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VENTILATION SOLUTIONS TO THE OVERHEATING PROBLEM IN THE ATRIUM: TRAKYA UNIVERSITY VOCATIONAL SCHOOL OF TECHNICAL SCIENCES BUILDING

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Highlights

- Atriums are architectural solutions that are addressed during the design phase of buildings and aim to make the outdoor lighting conditions feel inside the building thanks to their large glass surfaces.
- The greenhouse effect occurs when the indoor temperature rises excessively with the limited circulation of the air as a result of overheating in the building.
- Mechanical ventilation solutions can offer effective cooling solutions in areas where natural ventilation is not sufficient.

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Abstract

Atriums are architectural solutions that aim to make the outdoor lighting conditions feel inside the building, thanks to their large glass surfaces. In addition to the aesthetic appearance it gives to the buildings, it provides maximum benefit from daylight. However, if the correct glass type is not used and does not contain sufficient shading elements, it is difficult to produce permanent and sustainable solutions with subsequent measures. In this case, turning to mechanical solutions emerges as an option that helps to idealize indoor comfort conditions. In this study, it is aimed to reduce the greenhouse effect created by the atrium of Trakya University Technical Sciences Vocational School with passive cooling strategies within the building and construction elements in terms of summer comfort. Although it is disadvantageous in terms of energy consumption and high cost in terms of initial investment, mechanical ventilation is an effective suggestion for solving the problem.

Atriyumda Sera Etkisi Problemine Havalandırma Çözümleri: Trakya Üniversitesi Teknik Bilimler Meslek Yüksekokulu Binası

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Öz

Atriyumlar, geniş cam yüzeyleri sayesinde dış ortam aydınlanma koşullarını bina içerisinde hissettirmeyi amaçlayan mimari çözümlerdir. Binalara verdiği estetik görüntünün yanında günışığından maksimum derecede faydalanmayı sağlar. Ancak doğru cam tipi kullanılmadığı ve yeterli gölgelendirme elemanı barındırmadığı takdirde yapıda aşırı ısınma, kamaşma vb. problemler meydana getirebilmektedir. Aşırı ısınma başka bir deyişle sera etkisi yaratan cam yapının üretim aşamasında uygun cam kullanılmaması durumunda sonradan alınan önlemlerle kalıcı ve sürdürülebilir çözümler üretmek zor olmaktadır. Bu durumda mekanik çözümlere yönelmek, iç ortam konfor koşullarını idealize etmeye yardımcı bir seçenek olarak ortaya çıkmaktadır. Bu çalışmada Trakya Üniversitesi Teknik Bilimler Meslek Yüksekokulu'nun atriyumunun yarattığı sera etkisinin, yaz konforu açısından bina ve yapı elemanları bünyesinde pasif soğutma stratejileri ile azaltılması hedeflenmiştir. Enerji tüketimi ve ilk yatırım açısından yüksek maliyetli olması dezavantajlı olmakla birlikte sorunun çözümünde mekanik havalandırmanın efektif bir öneri olduğu sonucuna varılmıştır.

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1. Introduction

Atriums are architectural solutions that are addressed during the design phase of buildings, aiming to make the outdoor lighting conditions feel inside the building, thanks to their large glass surfaces. Along with the aesthetic and functional advantages it provides to buildings, it positively affects the psychology of the individual with the effective use of daylight. People spend about ninety percent of their day indoors (Le-Thanh et al. 2022). Studies have shown that natural daylight and solar radiation have a positive effect on the physiology, psychology and work efficiency of users [Rastegari (2021); Mohsenin&Hu (2015); Almodóvar-Melendo et al. (2022); Motamedi&Liedl (2017)]) and that daylight improves visual perception. and showed that it can improve the synchronization of circadian stimuli in the human body.

As they provide the connection between the floors in the architectural structure, they are generally used as a gathering, exhibition hall, entrance hall, etc., because they are located in the center of the buildings. It is also preferred in solving functions. In modern architecture, atriums provide common space solutions in commercial and educational buildings, entrance halls or courtyard volumes in hospitals, and in malls, by connecting floors with different functions in the center, they improve the visual perception of the space, reflect the environmental effects to the interior volume, making long times spent in closed spaces more enjoyable for individuals (Bednar, 2007; Saxon, 1986).

