How to Simulate Thermal Behavior of an Atrium Building

Introduction:

It has been years since atrium buildings have become one of the major spaces of most buildings. Providing a better daylighting condition for the entire building, providing ventilation through its roof and giving a better view to the occupants; are the main reasons why atriums can help a building to perform better based on different climates. For its both aesthetic and functional aspect, many studies and a great deal of researches have been conducted on atriums. Different types of atriums were defined based on studies and each of them can suit a building based on its climate and function.

As atriums can bring so many advantages for a building's thermal behavior, it is so important to specify thermal performance in an atrium building in order to exploit its features. However, knowing the thermal behavior of an atrium is difficult due to complex thermal phenomena that occur in the atrium space. Many studies have been done to find the best way of exploring thermal behavior of atriums, yet no definite answer has been made and the reason is that each building has its own characteristic and there is no single solution which can go to all the atriums.

Problem Posing:

Based on what was discussed about atrium buildings and the complexity to define a way to simulate thermal behavior of atrium buildings, this project is going to focus on an optimum way to simulate energy performance of atrium building in an accurate way. Since the answer would not be a single approach, the final purpose is to find the best option that can be used to simulate thermal behavior of the atrium based on their type specifically using the whole building energy simulation tool – EnergyPlus for the test of study. For instance, in some cases it is just enough to consider atrium to be a single zone, however this approach would not give us an accurate result for highly glazed atrium buildings and they have to be classified in height. Consequently, the solution should not essentially be one final answer. The effort is going to be made to optimize the simulation process based on each type of atrium.

Analytical Approach

Step one (Typology): Finding out basic typologies of atrium buildings, classify them in shape, height and size and group them as in each group they are similar in performance.

Step two (Atrium Energy Simulation Models): Giving the range of tools and ways in which atriums' energy performance can be simulated within EnergyPlus, how they are used and what parameters are important in each of them.

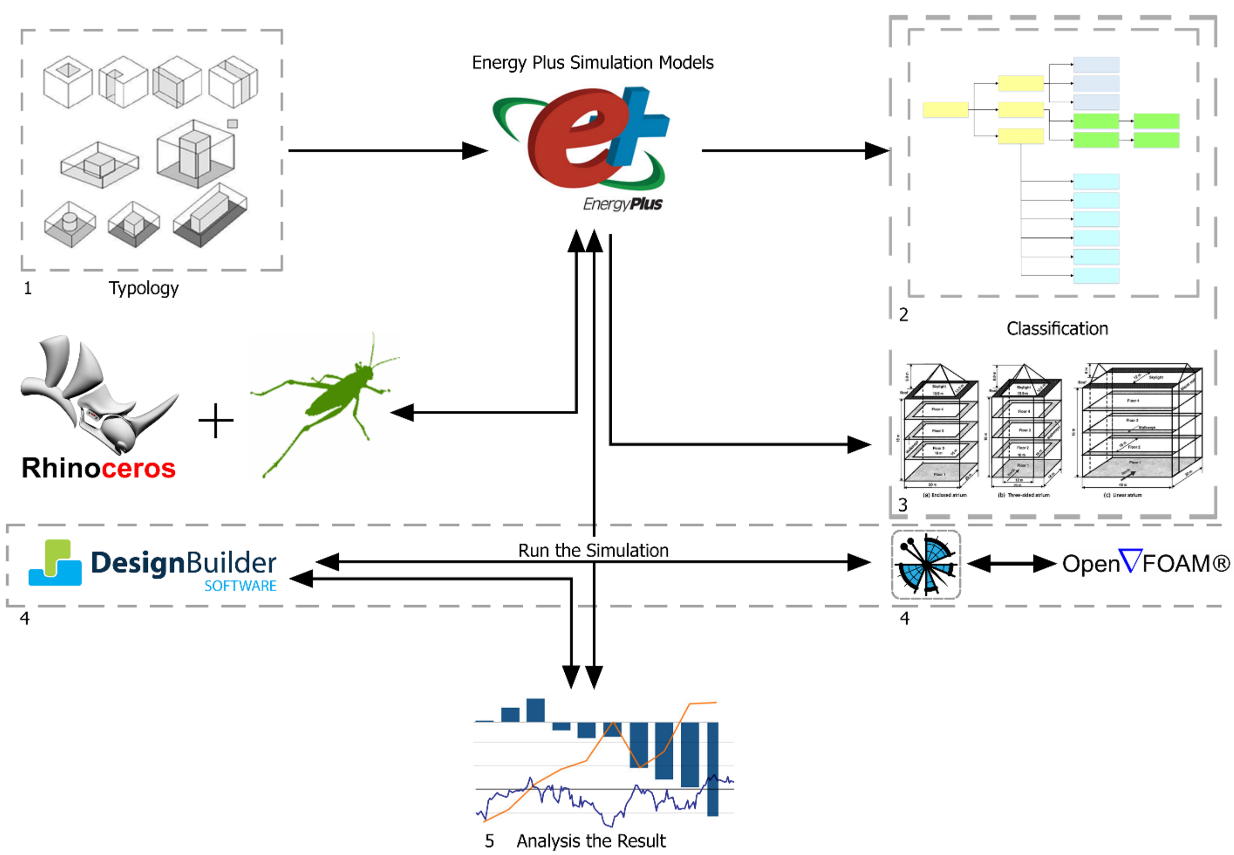
Step three (Classification): Classifying the simulation type of atrium based on atriums size, height and function (Typology).

Step Four (Run the simulation): Modeling and running the simulation of each type of atrium by all of the classifications of simulation. In this step, we should define a location, typical hot week in summer and typical cold week during winter and run the simulation within this frame.

Step Five (Analysis of the result): Making a broad analysis of the result based on the performance of the atrium, their diurnal temperature change, solar radiation and natural ventilation change.

