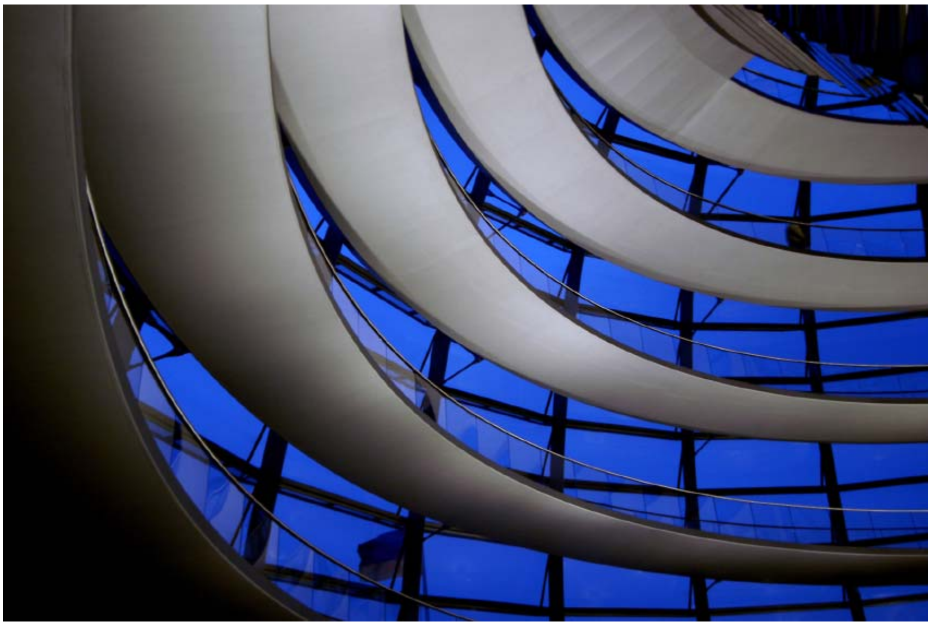
Chapter 9 – Atrium Ventilation Strategies

Building Energy Efficiency Technical Guideline for Passive Design (Draft 1)



CK Tang

Foreword

This document is produced as part of Component 4, Building Sector Energy Efficiency Program (BSEEP) by CK Tang (ck@gbeet.com) and Nic Chin (nc.environmentology@gmail.com).

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CK Tang
August 23, 2012

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9.1 Introduction

It is commonly considered that natural ventilation in atrium spaces is an energy efficient feature in buildings. However, if the atrium space is surrounded by air-conditioned spaces, the exposure of the atrium space to outdoor air will introduce more surface area of the building to be in contact with outdoor air temperature and humidity. This type of exposure increases the risk of conduction heat and air leakages into the air-conditioned space.

Therefore, there is a need to provide a clear guideline on conditions where an atrium is better to be naturally ventilated, when it should not be naturally ventilated or partially naturally ventilated.

Results from simulation studies testing these conditions will be presented in this Chapter.

9.2 Key Recommendations

In terms of comfort at atrium ground floor level it is most comfortable for the space to be air-conditioned. Even the best case of natural ventilation tested for this chapter, it was not able to provide 100% of the occupancy hours at a thermally comfortable environment. At best, a hybrid natural ventilation can maintain thermally comfortable condition for 66% of the building occupancy hours, mostly in the morning hours. In the afternoon, discomfort hours are approximately 3.4 hours per working day.

A hybrid natural ventilation strategy is a system where natural ventilation is promoted whenever the outdoor air temperature is lower than the atrium air temperature and kept air-tight, whenever the outdoor air temperature is higher than the atrium air temperature. This strategy may be implemented using a set of temperature controlled motorized louvers install at the ground floor of the atrium space or manually by the building security/maintenance staff that open the doors for natural ventilation at a fixed time every evening and closed it at a fixed time every morning.

It terms of energy efficiency, the best case of hybrid natural ventilation strategy reduces (based on this case study model) total building energy by a significant 3.3%. Combining air-conditioning system with natural ventilation strategy (natural ventilation during weekend and night time) reduces total building energy by 0.6% as opposed to the base case of air-conditioned scenario with the atrium space kept air-tight all the time.