Together with the advantages it provides, atriums can bring negative loads on the structure in terms of heating and/or cooling energy depending on the climate, geometric form and the properties of the glass and metal elements that make up the surface (Abdullah et al. 2009; Mills 1994). The presence of skylights with large surfaces causes the atrium to be affected by unfavorable conditions such as overheating, high energy consumption and glare (Xue & Liu, 2023). However, the constant rise of the heated air and its inability to evacuate can cause the air to remain in the volume, and the inability to circulate fresh air as well as heating can cause factors that negatively affect the comfort conditions. Indoor conditions and quality are essential requirements for users to be healthy and productive. However, it is known that indoor comfort conditions have important effects on educational structures in terms of learning ability. Having the desired level of visual comfort conditions is necessary in university buildings with different functions and sizes, such as classrooms, offices, laboratories, in order to improve visual and spiritual performance, keep learning performance high, and increase motivation and work productivity (Yener, Güvenkaya, & Şener, 2009).

In the Trakya University Vocational School of Technical Sciences Building, which is discussed in this study, due to the overheating (greenhouse effect) caused by the atrium and the inability to evacuate the heated air, the user cannot meet the comfort conditions in the current situation, the orientation of the building and the choice of the building envelope (glass surfaces) (especially the glass surfaces). There are thermal comfort problems (which are much more evident in summer). In this current situation, it is necessary to use cooling systems that will increase the energy load at a high rate in order to provide summer comfort conditions. One of the main problems of the study is to provide the necessary comfort conditions by using energy efficiently in the education building. Continuous cooling/air conditioning is necessary for the building to be used in its current state. This situation brings a high cost to the energy consumption expenses, which is one of the most important operating costs for public buildings, and thus to the university budget. For this reason, the building has not been able to actively function and be used since its implementation. In order to ensure the effective use of the building, ventilation solutions should be made as well as daylight control.

For the improvement solution of the building, ventilation solutions were developed in addition to the solutions proposed for daylight control of the building with a Scientific Research Project within the body of Trakya University. In this study, the mechanical ventilation solutions of the building are emphasized.

1.1. Literature Review

In order to ensure healthy air circulation in the atriums, it is important to make use of natural ventilation and to address this at the design stage. Holford & Hunt (2003) revealed the most suitable atrium size for natural ventilation with mathematical calculations. Moosavi et al. (2014) compiled the literature on natural ventilation of atria and revealed that the size of the air outlet opening in the atria is one of the most important parameters in ventilation.

It is known that the geometric design of the atriums (aspect-length-height ratio) affects the energy performance of the building. Koç & Maçka Kalfa (2019) determined the energy performance of different atrium types of a mid-rise office building according to different climatic zones. Similarly, Arslantaş & Ayçam (2021) discussed energy efficient atrium designs in different climatic regions. In another study, Sevim & Engin (2019) examined the effect of the atrium on natural ventilation in office buildings with atriums through examples of the shape and location of the atrium. Abdullah & Wang (2012) evaluated the comfort conditions created by two different types of atrium, namely overhead lighting and side lighting, in their study.

There are many studies in the literature on the control of the light taken into the building and the shading elements of the atriums consisting of large glass surfaces. Göçer & Tavil (2008) worked on the simulation of the glazing systems of atriums to provide comfort conditions. Abdullah et al. (2009) aimed to solve the negative comfort conditions caused by daylight in atriums with blinds and curtains.

Acred & Hunt (2014) developed a design strategy for chimney ventilation in multi-storey atrium buildings in their study. Holfor & Hunt (2003) focused on developing strategies to improve the flow of natural ventilation in buildings with limited direct connection to the outdoor atrium. Liu, Lin & Chou (2009) focus on developing a method for predicting buoyancy-induced ventilation performance in buildings with atriums during the design phase. Fini & Moosavi (2016) examined the changes in the performance of the atrium walls due to their geometric forms and concluded that the combination of vertical and sloping walls performed best when using sloping walls for lower floors and vertical walls for upper floors.

2. Ventilation Solutions in Atriums

It is important to foresee the thermal comfort problems of the atrium structures at the design stage and to address the solutions for this at this stage. Although it is costly to solve such problems after the building is implemented, the desired level of efficiency may not be achieved.

The most effective solution applied during the design phase of the building is the application of solar chimney and wind scoop techniques together.

