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RESEARCH ARTICLE

COMPUTATIONAL and TEORIC INVESTIGATION of the EFFECTS of FINNED TRICKLEVENT SYSTEM on BUILDING ENERGY SAVINGS

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ABSTRACT

In our study, the effects of the finned Tricklevent passive air condition system on building energy savings were investigated. The system has been patented internationally with the patent number 2013/08326. A 14 m^2 sample prototype office room was built for the study. Numerical studies were performed with FloEFD software. Theoretical calculations and numerical work values confirmed each other. In the analyses, independence from mesh was studied. The solar load is defined as 1009 W/m^2. Office exterior windows are designed with a thickness of 6 mm and an air gap of 16 mm. In the study, it was determined that there was a fresh air inlet at a volumetric flow rate of 0.024 m^3/s in the prototype office. It has been determined that the finned Tricklevent system cools the hot air coming from the outside environment and takes it in with a temperature drop of 5-6 ^oC. When the system is operated at the same time as the air conditioner, the air conditioner set temperature can be adjusted to higher temperatures, saving 28 kWh/m^2 of energy and reducing the carbon footprint by 15.4 kg/m^2. With the sequential operation of the system with the air conditioner, 21 kWh/m^2 of energy was saved in a 3-hour period, while a carbon footprint of 11.5 kg/m^2 was reduced.

Keywords: *Heat transfer, passive ventilation, energy, zero building, energy saving, carbon foot print,*

1. INTRODUCTION

As a result of population growth, high demands for building construction have arisen and the number of high-rise buildings has increased. As a result of the increase in building and building heights, the heating and cooling needs of the houses have increased. As a result, energy is needed to cool and heat buildings. Housing and office heating and cooling increased to 6.7% of the world's total energy consumption [1]. According to the 2008 World Business Council for Sustainable Development

(WBCSD) report, 40% of the energy produced in the world is consumed to provide thermal comfort in buildings [2]. The carbon emission and energy consumption of a house cooled with an air conditioner for ambient comfort are 67% and 66%, respectively. These rates are higher than in a naturally ventilated home. Scientific studies have shown that passive cooling systems can reduce the energy spent for thermal comfort conditions by 2.35%. Passive cooling is to ensure the comfort of the environment by making use of the natural air flow. Passive cooling is a method that directs architecture to create comfortable indoor conditions naturally [3]. In order to minimize the rising energy need in buildings, the energy performance of the buildings has been examined. Official decisions have begun to be taken to construct zero-energy buildings for energy saving [4-6]. Double skin facades (DSF) have become frequently used in architecture to save energy and support passive ventilation of the building. Building facades can reduce the energy consumption of the HVAC system if well designed. Well-designed façades can absorb some of the solar radiation in winter, while preventing overheating during hot periods [7]. Double-skinned facades are generally structures consisting of two transparent surfaces with air between them [8]. Facade in buildings; It is a part of the building structure that acts as a kind of filter and sheath for the building, which keeps the outdoor conditions outside the building, protects the building from various external effects, and also adds aesthetics to the building. Some factors affecting the design and construction of the facade are listed as the height of the building, the environment, and the purpose of use of the building [9]. There are several different types of DSF that provide ambient ventilation. These are grouped under the box window façade, the shaft box façade, the corridor façade, and the multi-level façade [10-12]. DSF can operate under different forms of ventilation (Fig. 1a–c) or connected to the building ventilation system with adjustable flaps (Fig. 1d) can work [13].

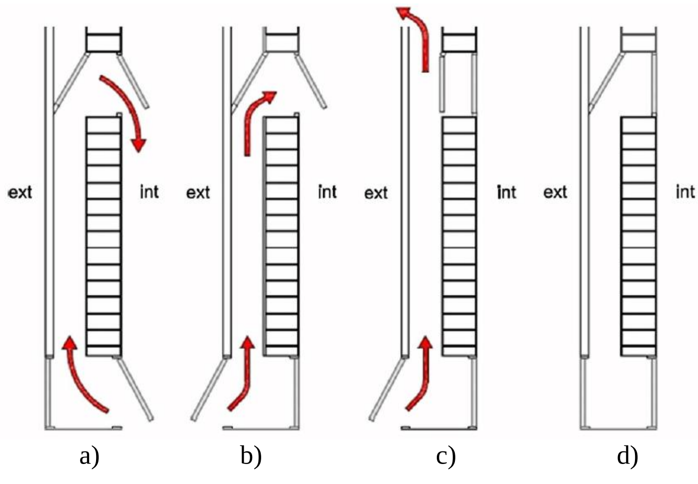

Figure. 1. Different operational modes of a ventilated DSF [2].

In another study, in the façade system designed for cold seasons, outside air is taken into the indoor environment as in Figure 2.a, while indoor air conditioned by air conditioner in hot seasons is filled between the façade as in Figure 2.b, working towards providing interior comfort [14].