In summary, if an average discomfort level of ~3 hours every day is acceptable at the atrium space, it will be most energy efficient to provide hybrid natural ventilation strategy. However, if it is not acceptable to have any discomfort hours at all for the atrium space, air-conditioning an air-tight atrium space is the simplest solution. An energy efficiency reduction of 0.6%

Finally, these studies were made with the assumption that daylight harvesting was optimized for the atrium space and very low small power is used in the atrium space. I.e. Daylight Factor is less than 6% at the atrium ground floor level and a maximum of 1 computer is used.

9.3 Comfort

In the test reference building scenario, it was found that the most comfortable strategy is to provide air-conditioning to the atrium floor level. This strategy will ensure that comfort conditions are provided during the entire building occupancy hours of 8am to 6pm.

A test was also conducted with the top of the atrium space open to ventilation (i.e. to allow hot air to escape out of the top of building) while keeping the ground floor level air-conditioned. The result of this test showed a total building energy consumption increase of 1.8%. This increase in energy consumption of the building is largely caused by a higher infiltration rate at the air-conditioned ground floor level when doors are opened for people to walk in and out of the building. This condition could be solved by the installation of a revolving door system at the ground floor (however this situation was not tested due to the limited time available). In short, it was found in these simulation studies that keeping the atrium roof air-tight reduces the infiltration rate at the ground floor level when doors are opened and closed for occupant assess. Therefore, it is better to keep the atrium roof air-tight to reduce building total energy consumption as oppose to having a ventilated atrium roof space to exhaust hot air out. It is also possible to improve energy efficiency further by providing high U-value materials at the atrium roof top level to allow heat to be easily conducted out of the building while keeping the atrium space air-tight because the simulation showed that the top of the atrium space has a consistently higher temperature than outdoor air temperature.

It was also simulated that it is possible to improve tested building energy consumption by 0.6% if natural ventilation strategy is employed whenever the outdoor air temperature is colder than the atrium air temperature even when the ground floor atrium space is air-conditioned.

However, if a lower comfort level is acceptable for the atrium space, it is possible to save more than 3% of total building energy with the application of optimized natural ventilation strategy for the atrium space.

9.4 Natural Ventilation

After a few attempts to optimize natural ventilation in atrium space, it was found that the optimum scenario of natural ventilation tested for this chapter would provide 66% of building occupancy hours of 9am to 5pm, within comfort conditions, i.e. operative temperature below 29°C (refer to Chapter 1 on thermal comfort of naturally ventilated spaces). This study also showed that on the hottest day scenario, where the outdoor temperature exceeds 35°C, the atrium ground floor operative temperature was able to maintain 4°C lower than the outdoor air temperature. In addition, a total building energy reduction of 3.3% was achieved using the optimum natural ventilation tested for this chapter.

The optimum natural ventilation strategy tested for this chapter is a type of hybrid ventilation system that open the atrium space to natural ventilation when indoor air temperature is higher than the outdoor air temperature and closed the atrium space natural ventilation ability when the outdoor air temperature is higher than the indoor air temperature. This requires controls over the openings at the atrium ground floor level. This hybrid ventilation strategy is as follows:

1. Ground Floor space should be air-tight from the hours of 7am to 4pm and open for natural (stack) ventilation effect from 4pm to 7am daily. The opening hours of 4pm to 7am daily allowed the cooler outdoor air to cool the atrium space down during night time to early morning hours. The closing of the ground floor atrium space from 7am to 4pm, will keep the

atrium space cooler for longer hours because it prevent the hot outdoor air from heating the atrium space during daytime. In addition, the leaked cooling from the offices is retained by the closed atrium space.

2. The atrium roof space is recommended to remain permanently open for natural ventilation. When the ground floor space are kept air-tight (i.e. during daytime), it is difficult for outdoor air to infiltrate into the atrium space. However, when the ground floor space are open for ventilation during night hours, it will promote natural ventilation (due to stack ventilation effect), where the hot air rise up to exit the atrium space at the roof level and colder outdoor air will enter the atrium space from the ground floor openings below.
3. Further improvement can be obtained from having an automatic system that open the ground floor and roof to natural ventilation whenever the measured indoor air temperature is higher than the outdoor air temperature. However, the advantage achieved from such automatic system is not significant enough to insist on such recommendations.

