

# Sustainable energy saving alternatives in small buildings

Farooq Sher<sup>a,b,\*</sup>, Aiki Kawai<sup>c</sup>, Fatih Güleç<sup>b</sup>, Hamad Sadiq<sup>b</sup>

a. *School of Mechanical, Aerospace and Automotive Engineering, Faculty of Engineering, Environmental and Computing, Coventry University, Coventry, CV1 2JH, UK.*

b. *Department of Chemical and Environmental Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, UK.*

c. *Department of Architecture and Built Environment, University of Nottingham, University Park, Nottingham NG7 2RD, UK.*

## Abstract

Day lighting significance in architectural designs is well established for enhancing visual comfort, energy-efficiency and low carbon buildings development. Practicing the atrium element in the modern architectures has been increasingly popular in recent years because of the fact that the transitional space with good environmental elements can improve the quality of the buildings and reduce extra energy utilisation. The present study explores the advantages and effect of atrium on the energy performance of small buildings, a case study of 'The Azuma Row House'. Based on local micro-climate data Autodesk Ecotect Analysis was performed to calculate the daylight factors and the energy demand of the building. A comparison was made with atrium and without atrium in the building to evaluate overall energy savings. The results show a higher annual heating energy demand with atrium 3,443 kWh compared without atrium 2,526 kWh. The annual cooling energy demand without atrium 2,516 kWh is significantly greater than with atrium 912 kWh. The total energy requirements under no atrium case is about

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\* Corresponding author. Tel: +44 (0) 747 255 0250, Fax.: +44 (0) 747 255 0250

E-mail addresses: [Farooq.Sher@gmail.com](mailto:Farooq.Sher@gmail.com), [Farooq.Sher@coventry.ac.uk](mailto:Farooq.Sher@coventry.ac.uk) (F.Sher).

24 5,042 kWh which is considerably higher than the total annual energy demand with atrium 4,355  
25 kWh. The total amount of energy saved is about 15.7% per year by introducing the sunlight  
26 through the atrium. Along with the increasing issue of the energy crisis, environmental problem  
27 and the beautiful design of atrium, the development of atrium in modern architecture designing  
28 is feasible to have a good future.

29

30 **Keywords:** Sustainable Energy, Low carbon buildings, Solar energy, Atrium, Transitional  
31 spaces, Simulation and Autodesk Ecotect.

32

### 33 **1. Introduction**

34 Buildings are responsible for a large amount of energy consumption because of heating  
35 ventilating, and air conditioning (HVAC) systems [1-3] for different weather conditions during  
36 the year. This energy is mostly coming from fossil fuels such as coal, oil and natural gas.  
37 According to predictions, the energy consumption in this sector continues to increase [4] and  
38 this increase will clearly raise the global carbon dioxide (CO<sub>2</sub>) emissions. Energy saving  
39 technologies have, therefore, become more popular from last few decades with decreasing the  
40 energy sources and increasing the negative effect of CO<sub>2</sub>. Additionally, reduction of the energy  
41 using in buildings is to utmost importance in achieving to reduce CO<sub>2</sub> and other GHGs  
42 emissions [5]. The atrium has become a popular architecture form to bring sunlight into the  
43 building and to enhance the sense of spaciousness [4, 6-8]. In the construction industry, it can  
44 be predicted that the atrium could have a good developing foreground in future.

45

46 The atrium is a transitional space widely used in the architecture design. The design feature  
47 Atria gives a "feeling of space and light" in a building. The atrium was introduced in the 19th  
48 century, with the industrial revolution in iron and glass manufacturing techniques. It became a  
49 popular practice after 1970's energy crisis [9]. Nowadays, the modern architecture designers

50 practice the atrium widely in large-scale commercial buildings. Despite the aesthetic  
51 advantages other potential benefits of this feature are low carbon, energy saving, solar gain and  
52 natural ventilation. It is, therefore, considered that the good characteristics of the atrium can  
53 save energy consumption and can widely be used in the modern world's buildings [6]. In the  
54 19th century, the atrium in buildings appeared for the first time, due to the progress of  
55 construction technology in the manufacturing [9]. Then in the 20th century, Sharples and Lash  
56 [9] considered that the atrium has lost some concerns, perhaps because of the increasing  
57 attention on lighting potentialities and air conditioners. However, after 1970's energy crisis,  
58 atrium again attracted by lots of people due to its sustainable advantages [9]. In recent years,  
59 designing of the atrium in modern architecture has become very popular at small and large-  
60 scale commercial buildings [10].

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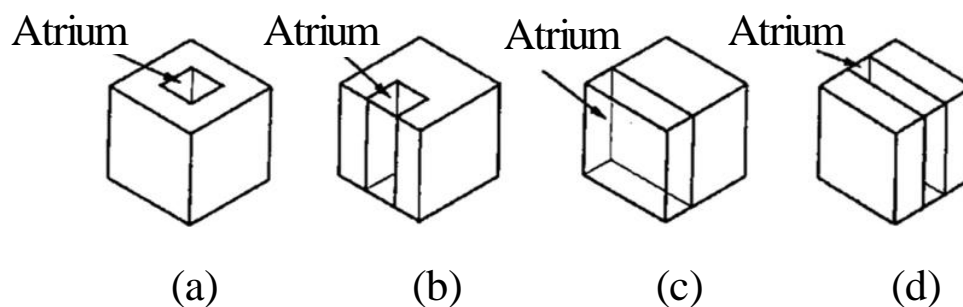
62 There are many key factors which influence the energy performance of atrium building such  
63 as; the geometric shape of the atrium, orientation to the sun, penetration of daylight into  
64 adjoining space, reflectivities of the atrium's surface and transmittance of the atrium roof and  
65 latitude [4, 11-15]. These parameters should be carefully considered to design an effective  
66 energy saving atrium. Previous studies revealed that atrium geometry has a strong relationship  
67 with the daylight factor [4, 12, 16-18]. Aizlewood and Maurice [19] have documented the  
68 several forecasting techniques to assess the average of the daylight factors and also mentioned  
69 the significance of atrium position in the building. The atrium position is a critical characteristic  
70 for the quantification of a complex daylight factor, i.e. the daylight of the atrium spaces and its  
71 adjacent spaces [20]. Latitude has a significant effect on solar radiations an through atrium in  
72 buildings. The optimum tilt angle of the roof can be changed in different latitude in order to  
73 get required solar radiation which is confirmed in previous literature [21, 22].