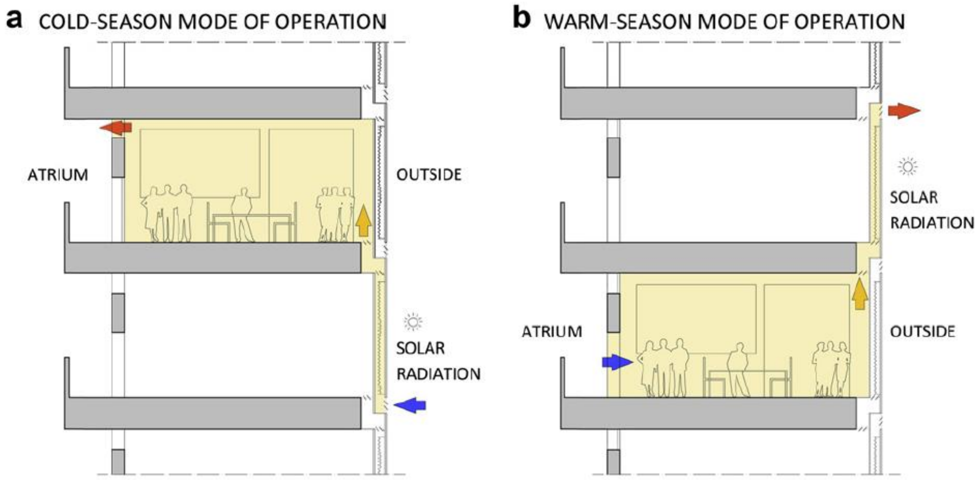

Figure. 2. a) Cold-season and b) warm-season modes of operation of a basic double-skin facade system [14].

Influential design parameters for DSF are cavity thickness, glass materials, glass coating, shading condition, cavity openings. Most of the energy lost in buildings comes from windows. The material, transparency and reflective properties of the glass used in facade systems prevent overheating in summer and minimize heat loss in winter. Therefore, the selection of suitable windows with the necessary characteristics is important [15]. The thermal performance of double-skinned facades has been examined in studies and it has been reached that it reduces the effects of radiation. As a result of the study, it was revealed that double-skinned facades have an effect on radiation in summer and insulation in winter [16]. Double-layer facade systems have been examined with the CFD method and it has been revealed that such systems cause reductions in building energy consumption [17].

An exemplary double skin façade (DSF) system has been examined. As a new approach, the facade where the PV system is placed showed the best performance [18]. In another study, heat transfer in double-skinned facades was investigated. Its performance was investigated with various glass systems [19]. In particular, the effects of shading on the windows on thermal comfort have been revealed. The use of Aluminum blinds in double-walled systems was investigated with CFD and examined in terms of heat transfer [20]. In another study conducted in Singapore, a double glazing facade was compared with a single glass facade in buildings with high humidity and sun load. CFD application was made in the study. It has been determined that double glass facades contribute to building energy savings. In another study, single layer and double-glazing application was examined with another software. According to the results obtained in the study, double glazing is recommended for energy saving and indoor thermal comfort. In another study conducted with a passive ventilation system, double glazing was supported by passive ventilation in accordance with the literature. It has been demonstrated that 16% savings are achieved in the mechanical ventilation system energy that provides indoor thermal comfort. [21].

Zero energy buildings are attracting a lot of attention internationally to reduce energy consumption in buildings, save on energy bills and protect the environment at the same time [23]. It has been determined that people spend an average of 90% of their lives indoors, therefore the use of HVAC systems and the associated energy consumption increase [24]. The expected performance from double-skinned facades is to reduce the effects of air temperature, to meet the need for thermal comfort and to reduce energy consumption. Expected features from building facade systems are increasing [14].

In the studies in the literature, it has been determined that while providing air circulation in the double facade system, energy saving is achieved with passive ventilation. However, in these systems, there is no situation to reduce the outside air temperature. In our study, the mechanical and numerical analysis of the fin structured version of the passive ventilation system, which takes up very little space on the facade, takes the outside air from the facade and reduces the temperature to the indoor environment, and its effects on energy saving. The difference of our study from other studies is the patented passive ventilation system that provides energy saving by reducing the air conditioner operating time and power while providing indoor thermal comfort. The efficiency of the system with the finned design of the Innovative Passive Ventilation system (Tricklevent) , which brings an innovative approach to facade systems, has been examined. The effects of using fin material of materials with thermal capacity and high thermal conductivity on the efficiency of the system were investigated. Again, different from the literature, the contribution of the energy-saving system to the carbon footprint has been examined.

2. MATERIALS AND METHOD

2.1. Working Principle of Tricklevent Passive Ventilating System

The tricklevent system, which is in question in the study, can reduce the temperature of the outdoor air with the help of a fin and take it to the indoor environment. In addition, the Tricklevent system also performs the task of providing air circulation, as in the literature studies. The working principle of the Tricklevent passive ventilation system is as follows. First of all, the room is conditioned with air conditioning. When the interior volume becomes stable at the set temperature, the tricklevent system made of Al material comes to the indoor temperature. After the air conditioner is turned off, natural ventilation of the system from the outside is started. The air coming from outside at a higher altitude cools in the cold finned system and enters the interior volume in a cooled state. In this way, the temperature of the air entering the interior volume for a certain period of time is reduced and the use of air conditioners is reduced. At the same time, the system can be operated in parallel with the air conditioner. The air conditioning setting temperature is set above the normal temperature, and the Tricklevent system is kept open all the time. The hot air coming from the outside will constantly reduce the temperature in the system and ventilate the indoor environment. The working schematic of the Tricklevent system is given in Figure 3.

