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ScienceDirect
Procedia Engineering 121 (2015) 1869 – 1879
Procedia Engineering
www.elsevier.com/locate/procedia

9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Functional Relationship Between Lighting Energy Consumption And The Main Parameters For Double Atrium Offices

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Abstract

In order to obtain as much sunlight as possible, architects are chiefly concerned with the design of atrium forms and sky roofs at the stage of schematic design, with the effort of using the daylighting area in the greatest extent. Compared with previous single atrium forms, this paper focuses on the daylighting effect on double atriums. Based on the four parameters of double atrium daylighting, which are spacing, shape, position and area distribution of atriums, this paper analyses the influences on the daylighting effect to the first and sixth floors with the use of simulation software DAYSIM and the investigation of 5 indices of the lighting consumption of working planes such as DA, UDI100-2000, UDI>2000 and lighting evenness. It was found that for most indices, changing the spacing of the atriums brings a clear U-shaped curve; rectangle atriums are superior to square atriums, but the specific conclusion regarding the orientation of rectangle atriums needs to exclude the influence of their spacing; changing the shape and position of atriums has little influence on their lighting energy consumption; in the middle area of atriums, covering less, lighting is better.

Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015

Keywords: Double Daylighting Atrium; Daysim; Lighting Energy Consumption; Spatial Form

1. Research Background

The main subject of this research is the daylighting effect of the area surrounding the atrium. In modern times, the demand for daylighting is closely related to occupant's activities. The lighting energy consumption occupies a large proportion of the whole architectural energy consumption. Statistical data from domestic and international literature

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Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.09.169

indicates that the lighting energy consumption accounts for about a third of the whole building energy consumption in modern office buildings and large department stores （Cantin and Dubois 2011）.

In order to create a satisfactory indoor lighting environment, and at the same time, to avoid high building energy consumption, it is necessary to understand the different types of lighting models. According to the National Standard for lighting design of buildings GB 50033 (CABR 2004), currently the domestic requirements for architectural lighting differ depending on the type of building , and are divided into 8 classes including residential buildings, office buildings, schools, libraries, hotels, hospitals, museums and galleries, and industrial buildings (Daysin 2014).

Currently, there are two widely used emerging international standards of lighting: Daylight autonomy (DA) and Useful daylight illuminance (UDI). The former is an independent parameter of natural light and the latter is the effective day light intensity of illumination. Following will be the introduction and analysis of the two standards [4].

Daylight autonomy (DA) standard uses annual meteorological data to carry out the daylighting dynamic analysis on the building, and shows whether the minimum natural daylighting of a building can stay above 500Lux in a certain year (energy.gov 2014).

The definition of Useful daylight illuminance (UDI) When it is outside this range, whether greater than or less than, it will affect the normal user's visual work or cause discomfort, and will be called invalid (Daysin 2014). When it is outside this value, whether greater or less than, it will affect the user's ability to work or cause discomfort, and will be called invalid (Liu 2011; Mardaljevic 2000). Nabil and Mardajevic proposed that the effective daylighting illuminance value range should be determined between 100 ~ 2000Lux (Reinhart and Walkenhiorst 2001; Vineet al. 1998).

2. Research Approach

This paper researches four parameters of double atrium lighting, which are spacing, shape, position and area distribution of atriums, and their influences on the lighting effect to the first and sixth floors. It aims to “accumulate data to establish functional relationship between energy consumption of double atrium lighting and its main influential parameters”.

C Building Model

2.1. Building Model

The size of the building is set to 42m X 24m X 40m (length, width, height), floor number is 10, height between the floors is 4m, main facing direction is north-south. The exterior windows of the building are set as following: the height of the windowsill is 0.8m, window height is 1.8m, window width is 3m, width of walls between the windows is 0.6m. The construction of the building is shown in figure 1.

The building model is divided into four categories with a total of 18 kinds of atrium forms as shown in figure 2.3.4.5.

