Airlit – PV: Demonstrating an innovative building façade component.

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Synopsis

A major concern of those wishing to limit the energy use in buildings is the growing trend towards installing air-conditioning in new and refurbished buildings. Building design, high thermal loads, and a desire for perceived comfort, contribute to an ever-growing demand for full air-conditioning. Therefore, to counter the impact on building energy use, it is essential that building design and operation is developed to minimise the use of air conditioning systems. The Airlit - PV project has taken this challenge and has designed an innovative façade unit incorporating the latest thinking in natural ventilation, night cooling, fuzzy control and photovoltaic power. This part funded DETR Partners in Innovation project has developed an integrated modular façade unit that can reduce, or possibly eliminate, the need for air conditioning in appropriate buildings.

The Airlit – PV unit adopts an integrated approach to the role of the building envelope by:

- Providing controlled natural ventilation
- Optimising night cooling
- Controlling solar gain
- Utilizing PV power to operate the local intelligent control unit

The design of the first prototype was reached by adopting conventional components and adapting them as required. The main intention was to produce a working unit from which development could proceed. This first prototype unit and results of its performance have already been reported (1). The main conclusion of the testing carried out over the summer of 1999 was that by a combination of daytime and night-time cooling, based on internal and external temperatures and occupant control, the Airlit-PV unit could improve internal office conditions. However, these results, together with simulation studies, showed that the design could be enhanced by a number of modifications, both to the physical construction and the control and operation. This paper reports the developments made to the first prototype unit and the results of further testing.
Figure 1. The first prototype Airlit – PV unit

Figure 2. The second prototype Airlit – PV unit
Design Developments

In order to improve the performance of the Airlit – PV unit in line with the findings of the first year of testing and computer optimisation the following aspects were developed for the second prototype:

- Carbon dioxide demand controlled ventilation
- Improved airtightness and thermal performance
- Stand alone PV operation
- Quieter mechanical ventilation operation
- Fuzzy control

Each of these improvements is discussed below and the improvement in performance discussed.

Carbon dioxide demand controlled ventilation

Demand control of the ventilation was seen as an important function of the unit. Therefore carbon dioxide (CO₂) sensing was incorporated into the unit, as an indicator of indoor air quality. This allowed windows and vents to be opened in response to air quality rather than temperature alone, as in the first prototype, and ventilation control would be independent of internal or external temperature. The measurement of CO₂ in the office was implemented firstly into the ‘classical’ on/off control strategy under which the unit was operating. The following control strategy was adopted for the classical on/off demand control:

*If CO₂ concentration exceeds threshold, open trickle vent (assuming it is shut normally the trickle vent will be open during the occupied day unless manually closed by the staff). If the CO₂ concentration continues to exceed the threshold for a further 5mins, open top vent. As soon as the CO₂ concentration falls below threshold, close top vent.*

Improved airtightness and thermal performance of lower vent

The construction of the lower vent (a fire damper) in the first prototype provided a poor air and thermal seal. In redesigning the lower vent it was decided that:

- the opening area should be reduced,
- its closed thermal properties must be improved,
- the air tightness must be improved,
- there should be space below the vent to accommodate the Programmable Logic Controller (PLC) and batteries.

A new inward opening ‘hopper’ style ‘window’, that had a good seal and much improved thermal performance, was installed in place of the previous damper. There was also space below the unit to accommodate two batteries and the PLC. The fixed external louvres were retained.
One of the primary objectives for the Airlit-PV project was the development of an integrated stand-alone pre packaged façade unit powered by integral photovoltaics. The first prototype had used mains power for the control unit and motors but for the second prototype unit PV maintained battery power alone was the aim.

At BRE, the office selected for testing the Airlit-PV façade, faces almost due west so initially, the PV panel was mounted as a vertically pivoted side fin. This configuration was not ideally matched to the window it was protecting and unlikely to satisfy the aesthetic requirements of an architect. Computer simulations were used to investigate the reduction in overheating from the shading effect of the side fin and these also showed little benefit because the panel protects only one of the three window bays. As a result of these findings, the PV panel was moved from its vertical fin position and relocated across the external louvres of the lower vent.