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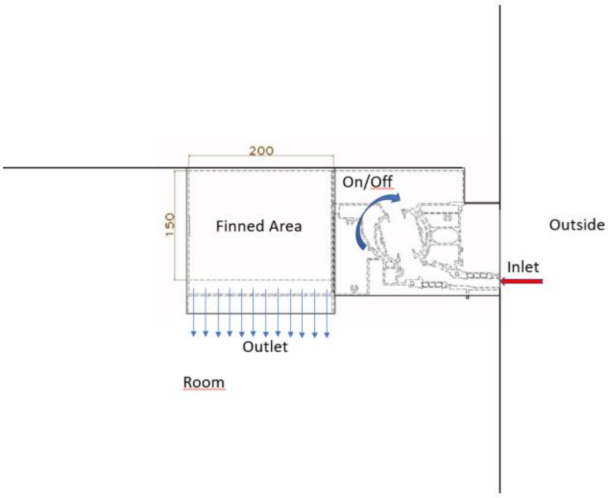

Figure 3. Working diagram of the Tricklevent system.

2.2. Geometry

The isometric view of the Tricklevent system, which changes the circulation air temperature developed in our study, is given in Fig. 4. System design was made in Catia V5 R19 software. A fin design has been made to reduce the temperature of the outside air in the system (Fig. 5).

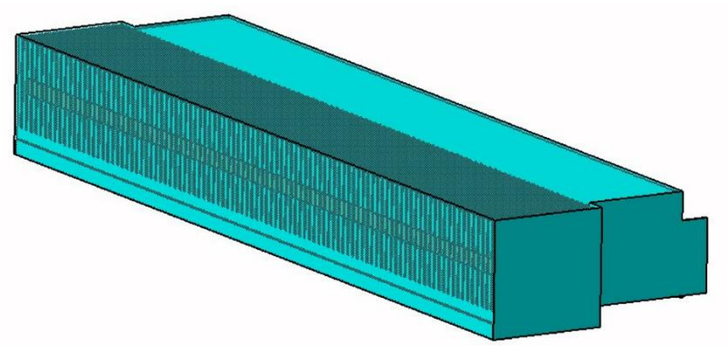

Figure 4. The isometric view of the Tricklevent system.

Fin thickness is designed as 5 mm, spacing between fins is designed as 10 mm.

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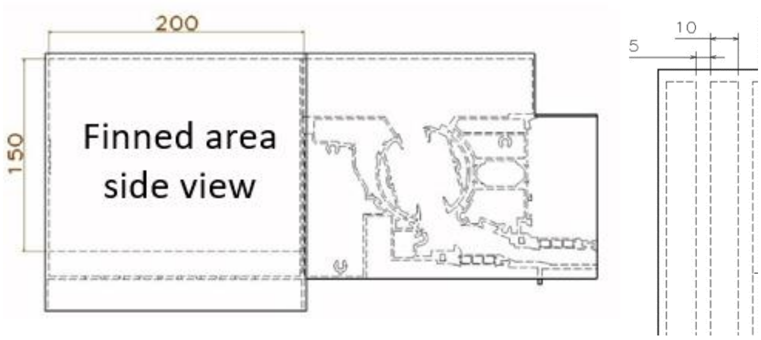

Figure.5. Fin system dimensions used in the system

2.3. Computational and Theoretical Work

For numerical analysis, first of all, the Tricklevent system is a data obtained through tests in which a maximum of 50 m^3/h air can be taken at a pressure difference of 1 Pa from the facade of the building (Fig.6). The measurement of the flow entering the system was obtained by calculating the velocity measurement taken from the entrance of the triclevent system on the prototype room. During the test phase, the amount of flow depending on the pressure difference was determined in the calculations made over the external air dynamic pressure. The external air temperature was measured using a Thermocouple from the location indicated by the circular sign in Fig.6. The outside air enters the interior volume through the sections depicted in Fig.6 with the red rectangular shape. Table.1 shows the measurement range and error rate of the thermocouples used in the measurements. Testo brand Telescopic 3-Function Air Velocity Probe was used for air velocity measurements. Velocity probe features are also given in Table 1.

Table 1. Probes' properties.

Probes	Measurement Range	Error Rate
Standard (K-type)	100℃ /+400℃	-/+0.1℃
Testo Telescopic	0-20 m/s	-/+0.1m/s

Figure.6. Prototype office room.

