Black Sea Journal of Engineering and Science
doi: 10.34248/bsengineering.1963170

Open Access Journal
e-ISSN: 2619 – 8991

Research Article
Volume 9 - Issue 4: 1838-1842 / July 2026

THE EFFECT OF TRIPLE-GLAZED WATER FLOW WINDOWS ON COOLING ENERGY CONSUMPTION

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Abstract: A novel idea called the Water Flow Window (WFW) involves a regulated water flow in the space between two glazing panes. Running water in the summer can greatly lessen the heat gain in the room. This study is carried out in summer for triple-glazed windows in Elazig. The electrical energy savings rate of the cooling systems obtained with the WFW system design compared to normal windows. One side of the cabinets used in the experimental study is completely windowed, while the other facades are made with insulation material on the upper and lower parts. The experimental cabinets' dimensions are 30x35x75 cm. As the water flow rate rises, the consumption rates fall. At the end of the experimental days, the minimum consumption (daily total) ratio of cooling devices of testing cabinets is around 0.33 and the maximum ratio of cooling devices is around 0.44 at the lowest flow rate.

Keywords: Energy, Water flow window, Electricity consumption, Solar effect, Cooling system

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Received: June 03, 2026
Accepted: June 28, 2026
Published: July 15, 2026
Cite as: Koca, A., Gür, M., & Yamaç, H. I. (2026). The effect of triple-glazed water flow windows on cooling energy consumption. *Black Sea Journal of Engineering and Science*, 9(4), 1838-1842.

1. Introduction

According to the International Energy Agency, buildings use around 36% of the total energy consumed globally. Considering the developed countries, this rate is around 38% in Europe and 39% in the USA. For Türkiye, this rate is around 36% (Shaikh et al., 2014; Piffer et al., 2021).

In Türkiye, as in other countries, the rapid increase in energy demand in the last two decades has led to an increase in energy imports. In 2016, the primary energy consumption of Türkiye increased by 71.5% compared to 2000 and reached 136.2 million tons equivalent of oil and the ratio of imported energy resources in the primary energy supply approached 75%. By 2030, the Ministry of Energy and Natural Resources predicts that imports would supply around 80% of global energy needs. Energy income for Türkiye's economy will undoubtedly increase till 2030 as a result of rising energy consumption and reevaluated yearly energy imports. Considering this situation and the share of buildings in energy consumption, when designing homes for energy efficiency, it's crucial to use passive systems and take steps to lower the heating and cooling loads of residential structures. So, in order to cut energy usage in homes, architects and engineers must put new ideas into practice (Dilaver and Hunt, 2011; Yaşar and Kalfa, 2012; Kayalica et al., 2020). The electricity requirement of buildings is increasing rapidly. Cooling systems are one of the largest consumers of electricity (Souayfane et al., 2016). Heating, ventilation and air conditioning (HVAC) accounts for more than 50% of total building energy use. Therefore, energy savings in this area are valuable in terms of economy and sustainability. Reducing heat transmission within the building's environment and thus lowering cooling and heating loads is an efficient technique to lower building energy consumption while still maintaining the comfort and convenience of building occupants (Peng et al., 2016). Reducing energy consumption plays an important role in the energy consumption cycle. Therefore, it is one of the focal points of countries to focus on performance improvement studies in this area (Javadi et al., 2020).

The new concept called Liquid-Water Flow Glazing (LFG-WFG) System or Liquid-Water Flow Window (LFW-WFW) System can be considered as a new field that has been studied in recent years (Gueymard and duPont, 2009; Pal et al., 2009; Chow and Lyu, 2017).

Within the scope of the EU's HORIZON 2020 research initiative, the InDeWaG (Industrial Development of WFW Systems) project has received funding from the EU. The WFW technology reduces heat transfer to the interior while maintaining the same natural light transmission as conventional glass. Additionally, water circulation makes it possible to utilize, store, or transfer the energy absorbed by the water-filled cavity (Li et al., 2016; Nikolaeva-Dimitrova et al., 2018). Insulation performance of triple glazing WFW system, vacuum glass and insulated glass unit is investigated in a study.

