Chapter Six
Conclusions

6.1 Modification of the Test Protocol

The preliminary results suggest that this experimental protocol can appropriately investigate and determine the performance of the double envelope system. The results also infer some potential improvements for this protocol. These are summarized in the following.

1. The thermocouples located in the air cavity and indoor space may from time to time be exposed to direct solar radiation. This may influence the temperature reading accuracy. Shielding protection is needed for these thermocouples to avoid the influence of the direct solar radiation.

2. Due to turbulence that might be presented in the cavity, the air velocity measured by the transducers may be inaccurate. For the active system, a preferred measurement location would be in the exhaust air duct.

3. The possible influence of internal and external pressure effects on the windward and leeward sides of the building, suggests the pressure differential between the interior and exterior of the window model should be monitored.

4. The preliminary results suggest that, for the active system, small unsealed cracks and openings may have a noticeable impact on the cavity air flow rate. A high level of craftsmanship is needed for model building to eliminate this problem.

6.2 Application of the Test Protocol and Preliminary Findings

This study preliminarily investigated and compared the thermal performance of a naturally ventilated and mechanically assisted ventilated double glass façade system under sunny and warm weather conditions. The objectives of this study were to provide the experimental rules on the correct and acceptable way to investigate the behavior of the double envelope system. In addition, the ultimate goal is to increase the understanding of the thermal performance of the double glass façade system.

The preliminary results were analyzed in Chapter Five. These preliminary results support the following conclusion.

1. This first hypothesis of states that during overheated periods, the average cavity heat removed rate will be higher for the active ventilation system. Table 5.1 shows the mean cavity heat removal rate is 57.0% for the active system, and 32.5% for the passive system. When comparisons are made with similar ventilation rates, the active system still has a higher mean cavity heat removal rate than the passive system. As the flow rate increases, the difference becomes larger (Table 5.2). This supports the first hypothesis.

2. The second hypothesis states that the average temperature difference between the indoor air and indoor glass surface will be lower for the active system. Based on Table 5.3, the active system has a lower temperature difference between the indoor glass surface and the indoor air (ΔTga) than the passive system at the upper cavity area, which supports the hypothesis. But at the lower cavity area, the active system has a higher (ΔTga) than the passive system. In addition, for the active system, the lower ΔTga is greater than the upper ΔTga. This was not expected. The active system seems likely to gain the solar heat near the lower cavity. Figure 4.4 shows the blinds form a barrier to reduce the air exchange between the space outside the blinds and inside the blinds, so the air inside the blinds becomes less active. In his paper titled " Active Envelopes: The Future for low-energy office design", Dirk Saelens shows that there is a possibility of higher temperatures in the lower portion of the cavity than in the higher portion of the cavity because of air infiltration (Saelens, 1999). Therefore, the blind barrier and air infiltration are the possible reasons for the higher ΔTga in the active system lower area.

3. ASHRAE Standard 55 shows limits for asymmetry temperature difference in rooms. As shown, occupants tend to be less tolerant of warm ceilings and cold walls when compared to cool ceilings and warm walls, see Figure 6.1. For warm walls (or windows), Figure 6.1 suggests that the percent of dissatisfied occupants is less than 2 percent with radiant temperature asymmetry less than 20°F (ASHRAE, 1997). In this study, the maximum temperature difference between indoor glass surface and indoor air is 14.4°F (Table 5.3). Therefore, for the well operated one story module double glass façade system such as the Lloyd's Building, the cavity overheated problem should only discomfort a small percentage of occupants. But if the double glass façade system is designed as a multistory continuous cavity such as the Business Promotion Center, the radiant temperature asymmetry for upper floors will be much higher than at low elevations, and probably will cause a higher percentage of dissatisfaction. Figure A14 to A17 show that the solar radiation plays a positive factor for the temperature difference between indoor glass surface and indoor air. Therefore, if a proper shading device can be provided to reduce the incident solar radiation, the asymmetric radiation temperature will be improved.

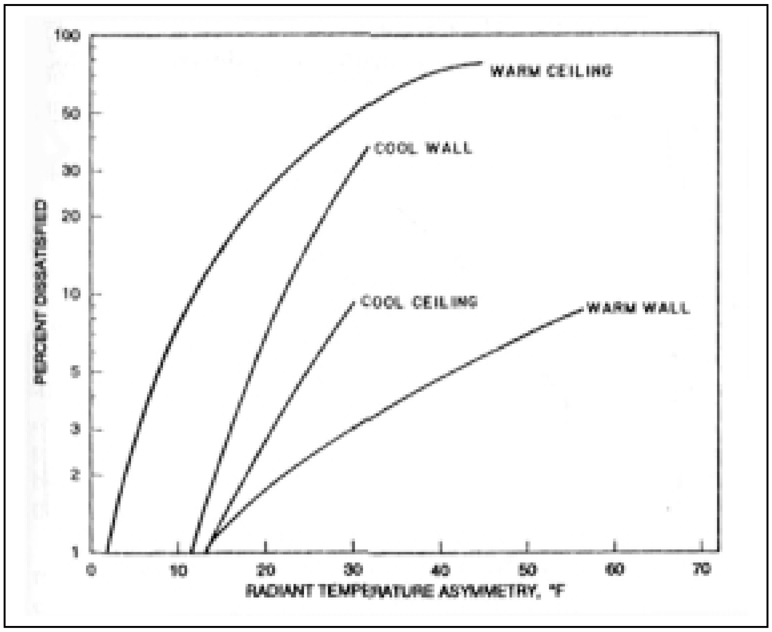

Figure 6.1 Percentage of people expressing discomfort due to asymmetric radiation (ASHRAE, 1997)

