#337: An evaluation of the thermal performance and energy efficiency of atria in hotel buildings in the UK

A case study of the Orchard Hotel, Nottingham

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Hotels are one of the most energy intensive sectors of the tourism industry. Research indicates that hotels consume more than half of their overall energy consumption for space conditioning alone. The building fabric has a major influence on hotels space conditioning needs. Atria, which are popular in hotel designs for their aesthetic value, can act as a thermal barrier between the exterior and interior spaces, therefore potentially contributing to a reduction in the space conditioning needs of a building. Despite this theoretical advantage, the body of available literature discussing the performance of atria in hotels is limited. In this work, the authors contributed to this knowledge gap through evaluating the performance of an atrium in a hotel based in Nottingham, UK. In situ temperature monitoring and dynamic building simulations were used. The atrium was initially assumed in a free running mode to test the thermal performance of the building envelope alone, and numerous cases were developed where parameters such as building orientation, fenestration characteristics, openings for ventilation and skylight properties were varied. Integrated Environmental Solutions Virtual Environment software was used to generate thermal comfort evaluations and to assess summer overheating risk. The simulation findings suggested that the skylight glazing ratio was the most important characteristic that influenced the indoor thermal condition which, combined with natural ventilation, significantly contributed to the overall hotels' energy usage. Based on the initial assessment, the existing atrium configuration in a free running mode would provide only 41% of comfort hours, and be at a risk of overheating for 8.7% of the summer. A substantial improvement in the thermal performance with 83% of comfort hours achieved in the summer and 0% risk of summer overheating was demonstrated through a combination of the proposed passive strategies along with natural ventilation in summer months. The best optimised case also presented an 88% reduction of summer cooling loads and 18% reduction of winter heating loads when active systems were assumed. Therefore, the authors concluded that there was significant room for the optimisation of the design of atria as contributors to comfort and energy efficiency in hotels in temperate climate zones.

Keywords: thermal comfort; atrium; energy efficiency; passive design strategies; building façade

1. INTRODUCTION

The current scenario of energy use in hotels worldwide and their contribution to the depletion of energy supplies is significant (CHOSE, 2001). According to studies on energy consumption in hotels in Europe, they use between 200 and 400kWh/m² of energy per year (Hotel Energy Solutions project publications, UNWTO, 2011), with over half of this consumed by heating, cooling and air conditioning alone (Energy efficiency in hotels, Cibse.org). It was also projected that energy costs would rise higher in the future, reaching up to 10% of overall gross revenue (Pateman, 2001). The high emissions at hotels can be ascribed to the fact that hotel guest comfort is generally prioritised (Energy policy, 2008). Moreover, hotels are open 24 hours a day, 365 days a year.

Furthermore, the necessity of sustainable design solutions has been recognised due to the worldwide rise of climate change, electricity shortages and sick building syndrome related to heavy use of space conditioning (Wand and Wong, 2006). This has sparked an interest in the use of passive design strategies, which may help hotels cut expenses. Among the numerous elements of the building envelope, atria, which comprises of the majority of hotel transitional spaces, not just adds grandeur to the building but also serve the purpose of improving daylighting and solar gains inside the building (Vujošević and Krstić-Furundžić, 2017). Atria may have three times the energy consumption per unit area or volume as the rest of the interior (Pitts and Jasmi, 2006). Also, it can be a cost-effective method of regulating its conditions using natural ventilation (Mohammad *et.al*, 2012) and help reduce the thermal discomfort usually caused by abrupt temperature changes for occupants moving in and out of the hotel (Nakano, *et al*., 1999). Additionally, the vast entrance doors and the extensive atrium glazing contribute to a stronger thermal link between the external and internal spaces, thereby giving a scope for reducing the dependence on fully air-conditioned systems (Hui *et al*., 2014). However, predicting their thermal performance is exceedingly challenging particularly in the temperate climate zone (Aldawoud, 2013). Therefore, it is worth looking at how this building type performs in UK hotels. The aim of this work was to evaluate the thermal performance of atria and their contribution to the energy demands for space heating and cooling of hotel buildings in the UK. The main objectives of this research were the following:

- To propose strategies to help mitigate the risk of summer overheating;
- To determine whether naturally ventilating the atrium zone of the hotel alone can reduce thermal discomfort during the summer months of temperate climate zones;
- To examine the impact of hotel atrium on the energy demands for space heating and cooling.