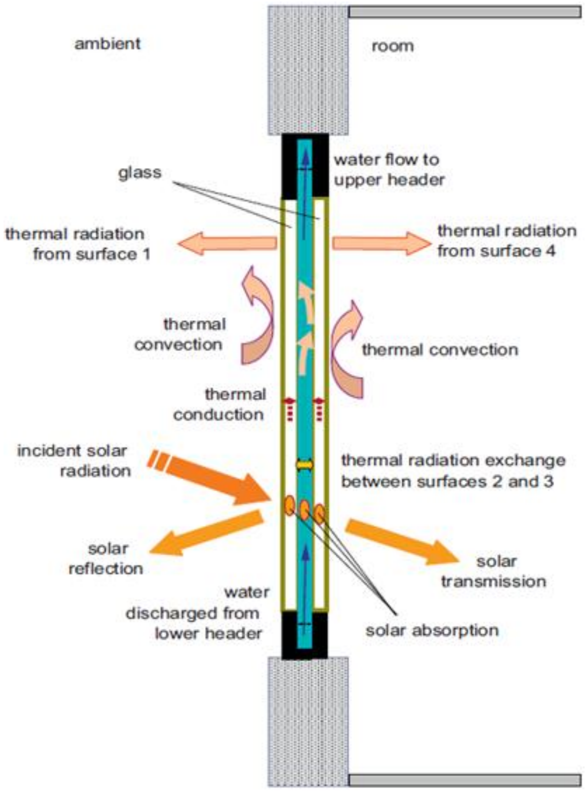

Figure 1. Schematic diagram of the heat-transfer modes in the WFW system (Chow et al., 2011).

The WFW system is found promising in terms of thermal performance as a collector. In the study on annual energy consumption calculations, numerical estimates and return times within the scope of WFW studies; WFW is found promising in terms of energy consumption reduction in heat removal, air conditioning and service hot water systems (Chow and Li, 2013). Especially in areas where cooling prevails, WFWs have proven to be an efficient way to use both solar energy and save cooling energy for air-conditioned buildings (Lyu et al., 2019).

2. Materials and Methods

One side of the cabinets used in the experimental study is completely windowed, while the other facades are made with insulation material on the upper and lower parts. One cabinet has a normal window and another cabinet has a WFW system window. The opaque surfaces of the test cabinets consisted of 10-mm-thick melamine-faced particleboard layers on both the inner and outer sides (thermal conductivity, k = 0.14 W m^{-1} K^{-1}), with a 100-mm-thick expanded polystyrene (EPS) foam layer (k ≈ 0.038 W m^{-1} K^{-1}) placed between them. The floor and ceiling contained two EPS layers, providing a total insulation thickness of 200 mm. Based on the thermal resistances of these layers, the approximate U-values were calculated as 0.36 W m^{-2} K^{-1} for the side opaque surfaces and 0.19 W m^{-2} K^{-1} for the floor and ceiling, excluding internal and external surface resistances. An aluminium cover installed above the roof served solely as a solar-shading element, while the ventilated gap beneath it allowed ambient airflow. Test cabinets and testing environment of experimental study can be seen in Figure 2.

Figure 2. Experimental test area (Yamaç and Koca, 2021).

In addition to the air temperature, incoming and outdoor radiation measurements are taken inside the cabinets. Experimentally, water flow rates range from 0.475 to 2.850 liters per minute. According to these numbers, the water fills the space between the windows in 6–1 minutes. The dimensions of the experimental cabinets are 30x35x75cm. The gap thickness between two glazing is 12mm. There are cooling systems inside the cabinets. Cabinets cooling process are done with typical refrigeration cycle elements (compressor, evaporator, condenser and expansion valve) used in refrigerators. The internal temperature controls of the cabinets are made with an Arduino processor system. The cooling system is activated when the total measurement value of the temperature sensors placed in the upper and lower parts of the cabinets exceeds 48°C. If the sum of these temperature measurements is below 48°C, the cooling system is disabled. Measurements take place every half minute. Cooling electricity consumption rates are obtained for normal window and WFW cabinets with triple glazing at five different water flow rates. The electricity utilized by cooling devices is measured using ENTES ES32-LS electricity meters. Electric meters are wired into the circuit prior to the Arduino-controlled relay board. The measurements are transferred from the meters to the computer via the RS485 conversion card via USB connection. Data are taken from electricity meters with MATLAB software.