It was also found in these studies that natural ventilation using permanently fixed openings are not as effective as those strategies that allowed the openings at the ground floor level to be opened and closed according to the measured temperature or timed. The following permanently fixed strategies will cause the atrium space to have more than 50% of the occupied hours above comfort conditions:

1. Permanently Closed Ground Floor Level and Closed Roof (38% comfort hours).
2. Permanently Closed Ground Floor Level and Open Roof (40% comfort hours).
3. Permanently Open Ground Floor Level and Open Roof (48% comfort hours).

Summary of simulation results are presented in Table 9.4.1 below:

Cases	Total Building Energy Saved (%)	Comfort Hours/Year at Atrium Floor Level, (8am to 6pm, Mon-Fri)	Comfort Hours/Year (%)
Base: Air-Conditioned Ground Floor. Atrium Permanently Closed at Bottom and Top	0.0%	2,600	100%
Case 1: Natural Ventilation. Atrium Permanently Open at Bottom and Top	1.0%	1,235	48%
Case 2: Natural Ventilation. Permanently Closed at Bottom and Top	2.3%	977	38%
Case 3: Natural Ventilation. Permanently Closed at Bottom and Open at Top.	2.3%	1,040	40%
Case 4: Natural Ventilation. Temperature Controlled Ventilation at Bottom and Top.	3.3%	1,713	66%
Case 5: Natural Ventilation. Time Controlled Ventilation at Bottom and Top.	3.0%	1,666	64%
Case 6: Natural Ventilation. Time Controlled Ventilation at Bottom and Permanently Open Top.	3.0%	1,669	64%
Case 7: Natural Ventilation. Temperature Controlled Ventilation at Bottom and Permanently Open Top.	3.3%	1,713	66%

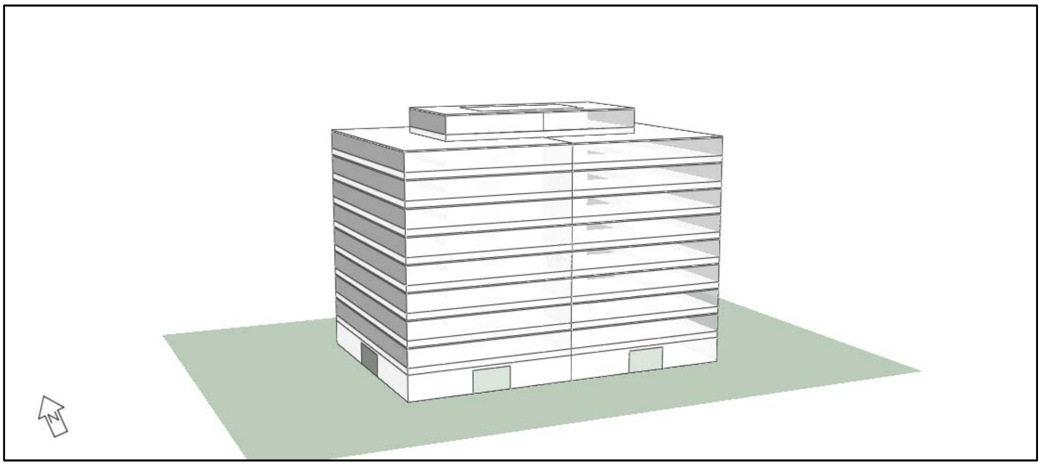
Case 8: Air-Conditioned Ground Floor. Atrium Permanently Open at the Top.	-0.9%	2,600	100%
Case 9: Air-Conditioned Ground Floor. Atrium Temperature Controlled at the Top	-0.4%	2,600	100%
Case 10: Air-Conditioned Ground Floor. Atrium Temperature Controlled at both Top and Bottom.	0.6%	2,600	100%

Table 9.4.1: Summary results of 11 simulated cases tested for Chapter 9.