To establish the capacity and type of batteries required for the system, simulation studies were carried out using the PV design tool program PVSYST. The results of this exercise indicated that satisfactory performance should be attained using two 12 volt, 30 amp hour sealed lead acid batteries wired in series to provide 24V. However, the prototype Airlit- PV façade had been equipped with an 85 Watt PV panel, with an output voltage of 18 volts. This made it unsuitable for charging two 12V batteries in series. Consequently an electronic switching system was devised such that the output from the PV panel fed into a “solar shunt regulator” (which limits the lead acid battery charging voltage to 13.8V) and the output from the regulator was then connected to each of the two batteries in turn. This was achieved by using a time-controlled relay. Although the cyclic time of the relay can be varied over a wide range, best performance was obtained with a cyclic time of about 5mins.
Quieter mechanical ventilation operation

An innovative feature of the Airlit-PV façade is the axial fan located within the trickle vent unit. The fan control strategy automatically provided assisted night cooling during periods of warm weather and enhanced airflow in the daytime if requested using the ‘fan’ button on the remote control box.

The fan operated satisfactorily at night as part of the night cooling strategy but was rather noisy for undisturbed daytime use under the control of the occupants. As the fan unit was known to be mechanically quiet, the noise was thought to be caused by the external grill restricting the flow of air into the office. Therefore, the external fan grill was replaced with one affording better airflow characteristics. In addition, a hopper style air deflector was been added to the trickle vent grill to avoid draughts at head height, Figure 4.

Fuzzy control of unit

The classical on/off strategy had been very successful in controlling the office conditions and achieving night cooling even in the lightweight building. With the second generation of PLC, the opportunity to use fuzzy logic became available.

Although the classical control had performed well from an energy and environmental point of view, the office occupants had reported that, on some occasions, the top vent opened and closed repeatedly. A study of the program logic revealed that while the internal temperature had an in built 5min-delay loop that smoothed internal temperature variations, the external temperature did not. In the autumn and spring the external temperature is close to the threshold set point at which the top vent is
allowed to open and can quite rapidly fluctuate causing the vent to open and close. Although the implementation of the fuzzy control logic would solve this problem, a quick interim fix was accomplished by introducing a 2°C dead band into the external temperature.

Fuzzy logic control has several key features that enable a system to perform better than a conventional set of classical control algorithms. The control language is related to normal human categorisation and it uses linguistic terms to describe the input values. It can deal with several inputs at once and take account of the value of each parameter. A typical fuzzy control rule will allow a boundary over which an input parameter may vary and the appropriate control output will not change. As a result of this fuzzy control can be an ideal way to control the environment of buildings.

To implement the fuzzy control logic it was necessary to fit limit switches to the upper vent in order that it could feedback intermediate positions to the control unit. These were installed on a temporary bracket fixed to the inside of the frame, Figure .

The fuzzy control algorithms were based on the successful classic control algorithms. A series of rules were developed relating the output parameters to a set of input conditions. Two series of rules were required to cope with the differing needs of daytime and night-time operation. The input and output parameters are shown in the tables below.

### Daytime fuzzy control

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. indoor air temperature.</td>
<td>1. position (%) of upper ventilation opening</td>
</tr>
<tr>
<td>2. average CO2 concentration during the last five minutes.</td>
<td>2. position (%) of lower ventilation opening</td>
</tr>
<tr>
<td>3. difference between indoor and outdoor air temperature</td>
<td>3. position of the trickle vent (open-close)</td>
</tr>
</tbody>
</table>

### Night-time fuzzy control

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. average indoor temperature during the day: Tintavg</td>
<td>1. vent position (%), that is the position of upper ventilation opening.</td>
</tr>
<tr>
<td>2. difference between indoor and outdoor temperature: DT_inout</td>
<td>2. position (%) of lower ventilation opening. (Note These openings have the same position during night time).</td>
</tr>
<tr>
<td>3. difference between indoor and heating set point temperature: DT_inset</td>
<td>3. ON/OFF operation of the trickle vent fan</td>
</tr>
</tbody>
</table>