74

75 In fact, the design and location of the atrium are based on the local climatic conditions,

76 expectations of thermal comfort level, building function and the experiments of architecture.  
77 Aldawoud [4] has investigated the response of different atrium forms and geometries in under  
78 various conditions. The results of the study demonstrate that the total energy consumption is  
79 significantly affected by the shape of the atrium. According to Moosavi et al. [18], the most  
80 important objective of the atrium is for daylight factor and ventilation. In addition, Moosavi et  
81 al. [18] have also pointed out that the atrium position and shape design in a building is the main  
82 factor which determines the advantages of the atrium in the building environment. Different  
83 shapes of the atrium are categorised as; centralised, semi-enclosed, attached and linear as  
84 shown in Fig. 1.

85



86

87 **Fig. 1.** Four different general forms of atrium; (a) Centralised, (b) Semi-enclosed, (c) Attached and  
88 (d) Linear [23].

89 The atrium position in the building is the main factor which determines the advantages of the  
90 atrium in the building environment. Ahmad [24] has mentioned that the horizontal top-lit form  
91 atrium is not suitable for tropical regions. Furthermore, Ghasemi et al. [13] have assessed the  
92 daylight performance in the adjacent spaces of the vertical top-lit atrium in the tropical climate  
93 regions with reference to Malaysia. The findings demonstrate that by providing sufficient  
94 daylight in the adjacent spaces of the vertical top-lit atrium, a model of the atrium with atrium's  
95 section aspect ratio 1, atrium's plan aspect ratio 1/3, and 3/8 atrium clerestory to atrium height  
96 is the most proper model of atrium [13].

97

98 Different kinds of daylight factors distribution in the atrium have a relationship with a  
99 geometrical shape index [17]. Kim and Boyer [16] presented relationships and dependencies  
100 between the centre of the daylight factors in open atrium spaces and atrium shapes. Aizlewood  
101 [19] pointed out several forecasting methods and techniques to assess the average of the  
102 daylight factors, as well as considered the parameter influences within the daylight of the  
103 atrium spaces and its adjacent spaces. It is always complex and hard to predict that the daylight  
104 of the atrium in a building. The atrium as a transition space not only presents the atrium space  
105 itself but also offer natural light to adjacent spaces [20]. Through exchanging inside and outside  
106 air, the building atrium also offers natural ventilation and daylight [25].

107

108 Buildings consume a lot of energy and resources, the atrium is the main potential source to  
109 offer daylight into buildings and provide other environmental factors; such as the reduction of  
110 energy consumption, solar gain and natural ventilation. The present study investigates the  
111 benefits of the atrium in small buildings and to explore main characteristics of the atrium which  
112 lead to energy saving. The focus is given to the linear shape atrium to investigate the advantages  
113 of the atrium, as well to know how much energy could be saved through introducing sunlight  
114 through atrium by using a sample case of the Azuma Row House (Osaka, Japan). Furthermore,  
115 the study evaluates the effect of the atrium on the energy consumption and demand of the  
116 building. Autodesk Ecotect tool has been employed to calculate the average Daylight Factor  
117 (DF) and to analyse the energy demand of this unique style of architectural practice. “Ecotect  
118 was developed by Square Research Ltd and Dr Andrew Marsh. Ecotech software is an energy  
119 simulation tool and it is compatible with BIM software, for example, Autodesk Revit  
120 Architecture. Several studies are carried out which demonstrated high accuracy of Ecotect  
121 simulation to perform preliminary building energy performance analysis [26, 27]. It offered a  
122 wide variety of simulation and building energy functionality analysis which helps to visualize

123 and simulate building performance especially day lighting simulation. The software for  
124 analysis combines an intuitive 3-D design interface with the performance analysis function set  
125 the interactive display of information[28]. This also provides Acoustic, thermal and lighting  
126 analysis. It includes monthly space loads, acoustic reflection, the impact of environment, cost  
127 of the project and artificial/ natural lighting level [29]. Although its modelling and analysis  
128 capabilities handle geometry of any complexity and size, the main advantage is to focus on  
129 feedback at an initial stage of building process design. In addition to the table and standard  
130 graph based reports results of the analysis can be mapped over the surfaces of the building and  
131 can be directly displayed within the spaces such as spatial and volumetric results analysis  
132 visualization. In building Ecotect simulation helps in achieving design by different  
133 architectural practices, in turn, reducing global warming potential. Secondly, it also helps in  
134 reducing building operating cost [30]. Since the release of 5.6 versions, Ecotect added the  
135 support for gbXML and IFC schemas. Ecotect can import CAD software like Revit, 3Ds Max  
136 and AutoCAD. It exports to a wide range of other programs and is supported by GBS, Energy  
137 Plus and Equest [31]”. The results provide very useful findings to compare energy consumption  
138 in the Azuma Row House with atrium and no atrium under the same circumstances. This study  
139 is a good example to demonstrate the energy saving and sustainability in small and narrow  
140 houses buildings.

141

## 142 **2. Methodology and data analysis**

143 The experimental program was divided into a few analysing steps. Initially, the time duration  
144 and mode of the daylight enters the interior spaces were analysed. The daylight factor was  
145 tested in the overcast sky of the whole year. The energy consumption of the Azuma Row House  
146 with the factor of the atrium was measured. Design modifications were then carried out by  
147 adding a roof at atrium position and measuring the energy consumption without atrium. The  
148 Ecotect Analysis tool was employed to calculate daylight factor, illuminance level and energy

149 consumption by incorporating a global weather information database [32].

150

## 151 **2.1 The daylight factor**

152 Daylight Factor (DF) is the most common index and easy to measure the light in buildings. It  
153 is the instant proportion of inside light level in the measuring points, to the outside light level  
154 in the same horizontal plane under a standardised CIE overcast sky [11] and is defined as  
155 follows:

156

$$157 \quad DF(\%) = \left( \frac{E_{di}}{E_{do}} \right) * 100 \quad (1)$$

158 where  $E_{di}$  = indoor horizontal illuminance measured under the diffuse sky and  $E_{do}$  is outdoor  
159 horizontal illuminance from the diffuse sky from the diffuse sky.

