Fırat Üniversitesi Müh. Bil. Dergisi
35(1), 363-377, 2023

Araştırma Makalesi
https://doi.org/10.35234/fumbd.1233300

Investigation of the Effects of Incorrect Installation of Air Conditioning Systems on Electricity Consumption Cost

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(Geliş/Received: 13/01/2023; Kabul/Accepted: 11/03/2023)

Abstract: Changes in air temperatures with the effect of global warming are seen with increasing temperatures especially in summer months. Due to temperature increases, the use of air conditioners is increasing in order to provide the desired comfort conditions. As a result of the researches, it was determined that the air inlets were closed as a result of incorrect installation or use of the condenser unit of the air conditioning systems and the electricity consumption increased because the desired amount of air passage could not be achieved. Within the scope of this study, the authors examined the cost of electricity consumed by the air conditioning system in case of incorrect installation or use for 12 different countries. As a result of the analysis made for Turkey, the cost of electricity consumption as a result of incorrect installation practices of the air conditioning system caused an annual cost of approximately 56-62.78 $ more than the electricity consumption cost of the reference system.

Keywords: Air Conditioning Systems, Electricity Consumption, Global Warming, Incorrect Installation.

Klima Sistemlerinin Yanlış Montajının Elektrik Tüketim Maliyetine Olan Etkilerinin İncelenmesi

Öz: Küresel ısınmanın etkisiyle hava sıcaklıklarında meydana gelen değişiklikler özelikle yaz aylarında artan sıcaklıklarla kendini göstermektedir. Sıcaklık artışları nedeniyle istenilen konfor şartlarının sağlanması için klima kullanımı artış göstermektedir. Yapılan araştırmalar sonucunda klima sistemlerinin yoğuşturucu ünitesinin yanlış kurulum veya kullanımı sonucunda hava girişlerinin kapatıldığı ve istenilen miktarda hava geçişi sağlanamadığı için elektrik tüketiminin arttığı tespit edilmiştir. Bu çalışma kapsamında yazarlar klima sisteminin yanlış montaj veya kullanım durumlarında tükettiği elektriğin maliyetini 12 farklı ülke için incelemişlerdir. Türkiye için yapılan analiz sonucunda klima sisteminin yanlış montaj uygulamaları sonucunda elektrik tüketim maliyetinin, referans sistem elektrik tüketim maliyetinden yıllık yaklaşık 56-62.78 $ daha fazla maliyete sahip olduğu bulunmuştur.

Anahtar Kelimeler: Elektrik Tüketimi, Klima Sistemleri, Küresel Isınma, Yanlış Montaj.

1. Introduction

The use of air conditioners is increasing to reduce the effect of increasing air temperatures with the impact of global warming and provide comfortable conditions in summer. However, the increased use of air conditioners has some disadvantages besides providing comfortable conditions. In this study, the authors examined the changes in electricity consumption cost as a result of not montaging the air conditioning systems in accordance with the instructions given by the manufacturers and incorrectly montage of the condenser units. It is said that the use of air conditioning systems or electric fans used to provide comfortable conditions in the summer months constitutes 10% of all global electricity consumption. According to the International Energy Agency (IEA), air conditioning systems are expected to triple global electricity demand by 2050 and will be the main driver of global electricity demand. According to the IEA, the global stock of air conditioners in buildings is projected to grow from 1.6 billion to 5.6 billion by 2050. [1]. In a study in the literature, two different air conditioning systems were examined. Variable flow refrigerant (VRF) systems have recently been widely preferred in terms of comfort, energy efficiency, ease of installation and operation. In that system, a single outdoor unit can be connected to more than one indoor unit, providing savings in energy usage by heating and cooling. Another application used in the air conditioning system is the fan coil system. It is a heating and cooling application in which energy is carried by water. For these two air conditioning systems, types of equipment were selected for the two systems according to