To develop the control rules the various input and output parameters are coded and rules established as to their interaction. To illustrate the nature of the control rules developed an example of some of the daytime rules is given below:

### Part of the rule base for fuzzy daytime control:

1. If (Tint is LOW) and (DTinout is POSITIVE) and (CO2 is OK) then (Upper is CLOSE)(Lower is CLOSE)(trickle is CLOSE)
2. If (Tint is LOW) and (DTinout is POSITIVE) and (CO2 is HIGH) then (Upper is CLOSE)(Lower is CLOSE)(trickle is OPEN)
3. If (Tint is LOW) and (DTinout is POSITIVE) and (CO2 is VERY_HIGH) then (Upper is CLOSE)(Lower is CLOSE)(trickle is OPEN)
4. If (Tint is LOW) and (DTinout is SIMILAR) and (CO2 is OK) then (Upper is CLOSE)(Lower is CLOSE)(trickle is CLOSE)
5. If (Tint is LOW) and (DTinout is SIMILAR) and (CO2 is HIGH) then (Upper is CLOSE)(Lower is CLOSE)(trickle is OPEN)
6. If (Tint is LOW) and (DTinout is SIMILAR) and (CO2 is VERY_HIGH) then (Upper is OPEN)(Lower is CLOSE)(trickle is OPEN)
7. If (Tint is LOW) and (DTinout is NEGATIVE) and (CO2 is OK) then (Upper is OPEN)(Lower is OPEN)(trickle is OPEN)
8. If (Tint is LOW) and (DTinout is NEGATIVE) and (CO2 is HIGH) then (Upper is OPEN)(Lower is OPEN)(trickle is OPEN)
9. If (Tint is LOW) and (DTinout is NEGATIVE) and (CO2 is VERY_HIGH) then (Upper is OPEN)(Lower is OPEN)(trickle is OPEN)
10. If (Tint is SLIGHT_COMFORT) and (DTinout is POSITIVE) and (CO2 is OK) then (Upper is CLOSE)(Lower is CLOSE)(trickle is CLOSE)
11. If (Tint is SLIGHT_COMFORT) and (DTinout is POSITIVE) and (CO2 is HIGH) then (Upper is CLOSE)(Lower is CLOSE)(trickle is OPEN)
12. If (Tint is SLIGHT_COMFORT) and (DTinout is POSITIVE) and (CO2 is VERY_HIGH) then (Upper is SEMI_OPEN)(Lower is CLOSE)(trickle is OPEN)
13. If (Tint is SLIGHT_COMFORT) and (DTinout is SIMILAR) and (CO2 is OK) then (Upper is CLOSE)(Lower is CLOSE)(trickle is CLOSE)
14. If (Tint is SLIGHT_COMFORT) and (DTinout is SIMILAR) and (CO2 is HIGH) then (Upper is SEMI_OPEN)(Lower is CLOSE)(trickle is CLOSE)

The complete rule set for daytime operation was 36 rules and for night-time operation 27 rules.

Results

The measurement period was from February to August 2000, thereby including conditions representative of winter, spring, and summer. The office was normally occupied by two or three administrative staff.

Ventilation performance under classic control

Over the first period of the testing (winter) there was very little demand for ventilation cooling. Therefore, the main interest focussed on air quality and the setting up and operation of the CO2 monitor. The control set point for the top vent was 1500ppm of CO2. This is higher than the typically used figure of 1000ppm but it was chosen to avoid exposing the occupants to high ventilation rates – given their known preference for warm and unventilated offices.

![Figure 5. Opening of the top vent in response to elevated temperature.](image)

Figure 5. Opening of the top vent in response to elevated temperature.