160

161 The daylight factor is used in building and architecture design not only for evaluating the  
162 interior natural daylight illuminance on the surface but also for ensuring whether there will be  
163 enough space for habitats to do their normal works [11]. It is a complex and repeated process  
164 to calculate the daylight factor, and thus it is necessary to use some software products, such as  
165 Ecotect, Radiance, DAYSIM and DIVA. These are a set of tools to present daylight simulation,  
166 including renders and many other features to measure simulated daylight levels. In these tools,  
167 radiance is one of the most popular and powerful daylight simulation products [33].  
168 More specifically, radiance should be able to predict the internal luminance and illuminance  
169 distributions in any sky conditions, and it has been widely validated during the past 20 years  
170 [7]. Ecotect simulates the performance of building with the context of the environment. The  
171 Ecotech inbuilt tools are used to present daylight simulation, including renders, radiance and  
172 many other features to measure simulated daylight levels [7, 33].

173

174 The daylight factor is often measured in an artificial sky or under an overcast day [11].  
175 According to the British Standards Institution (BSI, BS 8206) [34], when a space with an  
176 average daylight factor of less than 2% is considered as dim and dark, it means most of the day  
177 needs electric lighting. When the daylight factor is between 2% and 5%, there is a good balance  
178 between thermal and lighting aspects, as well as a little or no additional lighting is required  
179 during the daytime, moreover, supplementary artificial lighting is necessary. When the average  
180 value of the daylight factor is more than 5%, space appears strongly light, it seldom needs to  
181 use artificial lighting during the daytime.

182

183 Three simple steps to estimate and calculate the daylight factors in the centre of the atrium  
184 spaces are as follows [35-38]:

185

186 First, compute the Well Index (WI) by considering the represented values of  
187 height, width and length of the atrium.

188

$$189 \quad WI = height * \left( \frac{width + length}{2} \right) * length * width \quad (2)$$

190

191 Second, compute the horizontal DF (%) for unglazed roof. (Open atrium without roof).

$$192 \quad DF_{unglazed} = 100 * e^{-WI} \quad (3)$$

193

194 Third, estimate the transmission factor ( $\rho$ ) for a glazed roof and multiply the calculated DF  
195 with it.

$$196 \quad DF_{glazed} = \rho * DF_{unglazed} \quad (4)$$

197

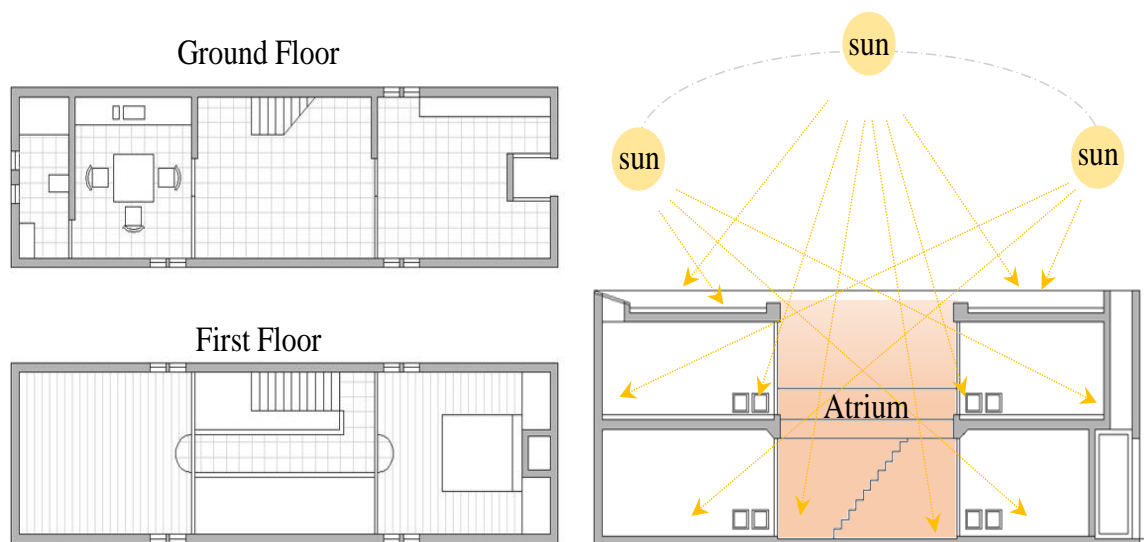
## 198 **2.2 The Azuma Row House**

199 The Azuma Row House (also known as Sumiyoshi by Japanese) was designed by Tadao Ando



200 in Osaka, 1976 [39, 40]. The Azuma Row House is located in Osaka. The latitude and longitude  
201 of Osaka are 34° 40' 0" N and 135° 30' 0" E respectively. The house is a narrow concrete  
202 rectangular house with covered area 70 m<sup>2</sup>, with rooms back and forth connection through the  
203 outdoor bridge. The floor plan of the house and the sun lights which pass through the atrium  
204 are illustrated in Fig. 2. There is a living room, a kitchen-dining room on the ground floor,  
205 separated by an external atrium and stairs to the two bedrooms on the floor above. The central  
206 atrium space is the sole source of natural daylight throughout the whole house. It is a small and  
207 narrow house in a rectangle area, with rooms back and forth connection through the outdoor  
208 bridge in the centre of the atrium. The Azuma Row House is chosen in the present study to  
209 highlight the effectiveness of atrium at small scale level where space is limited.

210



211

212

213

**Fig. 2.** The Azuma Row House floor plan and sunlight distribution [39, 40].

214

215 An external atrium is located in the central space between the rooms. It is a linear-shaped atrium  
216 type. There are three reasons to choose the Azuma Row House to test the daylight factor and  
217 to calculate the energy saving for the atrium. Firstly, Tadao Ando is an architect of light,

218 focusing on using natural light and ventilation for his architecture design. The second reason  
219 is that the Azuma Row House contact with light, rain, air and other natural elements. Almost  
220 the whole daylight goes through the atrium spaces, however, the one through several small  
221 windows is quite small. The last reason is that there is no air-condition in the simple and narrow  
222 house. Moreover, the Azuma House as a researching sample is easier to test and more  
223 convenient to analyses the importance of atrium in energy saving as compared to other modern  
224 buildings with an atrium.