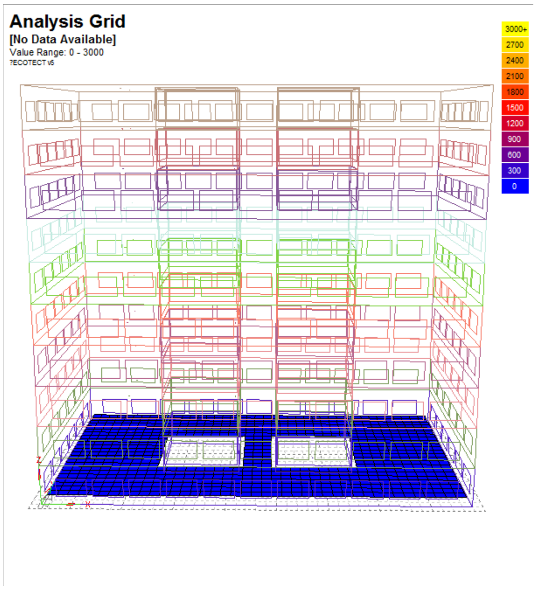

Fig 1. The pattern 42m X 24m X 40m X 10.

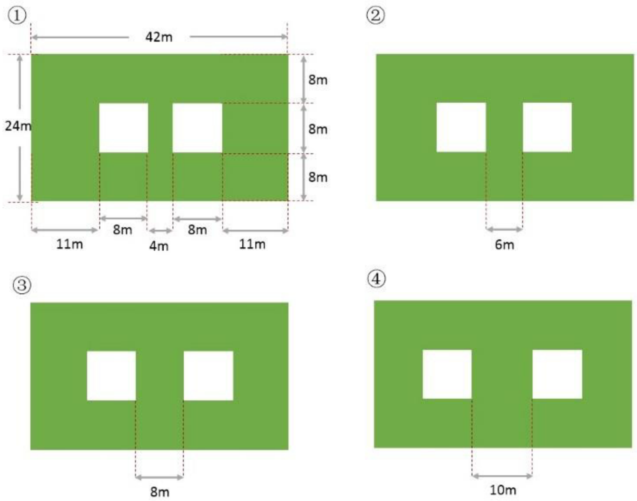

Fig 2. Changing the Spacing of Atriums.

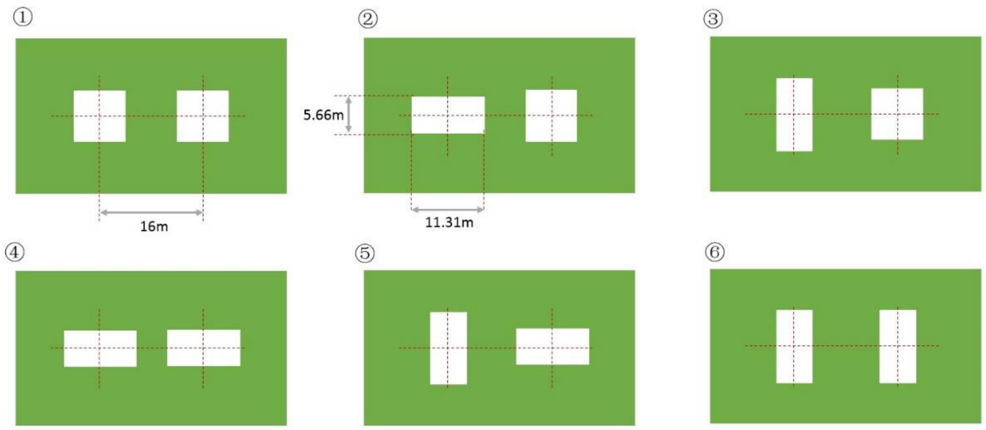

Fig 3. Changing the Shape of Atriums.