Final Step (Make a conclusion): Making a conclusion based on the results, specifying what results are more accurate than the others and trying to make a decision of what may be the optimum solution of simulations.

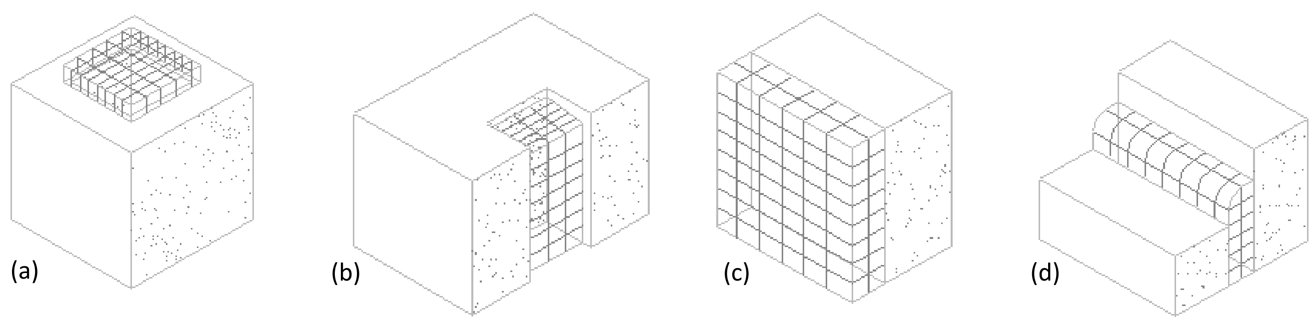
Flow Chart



Typology

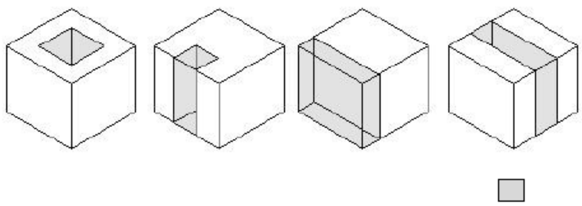
The design of an atrium is generally based on climatic conditions, architectural experiments, expected level of thermal comfort, and functions of building. The placement of atrium in building is the main factor which determines the potential environmental advantages of atria in the building. There are four different shapes of atrium, as main category of atria forms, which have been cited in literature based on the atrium location in the building.

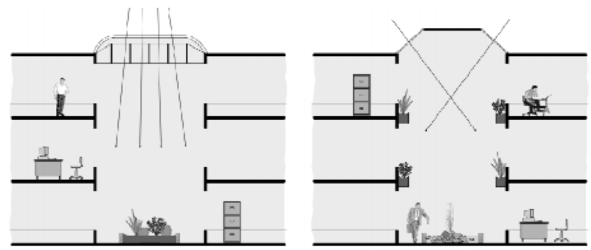
Each form of atria has a particular environmental advantage which is chosen according to its ambient condition, expected ventilation and daylight performance. For example, for temperate climates, in order to have more solar heat gaining in winter time and more attractive view during different seasons, atrium is attached to the building as a glazed façade. For hot and humid climates, from the four generic types, centralized and linear atria are the most effective types in minimizing temperature fluctuations during hot and moderate seasons. Besides, the overall temperature performance of these atria types is the closest to neutral temperatures. Hence, these centralized and linear atria are the most common generic forms in use in hot regions.

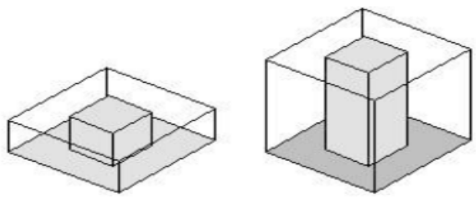


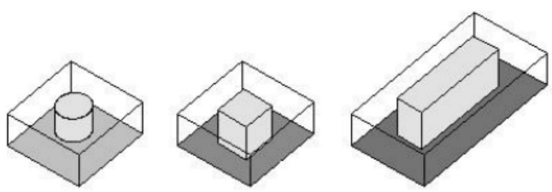
Four different generic forms of atrium and real samples. (a) Centralized, (b) semi-enclosed, (c) attached, (d) linear.

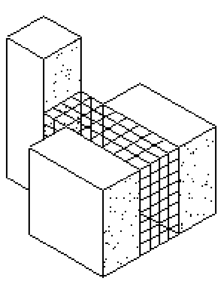
There are also more complex forms of atriums as some of them are shown below. Different classifications can be attributed to atrium buildings in terms of its height, size, glazing type of roof and shading system attributed to that. Some of these types can be seen in the figures below.



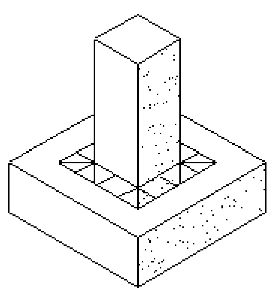




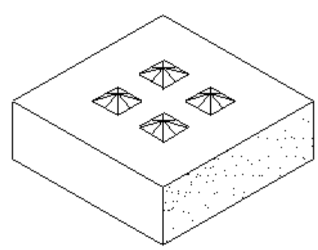




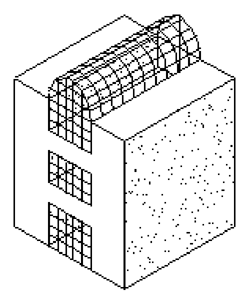
Bridging: Atrium connects several occupied portions of structure



Podium: Atrium sits at the bottom or below an occupied portion of structure



Multiple Lateral: Atrium spaces scattered throughout plan on single or multiple stories



Multiple Vertical: Atrium spaces scattered throughout height of tower structure

Based on different typologies that we have gathered and physical conditions that would affect the thermal behavior of atrium such as their size, height and type, we can conclude that atrium types can have an effect in the decision of what can be the efficient way to simulate them. In this case, specifically the classification is chosen to be based on height and floors and that is because of temperature stratification which happens in atrium buildings and affect the thermal behavior of them in different heights. For the purpose of this project I took a simple four floor atrium to check the effect of different types of simulation in one type of atrium and see how the result changes due to different stratification.