225

### 226 **2.3 Testing and calculations**

227 The testing can be divided into few steps as; the first step is to use Ecotect for analysing when  
228 and how long the daylight enters the interior spaces under the condition of no change. The  
229 second step is to calculate the energy consumption of the Azuma Row House with or without  
230 the factor of the atrium in this testing. With the purpose of research, the role of this atrium, a  
231 roof which can prevent daylight through Azuma Row house has been made in this atrium. In  
232 this way, it can be calculated how much energy should be used under the condition of a roof  
233 and without a roof. Autodesk Ecotect Analysis with a comprehensive concept-to-detail method  
234 is architectural design software to analyse sustainable building design. The tool is applied to  
235 calculate daylight factor and illuminance level at any point through the model, as well as to  
236 calculate the energy use of the whole building on annual, monthly, daily and hourly basis.

237

### 238 **2.4 Distribution of daylight factor**

239 The Azuma Row House is located in Osaka, Japan. The latitude and longitude of Osaka is 34°  
240 40' 0" N and 135° 30' 0" E respectively. According to the latitude, it is easy to present solar  
241 angle in different seasons and different time using Sun-Path Diagram, as shown in Fig. 3. The  
242 Azuma Row House was roughly divided into four main areas, respective to measure the  
243 daylight factors of these four rooms on an overcast day.

244

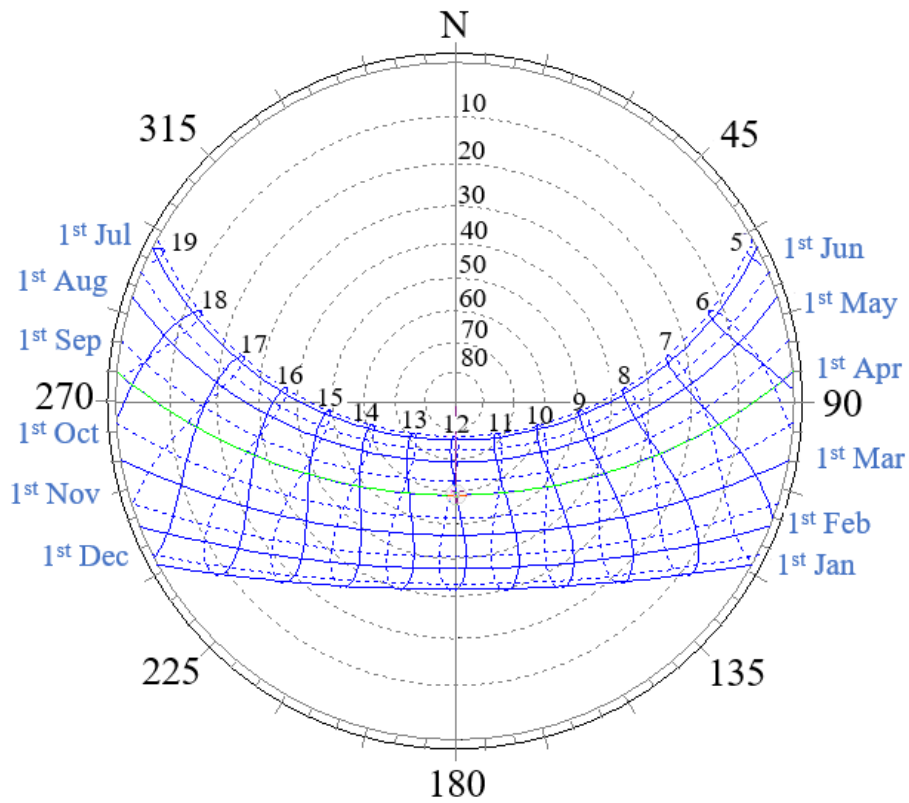
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**Table 1.** The solar angle during different seasons and time in Osaka [41].

Seasons	Day	8:00	12:00	16:00
Summer solstice	21st June	37.2°	78.6°	37.0°
Vernal equinox	21st March	23.1°	54.9°	23.1°
Winter solstice	21st December	9.3°	31.7°	7.9°
Autumn equinox	21st September	26.6°	56.1°	23.1°

246

247



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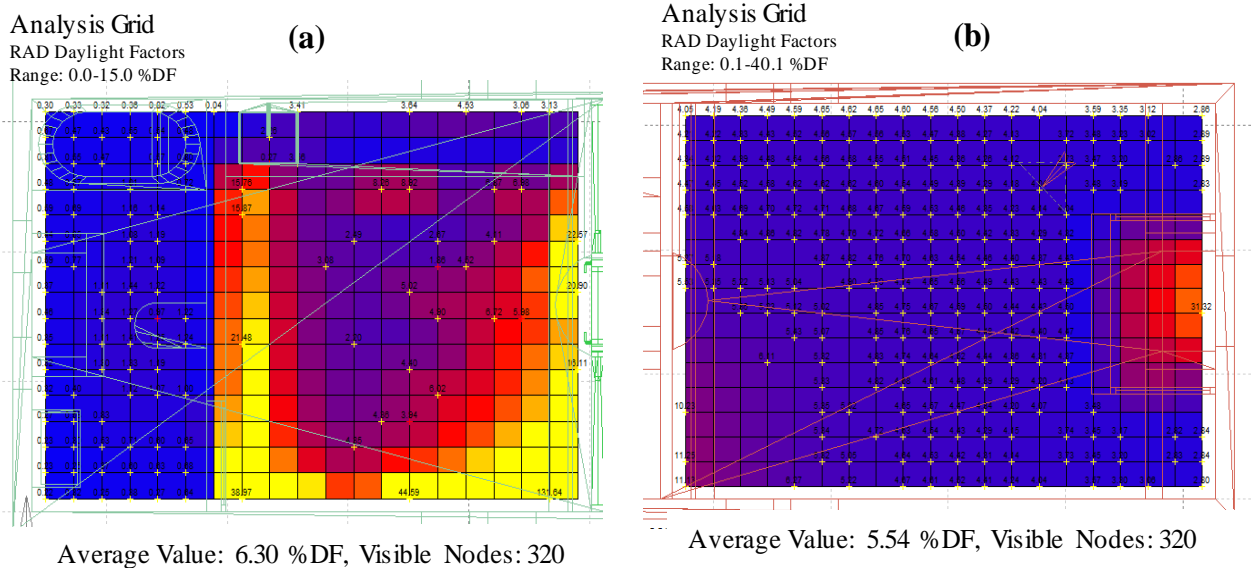
**Fig. 3.** Sun-path diagram in Osaka along with solar angles during different seasons and times [41, 42].

