Analysis on Green BIM based Atrium Sizes in the Early Design Stage

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ABSTRACT: This study for establishing specific standards of atrium design aims to discuss design of atrium to consider energy performance according to the types of atrium of office building. In order to evaluate a type and a scale of atrium at the early design stage, modeling details of mass design were set as standards of conceptual design. In the experiment, Project Vasari was used to analyze modeling and energy consumption, based on the LOD 100-step suggested by AIA, because there is no guideline to specify a level of modeling details at each design process. From this analysis, the correlation among a simple-typed atrium and scale and energy load was understood, and the followings are the considerations for designing an atrium. First, the single-sided atrium reduced energy the most, and it was followed by three-sided, two-sided, four-sided and continuous-typed ones. On the whole, they could decrease energy by up to about 15%. Also, the atrium with a wide facade facing in the south was more favorable to reduce energy. Second, planning an atria within 10~30% of the whole building area was more energy efficient. Third, rather than the depth, adjusting the length in designing an atrium could reduce cooling and heating loads by 1.5% per 1m. As explained above, energy performance evaluation considering types and planning elements of atrium helps to assess alternatives in a reasonable way. In particular, considering the use of building needs to be preceded to select a type of atrium, although it is also important to consider its planning elements.

Keywords: Green BIM, Atrium, Energy Performance Analysis, Cooling and Heating Load

1. INTRODUCTION

We don't have standard specifications for atrium in 'Design Guidelines for Energy Conservation in Buildings' and if any, it's been only classified as recommendations. Since atrium varies in size, shape, and distribution by building, reasonable plans are difficult and the difference in energy consumption by type of atrium is considered to be greater.

Therefore, this study aims to look at the type of atrium installation in office buildings, conduct BIM-based 3D modeling and energy performance analysis simulation, and study the correlation between the type of the heating and cooling load and the type and size of atrium.

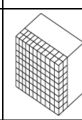
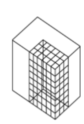
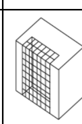
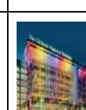
From this study, the eco-friendly plan of atrium is expected to provide rational and objective evidence for calculating the size of atrium getting out of the conceptual and subjective judgment. Thus, we aim to induce energy consumption saving with an appropriate plan of atrium by maximizing the utilizability of BIM-based modeling and energy performance analysis simulation from the initial design phase and lay a foundation for objective standard of judgment on the systematic standard of atrium design and the certification class of eco-friendly buildings.

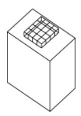
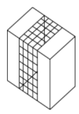
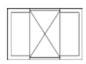
2. BACKGROUND OF CASE STUDIES

2.1 Type of Atrium

Atrium has long gone through various changes in functions and concepts, and in modern times is generally acknowledged as an open space covered with glasses. As the current atrium varies in use, relationship with buildings, shape, and size, it is difficult to define the role and shape of atrium as one definition. But, in general, atrium has various characteristics like cultural, economic, acceptable, and relaxable characteristics depending on the characteristics that the space holds and also properties combining the entire building.

Table 1. Type of Atrium

Atrium type	From	Plan	Explanation	Typical Building	Note
Sectional			atrium is bordering one full side of a building		Irwin Bank, Columbus, Indiana
Two-dimensional			two planes of atrium is bordering a building and inter-penetrated inside the building		Ford Foundation, New York
Three-dimensional			on the flat surface, atrium is bordering three planes of a building		Children's Hospital of Philadelphia

Four-dimensional			as the center of a building is open, atrium is arranged in the center of a building		Exeter Academy Library
continuous			a linear shape is penetrated into a building and the inside of the building divided into two is connected		Hennepin County Courthouse

As shown in Table 1, the type of atrium includes sectional, double-sided, three-dimensional, four-dimensional, and continuous atrium, and the name and shape depends on the number of the planes bordering a building in terms of flat surface. If the number of the bordering plane is one, it's called 'sectional,' if two, two-dimensional, if three, three-dimensional, if four, four-dimensional, and if continuous atrium, linear shapes are distributed in the center of a building.
Unlike the simple-type atrium, the type of complexly installed atrium varies in shape, property, and size and the criteria for classification is unclear. Thus, this study excludes the complex atrium, but instead classifies the type of simple-type atrium like Table 1 and selects the representative type of atrium.