9.5 Simulation model

An eight (8) floor office building was modeled for this study with the atrium located in the center of the building, surrounded by air-conditioned office space from 1st floor level to 8th floor level. The entire ground floor is modeled as part of the atrium space and will be air-conditioned or naturally ventilated depending on the case studies. The rest of the atrium spaces were not air-conditioned for all cases. In addition, the simulation model for Chapter 9 has taken these factors into considerations:

1. Internal walls facing the atrium space has a window to wall ratio of 70%. These internal walls separate the air-conditioned offices from the atrium space. The internal glazing was assigned as single glazing clear glass. In addition, 1% of the internal glazing area was assumed to be permanently open to model air leakages between the office and the atrium space. This assumption will be valid for most building where the internal windows are all kept closed to the atrium space. The 1% opening assumption made in this study will represent the leakages due to the cracks between the window frame and the wall.
2. Atrium roof top is modeled to be higher than the highest office floor level. The higher roof height of atrium spaces is typically designed for aesthetical reason but in this case it is also to create a space for storage of heat by the air for it to be conducted or ventilated out of the building.
3. 30% of the atrium roof was modeled as a skylight to allow natural daylight into the atrium space.



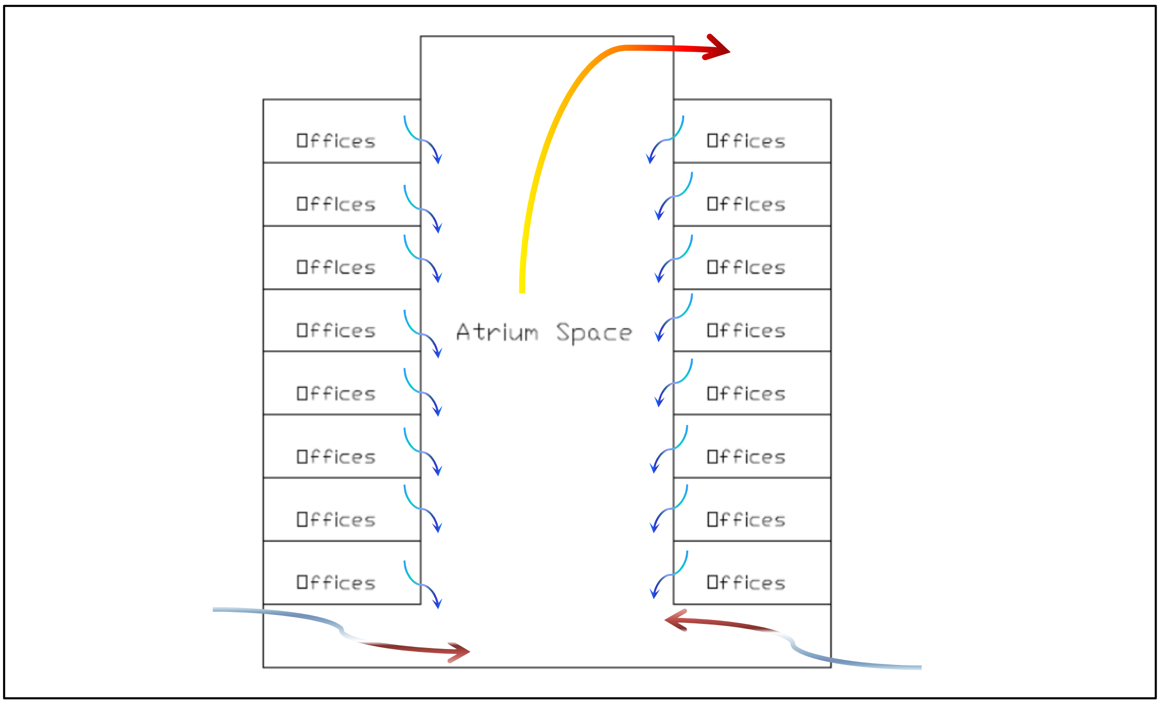
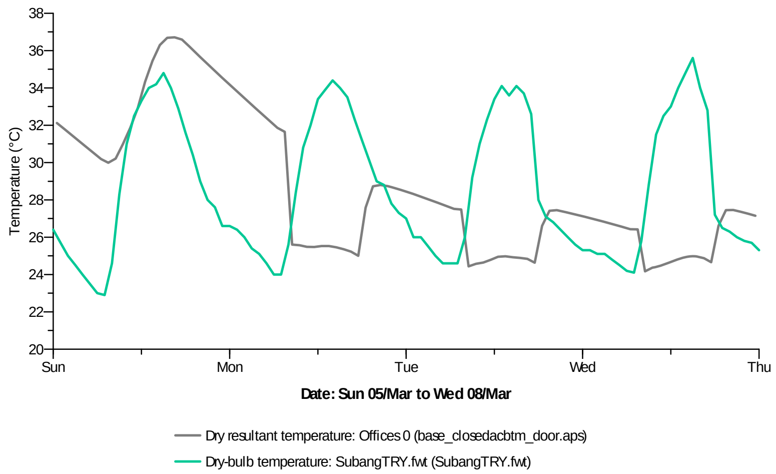


Figure: Cross-Section View of Atrium Simulation Model.