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the calculated heat loads of a street store. The initial investment, operating costs and energy analyzes of the two systems were compared according to the selected equipment. Analysis results show that the variable flow refrigerant system has 24.6% more advantages in investment costs, 32.5% in operating costs and 33.7% more in energy consumption [2]. For a building in Adana, two different air conditioning systems, fixed airflow and variable airflow air conditioning systems, were compared by calculating the initial investment and operating costs. The present value cost method and life cycle cost analysis were used and comparisons were made for different situations. In those cases, the use of the building in two different ways as a school and office center, two different operating scenarios for the air conditioning system and finally two different economic systems have been considered. It has been found that the present value cost of the variable airflow air conditioning system for all evaluated cases is lower in all cases than the constant airflow system at the end of its life [3]. In a study conducted by the researchers, a comparison of the same capacity multi-split air conditioning system, which can be an alternative to the mono-split air conditioning system used in a commercial building operating 24 hours a day, was made. It is aimed to make the right choice by comparing the electricity consumption data, which is the most important point of the initial investment and operating costs, with the lifetime cost analysis method for two different systems. According to the results obtained, it has been determined that multi-split air conditioners are more advantageous in operating costs due to their lower energy consumption compared to mono-split air conditioners. It has been determined that the payback period is less than one year in case of use all year. The initial investment costs of multi-split air conditioners vary. Before purchasing devices, good market research should be done [4]. The air conditioning systems are used in hospitals, shopping malls, industrial production centers, food production facilities etc. When the lifetime costs of air conditioning systems used in places are examined, it is seen that the electrical energy consumed by the fans takes the first place at the rate of 50%. In a study in the literature, it was emphasized that if the energy required for the operation of the fans is met from a renewable and clean energy source such as wind energy, the lifetime costs and the environmental effects of the system become more advantageous [5]. In a study by Söğüt et al., the energy and cost advantages of solar and wind-assisted fans in commercial buildings were modeled and calculated considering their regional uses. According to the analysis, in case of using wind-assisted fans, an average of 13365 kWh/year and approximately 83176 TL/year energy and financial savings can be achieved for 3-4 m/s wind speeds in Turkey average [6]. In one of the studies in the literature, it was seen that technological and strategic studies were focused on achieving better energy efficiency. One of the main reasons for this is that HVAC (Heating-Ventilating and Air Conditioning) systems constitute 50% of the electricity consumption of buildings. In that study, innovative developments in the electricity-consuming parts of the cooling system components were included and the effects of the studies on electricity consumption were examined. At the same time, in the automation and control of these systems, strategies that will increase the operating efficiency of the system and reduce electricity consumption costs have been studied [7]. Considering the energy performance of air conditioning systems, a compilation study was conducted with a statistical approach. In that study, when the data taken from many data centers and the studies were examined, it was seen that most of the systems did not work at sufficient efficiency values. The electricity consumption rate of those systems is 38% [8]. In its compilation studies on cooling and heating systems, it examines topics such as the latest technologies, innovative ideas, cost and energy-saving methods, and classification according to energy use. Energy savings come to the fore in those reviews [9–12]. With the electrical energy produced by placing photovoltaic panels on the roofs of the Pulman wagons, the electricity consumption originating from the cooling system in the train, especially between May and September, was tried to be met with the energy produced. As a result of the calculations, the amount of electrical energy produced from PV panels in the period when the air conditioner is actively used in order to meet the cooling load of 22 kW was calculated as 9.690 kWh, and the amount of electrical energy produced throughout the year, including the other months, was calculated as 17.005 kWh. It has been observed that the ratio of the energy produced between May and September to meet the energy consumed by air conditioning systems is between 41 – 53%. They calculated that if PV panels are applied to the roofs of 139 Pulman wagons that are actively used in Turkey, 1,346,910 kWh of electrical energy will be produced in the months of May-September when the air conditioner is actively used, and 2,363,695 kWh of electricity will be produced annually [13].

It is seen that many studies have been carried out on the costs arising from the use of air conditioners. Optimization of air conditioning systems, improved automation systems, models made according to climate parameters, and R&D studies on system components have calculated the costs related to the electricity consumption of these systems. There is no study in the literature examining the effects of air conditioning systems on costs if they are not installed correctly. In this study, the effects of incorrect installation of the outside unit (condenser) of the air conditioning system on the usage costs as a result of unnecessary electricity consumption were investigated. In this research, analyses were carried out considering the capital cities of 12 countries.

2. Research Methodology

Training and information on the montage of air conditioning systems are given to dealers and technical service employees by air conditioner manufacturers. According to the training provided by the air conditioner manufacturers, the appropriate conditions for the montage of the condenser unit are as follows. It is stated that 30 cm space should be left for the air inlet from the back and left side of the condenser unit, 60 cm from the right side and 200 cm from the front surface air outlet area. Despite all this information and training, it has been observed that the information shared by the air conditioner manufacturer companies by the technical service and dealers is not taken into account when montaging the air conditioner system. Technical service, dealers or air conditioner manufacturers are not the only ones responsible for the wrong applications in the assembly in question. It is also seen that the users force the technical personnel to make the wrong installation. Photographs of incorrect installation of the condenser section of air conditioning systems are shown in Fig. (1).