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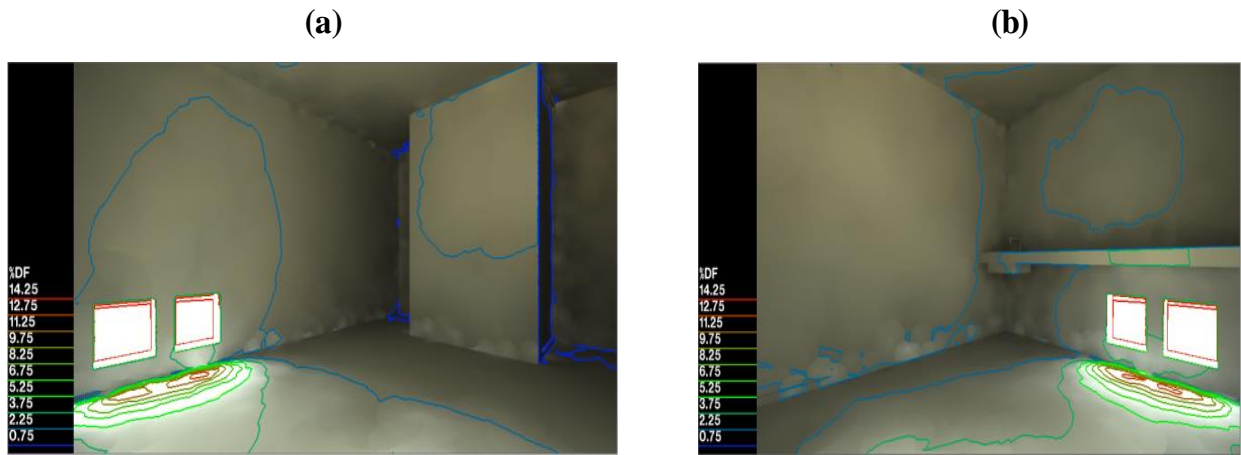
251 **3. Results and discussion**

252 **3.1 Daylight factor analysis**

253 Fig. 4 illustrates the distribution of daylight factor in the interior spaces based on the local  
254 weather data analysis. From Fig. 4(a), the first analysis grid it can be seen that the average  
255 value of the daylight factor is about 6.30% DF, which is more than the average daylight factor  
256 mentioned on the British Standard (BS 8206) [34]. The institution mentioned that the average  
257 DF should be at least 2%. If the average daylight factor in a space is at least 5% then electric  
258 lighting is not normally needed during the daytime, provided the uniformity is satisfactory [34,  
259 43]. Then in Fig. 4(b), the second analysis grid shows that the average value of the daylight  
260 factor is about 5.54% DF in the room, which is located at the front of the building. Although  
261 the value is slightly less than the back room still it is not necessary to use artificial lighting on  
262 most of the daytime. In this testing, the value range of the daylight factor is from 0.0% to 15.0%.  
263



264  
265 **Fig. 4.** The distribution of DF at a height of 800 mm above the ground floor; (a) Behind the building,  
266 (b) Front of the building.



267  
 268 **Fig. 5.** The ground floor room arrangement rendering in Ecotect; (a) Behind the building, (b) Front of  
 269 the building.

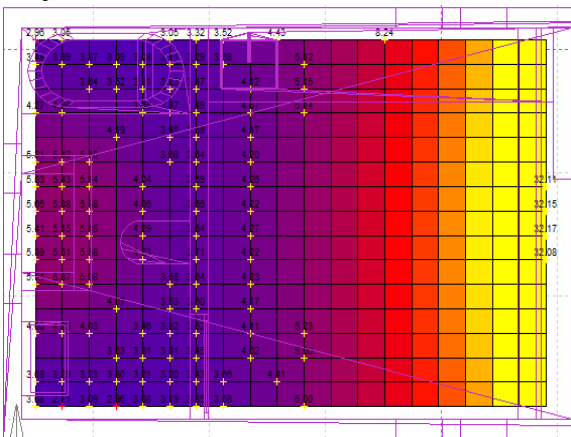
270 The contour lines for ground and first floors are presented in Fig. 5 and Fig. 7, respectively.  
 271 The different colours of the contour lines represent different levels of daylight factor. The blue  
 272 contour lines represent the lowest daylight factor, on the contrary, the red contour lines  
 273 represent that the highest daylight factor. Although there is an uneven distribution of the  
 274 daylight factor, it can still be found from the figure the light source mainly comes from the  
 275 atrium and small low-level windows.

276  
 277 Similarly, Fig. 6 indicates the daylight factor distribution in the first floor spaces at the height  
 278 of 800 mm. From the analysis grid Fig. 6(a), it can be seen that the average value of the daylight  
 279 factor is about 8.82% DF, which is strongly light and it seldom needs to use artificial lighting  
 280 during the daytime as it is much higher than the standard average DF mentioned in BS-8206  
 281 [34, 43]. Then the analysis grid Fig. 6(b) shows that the average value of the daylight factor is  
 282 about 5.05% DF for the room which is located at the front of the building at first floor. Although  
 283 the values are less than the back room, it is still unnecessary to use artificial lighting on most  
 284 of the daytime. In this testing, the daylight factor values range from 0.0% to 20.0%.