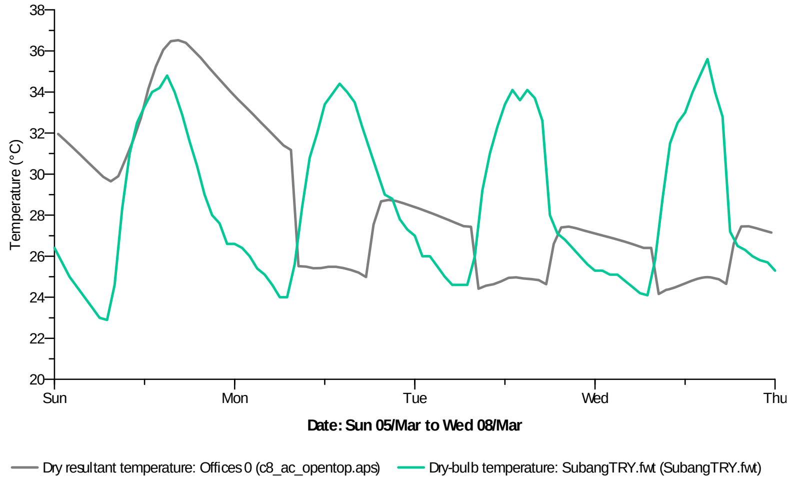
9.6 Air Conditioned Atrium Strategies

Base Case: Air-Conditioned, Permanently Closed Atrium Space.



In typical building scenario, the closed atrium space will remain closed day and night. Note that the temperature in the atrium space is significantly warmer than outdoor air temperature during night hours and weekends.

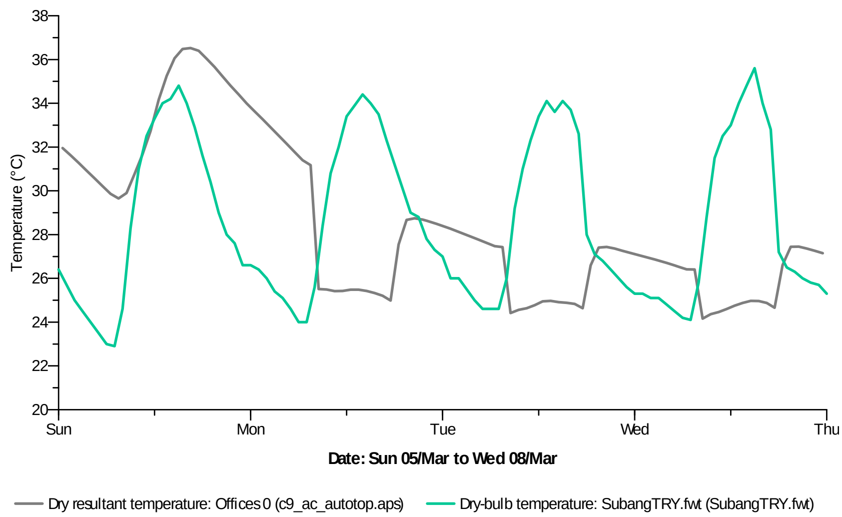
Case 8: Air-Conditioned Ground Floor. Atrium Permanently Open at the Top.



The Idea: Since cold and dry air-conditioned air is heavier than hot and humid air, this strategy will attempt to allow hot and humid air to rise in the atrium space and allows it to escape at the top of the building space.

The Reality: Having the top of the atrium space opened to ventilation increases the infiltration rate significantly at the ground floor level when doors are opened and closed for occupant access. This increase in infiltration rate increases both the sensible and latent load for the air-conditioning system at the ground floor level. The total building energy consumption was increased by 0.9% in this test case scenario compared to the Base Case scenario. The atrium ground floor doors were modeled to be open 10% of the building air-conditioning hours.