In the matrix (equation 1), the form of multiple regression is:

$$Y = X\beta + \varepsilon \tag{1}$$

3. Results and Discussion

The average maximum radiation value of the days when the experimental study is carried out is 518.73W/m^2, the average maximum air temperature value is 35.19°C. Within five days, there is less than 50W/m^2 difference between the maximum radiation values and there is less than 2.5°C difference between the maximum air temperatures. The difference between the daily average irradiance values is less than 25 W/m^2. The difference between the daily average temperature values is less than 2°C. Representing the five days of measurements; The radiation and temperature values measured on July 23, 2020 are shown in Figure 3.

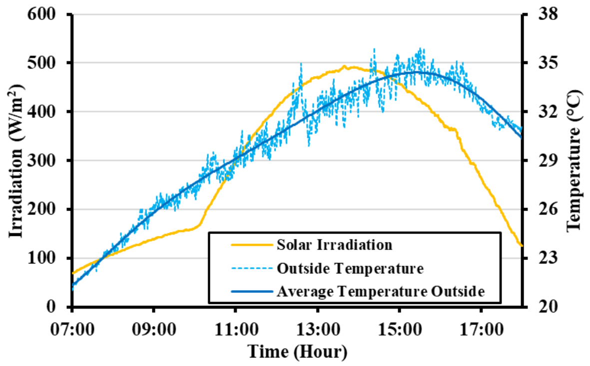

Figure 3. Environmental results of an experiment day.

The concept of day in the measurements includes the measurements taken between 07:00-18:00. Experimental measurement days have sufficiently similar climatic characteristics to each other.
The time-dependent ratios of the interior radiation of the cabinets to the solar radiation are shown in Figure 4 representing the other experimental days. Since shading from the side walls don't occur on the pyranometers between 13:00 and 16:00, it is found appropriate to use the results in this range when comparing solar radiation and indoor radiation. In the case of triple-glazed windows, the ratio of the interior of the WFW cabinet to solar radiation is 0.3. The ratio of normal window cabinet indoor radiation to solar radiation is 0.5. WFW and normal window indoor irradiance ratios are also about 3/5.

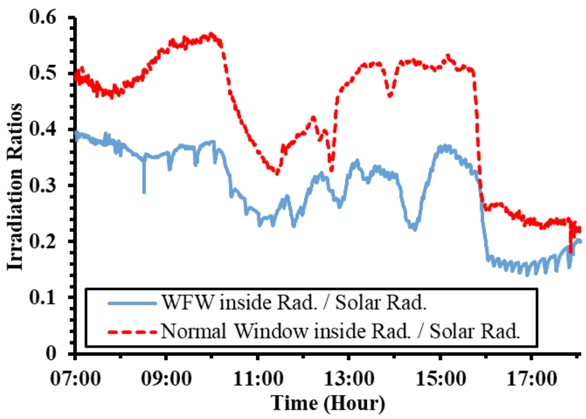

Figure 4. Radiation ratios of an experiment day.

As a result of the difference in the electricity consumption of the cooling system between the cabinets, it is understood that the radiation falling into the cabinets is different. The water entering from the lower part of the WFW is mains water. The water inlet temperature values are between 19-21°C during the day.

Mains water assisted WFW direct cooling system is used to reduce electricity consumption. By comparing the electricity consumption of the cabinet with WFW to the electricity consumption of the cabinet with normal windows (WFW cabinet cooling electricity consumption/Normal window cabinet cooling electricity consumption) under the same climatic conditions, the impact of the WFW system on electricity consumption is assessed. The flow rate graph of the consumption rate between 07:00 and 23:00 comparing the consumption rates according to the flow rate with triple glazing window is shown in Figure 5.