285

Analysis Grid  
RAD Daylight Factors  
Range: 0.0-20.0 %DF

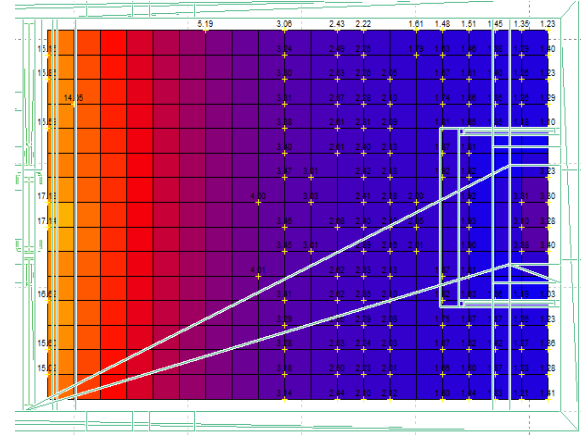
(a)



Average Value: 8.82 %DF, Visible Nodes: 320

Analysis Grid  
RAD Daylight Factors  
Range: 0.0-20.0 %DF

(b)



Average Value: 5.05 %DF, Visible Nodes: 320

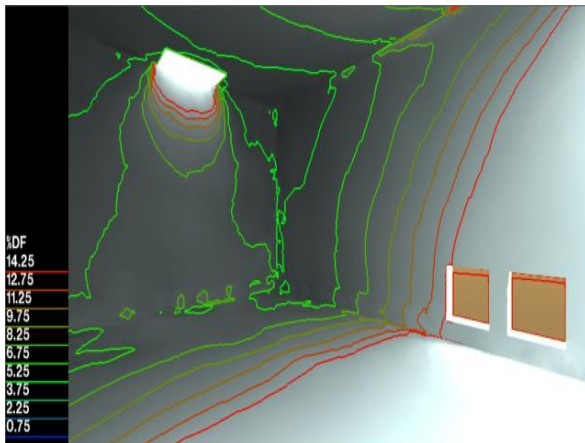
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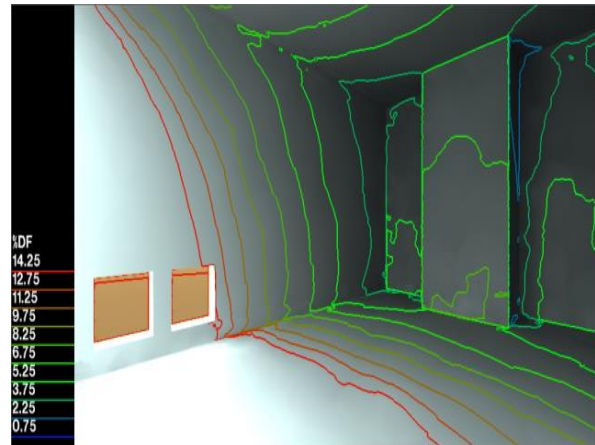
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**Fig. 6.** The distribution of DF at the height of 800 mm above the first floor; (a) Behind the building, (b) Front of the building.

(a)



(b)



289

290

291

**Fig. 7.** The room of the first-floor arrangement rendering in Ecotect; (a) Behind the building, (b) Front of the building.

292

293 The average daylight factors computed for front and behind rooms at ground floor were 6.30%

294 and 5.54% DF respectively, while 8.82% and 5.05% DF at first floor. The analysis shows that

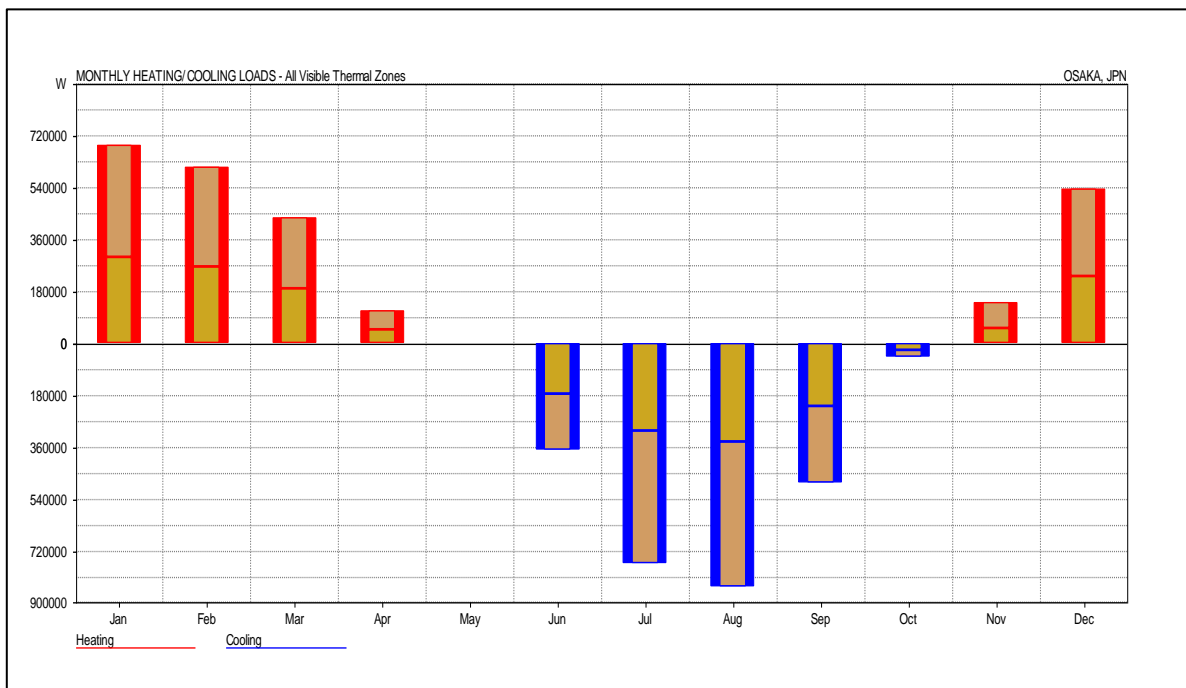
295 there is 40% more daylight on the first floor i.e. on the front room. According to BSI, the range

296 lies between the theoretical limits specified to use extra light energy (i.e.  $DF < 2\%$  considered

297 dim and dark) [34, 43, 44]. Therefore, even in the overcast day, it is not necessary to use extra  
298 artificial lighting during the daytime and to reduce energy consumption.  
299

### 300 3.2 Heating and cooling energy demands

301 All of the results from Ecotect simulation (radiances) have been analysed and interpreted. The  
302 testing comes out mainly from the illustrated heating and cooling energy demand of the whole  
303 year with or without atrium in the Azuma Row House. These results help to predict that how  
304 much energy can be saved by constructing atrium as a major source of daylight. Firstly, Fig. 8  
305 displays result under the condition of no atrium, the heating and cooling loads for the whole  
306 building from January to December, measured in Watts (W). The red bars represent when need  
307 to be heated and blue bars represent when need to be cooled. The total heating (red) and cooling  
308 (blue) energy being used by the building. In addition, each bar is divided into two parts, the  
309 dark brown bit is for the whole ground floor of the building and the light brown bit is on the  
310 first floor of the building.