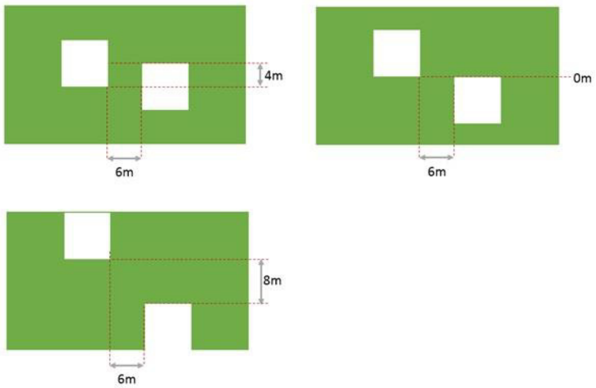

Fig 4. Changing the Position of Atriums

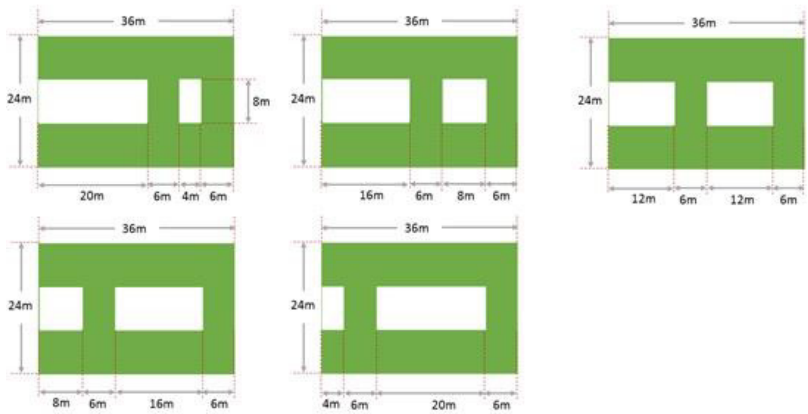

Fig 5. Allocating the Atrium Area.

2.2. Computer Software and Parameter Setting

This research mainly uses the meteorological data from Beijing, uses Ecotect for modeling, and uses DAYSIM for calculating the lighting throughout the whole year.

The height of the transparent part in the facade of atriums is 3.2m, non-transparent part is 0.8m; the transparent part in the facade of atriums is single layer of glass with the visual light transmittance of 0.8, windowing at the top of the atriums and its visual light transmittance is 0.6; the reflectivity of indoor ceiling surface is 0.8, the reflectivity of interior wall surface is 0.6, the floor reflectivity is 0.4; window-wall ratio is 0.375 with single layer of glass, and its visual light transmittance is 0.7; According to the regulation of Design stand for energy efficiency of public buildings, the indoor daylighting time is set from 7:00 to 20:00 (13 hours); the daylighting control mode is on-off control (to calculate DA); the height of working surface is 0.75m, simulation grid is 1m×1m; the ideal illuminance value of working surface is 300Lux.

3. Simulation Results

This research is designed to compare the 5 indices such as the lighting consumption of working planes in the first and sixth floors, DA, UDI100-2000, UDI>2000 and lighting evenness, in order to describe the four parameters of double atrium daylighting, which are spacing, shape, position and area distribution of atriums, and their influences on the daylighting effect to the first and sixth floors.

3.1. Changing the Parameter Setting of Atrium

Figures 6, 7, 8, 9 are the first floor's DA values with changed spacing. The difference of DA values cannot be seen from those figures. Hence, the energy consumption is analyzed by statistical data, as shown in figure 10, 11. Figure 2 indicates that corresponding number with changed shape. Figure 10 indicates the maximum relative deviation of energy consumption is 3.3% with changed spacing, and when the spacing is changed, the value of energy consumption increases at first and then decreases, when the horizontal spacing increases, the values of energy consumption increases a certain range with a wavy trend. Figure 3 is the number with the changed shape of atriums. Figure 10 indicates the maximum relative deviation of energy consumption is 5.2% with the changed shape. The relative deviations are very small according to all the figures. After changing the atrium shape, it is found that the energy consumption of rectangle atrium is less than that of a square one, but because of the same simulation spacing, it is not clear how to shape the atrium.

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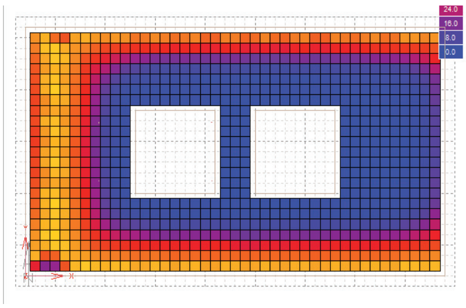


Fig 6. 1-1 for DA.

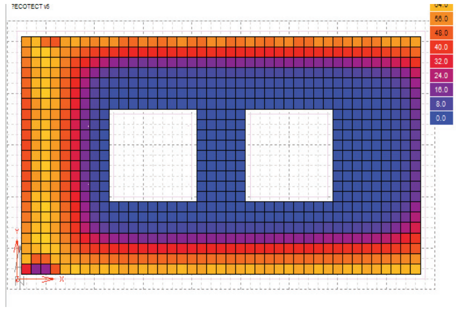


Fig 7. 1-2 for DA.