2. LITERATURE REVIEW

The key issues affecting the design of hotels are the site, shape, orientation, means of access, views from the hotel and storey height. Over the years, the sizes of guestrooms have become standardised for different quality of hotels. While the guest rooms still make up most of the floor area in most hotels, it is the public spaces that are most diverse and independent in design and type (Bohan Lin, 2011). This suggests that the two most common design objectives based on public space planning are to design and accommodate the public areas around the central lobby and to organise the public spaces with an understanding of their location in relation to the guestroom structure (Rutes *et al*., 2001). It has also been stated that atrium hotels are becoming a popular building type for newly constructed hotel buildings all over the world (Vujošević and Krstić-Furundžić, 2017).

2.1. Atrium in hotel design and its energy efficiency potential

The atrium zone is considered to be the largest and longer-term occupancy zone of a transitional space compared to the other transitional spaces such as the circulation areas and entrance areas. These spaces account for about 10% - 40% of the total building volume, with an estimated energy demand per unit area being as high as three times that of the rest of the building (Pitts and Jasmi, 2006). The main reasons being large glazing areas and significant air exchanges with the outside climatic environment (Hui and Jiang, 2014).

An atrium building typically consists of four commonly used forms as shown in Figure 1 i.e.: centralised atrium, semi-enclosed atrium, attached atrium and linear atrium

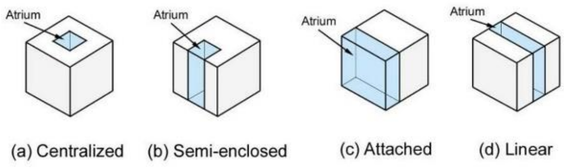


Figure 1: Four types of atria (Source: Hung and Chow, 2001)

It suggested that for the UK's temperate climate zone, in order to utilize most of the winter solar heat gain and to offer better views from the building during the different seasons, the attached and semi enclosed atrium types are the most effective forms.

2.2. Thermal comfort in atria

The thermal comfort standards considered for hotels include ASHRAE standard 55 and ISO standard 7730. The acceptable winter and summer operative temperature ranges for hotel lobby and foyer spaces as indicated by the CIBSE Guide A (2006, p. 9) are 19°C -21°C and 21°C – 23°C respectively. However, the operative temperature ranges for various facilities of the hotel have been slightly modified by the industry to suit their requirements. Hence, the proposed winter and summer comfort operative temperatures recommended for non-air conditioned hotel spaces suggests as 18°C -20°C in winters and 27±1°C in the summer months (Lawson, 2001). It has also been estimated that lowering the interior temperature by 1°C saves 10% of the heating costs (Gillan, 1999). In the UK, research has shown that on hot summer days, 25°C is an acceptable indoor temperature in non-air conditioned buildings (CIBSE Guide A, 2006, pp. 11-12). However, between 25°C and 28°C, an increasing number of occupants feel uncomfortable. Hence, building design should incorporate an assessment of the risk of overheating through the methods of thermal modelling. CIBSE guideline benchmark further suggests that in the UK, indoor operative temperatures of 30°C or more are rarely acceptable to occupants (CIBSE Guide A, 2006, p. 12).

3. CASE STUDY - ORCHARD HOTEL, NOTTINGHAM

The Orchard Hotel chosen for the purpose of this case study is a full-service mid-market business and leisure hotel, in Nottingham, UK (Figure 2). It is a four-star rated sustainable BREEAM certified hotel run by the De Vere hotels and constructed in the year 2012. Though there are plenty of hotels with atrium across the UK of a similar scale and category, this hotel was selected because of its sustainable design strategies which were worth considering not only for the current research, but also to find out possible design flaws, if any, with respect to the thermal performance of the atrium. Furthermore, the hotels' post-occupancy evaluation report and previous case study reports have little recorded documentation on the atrium space.