Incorrect installation of the condenser section of air conditioning systems

A B C D E F

Figure 1. İncorrect montage conditions

In the photo shown in Figure 1-A, the condenser unit is installed adjacent to the wall of the building. This prevents air inflow from the side surface of the condenser. At the same time, there is not enough space for air inlet from the back surface. When the assembly of the condenser seen in Figure 1-B is examined, it is seen that the air inlet from the back side and the discharge of air from the front side are prevented. In Figure 1-C, the condenser units are closed in order to protect them from factors such as snow and rain and to provide an aesthetic appearance outside the building, but the air inlets are blocked. Since the condenser units are behind the billboards in Figures 1-D and F, evacuation of air from the front surface is prevented. In addition, there is not enough space for air inlet from the back surface. Figure 1-E Condenser units are installed close to each other and the air inlet is prevented from the side of the unit on the left. At the same time, air inlet is blocked due to the porch being built to protect it from the effects of snow and rainwater.

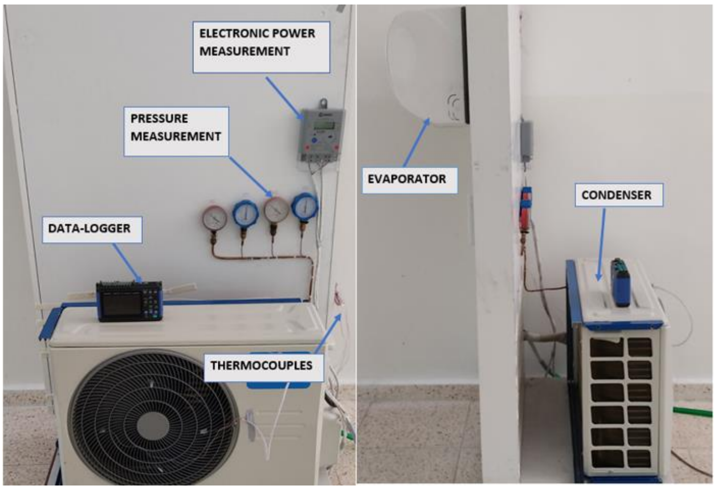

Figure 2. Experimental setup

In this study, the authors designed the experimental set in Fig. 2 to experimentally examine the effect of incorrect installation practices of the condenser unit of the air conditioning system on the electricity consumption cost. While the experiment set was being set up, support was obtained from the technical service of the related air conditioner manufacturer. In the experimental set, a split-type air conditioning system with 12000 BTU/h cooling capacity and using R32 as a refrigerant was preferred. The experiments consist of two stages. In the first stage, the indoor unit of the air conditioning system, which was installed in accordance with the installation procedure of the authorized service, was operated at fan speeds of 20%, 40%, 60% and 100%, and the electricity consumption values were determined and taken as reference values. In the second stage, especially the wrong assembly conditions of the condenser unit were created and experiments were carried out. The side and back air inlets of the condenser unit are gradually closed. The said stages are formed by closing 25-50-75% and 100% of the air inlet area. The back surface air inlet of the condenser unit was closed by 25%, the side surface air inlet was closed 25-50-75% and 100%, respectively, and each experiment was repeated for 4 different fan speeds. Experiments were repeated for all stages until the back surface was completely covered. During the experiments, the set value of the air conditioner was kept constant (16 °C). The ambient temperature was taken as 27 °C and the experiments were carried out in the laboratory in summer. By comparing the reference values with the data obtained as a result of preventing the air inlets of the condenser, the effect of incorrect montage on the electricity consumption cost was determined.

The Eq. (1) was used while calculating the cost analysis.

$$\text{Cost Analysis (\$/year)} = \text{AEC (kWh/year)} \times \text{ECP (\$/kWh)} \quad (1)$$

The AEC (Annual Energy Consumption) value in Eq. (1) gives the annual electricity consumption value of the air conditioning system. Electric consumption prices (ECP) value shows the unit electricity consumption price, see Table (1).

In Table (1), annual average electricity consumption values and unit electricity consumption prices as a result of air conditioning usage for 12 countries are given. AEC values were calculated by considering the air conditioner usage times of 12 countries for all experiments. The important value for cost analysis is the amount of electricity consumed by the air conditioning system. This value varies according to the climatic conditions in the location where the air conditioning system is used. For air conditioning systems used for cooling purposes, a certain value should be acted upon. The Spanish government has stated that air conditioning should be used at ambient temperatures above 27°C (Spanish Government to Allow Flexibility on Air-Conditioning, but Rules out U-Turn on Decree, n.d.). By taking this value as a reference, the authors examined the environmental temperature values by considering the capitals of 12 different countries around the world as locations. For the data received from NASA POWER, the hourly average of the temperature values above 27 °C for 12 countries between 2019, 2020 and 2021 was taken and this value was determined as the air conditioner usage time for the countries in question. (NASA, n.d.). Another factor affecting the cost analysis is the electricity consumption price. This value differs for each country. In this study, unit electricity consumption prices for 12 countries in March 2022 were taken into consideration in dollar terms and cost analyzes were carried out in this way [14].