2.1. Natural Ventilation with Solar Chimney

Solar chimney application can be a very good solution depending on the building characteristics. Solar chimneys are systems used to create convective air currents from inside the building to the outside. In general, two chimneys, one hot (solar chimney) and the other cold (wind scoop), open to the outside, help create air currents inside the building. The solar chimney should rise higher than the highest point of the building and should be properly designed to facilitate the exit of hot air in case of wind. The temperature differences in this system provide air circulation in the building and have the effect of ventilation and cooling in summer. Recently, it has been observed that natural ventilation has been made with solar chimneys in many modern and new buildings. The most important advantages of these systems are that they are very convenient and simple solutions that do not consume energy. It is a widely used method in evacuating the hot air accumulated in the atriums and creating the passive cooling effect.

2.2. Natural Ventilation with Windcatcher

The theoretically optimal solution in the Vocational School Of Technical Sciences Building is to provide natural ventilation with a solar chimney and an accompanying wind scoop. However, considering the solar chimney and wind scoop systems while the building is in the design phase is very important in terms of functionality. Analyzing airflows at the design stage requires the design of chimney systems where appropriate. In some special cases, it is possible to apply in existing buildings despite the loss of functionality. However, for the Vocational School of Technical Sciences Building, a contracting firm is required to make the specific solution and design and the correct application of the system. Therefore, although the solar chimney application is partially functional, it is seen that it is a compelling solution to implement it in practice for the Vocational School of Technical Sciences Building.

3. Method

In order to evaluate the current comfort conditions of the building, indoor temperature, relative humidity, air flow rate and lighting values were determined by using the TESTO 440 device with on-site measurement technique (Fig. 1). This device is Precise, reliable measurement of all air velocity and indoor air parameter parameters with a single measuring device (Testo, 2023). This device's measuring range Temperature (NTC) -40 to +150 °C Accuracy (±1 digit) ±0.4 °C (-40 to -25.1 °C) ±0.3 °C (-25 to +74.9 °C) ±0.4 °C (+75 to +99.9 °C) ±0.5% of m.v. (remaining meas. range) ande resolution 0.1 °C.

Figure 1. Testo 440 Measurement Device

In order to improve the thermal comfort conditions of the building, suggestions for covering the sun-blocking film on the transparent surfaces and adding fringes to the structure were studied together with the cross ventilation solutions. If these suggestions are applied separately, it has been seen that the building does not solve the overheating problem and is insufficient to idealize the thermal comfort conditions. For this reason, mechanical ventilation solution was studied. In this study, classical natural ventilation and mechanical ventilation methods are discussed. Natural ventilation is one of the most practical techniques for reducing energy use in buildings and can be operated without mechanical assistance by pressure differences between the inside and outside of a building. Natural ventilation is generally applied as wind-driven ventilation (also known as cross-ventilation) and buoyancy-driven (also known as stack effect) ventilation. Mechanical ventilation, on the other hand, consists of the processing and distribution of the air inside the building with the use of various equipment and devices. It is a controlled operation compared to natural ventilation, but can consume large amounts of energy.

3.1. Sample Building Information

The architectural structure of the building consists of a total of 5 branches located in different directions. The building is located on a sloping land and gradually sits at a total elevation of approximately 18 m. Due to the gradual settlement in the building, there are a total of 5 floors sitting at different levels (Table 1). The building has an indoor atrium. A mixed system of steel and reinforced concrete was used as the structure system. The steel structure part is constructed with glass components by applying the structural silicone curtain wall technique. In the reinforced concrete part, masonry wall elements are used (Fig. 2-3).