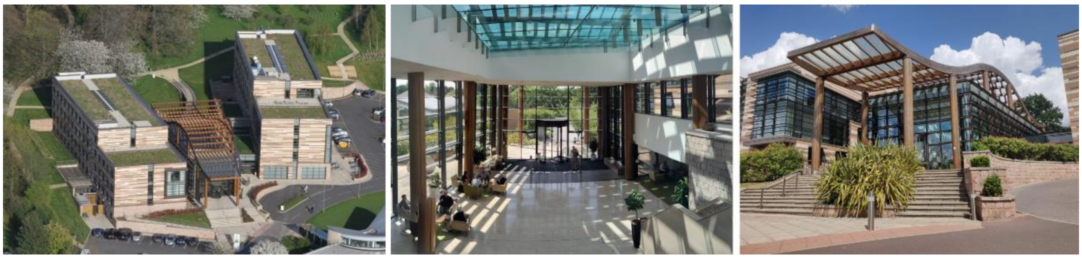


Figure 2: Aerial view of Orchard Hotel (Photo Courtesy: Robin Macey, blogs.nottingham.ac.uk, 2014) and Interior and exterior of the atrium building

Figure 3: Floor plan of the hotel

Designed by RHWL Architects and built by BAM Construction, this 9,300m^2 hotel is divided into three buildings consisting of two 5-storey guest room wings and a grand 2-storey atrium in the centre. The hotel consists of a total of 202 rooms which are oriented facing the north and south. All the rooms are suitably sized and configured for natural ventilation and daylight penetration.

The atrium building is a timber-laminated structure with extensive glazing on all facades. It is located between the two linear, north and south facing guest room wings with a total area of 647.9 m^2. As illustrated in Figure 3, the atrium is east – west oriented with the longer facades facing north and south and the entrance is from the west façade of the building. It is a double height space of height 6.4m. The lower level consists of the main entrance, reception lobby, library and a free-standing bar. The atrium has a large skylight of area 192 m^2, which is shaded by a timber canopy consisting of a series of angled fins acting as a brise soleil.

4. METHODOLOGY AND BASE CASE

The hotel atrium was simulated and assessed for its thermal and energy performance. For this, an initial model was developed with the existing design inputs and simulated using Integrated Environmental Solutions Virtual Environment software (IESVE). The criteria for this assessment were a free running mode which implied there may be a wider scope of energy savings in buildings compared to those with centralized HVAC systems. The parameters considered for the simulation are listed in Table 1

Table 1: Thermal Simulation Assumptions and Input data

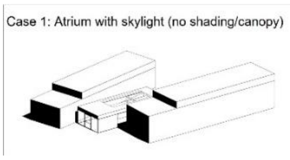
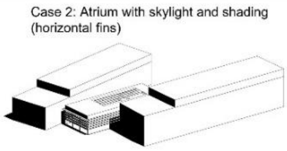
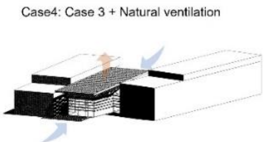
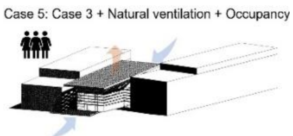
<table>
<tr><th>Parameter</th><th>Description</th><th>Assumption/ Key simulation inputs</th></tr>
<tr><td>Weather File</td><td>Nottingham - Climate Consultant 6.0 used to extract weather data</td><td>Typical weather year -Nottingham_CIBSE-DSY 033540 WMO Station number</td></tr>
<tr><td>Air permeability</td><td>For all cases</td><td>3 m^3/hm^2 @ 50Pa (as achieved by the hotel in post-completion testing)</td></tr>
<tr><td rowspan="3">Internal gains</td><td>Occupancy</td><td>Occupancy density 30 per 100 m^2 (i.e., 3.3 m^2 /person) considered from ASHRAE 62.1 occupancy standards for hotel lobbies, occupancy profile with 0.5 modulating value, maximum sensible gain 90W/person, and maximum latent gain 60 W/person.</td></tr>
<tr><td>Lighting loads</td><td>Since internal heat gain was not a criterion for the base case simulations, lighting and power loads were not considered.</td></tr>
<tr><td>Equipment loads</td><td>The thermal performance of the atrium fabric alone was the criteria for assessment. Hence no equipment gain was considered for the baseline simulations.</td></tr>
<tr><td>Comfort Temperature Range</td><td>CIBSE Guide A - Recommended comfort criteria</td><td>19°C - 21°C - winter operative temperature comfort range
21°C - 25°C (+1 °C) - summer operative temperature comfort range
Above 28°C - Summer overheating risk criteria</td></tr>
<tr><td>Atrium Building Envelope Materials</td><td>The building utilised energy-efficient measures and locally sourced construction materials</td><td><table>
<tr><th>Envelope & Principal material</th><th>Thermal properties (U-value)</th></tr>
<tr><td>Roof - Timber</td><td>0.10 W/m^2k</td></tr>
<tr><td>Walls - Timber</td><td>0.15 W/m^2k</td></tr>
<tr><td>Floor - Concrete</td><td>0.10 W/m^2k</td></tr>
<tr><td>External windows – triple glazing unit</td><td>1.50 W/m^2k</td></tr>
<tr><td>Curtain wall – triple glazing unit</td><td>0.13 W/m^2k</td></tr>
</table></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Heating & cooling profile</td><td>Winter period- November to February
Summer period- June to August</td><td>For Base cases- Case4 & Case5, parameters of fixed wall glazing and skylight changed to partially operable with 15% aperture opening, and the aperture type was louvers. The windows were assumed open when the internal temperature begins to exceed 22°C and closed if the outdoor temperature exceeds 26°C</td></tr>
</table>