3. Selection of Representative Type of Atrium

In this section, we describe the size of office buildings and the size of atrium, and the selection process of representative type. As shown in Table 2 below, this table shows the distribution of office buildings in the cities with the level of metropolitan city or more based on the data from National Statistical Office and the representative city is set as Seoul Metropolitan city with the highest distribution of office buildings.

Table 2. Distribution of Business Building by Metropolitan City as of 2012

	Seoul (40%)	Busan (18%)	Daegu (14%)	Incheon (13%)	Gwangju (8%)	Daejeon (7%)	Total
Business use	140,987	66,494	49,462	47,654	28,906	28,999	358,202

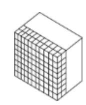
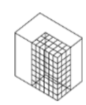
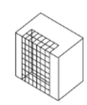
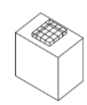
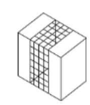
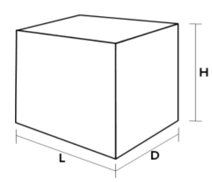
Table 3 represents the distribution of office buildings from the top 3 districts, of the total number of 25 Seoul Metropolitan city districts. For the districts of this study target, Gangnam-gu and Gwanak-gu which occupy the top 13% of these districts are set. As the certification standards of eco-friendly buildings for business use in the domestic eco-friendly buildings system has been enacted since 2003, we restricts our targets to the buildings newly built in Gangnam-gu and Gwanak-gu, Seoul Metropolitan city since the year of 2003.

Table 3. Distribution of Business Building by District in the Metropolis of Seoul

	Gangnam-gu (7%)	Gwangak-gu (5%)	Songpa-gu (4%)	Gangseo-gu (4%)	Yang cheon-gu (3%)	Nowon-gu (2%)	Total
Business use	9,830	6,418	5,831	5,103	3,755	3,214	140,987

With regard to the size of newly-built office buildings in the two regions of Gangnam-gu and Gwanak-gu, Seoul Metropolitan city since 2003, we excludes the top 10% and the bottom 10% and then extracts samples to set the size. The average level from the extracted samples is 25m in length, 16m in depth, and 36m in height, and we set these values as the sizes of our representative typed office buildings. Thereafter, we set the direction as southward equally and divides the two-dimensional atrium into southeast(two dimensional-1) and southwest(two dimensional-2) and install the simple-type atrium into the office buildings with size determined as shown in Table 6 below by size and type.

Table 4. Typical type of Atrium

Category	Sectional	Two-dimensional	Three-dimensional	Four-dimensional	continuous
Image					
Floors / Height	9 floors / 36m				
Building Volume	14,400m^3				
Atrium Floor Area (m^2)	100	156	156	156	144
Atrium Volume (m^3)	3,600	5,616	5,616	5,616	5,184
Office Scale (mm)				L = 25,000 D = 16,000 H = 36,000	

4. Selection of simulation tools

This paragraph is intended to discuss the selection of tools appropriate for research simulation. Ecotect which consists of a simple interface, is easy for beginners to use. However, it leads to a loss of information while converting data modeled by the BIM tool into IFC/gbXML and loading it.

Energy Plus organized with a variety of modules has an excellent extendability among programs and makes it possible to analyze in various ways. But it requires entering detailed parameters and thus isn't appropriate for forming lots of control groups during conceptual design process to demand varied alternatives, although it's good for working design process.

In contrast to Ecotect, Project Vasari doesn't cause a loss of information, when it is connected with the Revit BIM tool using the rvt extension, and mass design-level modeling details are enough for it, because this research evaluates form and scale at the initial design stage of atrium. Besides, Project Vasari is able to extract correct data results, since it uses DOE-2 engine and parameter input information values, based on the ASHRAE Standard 2007. Accordingly, it was adopted as a simulation tool suitable for this study.