Table.1. AEC and ECP values

Country	Average AEC (kWh/year)	Electric consumption price $/kWh [14]
Canada	231.38	0.117
China	1259.61	0.076
England	64.14	0.332
France	207.43	0.190
Germany	336.11	0.455
India	4940.21	0.074
Japan	1047.71	0.227
Mexico	178.62	0.089
Spain	1109.82	0.333
Sweden	68.20	0.280
Turkey	694.55	0.069
United States of America	1091.15	0.162

3. Results and Discussions

Within the scope of cost analysis, considering the capitals of 12 countries, the effects of air conditioning usage on electricity consumption costs were examined with the assumption that similar wrong installations were made in these countries. It is seen that the AEC value due to the electricity consumption of air conditioning systems increases in countries where the ambient temperature of the country where the air conditioner is used is above 27 C. The main reason for the increase in the AEC value is that the heat energy taken from the indoor unit (evaporator) cannot be discharged to the environment as a result of blocking the air inlet sections of the outdoor unit in incorrect installation situations, in the cooling cycle. Since the heat energy cannot be discharged to the environment, the heat taken from the indoor unit is stored in the systems. In these systems working with inverters, compressor power increases because the heat in the system cannot be discharged to the environment. This situation increases the electricity consumption values of the air conditioning system and causes an increase in the electricity cost of the system. Fig. (3) shows the values obtained for Turkey.

The x-axis in the graphs shows the closure rates of the air inlet sections of the Back (B) and Side (S) condenser. F indicates the fan power capacity of the evaporator unit. Ankara, the capital of Turkey, experiences four seasons due to its geographical location. The average number of hours for temperatures above 27 °C for 3 years has been calculated for Ankara. According to the data obtained, it is revealed that there is an average of 570 hours of air conditioning use per year. For Turkey, based on March 2022, the unit electricity consumption price in dollar terms has been determined as 0.069 $/kWh. Cost calculations were made in line with these data. It is seen that the air inlet of the condenser is not blocked and the electricity consumption cost values, which are considered as reference values, vary between 38.54 and 40.15 $/year. According to the wrong installation scenario of the condenser, it is observed that the cost of electricity consumption increases as a result of the gradual closing of the air inlet. It is seen that the cost of electricity consumption increases up to 56-62.78 $/year due to the closure of the air inlet as a result of incorrect installation. This shows that at the same fan speed but in the wrong installation application, the electricity consumption cost increased by approximately 56%. Fig. (4) presents the values obtained for Japan.