4.1. Base case scenarios

The following were the cases considered for the baseline simulation:

- **Case 1**: This case represents just the atrium envelope with the skylight and without any shading or canopy.
- **Case 2**: This case consists of the atrium with skylight, equipped with a shading system. A set of 6 horizontal fins act as shading elements, to control the solar ingress. These metal fins run all along the atrium building perimeter and are projected out by 0.5m and are fixed 0.9m apart.
- **Case 3**: This case represents the current hotel atrium scenario with the skylight, shading system (same as that of case 2) and an addition of a timber canopy over the atrium roof. The canopy consists of a series of angled louvers (a tilt of 30° facing south) which acts as a brise soleil.
- **Case 4:** Case 4 is the same as case 3 but is evaluated by changing the parameter of fixed wall glazing and skylight to partially operable, hence enabling natural ventilation in the warm seasons. 15% aperture opening was considered for both the building fenestration and the aperture type were louvers. The windows were assumed open when the resultant temperature in the atrium zone begin to exceed 19°C and closed when the external temperature was low to reduce heat loss from the building.
- **Case 5**: Case 5 is similar to case 4 but with an addition of occupants in the assessment which will contribute to the internal heat gains. This was done to finally assess the space when in use.

Table 2: Summary of all base case simulations

Case Type	**Maximum summer resultant temperature (triple glazing)**	**Maximum winter resultant temperature (triple glazing)**	**CIBSE recommended summer comfort temperature band (21°C – 25°C)**	**CIBSE recommended winter comfort temperature band (19°C – 21°C)**	**Summer overheating risk above 28°C criteria (% of hours)**
Case 1 	60.5°C	33.5°C	X	X	42.2%
Case 2 	47.7°C	20°C	X	√	27.7%
Case 3 	34.8°C	13.7°C	X	X	8.7%
Case 4 	25.3°C	- (Windows closed)	√	-	0%
Case 5 	28.4°C	- (Windows closed)	√	-	0.3%

4.2. Results and discussion

A summary of thermal performance simulations for all the baseline cases are illustrated in Table 2. The simulations indicated that Case1 achieved significantly high summer and winter resultant temperatures, which did not comply with the CIBSE comfort range. This was due to the extensive glazing which resulted in the atrium acting as a heat trap and storing high amounts of solar gains thus resulting in thermal discomfort.

Next, Case2 with shading was analysed. This case showed a slight reduction in the percentage of hours reaching summer over heating risk criteria. However, it did not fit in the comfort temperature band either.

To test for further improvements, Case3, which is as built (present atrium) was evaluated. The addition of a canopy, indicated a significant improvement by achieving 41% of hours between the comfort range. Additionally, there was a massive improvement in reducing the summer overheat risk factor to 8.7% of hours.

In order to further reduce the summer overheating values, Case4 was tested which proved to eliminate the risk of summer overheating completely to 0% and reduced the overall percentage of discomfort hours (25°C and above) to 0.2% only. The maximum summer operative temperature as shown in Figure 4 was recorded as 25.3°C and the relative humidity period within the CIBSE recommended comfort range was 53.1%.