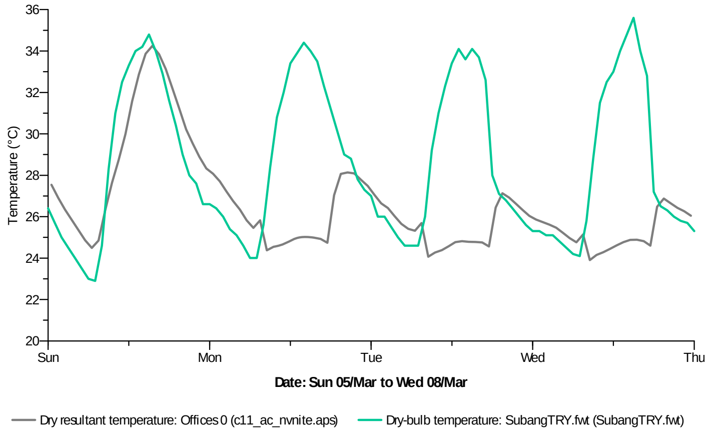
Case 9: Air-Conditioned Ground Floor. Temperature Controlled Openings at the Top.



The Idea: Instead of keeping the top of the atrium roof permanently open to natural ventilation, an attempt is made to have the roof ventilation open to exhaust hot air out of the atrium space whenever the measured indoor air temperature at the roof space is warmer than the outdoor air temperature. Otherwise the atrium space is kept air-tight.

The Reality: The simulation result was similar to Case 8 where the top of the atrium space was kept permanently open. Total building energy consumption increased by 0.4% in this test case scenario compared to the Base Case scenario where the atrium space was kept air-tight. Again, it was found that having the top of the atrium space opened to ventilation increases the infiltration rate significantly at the ground floor level when doors are opened and closed for occupant access. This increase in infiltration rate increases both the sensible and latent load for the air-conditioning system at the ground floor level. The atrium ground floor doors were modeled to be open 10% of the building air-conditioning hours.

Case 10: Air-Conditioned Ground Floor. Temperature Controlled Openings at the Top and Bottom.

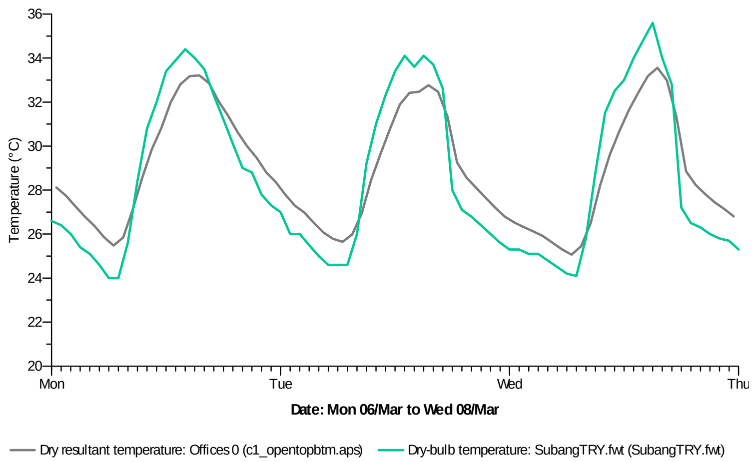


The Idea: It was observed that the ground floor atrium space air temp is significantly higher than the outdoor air temperature whenever the air-conditioning system is switched off. In this case study, once the air-conditioning system is switched off

The Reality: The simulation result was similar to Case 8 where the top of the atrium space was kept permanently open. Total building energy consumption increased by 0.4% in this test case scenario compared to the Base Case scenario where the atrium space was kept air-tight. Again, it was found that having the top of the atrium space opened to ventilation increases the infiltration rate significantly at the ground floor level when doors are opened and closed for occupant access. This increase in infiltration rate increases both the sensible and latent load for the air-conditioning system at the ground floor level. The atrium ground floor doors were modeled to be open 10% of the building air-conditioning hours.