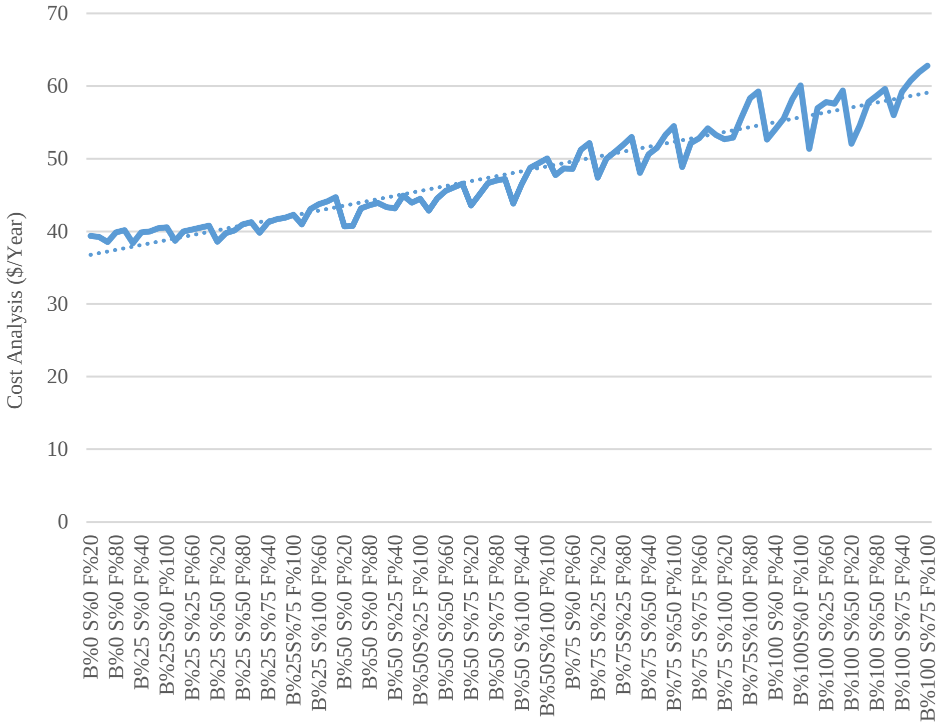

Figure 3. Effect of Wrong Montage on Electricity Consumption (Ankara)

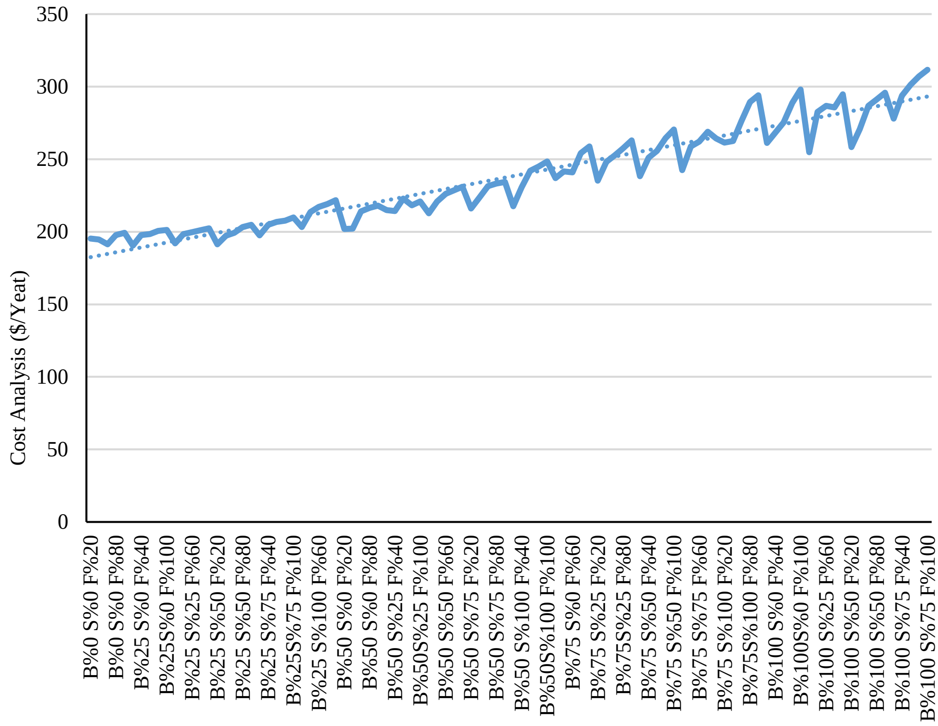

Figure 4. Effect of Wrong Montage on Electricity Consumption (Tokyo)

Japan is a country where air conditioning usage is intense. According to the home-saving measures published by the Ministry of Economy, Trade and Industry of Japan, it has been said that approximately 30% of the domestic electricity consumption of the Japanese people is due to the use of air conditioners [15]. For Tokyo, the capital city of Japan, three-year temperatures above 27 °C were found to be an average of 860 hours. For Tokyo, an average of 860 hours of air conditioning usage per year is taken into account. The unit electricity consumption price for Japan in March 2022 was determined as 0.227 $/kWh. It is seen that the air inlet of the condenser is not blocked and the electricity consumption values considered as reference values vary between 191.29 and 199.27 $/year. As a result of the gradual closure of the air inlet of the condenser, it is seen that the electricity cost is up to 277.92 – 311.60 $/year. In Fig. (5), the values obtained for China can be examined.