In this study, for a sample office with a height of 10 m, the air velocity is 1.508 m/s and the pressure difference is 1.714 Pa, calculated from Eq. 1 and 2. The velocity value obtained in the tests are respectively 1,49 m/s.

$$V(z) = V(Z_R)\frac{In(\frac{Z}{Z_0})}{In(\frac{Z_R}{Z_0})} \quad (1)$$

$$P = \frac{1}{2}\,\rho\,{V_z}^2 \quad (2)$$

The Tricklevent system takes the outside air into the indoor environment due to the dynamic pressure caused by the speed of the air. According to the calculated pressure difference, the inlet flow rate of the outside air to the Tricklevent system was calculated as 0.024 m^3/s. As seen in Fig. 7, the area where the air enters was determined as 0.016 m^2.

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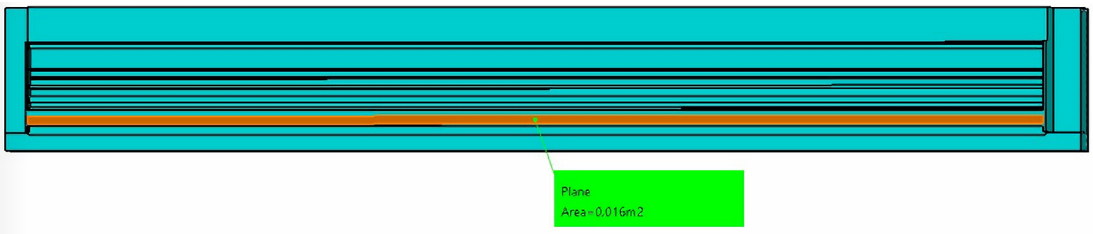

Figure 7. Tricklevent air intake area area.

The velocity value calculated with Equation.3 was calculated as 1.5 m/s in order to verify the air entry velocity into the system.

$$\dot{m} = \rho.V.A \quad (3)$$

The Re number in the first entry zone of the outside air into the system was calculated as 2296 (Eq.4). This data revealed that the flow characteristic in the entrance region of the system is laminar.

$$Re = \frac{\rho V D_h}{\mu} \quad (4)$$

D; hydraulic diameter is calculated by Equation (5).

$$D_h = 4 * A/P_s \quad (5)$$

The air entering the system is 32 °C ambient air. The initial temperature of the Tricklevent system and fins was accepted as 24 °C equal to the indoor air. The average temperature value of the exit temperature of the air from the system and the entrance to the indoor environment was accepted as 28 °C. The μ (Dynamic viscosity) value expressed in Eq. 2 in the calculation of Re number is taken from the tables for 28 °C. μ is taken as $1.867x10^{-5}$ kg/m.s.

The air inlet velocity to the system obtained in the computational study was taken as both a validation for the study and the basic parameter for the element number independence study. Table 1 shows the air inlet velocity data confirming the element number independence study and Fig. 8 confirming the numerical study with computational work. Mesh number is determined 2578585 in this study according to Table 2.

Table 2. Mesh independence study.

No	Fluid Element	Solid Element	Total Element	Results (Velocity inlet air, m/s)
1	632586	723589	1356175	1,454
2	1002548	958642	1961190	1,486
3	1321598	1256987	2578585	1,505

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4	1575896	1421589	2997485	1,506

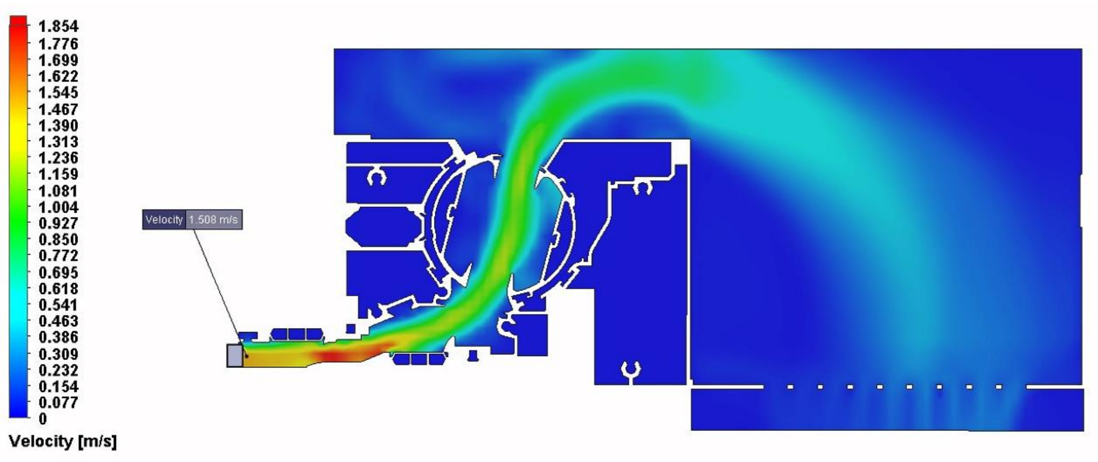

Figure.8. Tricklevent air inlet zone velocity result.