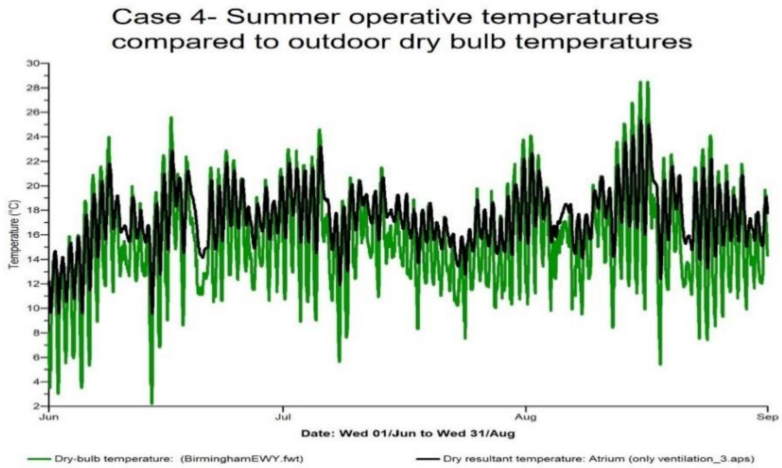


Figure 4: IES generated summer operative temperatures for case 4

It also showed that the fluctuations in temperature band in this case were relatively low. This indicated that the use of active cooling systems could be totally avoided even in the summer months inside the atrium space, thus allowing a massive positive impact on the building cooling loads and energy savings. However, in spite of the extensive glazing on all facades, the winter temperatures were below the comfort band throughout for all the cases, indicating that winter heating was inevitable. This was possibly due to the well-insulated building envelope hence not having a great impact on solar gains. Therefore, active heating measures should be employed to maintain thermal comfort within the space in the winter period.

The final case (Case5), which was as Case4 but with the addition of occupancy density, indicated that the percentage of discomfort hours based on summer overheat risk criteria was just 0.3%. A comparative evaluation of operative temperatures with Case4 suggested that the overall summer temperatures had just a marginal increment of 1°C, whereas the lower temperature range (minimum values) showed a rise in temperatures by 3°C. This indicated that the internal gains from occupancy did not adversely affect the overall summer operative temperatures and actually positively contributed to the energy savings by reducing the heating loads of the building. Therefore, out of all the baseline cases evaluated, it was concluded that the thermal comfort was best achieved in the final case.

5. PASSIVE STRATEGIES PARAMETRIC STUDY

To further assess the thermal performance of the atrium, suitable passive strategies were adopted to the baseline design such as orientation, wall glazing optimization and roof optimization.

5.1. Orientation

The following four orientations were considered for simulation (as illustrated in Figure 5) with Case-A representing the current base case (as built):

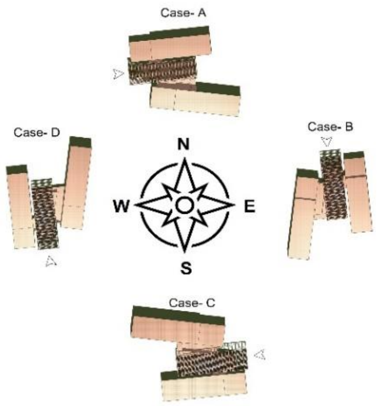


Figure 5: Different orientation of the basic atrium type hotel building

Results: The simulations suggested that the least effective orientation with very high summer solar gains, high summer temperatures and very low winter solar gains was observed in Case C. The possible reason being the majority of the glazed eastern portion of the atrium was exposed to the morning sun and the glazed atrium also acting as a heat trap resulting in temperature gains and external conduction gains and losses throughout the day.

However, the most effective orientations were identified as Case A and Case D. Case A, which is the current atrium with longer axis running east – west, recorded the lowest solar gain value in the summer period, suggesting the least possibility for summer overheating compared to all the other cases.

5.2. Wall glazing optimisation

In the current case, the elongated facades of the double height atrium, i.e. the north and south facades, face the 5-storey guestroom wings. Of this, the north façade remained completely in the shade of the north wing, whereas for the south façade, 38% of the glazing was exposed to the exterior which was not affected by the shadow from the southern guestroom wing. Furthermore, since outside views are considered a priority in hotels, the glazing on the east and west (main entrance) facades were not altered.

Hence, based on the factors mentioned above, two scenarios were considered for assessment. A summary of the building envelope areas indicating the proposed changes in the cases are illustrated in Table 3.