Model	Type	Number of Floors	Width of Atrium	Length of Atrium	Height of Atrium	Ratio of Width to Length	Floor Area of Atrium	Zone Stratification	Zone Connection
1	Central Atrium	4	12m	12m	16m	1	144m2	Single zone	---
2	Central Atrium	4	12m	12m	16m	1	144m2	Floor by Floor	Airwall
3	Central Atrium	4	12m	12m	16m	1	144m2	0-10m,10m to Top	Airwall

Atrium Energy Simulation Models within EnergyPlus

Classifications of Atrium Simulation Types:

Based on Atrium Classifications due to their condition and differentiate, there are different parameters that can be considered in categorizations of energy simulation models. Charts below shows some of these parameters and also variations of energy simulation types.

One of the difficulties that exist in atrium thermal behavior simulation is about modeling the air flow within the space. It is hard to predict the air pattern in atriums specially in highly glazed ones. Consequently, there has been a great deal of researches on the topic of how to model the air flow. Below some of these modeling types is defined.

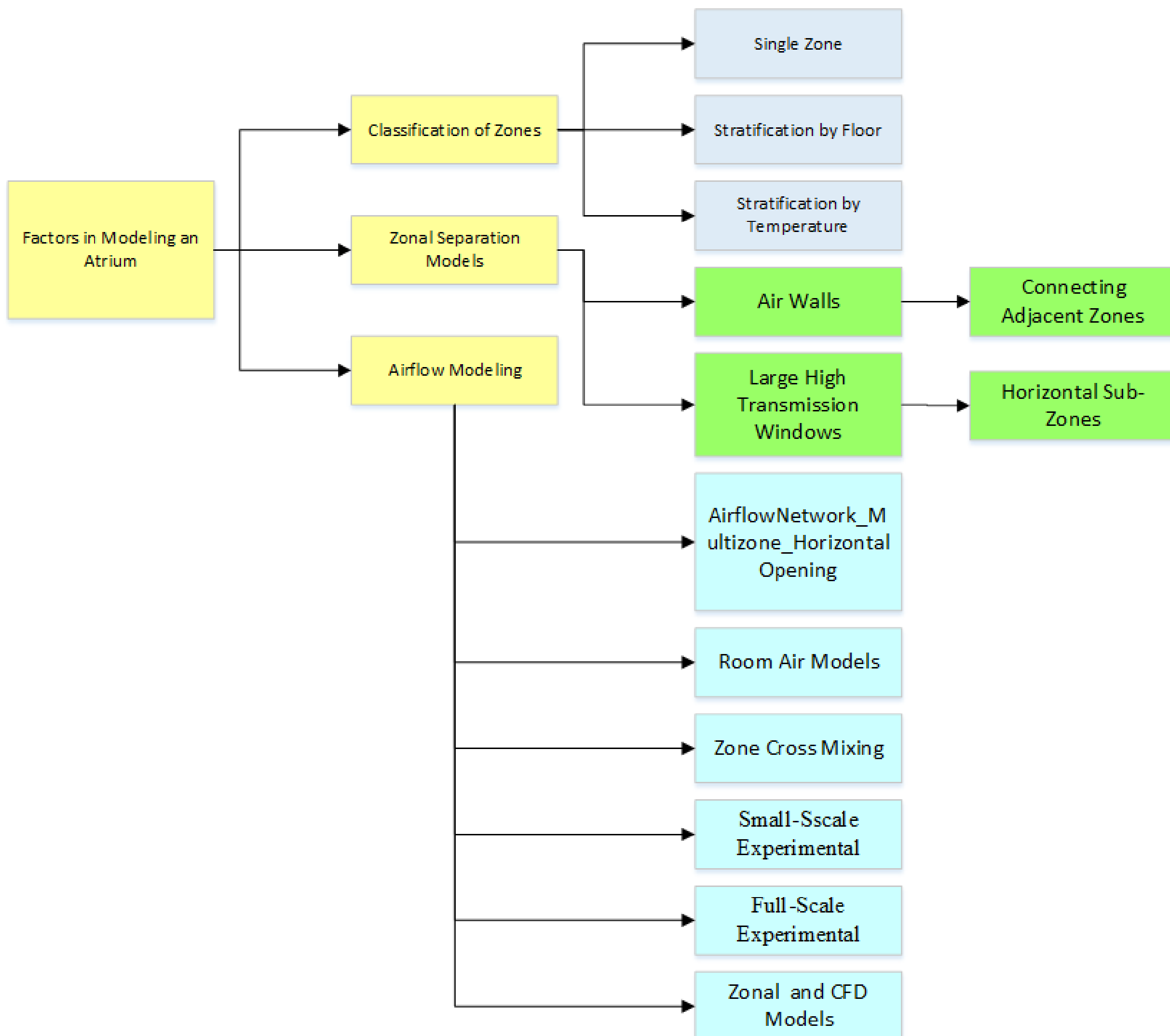


Figure 7, Classification of Factors Contributed into modeling an atrium

Based on this table, there are different options for zone classifications and also separation models. The question is how to choose between these options and which one can give the best answer. There may also be some regulations for defining which method can be implemented. We can come to conclusions based on type and function of the atrium which will be covered later.

EnergyPlus Room Air Models

Because the focus of the project is on EnergyPlus one important study is to define its potential and capability of modeling the air flow in atrium space and the classification of them. With regards to energy plus room air models, there is a method in which atrium is divided into two parts, the upper part which is from the roof to 10 meters below the roof and the lower part which is from the ground up to 10 meters below the roof level. This stratification allows to have a better result from temperature behavior in the atrium spaces as in atriums most of the heat remains in the upper part and the lower part does not have a significant temperature change. Consequently, separating these two parts will give a more accurate result in terms of thermal behavior in atrium buildings.