9.7 Natural Ventilation Strategies

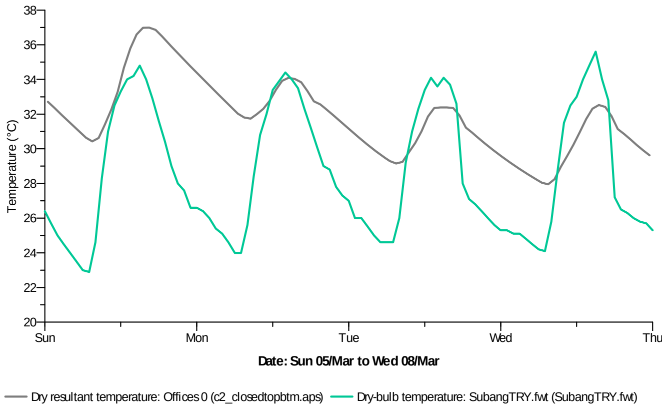
Case 1: Permanently Open Top and Bottom.



The Idea: To allow natural stack ventilation to cool the atrium space the entire day.

The Reality: The operating hours of office building coincides with the hottest temperature of the day. Allowing such natural ventilation strategy allowed hot outdoor air temperature to heat up the ground floor space during daytime. However, during night time, the colder outdoor air temperature do helps to cool the space down.

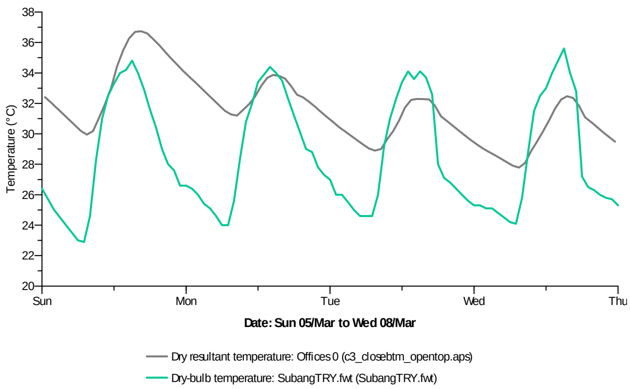
Case 2: Permanently Closed Top and Bottom.



The Idea: Let's try to capture all the cooling that is conducted and infiltrated from the offices into the atrium space.

The Reality: Keeping the atrium sealed air-tight turn this space into a green-house, especially during the weekends, without the air-conditioning system running in the offices, the atrium space become hotter than outdoor air temperature. During weekdays, with the air-conditioning running in the offices, the conduction and infiltration leakages into the atrium space reduces its daily peak operative temperature but not enough to keep it at comfortable level.

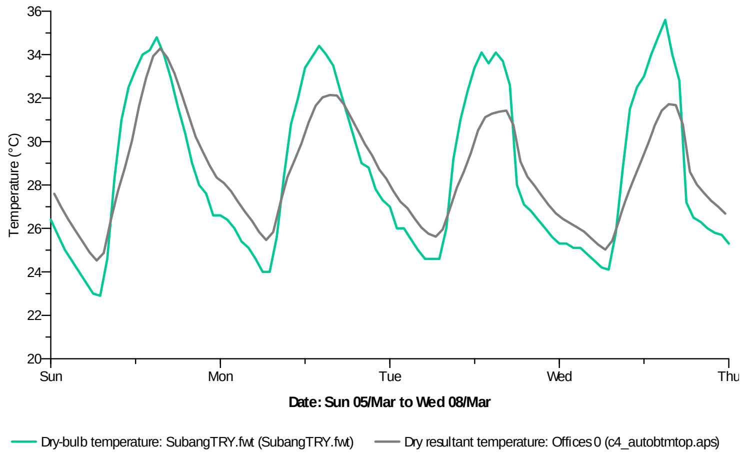
Case 3: Permanently Closed Bottom and Open Top.



The Idea: This case study attempts to capture all the cooling that is conducted and infiltrated from the offices into the atrium space, while allowing the hot air to escape via the top of the atrium roof.

The Reality: Although it worked as planned, the amount of hot air escaping from the top of the atrium space is not significant enough to reduce the operative temperature of the ground floor level much.