Table 5. Comparison of Simulation Tools

Tools	Characteristics
Ecotect	· As a tool for a designer, it expresses visual results excellently and is easy to judge data intuitively. · It is compatible with IFC/gbXML.
Energy Plus	· As it consists of varied modules, it has an excellent extendability among programs and makes it possible to analyze in various ways. · It uses the DOE-2 engine. · Generator(converter) is required to connect it with the BIM tool. · It is inappropriate to consider alternatives at the initial design stage, because it is complicated to input parameters and takes a long time to analyze.
IES VE	· It enables a designer to analyze different environmental performances using several modules. · It is insufficient to express a result graph.
Green Building Studio	· As a web-based tool, anyone can analyze performance readily using this. · It takes time to receive simulation results from a server. · It's impossible to set up climate data of particular regions.
Project Vasari	· It uses the DOE-2 engine. · It can be converted into gbXML/IDF. · It supports mass design only and thus is impossible to create detailed modeling

5. Parameter Input Condition

The input values of office buildings parameters for simulation is as shown in Table 6. As this experiment should draw cooling and heating load values by the shape and size of atrium, the performance that the materials of major architectural elements is excluded and the construction method of each element is unified with lightweight construction. For external wall, we use general warm temperate climate insulating materials, and for roof, general insulating materials. For window, we use a coatless double-pane window, and exclude insulating materials for the bottom and the slab.

After determining the materials of building elements and the construction method according to the modelling limitations, we install the atrium by type based on the size of offices as shown in Table 4 in Chapter 3 Thereafter, we change the size of atrium and conduct a simulation on the cooling and heating load.

Table 6. Material SI Value

	R-value W/(m²·°K)	Density kg/m²	Heat capacity J/(m²·°K)
External Wall	0.24	669.35	1.075
Floor	1.08	602.93	1.203
Roof	0.35	227.82	
Window	U-value: 3.17, SHGC: 0.69, Tvis: 0.78		
HVAC	Central VAV, HW Heat, Chiller 5.96 COP Boilers 84.5 eff		
Ventilatiory Volume	15 CFM (Cubic Feet per Minute)		

6. Limitations of modeling

The experiment of this article was designed to evaluate a type and a scale of atrium at the early design stage, and modeling details of mass design were established as standards of conceptual design. Here, the LOD 100-step suggested by AIA was used for modeling, because there is no guideline specifying a level of modeling details at each design process. The LOD 100-step defines volume of mass form and types of building in accordance with the domestic conceptual design standard, and performs modeling after setting up area, height, volume, location and direction of the entire building.

In this research, based on the LOD 100-step, the office building was modeled according to parameter basic information of office and atrium that follow the ASHRAE Standard, as Table 7 and 8 displays and then, office building's cooling and heating loads were experimented depending on the types of atrium.

Table 7. Office type data

Parameter	Default Value
Occupancy Schedule	Common Office 8 am - 5 pm
Lighting/Equipment Schedule	Office Lighting 6 am - 11 pm
People/100 sq. M.	3.5
People Activity Level	Standing, Light Work, Walking
People Sensible Heat Gain (W/person)	73
People Latent Heat Gain (W/person)	59
People Sensible Heat Gain (Btu/person)	250
People Latent Heat Gain (Btu/person)	200
Lighting Load Density (W/sq. ft.)	1.00
Equipment Load Density (W/sq. ft.)	1.30
Electrical Equipment Radiant Percentage	0.3
Condition Type	Heated and Cooled
OA L/S Person	10
OA Flow Per Area (cu. M./hr/sq. M.)	3.7
Unoccupied Cooling Set Point (F)	82

Table 8. Atrium type data

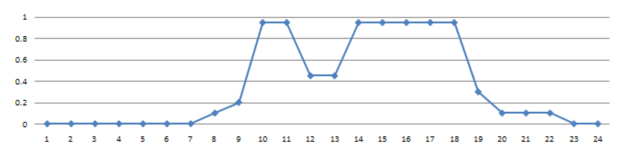
Parameter	Default Value
Occupancy Schedule	Retail Facility 7 am - 8 pm
Power Schedule	Retail Lighting 7 am - 8 pm
People/100 sq. M.	150
People Sensible Heat Gain (Btu/hr)	225
People Latent Heat Gain (Btu/hr)	105
Lighting Load Density (W/sq. ft.)	0.93
Power Load Density (W/sq. ft.)	1

Electrical Equipment Radiant Percentage	0.5

6.1 Limitations of location information and weather information

Project Vasari provides location information and weather information of our country, by connecting ASHRAE Standard's location and information and weather information with Google Maps. For the experiment of this study, location information and weather information of Seoul Metropolitan City offered by Project Vasari were employed. Fig. 1 shows data regarding cooling and heating schedule information of office. Here, x axis and y axis mean the time zone of use and the ratio of use of the maximum load, respectively.