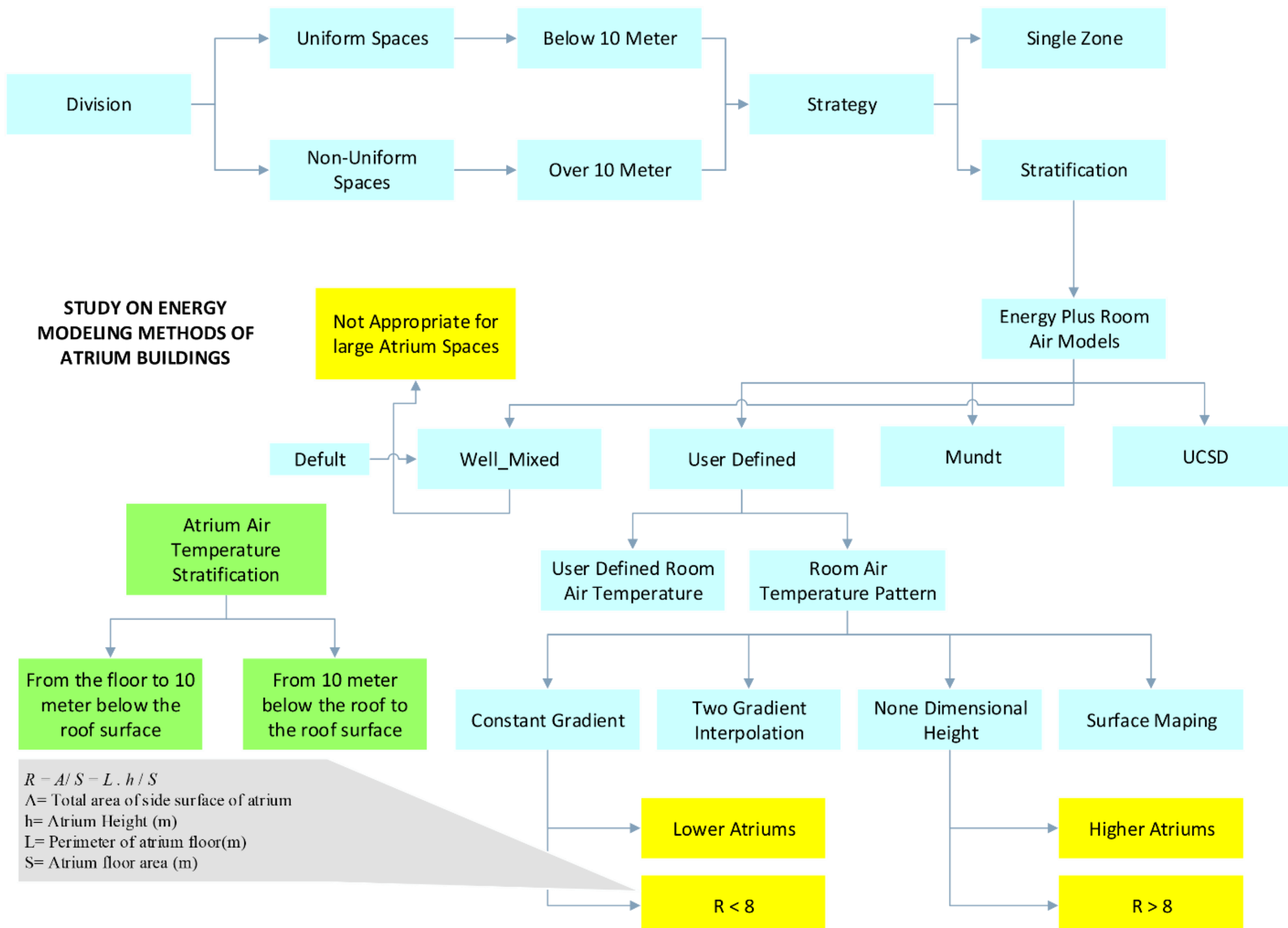


Figure 8, Energy Modeling method in atrium buildings based on Room Air Models

There is also a factor introduced in this model which is the ratio of side surface area of the atrium to floor area of the atrium. In this table, based on R factor two types of energy modeling of atriums can be specified which is shown in the figure above. From these classifications, we can figure out that size, area of floor and height are important parameters in defining different methods of simulations. Also, based on the stratification of temperature and the statement about 10 meter being the set point, the four model that is chosen for this project took this set point as one of its parameters, means that in each type of atrium (Central and Attached) there is a version which its height is less than 10 meters (2 floors) and the other version which has four floor and its height is more than 10 meters. This way the accuracy of simulation in each type can be achieved.

Method Introduction

I have chosen DesignBuilder and CFD simulation by Open Foam for this project. CFD would give us temperature stratification of each atrium and DesignBuilder will give us data based on simulation. Our main question is how to simulate thermal behaviors and mainly airflow network in atrium buildings in EnergyPlus. Based on available researches and articles, there are so many proposed ideas and methods about this topic and so many classifications have been made as we talked about some of them. Based on our findings we have reached to one classification of atrium types which can hugely effect the method in which energy modeling happens. We considered three main types of classification in atrium buildings which are related to how we stratify atriums in floors which is a new type of studying as we are trying to do a side by side simulation based on these three classifications and make a conclusion of which is best for what type of an atrium. This method mainly goes to DesignBuilder.

Single Zone-The simples one is to consider atrium to be one single zone and do the energy modeling with one zone.

Floor by Floor-The second type is to separate the atrium into each floor area. It means that to consider each floor as one zone, so the number of zones would be equal to the number of floors.