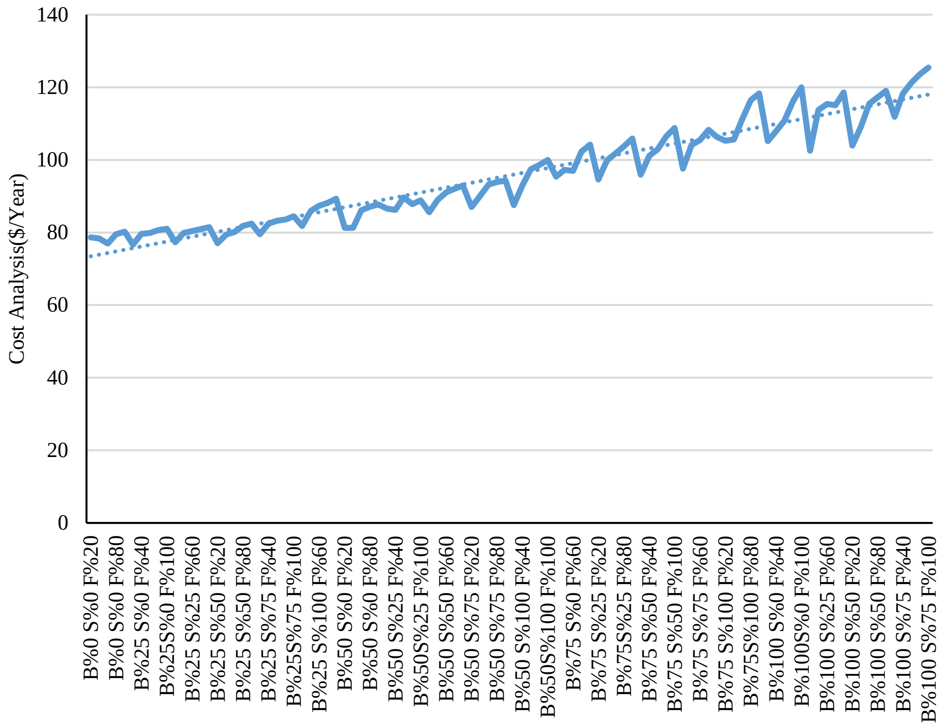

Figure 5. Effect of Wrong Montage on Electricity Consumption (Beijing)

An average of 1034 hours of air conditioning usage per year is calculated for Beijing, the capital of China. The unit electricity consumption cost for China in March 2022 has been determined as $0.076/kWh. It is said that a 1% increase that may occur in the Chinese economy increases electricity consumption by 0.79% on average [16]. Considering that the Chinese economy has increased today and the use of air conditioners will increase with the changing climatic conditions, it can be predicted that electricity consumption values will increase more as a result of incorrect installation practices. Reference values for cost analysis vary between 76.99-80.20 $/year. As a result of the gradual closure of the air inlet of the condenser, it was observed that the cost value due to electricity consumption increased to 111.86-125.42 $/year values. Fig. (6) shows the values obtained for India.

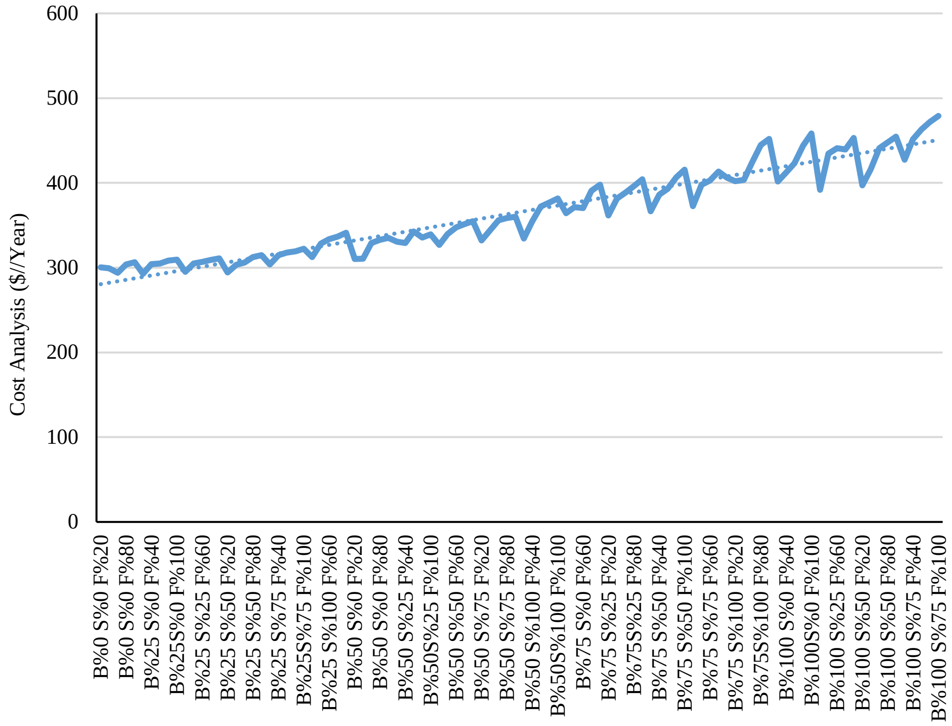

Figure 6. Effect of Wrong Montage on Electricity Consumption (New Delhi)

India's capital city, New Delhi, has the highest air conditioning usage time among 12 countries. The main reason for this is that it has a hot climate as a location. India's total air conditioner usage time is 4056 hours. In this case, it causes a lot of electricity consumption. With the effect of global warming, it is estimated that the electricity consumption due to the use of air conditioners in India will increase from 10% to 50% by 2050[17]. The unit electricity consumption cost for India has been determined as 0.074 $/kWh. Reference values for cost analysis vary between 294.03-306.30 $/year. According to the wrong installation scenario of the condenser, the electricity consumption cost increased to $427.20-478.87/year. Fig. (7) presents the values obtained for Spain.