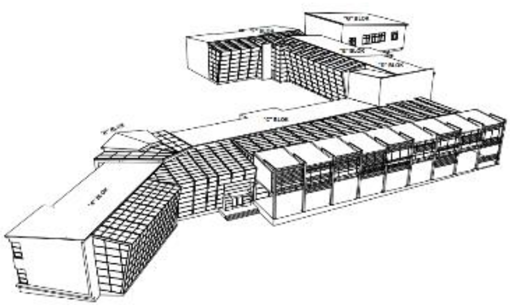

Figure 2. Building Digital Modelling

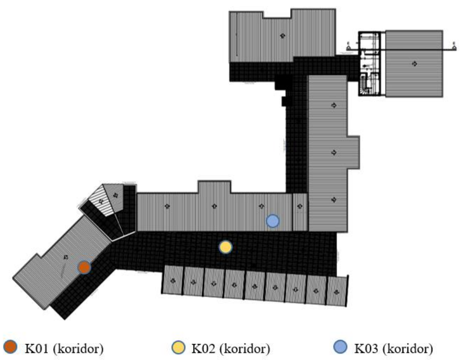

Figure 3. Architectural Plan

The building has transparent surfaces on the facade and ceiling in the south, southwest and west directions (Fig 4-5). The total area of the transparent surfaces on the roof is 941.37 m², and the distribution of the transparent surfaces on the facades of the building according to the directions is given below (Table 1). The method widely used in building ventilation and air conditioning is mechanical ventilation. Although natural ventilation in Atriums is an application that should be preferred as a priority, this situation should be addressed at the design stage of the building. Therefore, in the current situation, mechanical ventilation comes to the forefront as a necessity for the Vocational School of Technical Sciences Building.

Table 1. Distribution of Transparent Surfaces in the Building According to Directions (m²)

Facade Name	Surface Area (m²)
South	409,59
South East	85,38
West	348,6
Total	843,57

Figure 4-5. Building Exterior View

There are transparent surfaces on the facades and ceilings of the building in the south, southwest and west directions (Figs. 4-5). The total area of the transparent surfaces on the roof is 941.37 m², and the distribution of the transparent surfaces on the building facades according to the directions is given below (Table 1).

3.2. Experiment Measurements

First of all, the current state of the building was analyzed, and the indoor comfort conditions were determined with the TESTO 440 device. Accordingly, the temperature and relative humidity values in the current state of the building are as in Table 2. There are 5 scenarios presented as suggestions in our scientific research project in order to improve the existing data of the building whose values were measured in May. Firstly, covering the transparent surfaces on the roof with film coating, secondly, opening the windows for natural ventilation, thirdly adding eaves to the building, and fourthly, landscaping were considered as the main options. In addition, the options where two of these methods come together were also evaluated. In this study, mechanical ventilation solution is considered as the fifth option, which is evaluated completely independently of the given options.

The method widely used in building ventilation and air conditioning is mechanical ventilation. Although natural ventilation in atriums is an application that should be preferred as a priority, this should be addressed during the design phase of the building.

Table 2. Average Temprature and Humidity Measurements

		Corridors	K01			K02			K03		
GROUND FLOOR		**Criteria**	**(ppm)**	**(%rH)**	**(°C)**	**(ppm)**	**(%rH)**	**(°C)**	**(ppm)**	**(%rH)**	**(°C)**
	MORNING	Average	417	38,0	33,9	280,6	39,3	31,5	375	26,3	34,7
	NOON	Average	372	25,7	43,8	243	36,0	33,8	381	20,5	39,8
	EVENING	Average	384	33,8	34,1	269	32,2	36,09	388	21,7	38,6
FIRST FLOOR		**Corridors**	**K01**			**K02**			**K03**		
		Criteria	**(ppm)**	**(%rH)**	**(°C)**	**(ppm)**	**(%rH)**	**(°C)**	**(ppm)**	**(%rH)**	**(°C)**
	MORNING	Average	372	25,7	43,8				386	23,9	37,0
	NOON	Average	364	21,0	53,3	212	24,7	46,5	391	19,1	42,4
	EVENING	Average	381	24,8	44,8	267	26,5	42,3	416	20,5	40,1

Therefore, mechanical ventilation comes to the fore as a requirement for the Technical Sciences Vocational School Building in the current situation.

Primarily, the discharge of hot air on the roof and the supply of fresh air to the building with the help of ducts and fans in order to prevent negative pressure will be effective in reducing the overheating problem and controlling it at a certain level. At this point, many options for mechanical ventilation come to the fore. These options will be briefly discussed here. Because this issue requires a separate project study where the best solution will be possible with a final and detailed ventilation design. There are basically two different applications for the mechanical evacuation of the hot air formed in the Atrium of the Vocational School of Technical Sciences Building with the help of channels. In the first application, as shown by the orange drawing in the figure 6, the hot air accumulated on the ceiling of the Atrium is discharged from the side through a suction channel to be made along the Atrium. Although this application is a part of the standard ventilation application, because the amount of hot air to be discharged is high here, large-diameter suction ducts must be made. In addition, the long distance, the structure of the duct and the excess air to be expelled will cause high energy consumption. The other negative is seen as problems related to the places where the ducts can be installed. As a result, it is possible to apply a suction duct throughout the Atrium with the appropriate engineering design.