After the velocity data in the inlet region was verified numerically, the flow characteristics of the air in the inlet region between the fins were examined again. This review is based on the result obtained from the numerical study and given in Figure 6. The speed of the air entering the fin area was determined as 0.659 m/s and the Re number was calculated as 6298. The flow characteristic between the fins was determined as turbulent flow. FloEFD script was used in the analysis. The software determines the flow characteristic by determining the Re number in the analysis steps and continues the calculations according to the result. In regions where the flow is turbulent, the k-Ɛ turbulence model is used. In the analysis for sample office room 1009 W/m^2 of the solar load was taken. The facade system is defined as 6 mm thick double glazing.

The variation of air temperature with altitude was taken into account in the analysis. With the help of Eq. 6, the temperature drop according to the building height is defined in the analysis. It has been revealed from a study in the literature that the change in air temperature with altitude varies depending on equation 6. In the study, it was stated that the temperature decreased according to the height difference and the higher floors encountered lower temperatures. This data has been a result supporting our study [25].

$$\frac{dT}{dx} = -\frac{0{,}0066\ °C}{m} \tag{6}$$

The fin system is calculated by assuming a fin with a constant surface temperature. Nu number was found with the help of Eq. 7.

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$$Nu = \frac{hS}{k} = \left[\left[\frac{576}{(Ra_{s.}S/L)^2} \right] + \left[\frac{2{,}873}{(Ra_{s.}S/L)^2} \right] \right]^{-1/2} \quad (7)$$

The heat transfer coefficient between the designed fins is calculated as h_{mid}= 12 W/m^{2}K.

3. RESULTS AND DISCUSSIONS

When the results obtained in the numerical and numerical examination of the Trickle Vent passive ventilation system are examined, the data obtained are as follows. According to the numerical analysis results, it has been determined that in the Tricklevent system, the heat transfer area can be increased with the fin design and the outdoor air can be taken in by reducing the indoor temperature. It was observed that in the tests the temperature of the air entering the Tricklevent system decreased to 29.01 °C until it entered the fins and decreased to approximately 25.5 °C at the exit of the fins (Fig. 9 a). This shows that a temperature drop of about 7 °C is achieved. The comparative values of the analyzes and tests are given in Table 3. According to these data, it was determined that the result of tests and analyzes were compatible. The comparison of velocity values, as well as temperature values, is given in Table 4. It has been determined that the velocity values are compatible in terms of test and analysis, just like the temperature data.

Table 3. Temperature comparison of test and analysis results.

Test Results	**Test Results (°C)**	**Analysis Results (°C)**
Temperature (entrance of fins)	29,01	29,12
Temperature (outlet fins)	25,5	25,10

Table 4. Velocity comparison of test and analysis results.

Test Results	**Test Results (m/s)**	**Analysis Results (m/s)**
Velocity (entrance of fins)	0,65	0,662
Velocity (outlet fins)	0,15	0,101

In Figure 9 b, the velocity values of the air entering the system are taken randomly over the air flow profile. It has been determined that the entrance speed of the cooled air into the interior does not disturb the thermal comfort and enters the room with a speed below 5 m/s. The temperature distribution data taken over the curve in Fig. 9 c are given graphically in Fig 10.