Figure 1. data regarding cooling and heating schedule information of office



ASHRAE Standard Energy Performance Analysis applied to this paper is to measure load using three-dimensional spatial shape information, thermal zone information and parameter values and here, default values provided by Project Vasari were used, based on the ASHRAE Standard, since there are no separate domestic criteria of occupancy such as environment-friendly building certification system, EPI, building energy efficiency rating and so on. As Table 10 shows, heat quantity value per head depending on behaviors of occupants in offices was used for information of occupants.

Table 9. Quantity of heat per head depending on the behaviors of occupants

	Total Heat (Btu/H)			
Activity	Sensible Gain/ Person	Latent Gain/ Person	Low Radiant %	High Radiant %
Seated in theater	225	105	60	27
Seated in theater, night	245	105	60	27
Seated, very light work	245	155	60	2
Moderately active, office work	250	200	58	38
Standing, light work, walking	250	200	58	38
Walking, standing	250	250	58	38
Sedentary work	275	275	49	35
Light bench work	275	475	49	35
Moderate dancing	305	545	49	35
Walking 3 mph, light machine work	375	625	49	35
Heavy work	580	870	54	19
Heavy machine work, lifting	635	965	54	19
Athletics	710	1090	54	19

7. Simulation Result

We conduct an energy performance analysis simulation of the cooling and heating load values according to the shape of atrium and the changes of size. Each type of atrium affected the cooling and heating load according to the shape and size. The average load value by type is as follows:

Table 10. Average Load by Type of Atrium

	sectional	two-dimensional 1	two-dimensional 2	Three-dimensional	Four-dimensional	continuous
Average load (MJ)	1,854,702	2,003,827	2,009,550	1,967,515	2,018,827	2,142,143

In the change elements, we set depth only for sectional atrium and length only for continuous atrium. Thus our comparison by element is impossible. However, sectional atrium had lower average load value than the other atriums and was about 15% lower than the continuous atrium with the highest average load value.

In the two-dimensional atrium, length was more influential by about 1% than depth on the cooling and heating load. As a result of simulation after installing the direction of atrium to the southeast and southwest, the impact of the direction was similar at 0.2%. Unlike the other types, the three-dimensional atrium showed that depth was higher by 1.23% than length in the impact on the cooling and healing load, and the four-dimensional atrium showed that length was higher by 5.92% than depth in the impact on the cooling and healing load.

