of the test the T_s grew quickly to balance the thermal load and to bring as soon as possible T_e to the set-point. In fact, after a first step in which SIVeMeC worked with only passive recovery, the compressor was turned on. When T_e reached the set point the heat pump was modulated and then disactivated. However, when only passive recovery occurred T_e is slightly decreased so the compressor was turned on again.

Figure 4 shows the air temperature inside the greenhouse. The NTC probes are installed along the greenhouse at 2,5 m distance each other. The probes are numbered from 1 to 4 moving away from the recovery intake.

A heat loss along the recovery duct explains a slightly higher temperature in the greenhouse respect to T_e. However, it could be seen that the internal distribution of temperature is almost homogeneous. A slight gradient of temperature towards the final part of the compartment was revealed. This is mainly due to the return air system configuration. A single intake grid was installed at the beginning of the greenhouse. Thus,

the air introduced in the first part of the compartment is also the first to exit. Divide the return air system with a grid on the beginning side and a second grid on the end side could equalize the indoor air temperature.
Additional investigation could lead to a further adjustment of the regulation of the unit. For example, is possible to set an appropriate offset on the exhaust air read temperature to avoid a higher value of the internal air temperature than desired one or by using an indoor air temperature probe to regulate the supply air temperature.

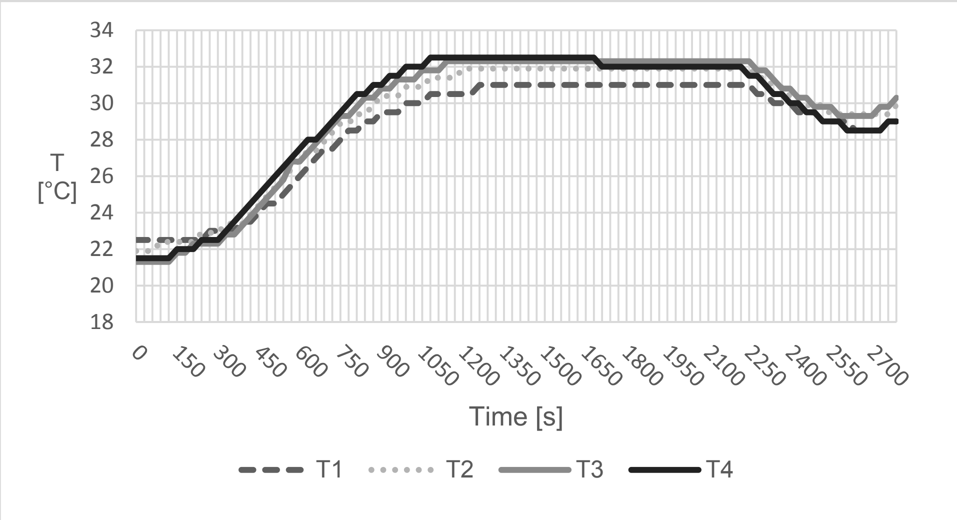

Figure 4: Temperature distribution inside the greenhouse

5. Conclusions

Energy savings to manage the internal microclimate conditions of greenhouses is becoming increasingly important. A new concept of mechanical ventilation with heat recovery and heat pump was installed at service of a mini-tunnel greenhouse. The experimental apparatus involves also two supervisor systems, one for the monitoring of the field (greenhouse), the other for managing the mechanical ventilation unit. The ventilation unit should allow a proper control of indoor climate condition (temperature, relative humidity and CO_2).
A first test on the regulation of the indoor air temperature was carried out with a set point of 27 °C. The results show a suitable regulation when the reference probe is that installed on the recovery side, while an offset of few Celsius degree is observed with the probes inside the greenhouse. This is due to the heat loss along the recovery duct and the configuration of the recovery system (only one intake grid installed at the beginning of the greenhouse).
It can be concluded that the greenhouse conditioning is possible with this system (which had already shown high energy performance in civil sector).
Future tests will allow to evaluate the energy performance of the system and an economical evaluation in terms of energy saving and increasing of crop yield.

Reference

Coomans M., Allaerts K., Wittemans L., Pinxteren D., 2013, Monitoring and energetic performance of two similar semi-closed greenhouse ventilation system, Energy Conversion and Management 76, 128-136

Fucci F., Perone C., La Fianza G., Brunetti L., Giametta F., Catalano P., 2016, Study of a prototype of an advanced mechanical ventilation system with heat recovery integrated by heat pump, Energy and Buildings 133, 111-121

Fuchs M., Dayan E., Presnov E., 2006, Evaporative cooling of a ventilated greenhouse rose crop, Agricultural and Forest Meteorology 138, 203-215

Sethi V.P., Sharma S.K., 2008, Survey and evaluation of heating technologies for worldwide agricultural greenhouse applications, Solar Energy 82, 832-859

Van de Bulck N., Coomans M., Wittemans L., Hanssens J., Steppe K.,2013, Monitoring and energetic analysis of an innovative ventilation concept in a Belgian greenhouse, Energy and Buildings 57, 51-57