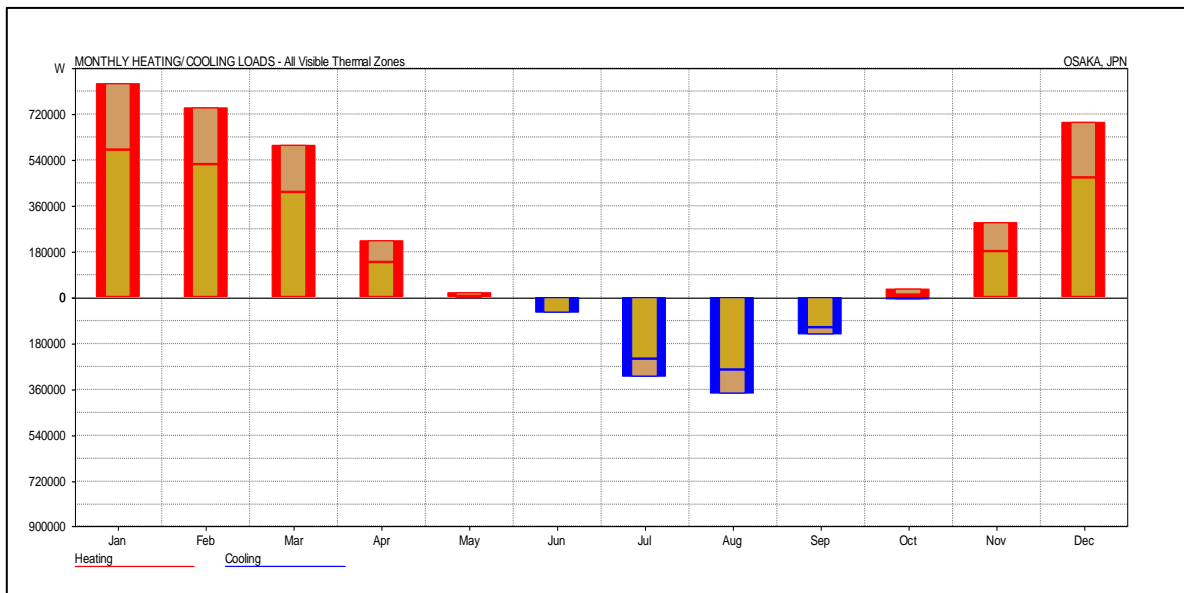
311  
312

**Fig. 8.** Annual heating and cooling energy demand with no atrium.

313 One thing should be concerned, the house is heated if the interior temperature is below 18 °C  
 314 and cooled if the temperature is above 26 °C. It can be seen that the energy requirement for the  
 315 first floor is observed higher than the ground floor for each month during the year. The total  
 316 annual energy demand for heating and cooling for the whole building is about 5,042 kWh,  
 317 which is separately 2,526 kWh for the heating and 2,516 kWh for the cooling. The highest  
 318 energy demand month for heating is January, total 675 kWh, and for cooling in August, about  
 319 820 kWh. Moreover, July is also the second highest energy demanding months of the year,  
 320 about 760 kWh. As the first month of the year, January is the coldest month and need the  
 321 highest energy requirement and the seventh month of the year, July, is one of the hottest months.  
 322 It is clearly understandable high energy requirement in these months.

323

324 As for the case with atrium, Fig. 9, the heating and cooling loads for the whole building from  
 325 January to December, measured in watts (W). Likewise, red represents a heating load while  
 326 blue represents a cooling load. The energy demand in a year for heating and cooling in this  
 327 whole building is about 4,355 kWh, which is separately 3,443 kWh for the heating demand and  
 328 912 kWh for the cooling demand under the case of the atrium.



329

330

**Fig. 9.** Annual heating and cooling energy demand with an atrium.



331

332 Although the total annual energy demand for heating under no atrium is 2,526 kWh which is  
333 little less for the condition with atrium 3,443 kWh total annual energy demand for cooling  
334 under no atrium is 2,516 kWh which is considerably greater than energy demand with atrium,  
335 912 kWh. The possible reason behind this is the heat gains are not too much in the atrium space  
336 during the cooling term. This may be considered that the exterior air temperatures are higher  
337 during the whole year and heat loss does not occur. As a result, the demand of the heating load  
338 is relatively lower. Additionally, whereas the energy requirement for the first floor dramatically  
339 decreased with the atrium case, it increases for the ground floor. This might be explained by  
340 atrium position; while the top of the atrium receives direct light, the ground floor receives much  
341 more reflected light rather than direct light as mentioned also by Aschehough [45]. Moreover,  
342 internal obstructions of the house such as walkways and flight of stairs can significantly reduce  
343 the daylight available in the ground floor [43]. However, Samant concluded that a progressive  
344 increase in the number of openings from upper to the lower floors can lead to higher DFs  
345 available at the ground floor [46].

346

347 Based on the tested data from Ecotect shown in Fig. 8 and Fig. 9, the energy consumption  
348 analysis for both cases, with and without atrium is presented. It is clear that the no atrium case  
349 consumed more energy as compared to the atrium case especially in the Summer solstice (21<sup>st</sup>  
350 June). Furthermore, the energy requirements for the first floor without atrium case is also  
351 higher than that with atrium case in the other terms; the Autumnal equinox (22<sup>nd</sup> September),  
352 Vernal equinox (21<sup>st</sup> March) and Winter solstice (21<sup>st</sup> December). On the other hand, during  
353 Winter solstice, the energy demand for the ground floor with atrium case is much higher than  
354 without atrium case. As a result, although the energy demand of the total annual for heating  
355 under no atrium is 2,526 kWh is slightly less than energy demand in the condition with atrium  
356 3,443 kWh. The total annual energy demand for cooling under no atrium is 2,516 kWh which

357 is significantly greater than energy demand with atrium 912 kWh. If there is no atrium, the  
358 annual heating and cooling energy demand is about 5,042 kWh. This value is considerably  
359 higher than total annual energy demand with atrium 4,355 kWh.