Figure 2. sectional vs two-dimensional vs continuous atrium

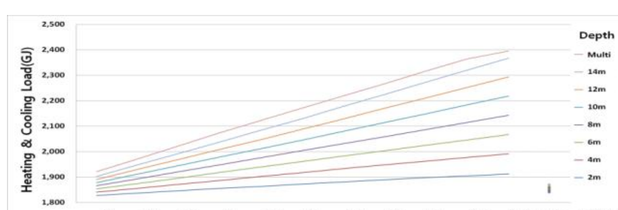


Figure 3. sectional vs three-dimensional vs continuous atrium

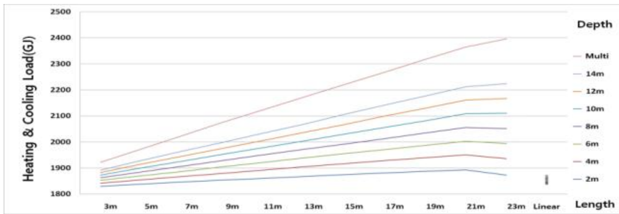


Figure 4. sectional vs four-dimensional vs continuous atrium

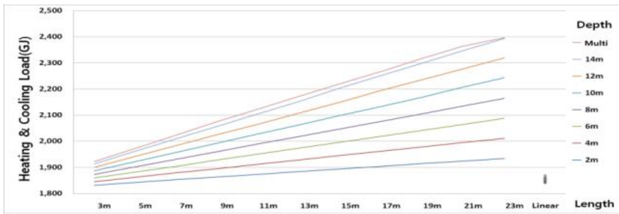


Figure 5. average cooling and heating load per unit volume of atrium by type

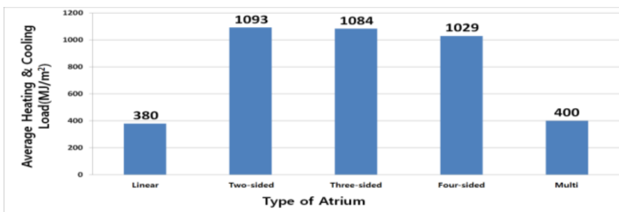
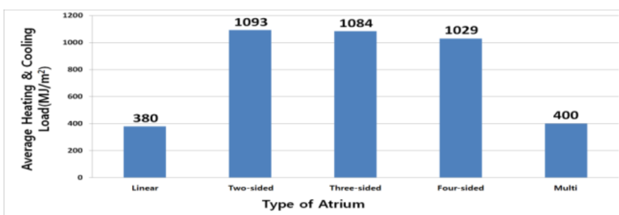


Figure 6. average cooling and heating load per unit volume of office by type



To compare the cooling and heating load values by type of atrium as shown in Fig. 2, Fig. 3, and Fig. 4, the simple-type was the lowest and the continuous-type was the highest. Also, from Fig. 5 and Fig. 6, the unit volume of atrium was found to be proportional to the cooling and healing load and the unit gross floor area of office was found to be inversely proportional to the cooling and heating load.

8. Scale computation using atrium's

8.1 Scale computation using atrium's volume

This paragraph described the unit volume affected by the change of atrium scale, by comparing and analyzing simulation results. Fig. 7, 8, 9, 10 and 11 indicate graphs on cooling and heating loads per 1m^3 of atrium volume depending on the types of it. They demonstrate that cooling and heating loads per unit volume of atrium are in inverse proportion to its scale as well as those per floor area. The bigger the atrium's scale gets, the higher the energy efficiency per unit volume of atrium gets, although cooling and heating loads rise too. In other words, cooling and heating loads are in a complementary relationship with one another depending on the scale.