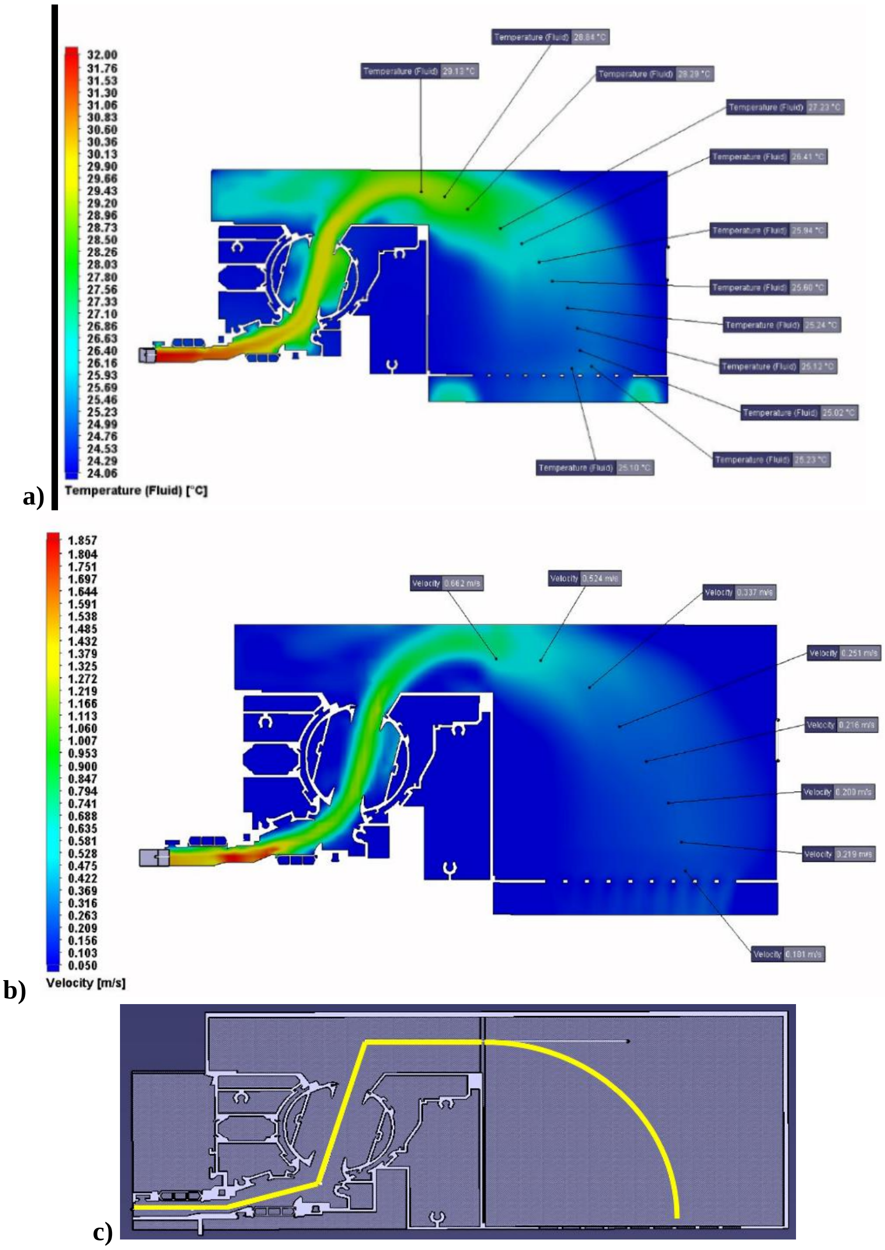

Figure 9. Within the Tricklevent system a) Temperature distribution b) Velocity distribution c) Temperature data curve.

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Figure 10 shows the comparison of the Tricklevent system with and without heatsink. As can be seen in Fig. 10, the temperature drop in the finned area is higher than in the finless area.

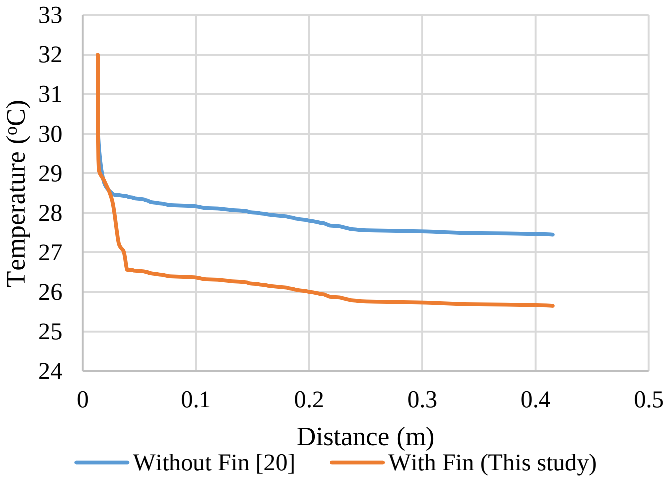

Figure 10. Temperature drop comparison chart in Tricklevent system with and without fins.

With the fin design, the heat transfer area has been increased and the target of further reduction in air temperature has been achieved. This result is theoretically expected. Studies are continuing to optimize the fin thickness and spacing design and to obtain the most efficient heat transfer. The graph of the heat transfer coefficient on the curve swept by the air inside the fin is given in Fig. 11 a. The heat transfer coefficient graph given in Fig. 11 a is taken over the curve shown in Figure 11 b. This graph shows the local heat convection coefficients along the curve. The value obtained by the calculation method is the average value of heat convection coefficients is 12 W/m^2K. The average value of the heat transfer coefficient obtained from the analysis was determined as 11.33 W/m^2K. It is thought that the reason for the difference between the two values may be that the fin surface area is not completely swept with hot air on the path followed by the air, and the curve seen in Fig. 11 b, on which the graph is based, cannot fully represent the path followed by the air. In addition to these comments, an error of 6% in the analysis value is considered to be an acceptable error.

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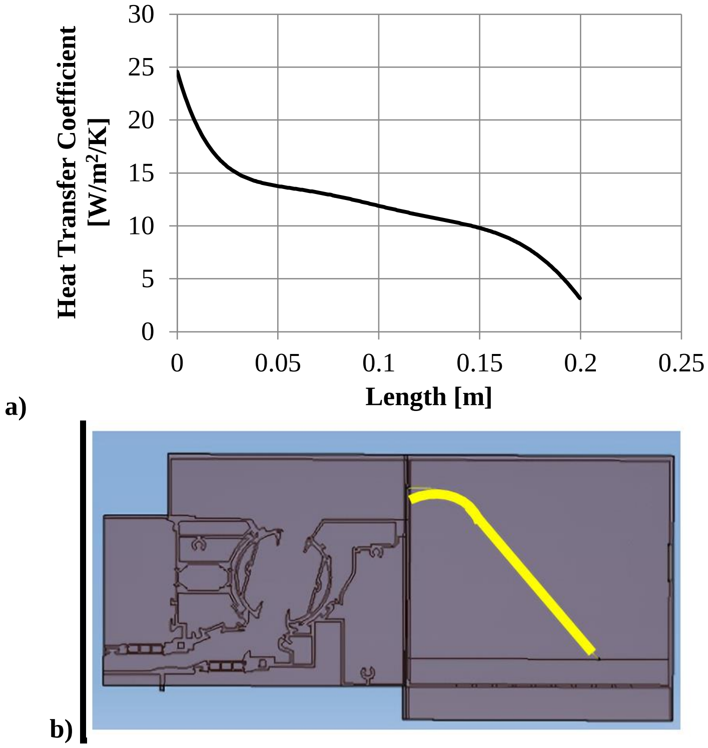


Figure 11. a) Variation graph of heat convection coefficient, b) the curve from which the graph is drawn.