Two Part- The last option is to separate the atrium area into two parts, one upper level which is from the roof of each atrium to 10 meters below the roof and the lower level is from 10 meters below the roof to the ground. This way we consider each atrium to be in two parts; one part is where the temperature difference is the highest and the lower part is where not much temperature difference exists.

For this purpose, two weeks of the year were picked; one typical summer week and one typical winter week and the data are gathered from these two weeks.

In DesignBuilder there are so many information in simulation part, yet we mainly focused on temperature, natural ventilation and solar gain of each zone of atrium. All the results of three types were gathered in this three information which can give us a better understanding and after that we drew a comparison between each atrium type and in each atrium itself, comparisons were made between the zones. The result was charts of temperature, ventilation and solar gain.

In Open Foam simulation, the purpose is to run a CFD simulation to see the temperature stratification in atrium model.

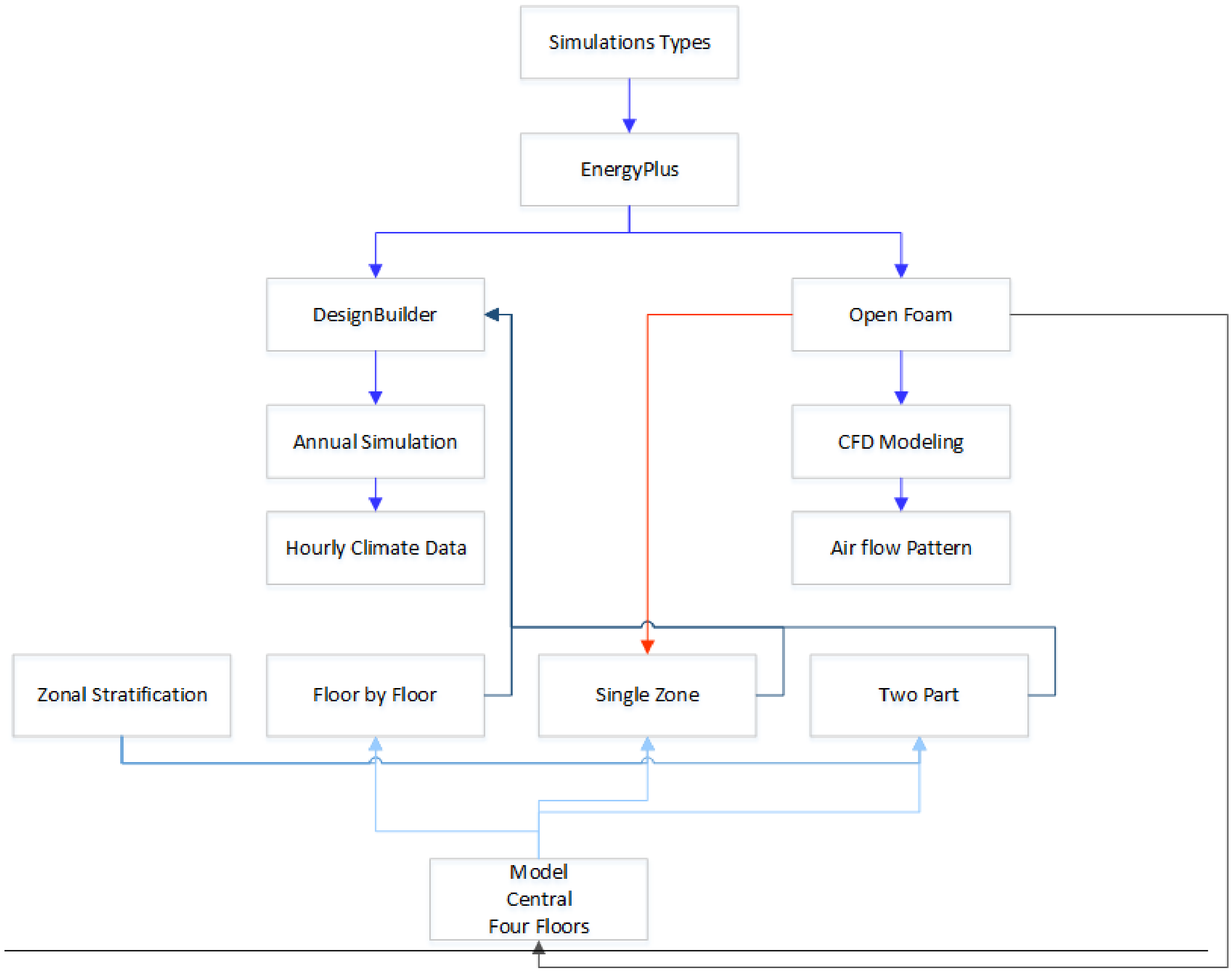
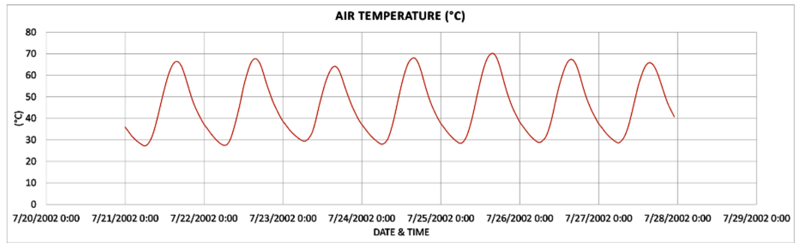
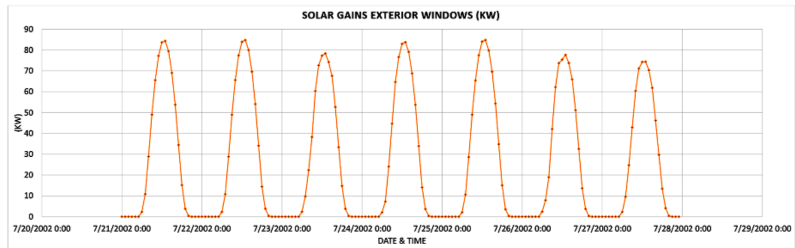
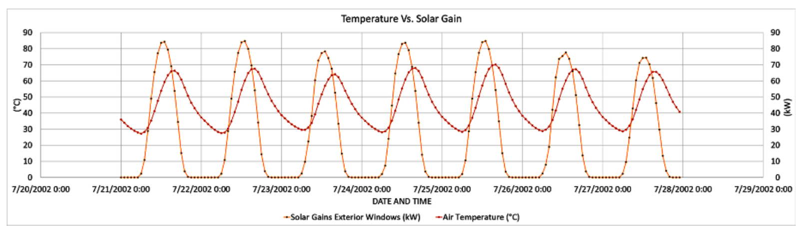
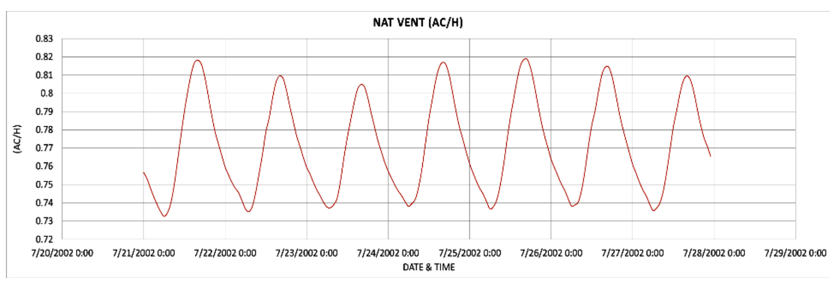
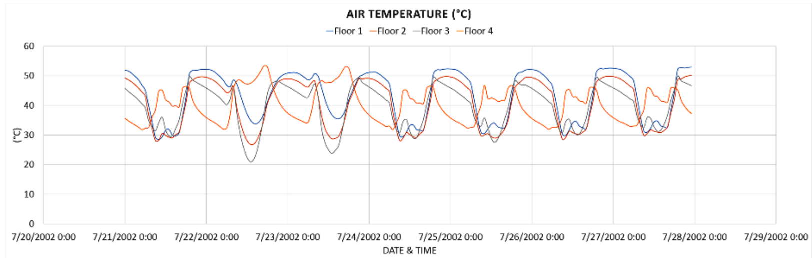
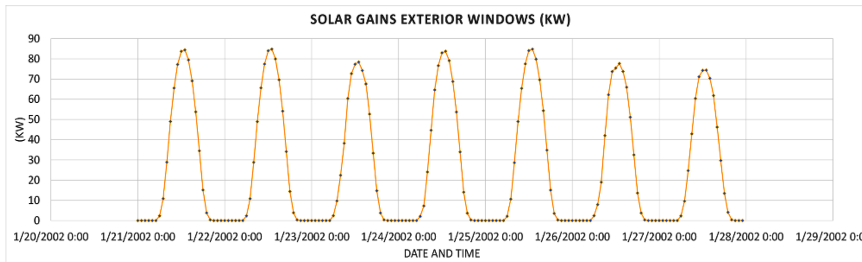
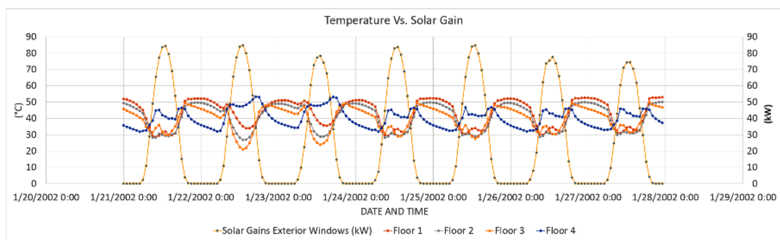
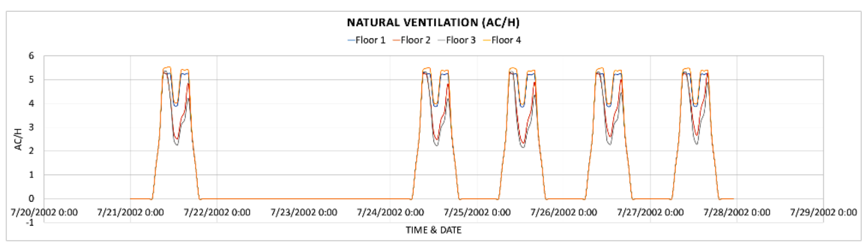