Figure 7. cooling and heating loads per 1m^3 of Linear atrium volume

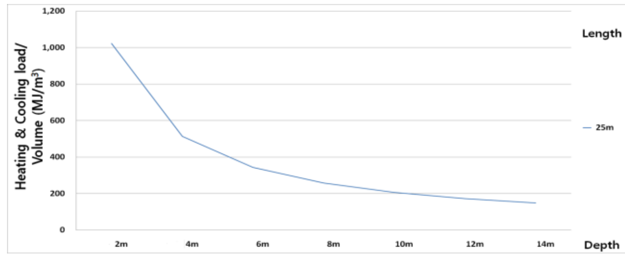


Figure 8. cooling and heating loads per 1m^3 of Two-dimensional atrium volume

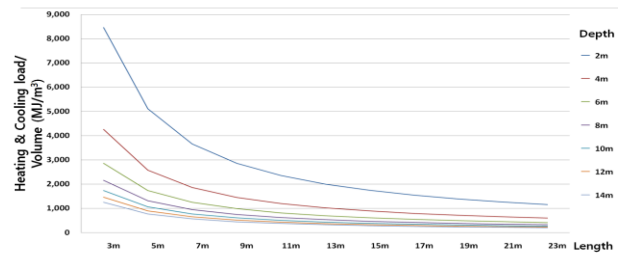


Figure 9. cooling and heating loads per 1m^3 of three-dimensional atrium volume

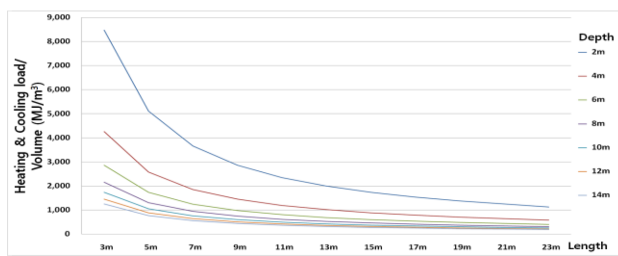


Figure 10. cooling and heating loads per 1m^3 of four-dimensional atrium volume

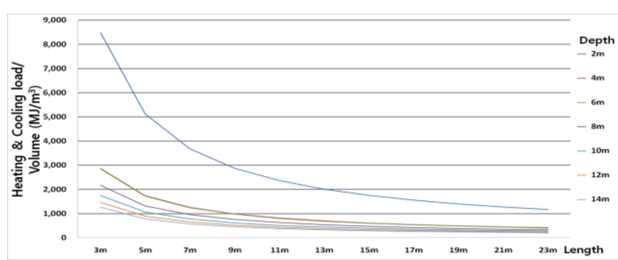
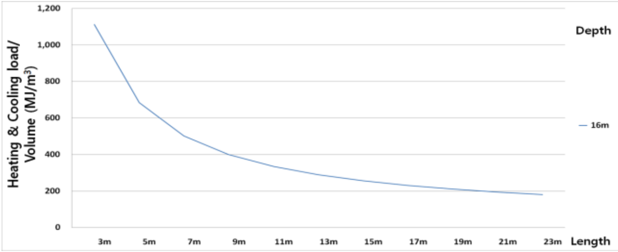


Figure 11. cooling and heating loads per 1m^3 of continuous atrium volume



Cooling and heating loads per unit volume increased by more than 20% and less than 15%, respectively, when the atrium's length was less than 5m and over 15m. It means that it lies within the range of appropriate values, if its length is 7~13m. Therefore, placing an atrium which is less than 7m or over 13m in length may waste space inefficiently during planning, although it increases energy efficiency per unit area.

Here, the atrium which is 7~13m long, accounts for nearly 30~50% of the entire building length and nearly 15~30% of the entire building volume. A depth of 6~10m is also at an appropriate level, in case of calculating it the same way. Here, the atrium that is 6~10m deep, accounts for about 35~60% of the whole building depth and about 20~35% of the whole building volume. In conclusion, it is considered that designing the length and depth of atrium within 30~50% of the whole building length and 35~60% of the whole building depth would be effective for improving energy performance.

8.2 Scale computation using atrium's facade area

This paragraph analyzed atrium's facade area, since it changes in the south, as the scale varies. From the analysis, it was found what should be a priority between length and depth, when planning two-sided, three-sided and four-sided atria. Though it was hard to determine a priority between single-sided and continuous-typed atriums as a consideration for planning each scale of it, because each of them has only one variation factor, Paragraph 7 shows that the continuous-typed atrium consumed energy the most, whereas the simple-typed one consumed energy the least.

Table 10. The Ratio of Facade Area to Atrium Volume

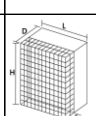
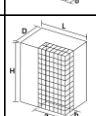
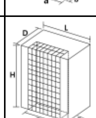
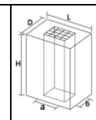
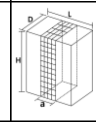
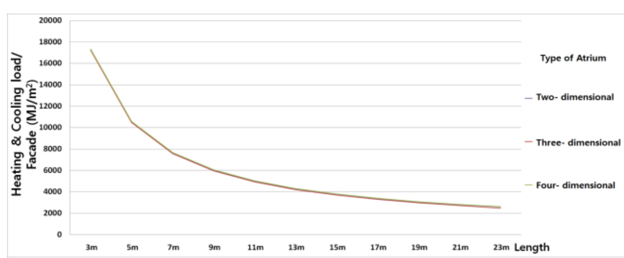
Atrium type	Variables of Atrium Elements	Size Values	The Ratio of Facade Area to Atrium Volume(β / α)	Notes
Sectional		L = 25m D = 16m H = 36m a = L b = depth	1/b+2/L+1/H	Atrium volume α = LbH Facade area β = LH+2bH+Lb
Two-dimensional		L = 25m D = 16m H = 36m a = length b = depth	1/a+1/b+1/H	Atrium volume α = abH Facade area β = bH+aH+ab
Three-dimensional		L = 25m D = 16m H = 36m a = length b = depth	1/b+1/H	Atrium volume α = abH Facade area β = aH+ab
Four-dimensional		L = 25m D = 16m H = 36m a = length b = depth	1/H	Atrium volume α = abH Facade area β = ab
continuous		L = 25m D = 16m H = 36m a = length b = D	2/D+1/H	Atrium volume α = aDH Facade area β = 2aH+aD
≪The Range of ratio of facade area to each type of atrium volumes≫ - Single-sided atrium : 0.17 ~ 0.6 - Two-sided atrium : 0.14 ~ 0.66 - Three-sided atrium : 0.09 ~ 0.52 - Four-sided atrium : 0.02 (constant) - Continuous atrium : 0.15 (constant)				

Table 00 is about the atrium facade ratio to each type of atrium volumes. The formula of the ratio displays that single-side type and three-sided type are affected by depth, and two-sided type are affected by length and depth to change the ratio. Moreover, the ratio of four-sided type and continuous type is constant rather than being changed by variation factors, due to their morphological properties.