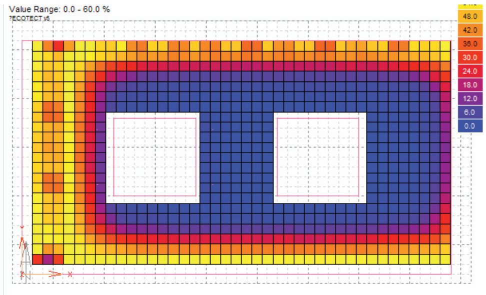


Fig8. 1-3 for DA.

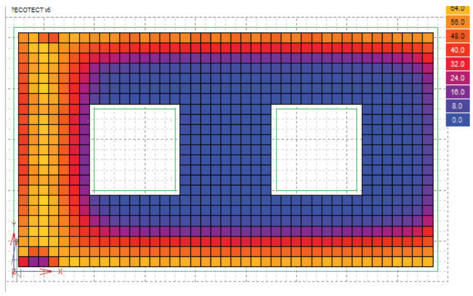


Fig 9. 1-4 for DA.

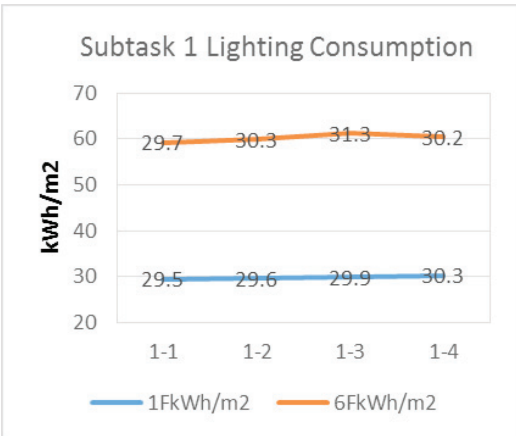


Fig 10. Subtask 1 Lighting Consumption.

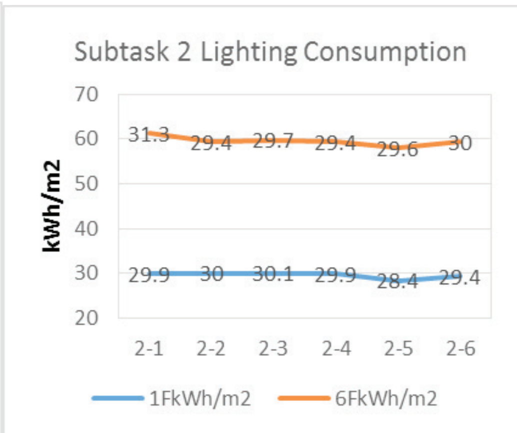


Fig 11. Subtask 2 Lighting Consumption.

It is assumed that there are two types of people who could use DA values in the DAYSIM software (Wu and Liu 2012; Zhu et al. 2010), they are: active person and passive person. The former could consider the daylighting conditions to adjust on-offs and beancurd sheets, while the latter could be inclined to keep beancurd sheets closed and lights opened at all times. It is known from the figure 12 that there's little influence on DA values with changed atrium spacing, but there is much difference between active users and passive users. According to figure 13 we could find that there's a corresponding relationship between the atrium shape and the DA values and its values of energy consumption, as shown in figure 12.When the value of UDI is in 100~2000, the maximum deviation value is 1.8% with changed atrium spacing as shown in figure 14, and the maximum deviation value is 3.9% with changed atrium shape as shown in figure 15, although the changing extent is not big but the fifth shape is still the best. When the value of UDI is above 2000, the maximum deviation value is 24% with changed atrium spacing as shown in figure 16, and the maximum deviation value is 25.9% with changed atrium shape as shown in figure 17. It is found that the figure with the values of UDI above 2000 could correspond with the figure with the values of DA trend. According to Table 1, it is found that the ratio of lighting uniformity is 3.9±0.5 in all, and good lighting uniformity ratio is less than 6.

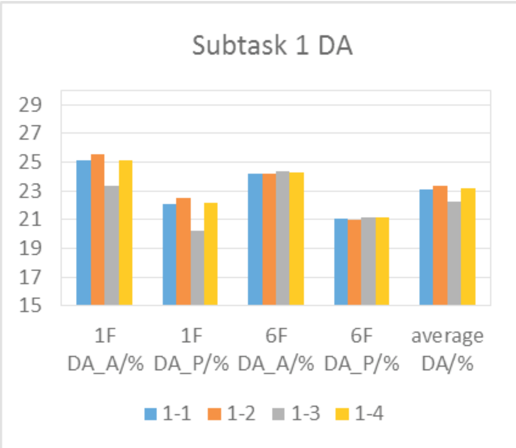


Fig 12. Subtask 1 DA.