Table 3: Building envelope areas for the cases

	Wall glazing optimization		Roof glazing optimization		
	Case- 1a	Case- 2a	Case- 1b	Case- 2b	Case- 3b
Total Atrium area including mezzanine (m²)	648	648	648	648	648
Roof area (m²)	480	480	480	480	480
Other spaces area (m²)	8,652	8,652	8,652	8,652	8,652
Gross Wall Area (m²)	646	646	646	646	646
East Façade glazing ratio (%)	90	90	90	90	90
West Façade glazing ratio (%)	90	90	90	90	90
North Façade glazing ratio (%)	0	42	0	0	0
South Façade glazing ratio (%)	45	25	45	45	45
Skylight area (m²)	191.6	191.6	96	191.6	384
Roof glazing ratio (%)	40%	40%	20%	40%	80%
Skylight opening aperture (%)	0	0	0	0	0

- **Case- 1a: Removing the north glazing –** In this case, the entire north glazing is eliminated. The reason being that the entire façade remains in shade and faces the north guestroom wing.
- **Case- 2a: Reducing the glazing on the south –** In this case, the effective and exposed portion of the south façade is retained which is 38% of the entire wall area to get maximum useful solar gains. However, the part of glazing which remained in shade (20m² area) from the adjoining south wing was removed and simulated for further assessment of the thermal performance.

Results: The results from the simulations revealed that Case 1a did not show a significant change in the summer operative temperatures compared to the dry bulb temperatures. This is because the north glazing had less impact on summer solar gains. The maximum summer and winter dry resultant temperature was recorded as 24.2°C and 10.7°C respectively. However, the proposed complete elimination of north glazing resulted in better values and total reduction of heat loss from the north side, thus showing a positive impact in increased winter resultant temperatures.

For Case 2a, the reduction of the glazing on the south side showed very little difference in the temperatures compared to the base case, indicating a negligeable positive impact on the overall thermal performance. Therefore, after the evaluation of the two cases for wall glazing optimization, it was concluded that Case 1a, with the removal of north glazing, performed better and hence can be included in further assessment scenarios.

5.3. Roof glazing optimisation

A summary of the cases for building envelope roof glazing ratios simulated under different scenarios is illustrated in Table 4.

Table 4: Summary of all case simulation

Case Type	**Glazing ratio**	**Maximum summer resultant temperature (Non ventilated scenario)**	**Discomfort hours in summer (Non ventilated scenario) (> 25 °C) (% of hours)**	**Overheating risk criteria (Non ventilated scenario) (> 28 °C) (% of annual hours)**	**Maximum summer resultant temperature (Day ventilation scenario)**	**Maximum summer resultant temperature (Day ventilation scenario + no north glazing)**	**Comfort hours achieved in summer (Day ventilation scenario + no north glazing)** (18°C- 25°C) **(% of hours)**
Case 1b	20%	32.8°C	14%	1.6%	24.4°C	23.8°C	83%
Case 2b	40% (as-built)	34.8°C	18%	2.4%	25.2°C	24.5°C	81%
Case 3b	80%	40.9°C	28%	5%	26.7°C	26°C	78%

Results: The above cases indicate that a combination of proposed passive strategies along with ventilation has significantly improved the thermal comfort levels and the summer operative temperatures would not exceed 28°C in the warm period, indicating no risk of summer overheating either.

The assessment of all the three cases indicated that the case that performed better in terms of thermal comfort was Case 1b with a glazing ratio of 20%. The differences in the results between the Case 1b and Case 2b were not substantial. However, the lower temperature values contributed to offsetting any additional internal gains such as those from the equipment, occupants and lighting. Hence atrium with 20% glazing ratio was considered the most optimum roof glazing configuration of the three cases.

6. DISCUSSION - THERMAL COMFORT AND ENERGY EFFICIENCY

In this chapter, the thermal performance and energy efficiency of the best performing and efficient passive strategy were compared to the base case in order to evaluate the percentage of improvement potential achievable in terms of thermal comfort and to assess if the strategy proposed could contribute to effectively reducing the overall heating or cooling loads of the hotel.

6.1. Main findings - summer temperatures

A comparison of the best performing passive strategy scenario i.e., atrium with 20% roof glazing and no north glazing, with the base case showed significant improvement in the thermal comfort performance in the summer months. The optimized strategy achieved 0% of discomfort hours compared to 18.2% discomfort hours in the summer months for the base case. This suggested that, by reducing the skylight ratio by 20%, removing the north wall glazing and by enabling natural ventilation during the warm summer period, the optimized strategy performed better and resulted in mitigating the risk of summer overheating by 100%. Figure 6 demonstrates that the cooling loads of the atrium reduced drastically in the optimised case compared to that of the base case by 88%. Overall, the result indicated that mechanical cooling during the warmer period can be avoided or used when necessary, thereby resulting in a significant improvement in the energy performance.