When yielding the appropriate ratio of each type, based on the range of size and ratio of atrium measured in Paragraph 8.1, the ratio of single-sided and two-sided type was 0.2~0.3, and three-sided type's was 0.1~0.2 and four-sided type and continuous type showed a constant ratio, because of their morphological characteristics, as Table 00 indicates.

Fig. 12 indicates cooling and heating loads per unit area of facade facing the south of two-sided, three-sided and four-sided atriums. As shown in the graph, the differences of cooling and heating loads per unit facade area of two-sided, three-sided and four-sided ones were almost fixed at less than 0.1%, and there was a slight influence of the variation of length on the differences of them at approximately 0.05%. It implies that the facade area didn't have a high impact on cooling and heating loads, even though the depth and type was changed.

Figure 12. indicates cooling and heating loads per unit area of facade facing the south of two-sided, three-sided and four-sided atriums



Therefore, changing the length in planning an atrium would be more energy efficient than changing the depth. Adjusting the ratio between length and depth at 0.7:1 ~ 2:1 in the light of the volume and facade area as above has a high energy efficiency and it occupies nearly 10~34% of the entire building volume.

To sum up the results considering atrium's volume and facade area, from the perspective of energy, it is likely to be efficient to set up the ratio between length and depth at

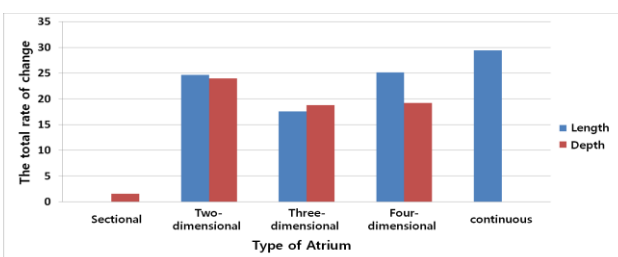
0.7:1~ 2:1 and to design it within about 30~50% of the entire building length and about 35~60% of the entire building depth.

9. Conclusion

In this study, we install atrium to office buildings by type or by size, conduct a simulation, and compare the relations with the cooling and heating load as the size of atrium by type changes. From this, it was found that the type and size of simple-type atrium was correlated with the energy load, and the following conclusions could be obtained.

1. Considering the cooling and heating load value by type of atrium, the cooling and heating load value of sectional atrium consumed the least and that of continuous atrium consumed the most. And in the two-dimensional, three-dimensional, and four-dimensional, the difference in the total value of cooling and heating load was only about 3%. Thus, the difference between each type can be redeemed through floor planning.
2. If the size is calculated when making a floor planning of atrium after determining the type of atrium, it should be determine within 30%～50% of the total length of a building, and for depth, it is appropriate in terms of energy efficiency to set the total depth of a building within 35%～60%. Also, it is favorable in terms of energy efficiency to plan the size of atrium within 10%～34% of the total volume of a building.
3. Reducing the size by adjusting the length rather than depth when making a floor planning is favorable in terms of energy efficiency when the skin area bordering the south of atrium is considered. If the length is reduced as shown in Fig. 15, 1.5% of the total cooling and heating load value can be reduced per 2m on average, and if the depth is reduced, 1.7% can be reduced per 2m. In other words, adjusting the size with depth and length except sectional and continuous types is considered to be more effective than the energy saving through the changes in the type of atrium.

Figure 13. The total rate of change by type of atrium



From the conclusion of this study, the changes in energy efficiency depending on the energy consumption and size by type of simple-type atrium was found. From this, this study can be utilized as a valuation basis for atrium energy performance in the initial design phase of BIM and can be used as an objective basis for eco-friendly design alternatives when designing simple-type atrium at an architecture firm or on the actual field. Also, the result value of this study should be accepted as relative value rather than absolute one.

THANKS TO

This work was supported by the National Research Foundation of Korea(NRF) grantfunded by the Korea government(MEST) (No. 2012-0008717)

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