The total air conditioner usage time for Spain is 913 hours. The unit electricity consumption price of Spain is taken as 0.333 $/kWh. Reference values for cost analysis vary between 297.25-309.64 $/year. According to the wrong installation scenario of the condenser, it was calculated that the electricity consumption cost increased to 431.87-484.20 $/year by preventing the air inlet. Fig. (8) shows the values obtained for France.

France has a low value in terms of hourly average air conditioning usage. In addition to the climate conditions, the French government prohibits the operation of air conditioning if the air temperature is below 26 °C [18]. This decision supports the reference ambient temperature value used by the authors for the analyses. The annual average air conditioning time is determined as 170 hours and the unit electricity consumption cost is determined as 0.190 $/kWh. Reference values for cost analysis vary between 31.69-33.02 $/year. According to the wrong installation scenario of the condenser, the electricity consumption cost increased to 46.05-51.63 $/year values by preventing the air inlet. Fig. (9) shows the values obtained for Germany.

When the average of the three-year temperature values for Berlin is taken, 276 hours of air conditioning usage per year emerges. For Germany, the unit electricity consumption cost for March 2022 is taken as 0.455 $/kWh. It is seen that the air inlet of the condenser is not blocked and the cost analysis values considered as reference values vary between 123-128.13 $/year. It is seen that the cost of electricity consumption increases up to 178.71-200.36 $/year due to the closure of the air inlet as a result of incorrect installation. Fig. (10) shows the values obtained for England.

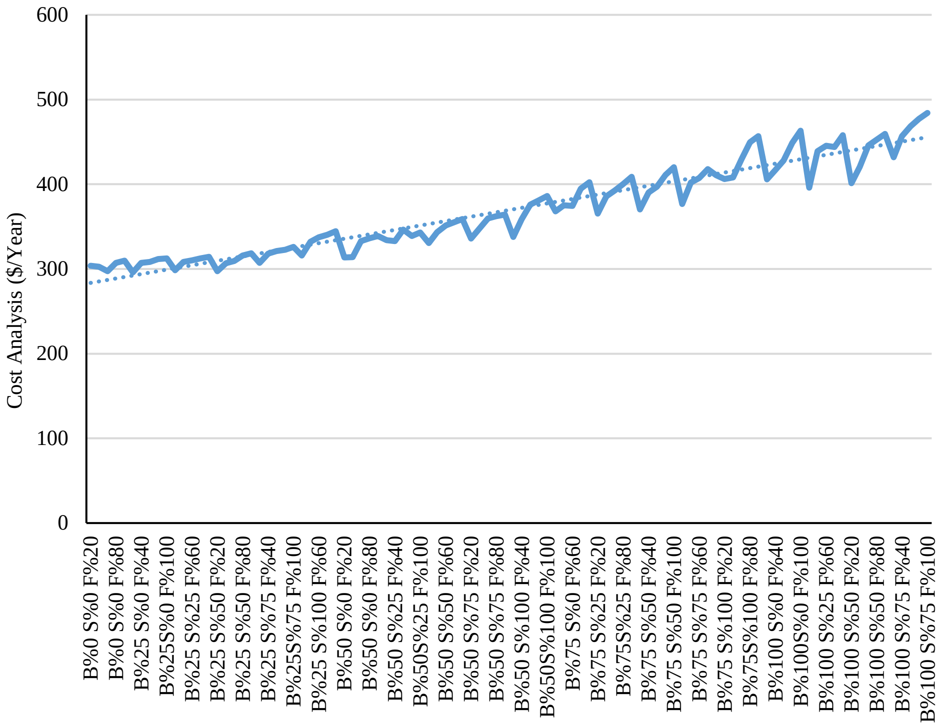

Figure 7. Effect of Wrong Montage on Electricity Consumption (Madrid)