Figure 9, Classification of Simulation Types based on the Base Models

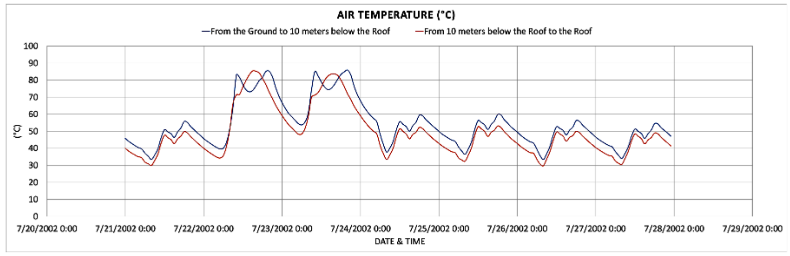
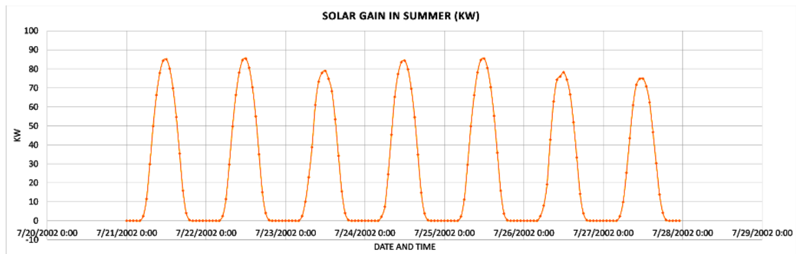
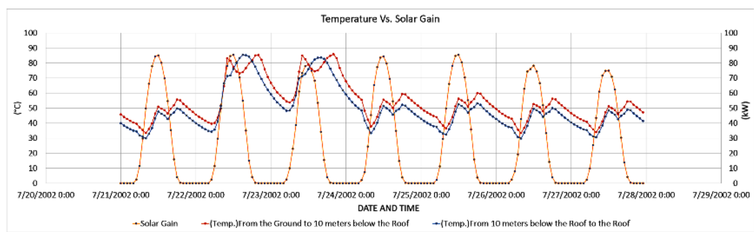
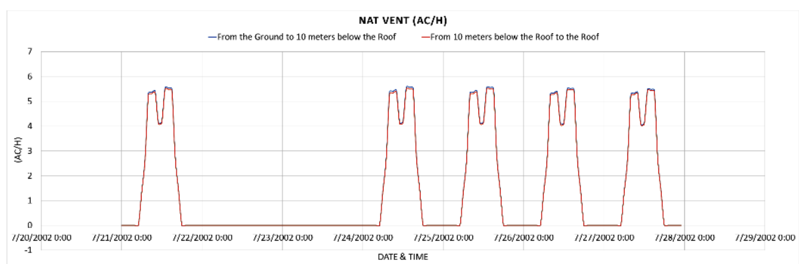
Below the results from simulation in DesignBuilder is placed in the order of floor by floor, two-part atrium and single zone. And data is gathered for temperature, natural ventilation and solar gain. There is also a summer evaluation vs. winter evaluation.

Summer Evaluation	Single Zone Atrium
Air Temperature	
Solar Gain	
Temperature Vs. Solar Gain	
Natural Ventilation	

The charts are showing temperature, solar gain and natural ventilation in a typical summer week based on hourly analysis. The behavior of the charts shows that temperature rises mostly at noon, same as solar gain and natural ventilation. This is what happens when we treat atrium as a single zone which is an obvious result. To exactly know what happens in the atrium and in each floor, we go further to next type of classification.

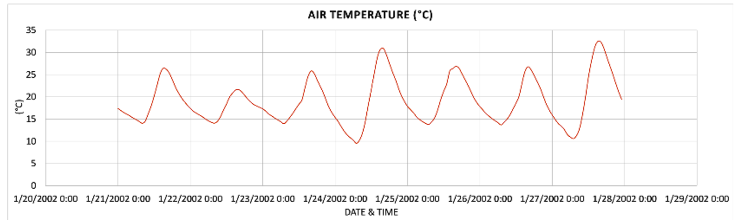
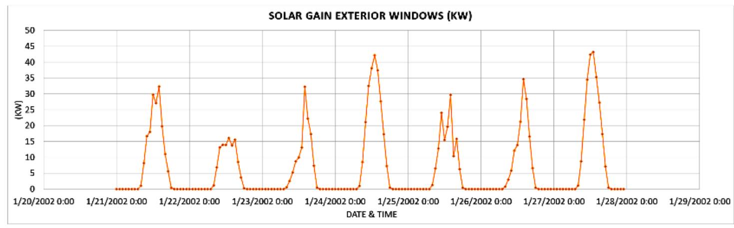
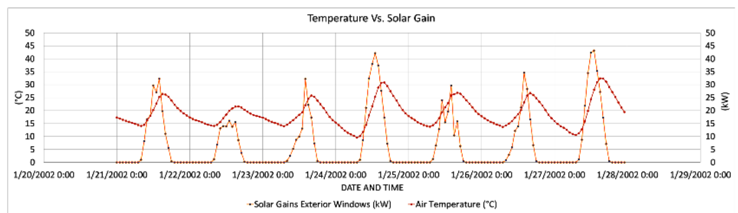
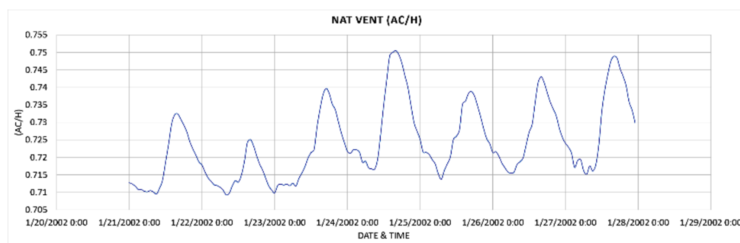
Summer Evaluation	Floor by Floor Type
Air Temperature	
Solar Gain	
Temperature Vs. Solar Gain	
Natural Ventilation	

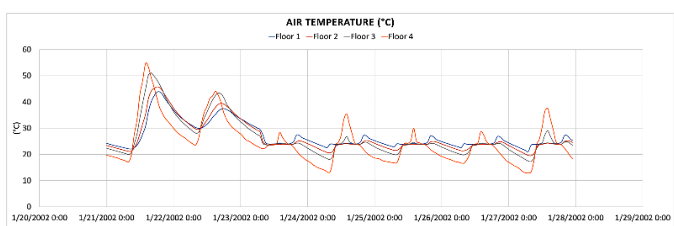
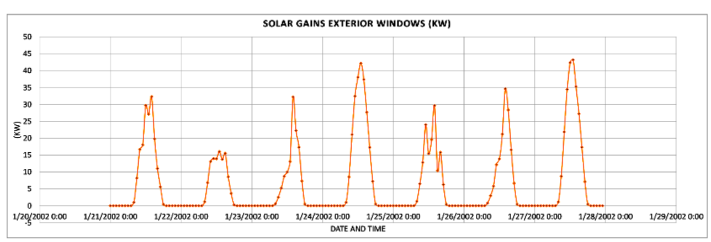
The main conclusion that we can get based on the charts in floor by floor stratification is that there is a huge difference in behavior of forth floor compared to other three floors in temperature and natural ventilation. This behavior can show that most of the temperature change happens at the top part of the atrium this is because of stack effect that occurs in highly glazed spaces and hotter air always tend to goes up. Solar gain is happening the same way, though.