Another result obtained in the study is the effects of the triclevent system on the temperature distribution in the interior volume. In the literature study, when the temperature distribution in the same sample office room in the Triclevent system without fins is compared with the temperature distribution at 1.75 m height, it has been determined that the room conditions become better with the finned structure. It can be seen in Figure 12 that the indoor temperature varies between 30-36 ^{o}C during operation without blades and when the system is closed. When the finless system is turned on, it can be seen from Figure 12 that the temperature distribution varies between 27-32 ^{o}C at height of 1.75 m. In the open state of the finned Tricklevent system, it was determined that the temperatures remained in the range of 25,5-29 ^{o}C at an altitude of 1.75 m. This clearly shows that the finned system is more effective (Fig. 12).

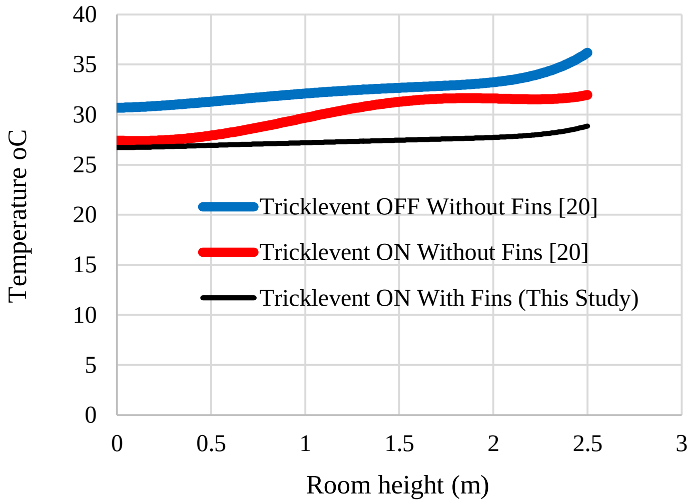
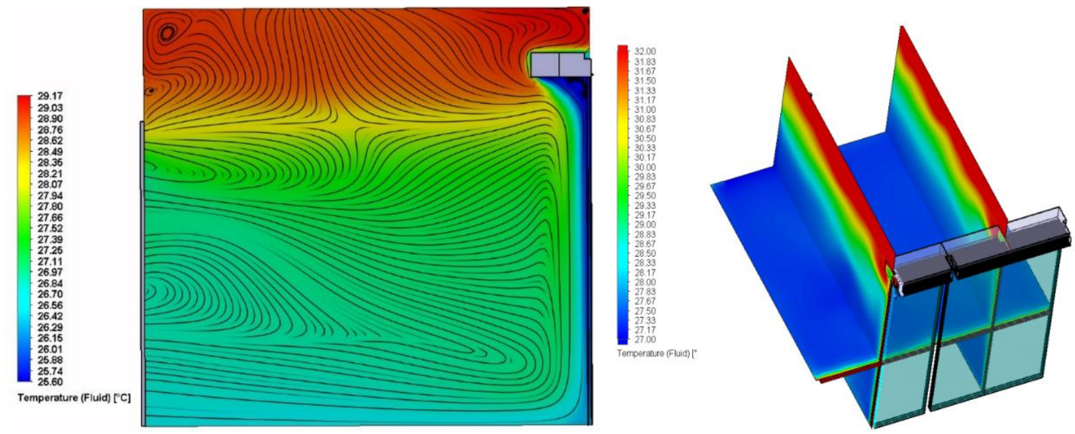


Figure.12. Example office room temperature change graph of 1.75.

As can be seen in Figure 13, Tricklevent system with fin structure can keep the temperature distribution in the room at lower temperatures than the system without fin structure. In the images given in Figure 13 a and b in comparison with the literature, it is seen that the temperature of the trickle vent system without blades is 32 ^{o}C at an altitude of 1.75 m as a result of the analysis.



a) b)

Figure 13. a) Example office room temperature change graph of 1.75 m b) Example office temperature distribution sections [21].