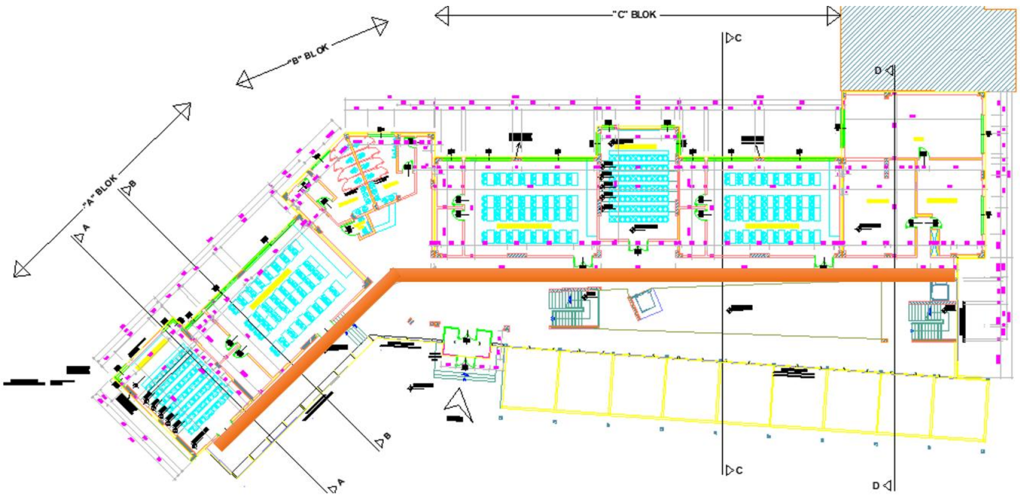

Figure 6. Atrium Suction Duct Schematic Illustration.

On the other hand, It is possible to make partial air evacuation at a certain point of the Atrium with short channels from the area W.C. (Figure 7).

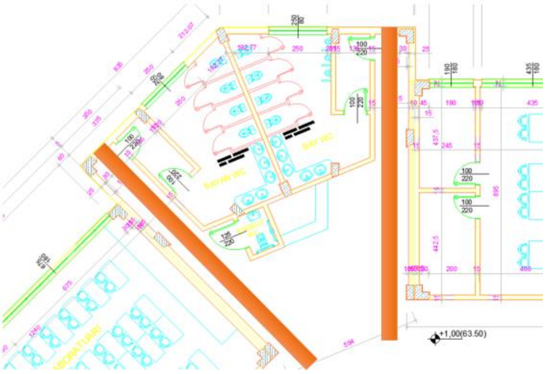

Figure 7. W.C. Schematic Representation of Air Evacuation with Short Channels.

Although it is a more convenient method in terms of cost and application, this method of discharge will cause irregular airflow. It will also not provide evacuation with the desired efficiency, because the Atrium is spread over a very large area.

The second alternative for the suction ducts is the suction from the Atrium by passing through the classrooms with the help of independent ducts as shown in the figure 8. The advantage of this method is that the duct diameters will be significantly reduced

and the suction points will be distributed properly. However, passing channels through the classroom will cause difficulties in terms of construction technique and application. In addition, in order to minimize the fan noise that will occur, placing the fans on the exterior or insulating if they will be placed indoors will bring a certain assembly difficulty. The discharge of the atrium hot air accompanied by the delivery of fresh air is absolutely mandatory, otherwise the suction alone will further impair the thermal comfort in the indoor environment. It is possible to apply a duct throughout the Atrium as shown in the figure 9 to mechanically deliver fresh air.

4. Findings and Discussion

There are two options for fresh air duct, metal duct and fabric duct application. Although metal duct is the classical and most common duct application, it has many disadvantages, especially when considering the Atrium structure, there are difficulties in terms of both design and installation. On the other hand, an important reason why natural ventilation is preferred in atriums is energy efficiency. Metal ducts are not energy efficient systems due to their high coefficient of friction. In this respect, it is recommended that high energy efficient fabric ducts are preferred primarily for the Vocational School of Technical Sciences Building due to its advantages such as equal distribution of air, ease of application and visuality.