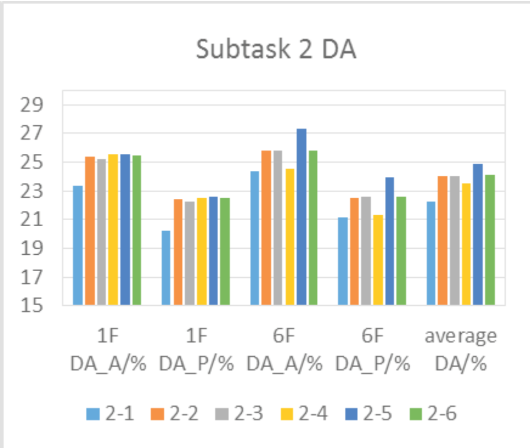


Fig 13. Subtask 2 DA.

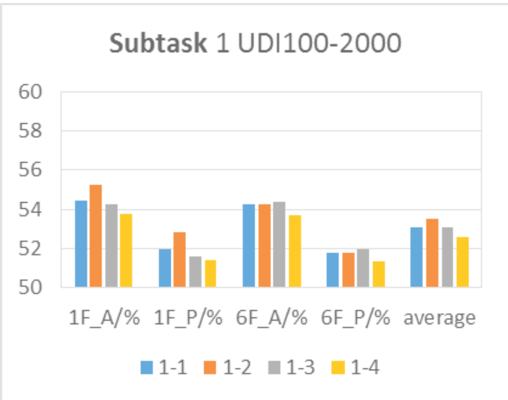


Fig 14. Subtask 1 UDI100-2000.

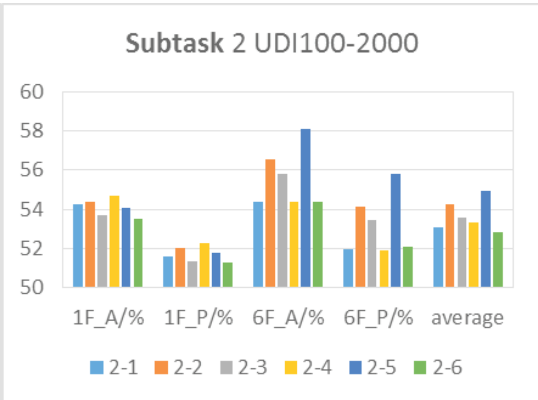
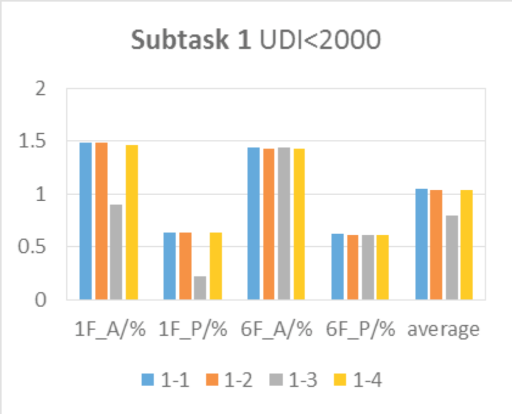


Fig 15. Subtask 2 UDI100-2000.



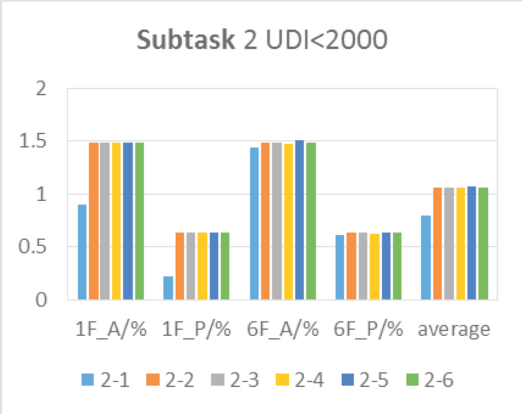


Fig 16. Subtask 1 UDI<2000.

Fig 17. Subtask 2 UDI<2000.

Table 1. Changing the Spacing and Shape of Atriums in DF.