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4. CONCLUSION

It has been determined that the system reduces the temperature of the air coming from the outside environment and provides the appropriate temperature value to provide thermal comfort to the indoor environment. The hot air taken from the outside air increases the temperature of the fins made of Al material over time. However, turning off the air conditioner during this time is the main parameter that will save energy. According to the data we obtained in our study. It is a great advantage in terms of heat transfer that the Tricklevent system is made of Al material, is not exposed to solar radiation, and quickly reaches the temperature of the air conditioned indoors according to the Al material properties. According to the literature studies, it was stated that every 1 ^{o}C increase in the air conditioner setting saves 3-6% in electricity consumption. [22]. According to the studies of ACEEE (American Council on Energy Efficiency Economics), the factors affecting the electricity consumption of the air conditioner are listed as: Indoor air temperature, Outdoor temperature, Heat insulation of the room and temperature setting of the air conditioner. Energy saving in air conditioners depends on the thermostat setting and indirectly on the compressor operating time. Since setting the thermostat to 18 ^{o}C and setting it to 25 ^{o}C will directly affect the compressor operating time, it is clear that less energy will be spent at high temperature settings. Another study revealed the energy cost per m^2 for each 1 °C reduction [10]. In the study, he reported that there is 1 kWh/m^2 energy saving for each ΔT= 1 ^{o}C temperature drop in the air conditioner setting. This means 14 kWh energy savings for a 14 m^2 sample office. Setting the air conditioner to higher temperatures such as 25-26 ^{o}C instead of setting it to 23 ^{o}C in hot summer months will cause the air conditioner compressor to consume less energy.

An A+ class air conditioner operating 3 hours a day for a month consumes an average of 97 kWh, while A++ air conditioner consumes 81 kWh and A+++ air conditioner consumes an average of 63 kWh. Energy companies draw attention to the fact that this difference will be reflected on the bills even more as the consumption increases depending on the usage period. An air conditioner operated 3 hours a day; It consumes 4 times more energy than an iron, 6 times more than a television, 4 times more than a computer, 8 times more than a dishwasher, and 3 times more than a refrigerator that works all day. Considering that air conditioning operation times are 6 hours for average workplaces, it is clear that the costs will double.

The Tricklevent system has 2 different ways of working. The first mode of operation is parallel operation with the air conditioner. While the air conditioner keeps the interior volume at a certain temperature, the fins cool the air coming from the outside at the indoor temperature and take it inside. In such a case, the air conditioner power is adjusted to higher temperatures and energy costs are reduced with the savings in compressor power. Working in parallel with the air conditioner the air passing through the fin structure enters the interior volume as 25.5 °C. The system took the air, which is 32-31 ^{o}C in the external environment, by cooling it into the interior volume. According to the literature, with a temperature drop of 5.5 ^{o}C, 70 kWh energy recovery was achieved. When the system is turned on at the same time as the air conditioner, 2 ^{o}C air conditioning power is gained by adjusting the indoor temperature to 25 ^{o}C instead of 23 ^{o}C. This data means 28 kWh savings per m^2. When the system is turned on after the ambient conditioning of the air conditioner, the Al material fins that reach the air conditioner setting temperature reduce the temperature of the air coming from the outside environment.

The second operation plan of the system is based on not operating the air conditioning system until the fin temperature, which is at the indoor temperature, reaches the outdoor air temperature after the air conditioner is turned off. In the computational analyzes made based on time, the temperature of the air coming from the outside environment reaches 31 ^{o}C after 19.6 minutes. This value means that the air conditioner does not operate for 20 minutes in a 1 hour period. This data provides an energy saving of 21 kWh by reducing the 3-hour air conditioner operating time by 30% in the energy consumed. In the studies in the literature, the effects of providing the integrated operation of the HVAC system and the facade system with the automation system on energy saving have been examined. It is stated that with the automation system, around 70% energy savings are achieved [25]. Our work continues with the optimization of the number and spacing of the blades as well as the automation system studies.

According to the data of the Ministry of Environment, Urbanization and Climate Change, 0.55 kg of CO2 is emitted for 1 kWh of electrical energy. When the system is turned on at the same time as the air conditioner, the carbon footprint of 15.4 kg per m^2 will be removed with the reduction in the air conditioning set temperature and the savings in air conditioning power. For the 14 m^2 office room designed in our study, this rate means that 215.6 kg of carbon is not released into nature. With the sequential operation of the system with the air conditioner, the carbon footprint of 11.55 kg will be erased from the nature in a 3-hour period with a 30% savings of approximately 21 kWh. It is calculated that 23 kg of carbon footprint reduction will be achieved in the carbon footprint during the six-hour air conditioning period.

With the addition of fins, the heat transfer surface area has been increased and the amount of energy saving has been increased compared to our previous study. Today, when energy problems are experienced, the development of the Tricklevent system and the integration of different modules into the system provide great savings in building energy use.

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NOMENCLATURE

A	cross-section
D_h	hydraulic diameter
k	heat conduction coefficient
L	length
$\dot{m}$	mass flow
Nu	Nusselt number
V	velocity
P	pressure
P_s	perimeter
Ra	Rayleigh number

Re	Reynolds number
T	temperature
Greek symbols	
ρ	density, kg m^{-3}
μ	dynamic viscosity
Abbreviations	
WBCSD	World Business Council for Sustainable Development
DSF	Double skin facades
HVAC	Heating, ventilation, and air conditioning
CFD	Computational fluid dynamics