Summer Evaluation	Atrium Divided in Two parts
Air Temperature	
Solar Gain	
Temperature Vs. Solar Gain	
Natural Ventilation	

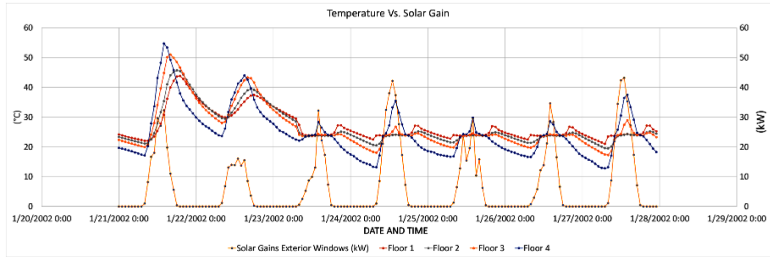
Conclusion

In this type, which we separated atrium in two parts, they are behaving more similar to each other than the previous chart, yet we know that the difference should be more on the top part. Thus, we can come to this conclusion that separating atrium of a four-floor building is better to be floor by floor which gives a more accurate result.

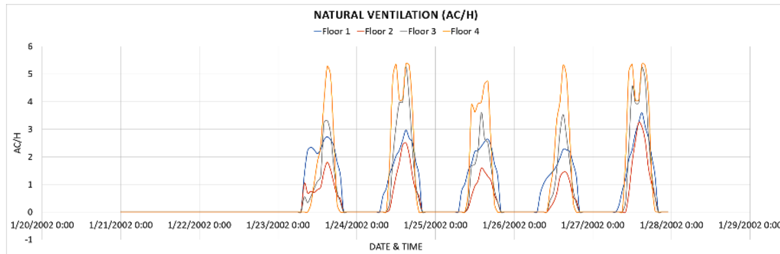
Winter Evaluation	Single Zone Atrium
Air Temperature	
Solar Gain	
Temperature Vs. Solar Gain	
Natural Ventilation	

Winter Evaluation	Floor by Floor Type
Air Temperature	
Solar Gain	

Temperature Vs. Solar Gain



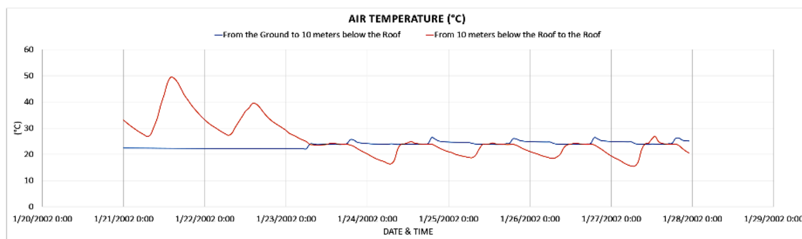
Natural Ventilation



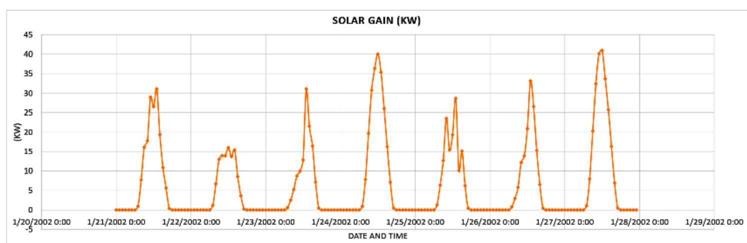
Winter Evaluation

Atrium Divided in Two parts

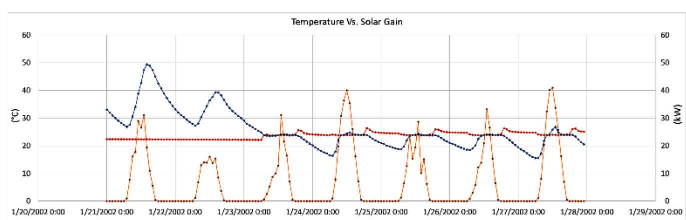
Air Temperature



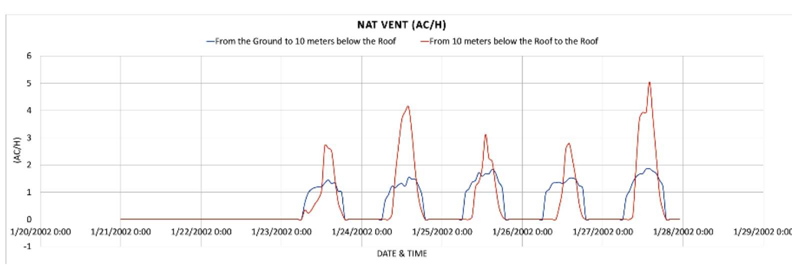
Solar Gain



Temperature Vs. Solar Gain



Natural Ventilation



Conclusion

Based on winter results, the first analysis is for single zone which is giving one simple answer and we cannot really understand which part of atrium is behaving different. In the second series of charts which is floor by floor stratification, same as summer evaluation the temperature change mainly happens at the fourth floor. The interesting part here is the third evaluation which is showing a different result. According to the third type, we see that in the lower level the change of temperature and even natural ventilation is hugely less than the change in the upper level. As a consequence, we can say that most of the temperature change happens from the roof to 10 meters below the roof. The rest is nearly showing a constant rate. So, in winter it is more efficient to stratify the atrium space in two parts which is the second type.