	1F average DF	1F maximum DF	1Fspecific value	6F average DF	6F maximum DF	6Fspecific value
1-1	5.2	20.3	3.9	5.2	20.2	3.9
1-2	5.2	20.6	3.9	5.2	20.3	3.9
1-3	4.5	15.3	3.4	5.2	20.3	3.9
1-4	5.2	20.3	3.9	5.2	20.2	3.9
2-1	4.5	15.3	3.4	5.2	20.3	3.9
2-2	5.2	20.4	3.9	5.3	20.2	3.8
2-3	5.2	20.4	3.9	5.3	20.4	3.8
2-4	5.2	20.5	3.9	5.2	20.3	3.9
2-5	5.2	20.4	3.9	5.5	20.3	3.7
2-6	5.2	20.5	3.9	5.3	20.5	3.9

The maximum relevant deviation of energy consumption is 2.0% with changed atrium position. With the increase of vertical spacing, the energy consumption values could decrease to a certain range, but the decreasing trend is very small as shown in Table2. Regarding the DA values, the maximum relevant deviation is 0.4% as shown in figure 18, and the maximum relevant deviation is 8.2% with the UDI values ranging from 100~2000 as shown in figure 19, while the maximum relevant deviation is 10.5% with the UDI values above 2000 as shown in figure 20, the ratios of lighting uniformity are al below 4 according to figure 21.

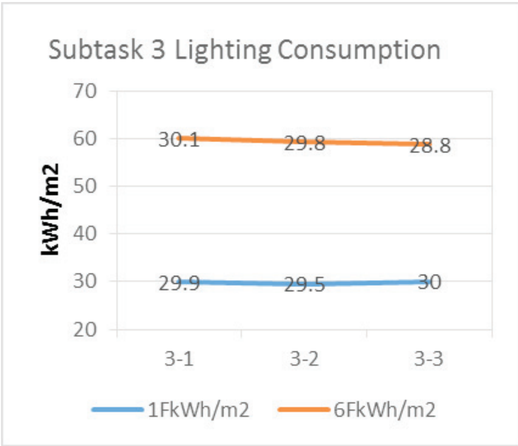


Fig 18. Subtask 3 Lighting Consumption.

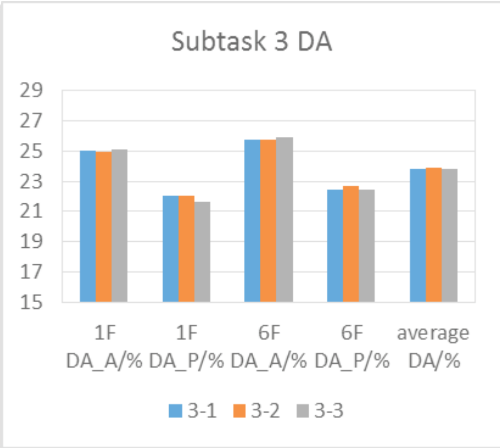


Fig 19. Subtask 3 DA.

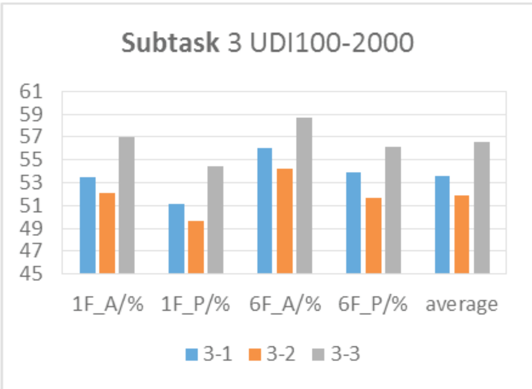


Fig 20. Subtask 3 UDI100-2000.

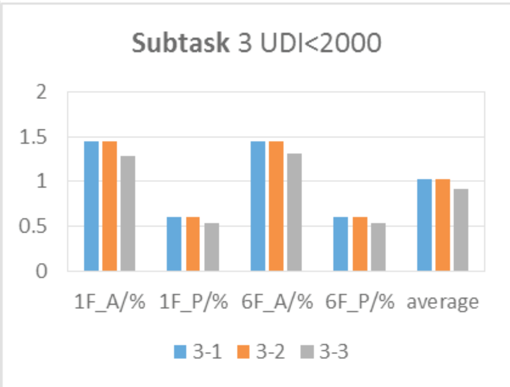


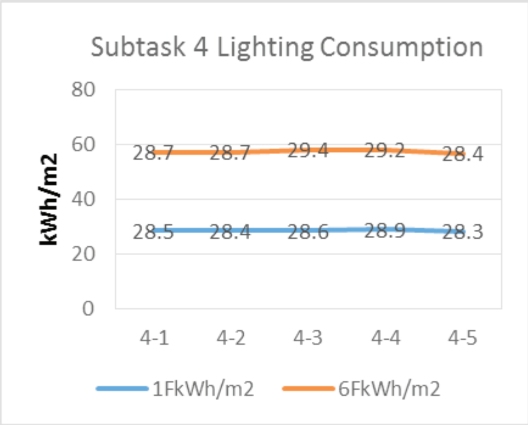
Fig 21. Subtask 3 UDI<2000.