Figure 5, shows how the controller opens the upper vent in response to temperature and illustrates the ability of the unit to provide ventilation to limit internal temperatures. Although this would indicate a higher temperature demand of the heating system than may be desired from an energy efficiency perspective, it was as required by the office occupants.
Figure 6. The top vent opens in response to elevated temperatures and CO$_2$

In Figure 6, the top vent status shows the top window opening in response to elevated internal temperature and high concentrations of CO$_2$. Typically, the unit is responding to high temperature rather than high CO$_2$ levels but on the occasion when CO$_2$ exceeds the threshold the vent is open and the CO$_2$ level falls.

The fuzzy logic approach to this situation would be to take into account the two input parameters (temperature and CO$_2$) and produce an output dependent upon the combined effect.

**Stand alone PV performance**

The results of a six month period – predominantly spring and summertime - indicated that for the most part, Airlit-PV could operate satisfactorily as a stand alone installation. Failures occurred over prolonged periods of sunless weather but for a period of almost three complete months the unit operated autonomously.

Figure 7, below, shows how the battery voltage can recover and be maintained by the PV panel and charging system. Figure 8, shows the current draw from the control unit and sensors and the output of the panel in sunny April conditions.
Figure 7. Battery voltage maintained by PV panel.

Figure 8. Power consumption of controller and output of PV panel and CO2 sensor.

Given the developmental stage of the controller, and the high load imposed by the CO2 sensor (approximately 2.5W which represents an addition of 25% load above that of the controller), it is considered that the losses of power experienced could be easily avoided without resorting to greater battery storage.
Ventilation performance under fuzzy control

Figures 9 and 10 show, respectively, the air temperature and CO₂ concentrations and the upper vent proportional opening in a summer period with moderate external temperature.

Figure 9. Temperature and CO₂ concentration in moderate summer conditions with fuzzy control.

Figure 10. Proportional opening of upper vent over the same period as Figure 9 above.
Relating the internal condition and the proportional opening of the upper vent shows the manner in which the proportional opening of the upper vent is responding to elevated office temperature and concentration of CO₂. On the 30th June the vent is either 50% or 100% open for the majority of the time, see Figure 10, this coincides with moderate temperatures and CO₂ concentration. Over the unoccupied period of the 1st and 2nd July, the upper vent rarely opened more than 25% in response to similar external temperatures but no occupant produced CO₂.

In Figures 11 and 12, the response of the whole façade is illustrated over a week in which both internal and external temperatures were quite high.

Figure 11. Temperature and CO₂ concentration in hotter summer conditions with fuzzy control.

Figure 12. Response of all components of the façade to increasing temperature and CO₂ for period above.
At the beginning of the week, 13th July, with the external temperature quite low, the upper vent opened to only 25% on average. Towards the end of the week, 18th July, both internal and external temperatures were very high but with low CO₂, the top vent was 50% open, the bottom vent 100% open and at night the fan came on for night cooling with the trickle vent open as necessary.

The above operation illustrates the manner in which the fuzzy control logic performed. This method of control was more acceptable to the occupants of the office as it resulted in less activity of the operating actuators and it still provided a significant level of control of both day and night conditions.

Conclusions

The continuation of the monitoring of Airlit-PV in its enhanced state continued to show that the underlying concept was valid. The modifications to the façade based on the experience of the previous years monitoring and simulation all gave positive results. The progression to fuzzy logic control maintained similar environment conditions in the office to the classical control but with better acceptance by the occupants. This could be a major benefit of the fuzzy control.

The results of this monitoring period indicate that the concept of a PV powered stand-alone system, which therefore relies only on renewable energy can be achieved. The experience of this unit’s operation shows that care must be taken to integrate all of the electrical components with respect to their voltages and loads. The control system in particular could be used more to manage the battery charging system and load control.

The current form of the unit most likely requires development from an aesthetic point of view. It is felt that it is not currently attractive to an architect or designer within the concept of an existing or new façade design. However, the current embodiment of the unit is rather more of a test-bed of the concept than a fully developed market prototype. This has been a significant demonstration of a principle that could have a wealth of applications in the refurbishment market place.

References


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