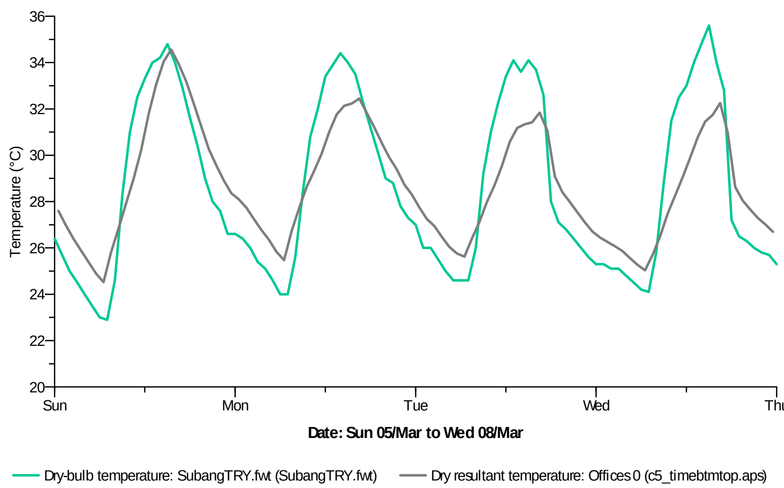
Case 4: Temperature Controlled Ventilation at Bottom and Top.



The Idea: Open the ground floor and rooftop for natural ventilation whenever, the air temperature of the indoor atrium space is higher than the outdoor air temperature. Close the natural ventilation whenever, the outdoor air temperature is higher than the indoor atrium space air temperature. This will allows colder outdoor air to cool the atrium space down when the time is right and when the outdoor air is hot, keep the atrium space air-tight to prevent it from heating up the space.

The Reality: Due to the captured cooling that was conducted and infiltrated from the offices to the atrium space, the peak operative temperature of the ground floor atrium space is approximately 4°C lower than the peak outdoor air temperature. In short, this strategy worked as planned and provides the best combination of comfort and energy reduction scenario. Unfortunately, we are still unable to achieve comfort condition at all time for the atrium space. In this best case scenario it was simulated that the operative temperature will be higher than 29°C (80% of the thermal adaptive comfort limit) for 887 hours a year, or an average of 3.4 hours per working day.

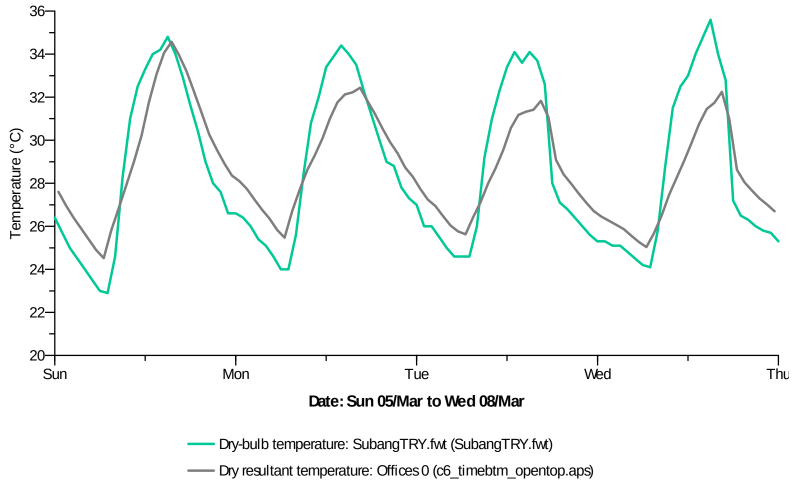
Case 5: Time Controlled Ventilation at Bottom and Top.



The Idea: Since the air temperature in Malaysia is fairly consistent daily, what would be the impact of using a time controller instead of differential temperature controller? In this case study, the atrium openings are kept open from the hours of 7am to 4pm and closed from the hours of 4pm to 7am.

The Reality: It increases the discomfort hours by 2% as compared to Case 4. It can be concluded herewith that the time controller is almost as effective as using differential temperature controller.

Case 6: Time Controlled Ventilation at the Bottom and Permanently Open at the Top.



The Idea: Instead of having controls at both top and bottom of the atrium space for natural ventilation, this simulation case study will test the option of leaving the top of the atrium space without any controls to allow hot air to escape out. In the meantime, the bottom of the atrium space may be manually or automatically controlled to keep hot outdoor air out of the building during daytime and allowing natural ventilation during night time when the outdoor air is colder than the atrium air temperatures.

The Reality: It increases the discomfort hours by 2% as compared to Case 4 and matched the result for Case 5. It can be concluded herewith that it is not required to place any controls on the top floor of atrium space when the atrium is naturally ventilated. Controls is only required at the ground floor level to increase comfort level in the building.

________________________________End of Chapter 9____________________________________