6.3 Discussion of the Preliminary Results

1. In this study, for the active system, fans are used to create the air flow through the cavity. For a perfectly sealed envelope, the wind should have little influence on the cavity air flow rate and should not be a factor of the active system's heat removal rate. The possible reason for the wind speed becoming a factor in this function is the air infiltration. The air infiltration affects the cavity air flow rate and consequently may affect the heat removal rate. The air infiltration may also cause the unexpected large range of the cavity air flow rate in the active system (22.3 to 46.9 ft/min).

2. For the passive system, the wind is strongly related to the cavity air flow rate. When wind flows over a rectangular building, like the test cell, it creates a positive pressure on the windward side, and a negative pressure on the Leeward side.

   Table 6.1 shows the wind typically comes from northeast direction, on the backside of the window. Therefore, the front side of the window becomes the Leeward side, which means it creates a negative pressure on the cavity air inlet and outlet opening area. The negative pressure around the cavity air inlet and outlet opening will change the flow pattern in the air cavity and may result in a change in the heat removal rate. This suggests that building pressurization should be monitored, and if possible controlled. It needs more sophisticated and deliberative experiments to investigate how the negative pressure influences the cavity heat removal rate.

Table 6.1 Frequency Distribution for wind direction (South: 0°, West: 90°, North: 180°, East: 270°.)

From (>=)	To (<)	Count	Rel. Freq.
0.000	45.000	0	0.000
45.000	90.000	0	0.000
90.000	135.000	42	.168
135.000	180.000	29	.116
180.000	225.000	33	.132
225.000	270.000	97	.388
270.000	315.000	49	.196
315.000	360.000	0	0.000
	Total	250	1.000

3. The preliminary results suggest how the environmental factors can potentially influence the thermal performance of the double envelope system. Because of the time and data constrain, the preliminary results can basically be used to verify the experimental protocol. The results still provide an initial concept for applying the test protocol.

4. The mechanical equipment plays a critical role in the active system. If the mechanical fan is operated improperly, it may result in the poor thermal performance. The data shows that if the fan is not on, the cavity air temperature can rise to between 120°F and 130°F when outdoor temperature is about 70°F. If the occupants can control the equipment, the possibility exists for misuse which could cause thermal discomfort. Ideally, the control of the mechanical equipment (ex: fans, shading devices) should be linked to the building management system.

5. For the active system, the average cavity solar heat gain is about 1991 Btu/hr. With the average of the 57% efficiency of heat removal rate, about 1134 Btu/hr can be recycled for space heating if without considering the heat loss during the heat transmission. For all commercial buildings, the annual energy consumption for space heating is 29000Btu/ft2 (Department of Energy, 1998). As a standard office space (5 ft x 15 ft), the heat needs for space heating will be about 250 Btu/hr. Therefore, the heat produced in the air cavity of the active system is enough for a standard office heating purpose.

6. During the model construction and data collection period, contamination became a problem for the passive system. Insects often entered the cavity through the inlet and outlets. For example, bees build a nest around the wood corners. Dust also accumulated at the bottom of the air inlet (Figure 6.2, 6.3). This suggests the passive system may need more maintenance.

Figure 6.2 Contamination in passive system: dust collection on the air inlet

Figure 6.3 Contamination in passive system: spider net at the air outlet

6.4 Suggestion of Future Studies

Based on the investigation of these models, some additional studies may follow.

1. Multi-story envelope
   The research can develop a model or computer simulation to investigate the multi-story double envelope system. The interaction of each module may need to be taken into account for thermal performance.

2. Energy analysis
   Based on the thermal performance, the energy consumption of buildings with these systems might be calculated. Also, the installation and operating costs of the double façade system can be analyzed.

3. Compare with traditional building facades
   Some buildings sacrifice the energy saving to accommodate the design aesthetic. A comparison between a building with a traditional façade and with the double façade can improve our understanding for the practicality of the double façade system.

6.5 Summary

This study is not trying to persuade people to believe how wonder of the double envelope system is, but trying to compare the thermal performance of these two different systems, and, hopefully, can provide some useful experimental information, or say protocols, for those people who interested in the study of the double envelope system.

According to the Klaus Daniels in his “Low Tech, Light Tech, High Tech- Building in Information Age,” “The use of double-leaf façades is currently in fashion and is usually justified by an apparent early return on the initial high investment. This is generally, in simple terms, a misconception. Double-leaf facades cost per square meter anywhere form 1,500 to 3,000 DM (about 665 to 1130 USD) and thus much more than well-insulated and finished single-leaf facades, while the energy savings often amount to only approximately 2% to 4% of the extra investment. Hence, in the case of double-leaf facades, it is worth considering whether they should be marketed solely on the basis of energy savings or whether other essential aspects argue for their use.”

The percentage of energy saving may vary from place to place because of the different construction and energy costs, but the cost-benefit of these systems still remains unclear. Because of the complexity and less predictable performance, the double façade systems still needs further study.