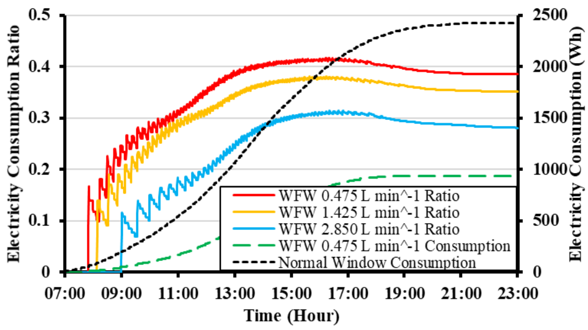

Figure 5. Electricity consumption ratios.

The electrical energy used by the cooling system during the summer is the cause of the consumption of electricity. As the WFW water flow rate is increased, it is seen that the consumption rate drops. Since there is no difference in the overall energy consumption data between the WFW cabinet consumption and the typical window cabinet consumption after 23:00 in the case of the WFW system with mains water support, the measurements are displayed in the graphs up to the time given. At the end of the day, the triple-glazing WFW cabinet uses about 950Wh of electricity while being circulated at a flow rate of 0.475 liters per minute. In the meantime, the typical window cabinet uses about 2400W.h. Utilizing the total energy consumed at the end of the day, the power consumption of five different flow rate WFW cabinets to the standard window cabinet is calculated. Figure 6 displays the WFW system's cabinets' rates of electricity consumption when using mains water.

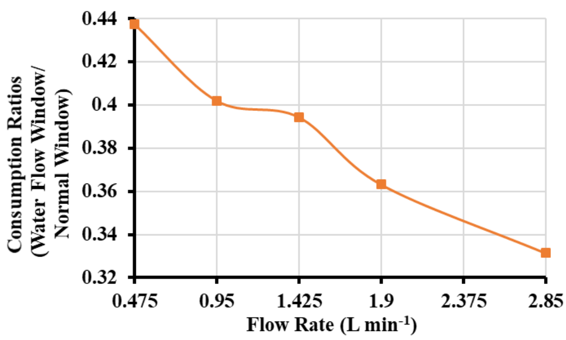

Figure 6. Electricity consumption rates at the end of the experimental day.

It is seen that the consumption rates decrease as the water flow rate increases. At the end of the experimental days, the minimum consumption (daily total) ratio of cooling devices is around 0.33, maximum ratio of cooling devices is around 0.44 at the lowest flow rate.

4. Conclusion

The air temperature and radiation values in the environment where the experimental study is carried out, the radiation values inside the cabin are also measured. Depending on the WFW flow rate, instant and daily total electricity consumption values are calculated. Graphs of measurements and calculations are shown.

As a result, when it comes to triple glazed water flow windows; It is seen that the use of WFW in the summer climate in Elazig greatly reduces the electricity consumption of the cooling system.

As a future work, the tests can be made with windows have commercial size. The experiments can be made in different cities in different seasons.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	A.K.	M.G.	H.I.Y.
C	40	30	30
D	40	30	30
S	40	30	30
DCP	40	30	30
DAI	40	30	30
L	40	30	30
W	40	30	30
CR	40	30	30
SR	40	30	30
PM	40	30	30
FA	40	30	30

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

Acknowledgements

This work was supported by the Scientific Research Projects Coordination Unit of Firat University. Project number TEKF. 18.20. This study was performed at Firat University within the scope of the Ph.D. thesis, numbered from the Council of Higher Education of Türkiye (YÖKTEZ) as 10368230, titled "Experimental and Numerical investigation of the Liquid Flow Windows Systems.". Within the scope of his thesis, we would like to thank the Department of Scientific Support (BİDEB) of TÜBITAK, which gave Halil İbrahim Yamaç a scholarship within the scope of priority fields.

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