Table 2. Changing the Position of Atriums in DF.

	1F average DF	1F maximum DF	1Fspecific value	6F average DF	6F maximum DF	6Fspecific value
3-1	5.16	20.48	4.0	5.09	20.24	4.0
3-2	5.11	20.43	4.0	5.25	20.33	3.9
3-3	4.86	20.49	4.2	5.10	20.50	4.0

3.4. Changing the Parameter Setting of Area

In the same building with the same size, we enlarge the area size of atrium and gradually change the spacing between the two atriums, the maximum relevant deviation of energy consumption is 2.4%, with the increase of spacing, the energy consumption values could change within a certain range as shown in figure 22, in the aspect of DA values, the maximum relevant deviation is 38.5% as shown in figure 23, and the ratios of lighting uniformity are all below 3.6 according to Table3 and are all in good condition.



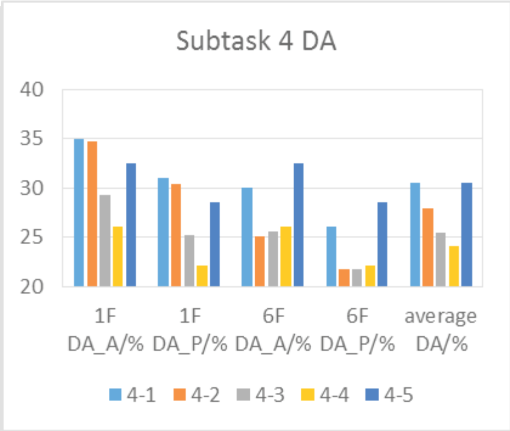
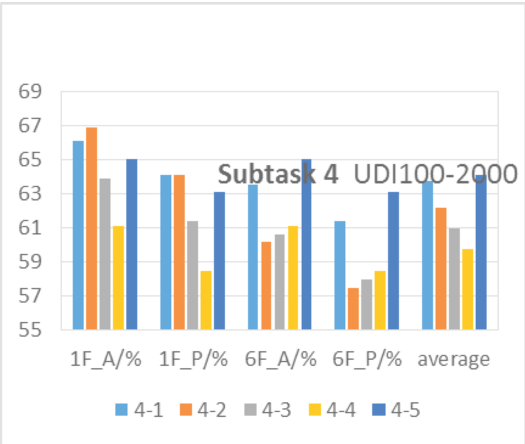


Fig 22. Subtask 4 Lighting Consumption.

Fig 23. Subtask 4 DA.



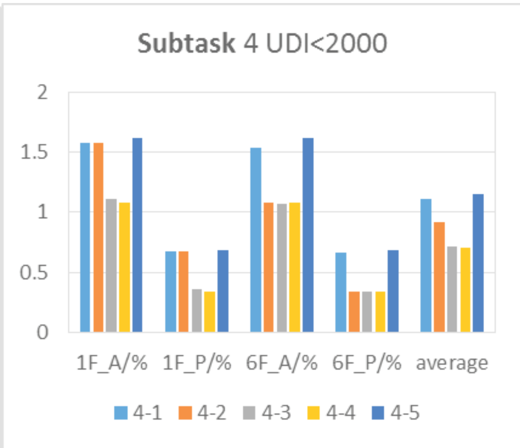


Fig 24. Subtask 4 UDI100-2000.

Fig 25. Subtask 4 UDI<2000.