360

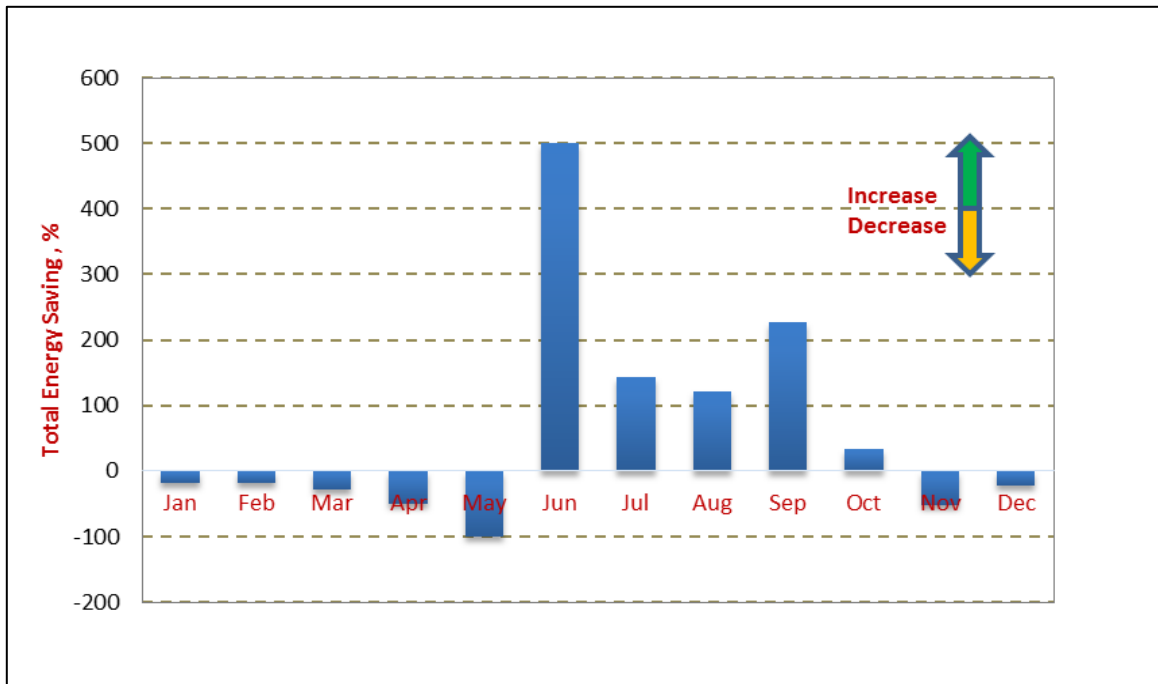
### 361 **3.3 Energy savings**

362 The energy savings are computed on monthly basis and are represented in Fig. 10. It can be  
363 observed that during cooling period from June to October, it is possible to save quite a lot of  
364 energy such as; 500% in June, 120% in July, 110% in August, 220% in September and 20% in  
365 October. As mentioned by Moosavi et al [18], atria and courtyards are commonly embedded  
366 in some buildings for natural ventilation and cooling purposes. It is clearly seen from this  
367 research the atrium on the Azuma Row House has non-negligible results on the energy saving  
368 for this purpose. However, during the heating term from November to May, the energy saving  
369 is on the negative side. As previously indicated, the measurements are taken in the real atrium  
370 of the Azuma Row House, which served as a model, confirms the effectiveness of the presence  
371 of the atrium as compared to the no atrium case. The energy performance of the atrium is much  
372 better at its first floor where more optimal conditions are produced.

373

374 As the solar angle during the winter solstice is the lowest as compared with other terms.  
375 However, the annual heating and cooling energy demand for the no atrium case is 687 kWh  
376 which is high as compared with the atrium case for the whole year. The probable reason for  
377 that is the heat gains are not too much in the atrium space. This may be considered that the  
378 exterior air temperatures are higher during the whole year and heat loss does not occur. As a  
379 result, the demand of the heating load is relatively lower.

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**Fig. 10.** Total energy saving in the case of with atrium on monthly basis.

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A simple atrium can save about 687 kWh, the building energy for a whole year. In other word, nearly 15.7% of the total energy of the building can be saved every year. Therefore, the atrium is effective to save an overall energy of the building, although the saving is small it could be improved by introducing different location, shape and size of the atrium with respect to the architectural design of the building. However, it may have negative effects on the annual energy demands if the location or climate changes. In addition, the results are tested by a model which is making by sketch-up, the predicting daylight factor of the atrium area sometimes can be uncertain and inaccuracy. Furthermore, the consequence may differ under different forms and structures of buildings. For example, there are different shapes of the atrium, centralized, semi-enclosed, attached, and linear etc. [18]. Therefore, for the better performance or higher energy savings, the characteristics of these different shapes of atriums under different weather conditions could be studied.

#### 397 **4. Conclusions**

398 In the present study, the Azuma Row House is taken as the model structure and tested under  
399 atrium and no atrium conditions as a sustainable energy-saving alternative. Nevertheless,  
400 atrium plays an important role in Architecture designing, especially in daylight factor and  
401 energy saving. Ecotect (Radiance simulation) is used to calculate and evaluate the daylight  
402 factors. The results showed that atrium has great importance in energy savings and reduce  
403 carbon footprints. The atrium can bring sunlight into the interior space of the building to reduce  
404 the usage of artificial lighting. Under atrium conditions, the ground floor daylight factor of  
405 indoor spaces at behind and front of the building is about 6.30% and 5.54% respectively.  
406 Whereas first-floor daylight factor at behind and front of the building is about 8.82% and 5.05%  
407 respectively, satisfying the requirement of the function for occupancy. The mentioned above  
408 the average value of the daylight factor is more than 5%, space appears strongly light, and it  
409 seldom needs to use artificial lighting in the daytime. Therefore, it is can be considered that the  
410 energy conservation decreased without using artificial lightings. The energy demand is  
411 calculated for linear shaped atrium by using the Ecotect. The overall average energy savings  
412 of the Azuma House is about 15.7%. However, future research could be focused on the other  
413 characteristics of the atrium. These may contain the shape of the atrium, the attitude of the  
414 building, the climate around the building and so on. Along with the increasing issue of the  
415 energy crisis, environmental problem and the beautiful design of atrium, the development of  
416 atrium in modern architecture designing is conceivable to have a good future.

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