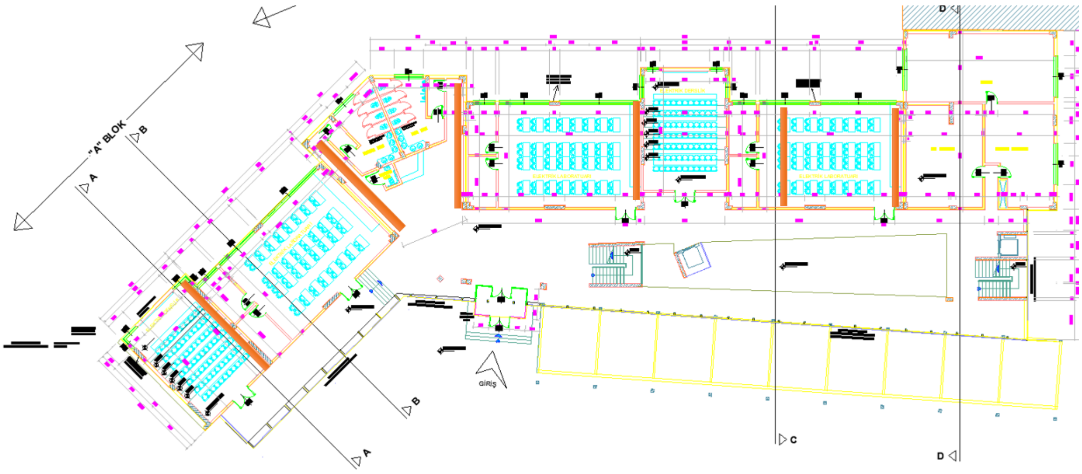

Figure 8. Schematic Illustration of Atrium Air Evacuation with Short Channels Through Classes.

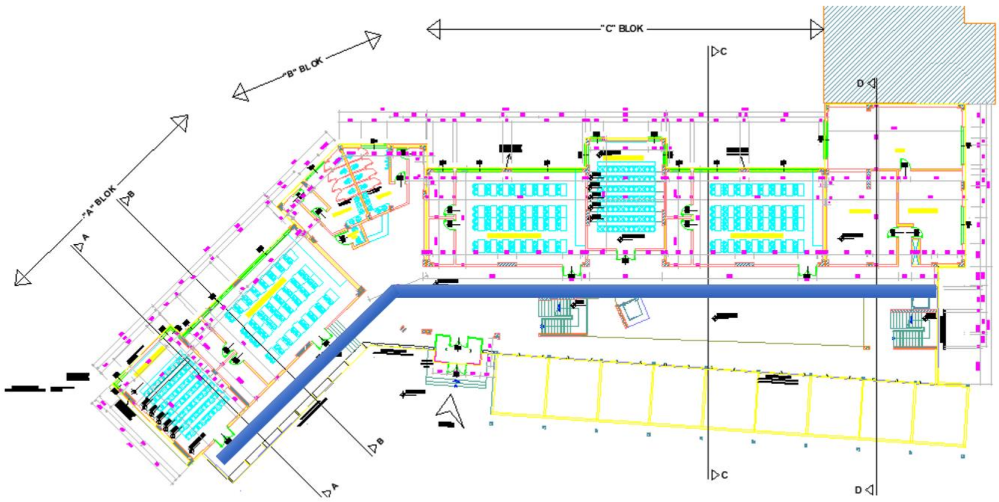

Figure 9. A Schematic Representation of Fresh Air Delivery Through the Atrium.

5. Conclusion

Wrong decisions taken while constructing buildings can be difficult and costly to solve later. Although it is costly, Mechanical ventilation solution is considered mandatory. In addition, the energy load of the mechanical ventilation system will be significantly reduced with the proposed reflective film coating. As a result, mechanical ventilation is a viable method to reduce and control at a certain level the Atrium overheating in the Vocational School of Technical Sciences. However, determining which of the above-mentioned options is suitable, both system selection and application method, requires a separate project and team work in terms of engineering. Here, in order to increase the efficiency of ventilation, partial air conditioning with evaporative cooling, which is more cost-effective than conventional cooling in terms of investment and operation, can also be applied to the supply air. This issue is also an issue that should be evaluated by the team that will make the ventilation project.

Natural ventilation strategies will be successful in the summer months to eliminate the hot air generated in the building atrium, however, due to the large volume of the atrium and uncontrolled natural ventilation, excessive cooling may occur in the building during the winter months. Therefore, the best solution is the application of mechanical ventilation that accompanies the natural ventilation strategies. In addition, in cases where natural ventilation is insufficient in summer, mechanical ventilation will help to provide thermal comfort.

Conflict of Interest

No conflict of interest was declared by the authors.

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