6.2. Main findings - winter temperatures

Though the optimised strategy showed improvement in increasing the indoor operative temperatures compared to that of the baseline case, the percentage of hours within the comfort band (i.e., 18°C - 25°C) remained low with 46% of the hours below 18°C. This indicated that mechanical heating during the winter period is inevitable. However, the overall dependency on active heating was reduced by 18% (refer Figure 6). Hence, the winter period also showed some improvement in the overall energy performance.

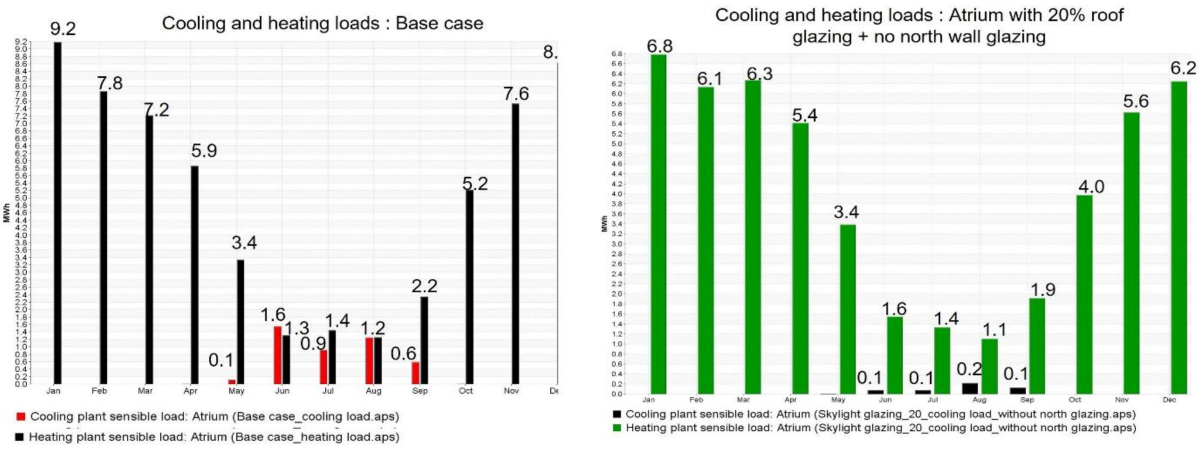


Figure 6: Annual heating and cooling loads - case comparison

7. CONCLUSION

The rapid deterioration of urban ecosystems along with rising energy prices should be compelling reasons to improve energy efficiency and conserve energy, not least in the hotel business. Even in hotels, the adaptive approach to thermal comfort has the potential to become a viable alternative. But this strategy is difficult to implement in hotel guest rooms since the rooms are independently controlled by the occupants. Hence the most effective implementation of this proved to be in the hotel atria which usually houses the majority of the hotel facilities. Moreover, the rising popularity of atria in hotel designs and the vastness of space and extensive glazing gives more scope for implementing passive strategies with an adaptive approach. However, there is still a lot of ambiguity about how hotel guests would react to the adaptive strategies of the hotel. Nevertheless, on a positive note, there is hope that these strategies will eventually gain prominence and serve as future successful cases.

The main purpose of atrium design is for use as a thermal buffer zone and to be more comfortable and useable for longer periods, in addition to the aesthetic, social and cultural objectives. Overheating during the summer months and the possibility of excessive heat loss during the winter months were some of the concerns addressed in this research. It also demonstrates that considerable savings in energy may be realised by just changing the hotel's fabric. The entire research proposal was to choose an acceptable range of passive design outputs from the case study hotel and to investigate other alternative inputs, such as what is achievable using natural ventilation compared with mechanical. According to the simulation results, the skylight glazing ratio was the most critical factor in influencing the thermal condition with natural ventilation. The final outcome indicated a considerable improvement in the thermal performance, along with mitigating the risk of summer overheating and eventually, its contribution to overall energy efficiency.

As will be evident throughout this research, one size does not fit all, and each hotel is unique. Despite the fact that the interventions necessary may vary, the rationale and technique outlined here give a high-level framework for establishing a thermally efficient atrium in a hotel.

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