Table 3. Allocating the Atrium Area in DF

	1F average DF	1F maximum DF	1Fspecific value	6F average DF	6F maximum DF	6Fspecific value
4-1	5.89	20.42	3.5	5.65	20.42	3.6
4-2	5.74	17.59	3.1	4.86	16.97	3.5
4-3	5.16	16.94	3.3	4.89	16.91	3.5
4-4	5.09	16.99	3.3	4.94	16.89	3.4
4-5	6.17	20.41	3.3	6.05	20.21	3.3

As we can see from the figure of energy consumption, the curve firstly increases and then decreases (Fig22), which indicates although the energy-consuming gap is not big, there's still the best allocation. For example, compared the indicators of 4-1 with 4-2 and 4-5 in Fig 22, the indicator of 4-5 with the energy consumption of 28.4k Wh/m2 is the minimum, but it's not the highest in terms of DA and UDI100-2000 (Fig23 & Fig24), which means though the energy consumption is reduced, the daylighting is not the best. Therefore, it is recommended to use the indicator of 4-2 in the design (Table3).

4. Conclusion

It is found that the first three of four parameters of double atrium daylighting studied in this paper which are spacing, shape, position and area distribution of atriums, have little influence on the daylighting effect to the first and sixth floors. We thought in the situation with the same size of atrium area, to change the above first three parameters can increase the indoor daylighting. But it is found that from the results of the study that under the circumstance of the same size of atrium area, there's no obvious increase indoor daylighting effect, no matter how to change the parameters. However, the size of the atrium area is the principle factor to influence the effect of indoor daylighting, that is to say the larger size of atrium area can make better indoor daylighting effect.

When establishing the functional relationship between the energy consumption of double atrium lighting and its main influential parameters, it is also found from the simulation that it's necessary to consider the angle of the sun, which means the opening direction of atriums should comply with the angle of the sun, otherwise the indoor lighting effect is affected by the building's own shadow. Therefore, the less central atriums are covered the better effect the indoor lighting will have with the design of double atriums.

Additionally, using cases 1 and 2 (Fig2 & Fig3), this research makes the experiments with the reflection number 2 to 5 for the study of accuracy, i.e. figure 26. It is concluded that when calculating the natural daylighting effect of the atriums, the reflection can be considered choosing the above 3 times for better accuracy.

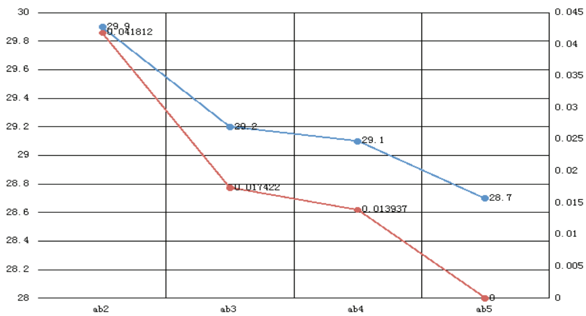


Fig 26. Reflection in Lighting Consumption.

References

[1] Y.X. Zhu, Y.P. Zhang, X.T. Li X.T, Y.G. Qin Y.G, Q.X. Zhan, Building Environment, China building industry press, 2010.

[2] China Academy of Building Research, Standard for daylighting design of buildings GB/T50034-2004, China building industry press, 2004.

[3] W. Wu, K.P. Liu, An Introduction of New Daylighting Evaluation Criteria: A Replacement for Daylight Factor. Nanjing. China, Illuminating Engineering Journal, Vol 23. No 2, 2012.

[4] J. Love, M. Navvab, The vertical-to-horizontal illuminance ratio: A new indicator of daylighting performance, Journal of the Illuminating Engineering Society. 23 (1994) 50-61.

[5] K.P. Liu, A Study on the Application of Dynamic Daylight Simulation Software DAYSIM in Natural Lighting Design, A Dissertation Submitted to Nanjing University For Master Degree, 2011.

[6] F. Cantin, M.C. Dubois,Daylighting metrics based on illuminance, distribution, glare and directivity. Lighting Research and Technology. 43 (2011) 291~307.

[7] E. Vine, E. Lee, R. Clear, D. DiBartolomeo, S. Selkowitz, Office workers response to an automated Venetian blind and electric lighting system-a pilot study, Energy and Buildings. 28 (2) (1998).

[8] C.F. Reinhart, O. Walkenhiorst O, Dynamic RADIANCE-based daylight simulations for a full-scale test office with outer venetian blinds. Energy and Buildings. 33 (2011) 683-697.

[9] J. Mardaljevic, The simulation of annual daylighting profiles for internal illuminance, Lighting Research and Technology. 32 (3) (2000).

[10] http://www.daysin.com.

[11] http://www.eere.energy.gov.