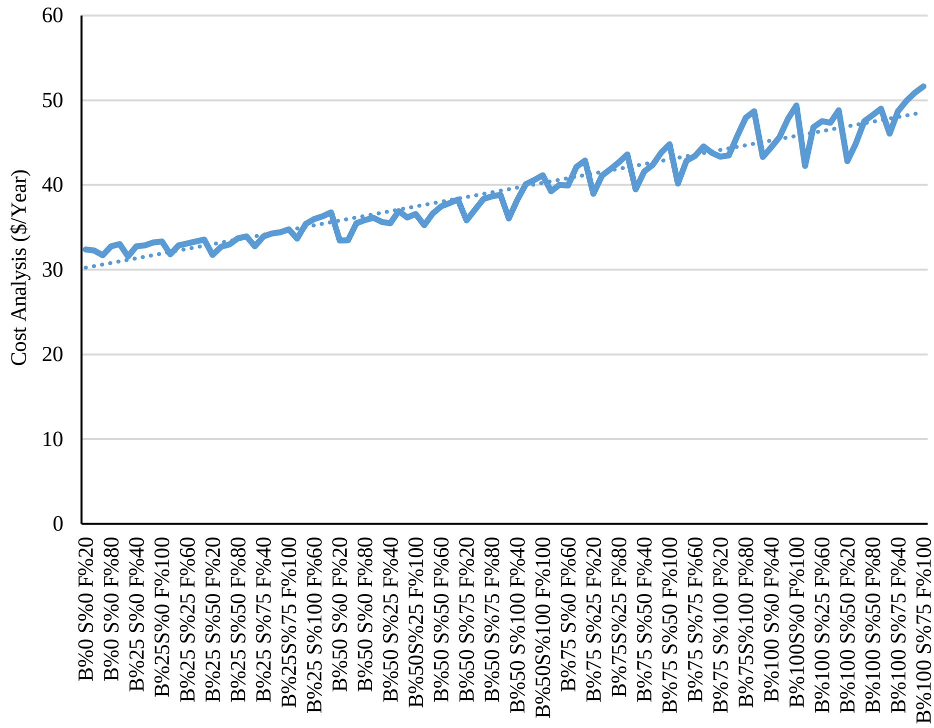

Figure 8. Effect of Wrong Montage on Electricity Consumption (Paris)

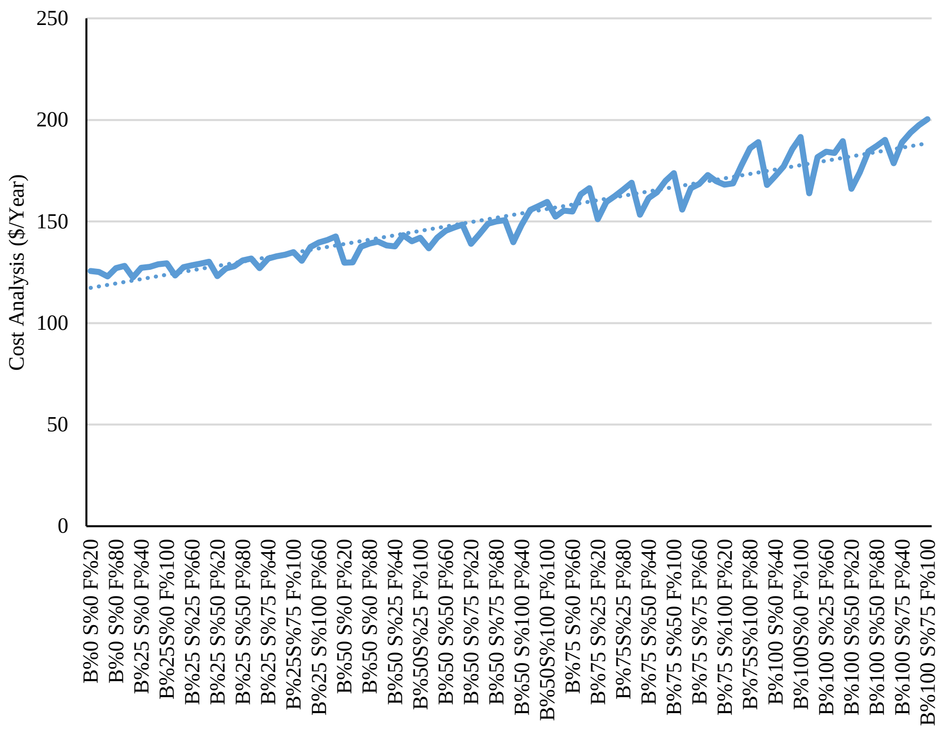

Figure 9. Effect of Wrong Montage on Electricity Consumption (Berlin)

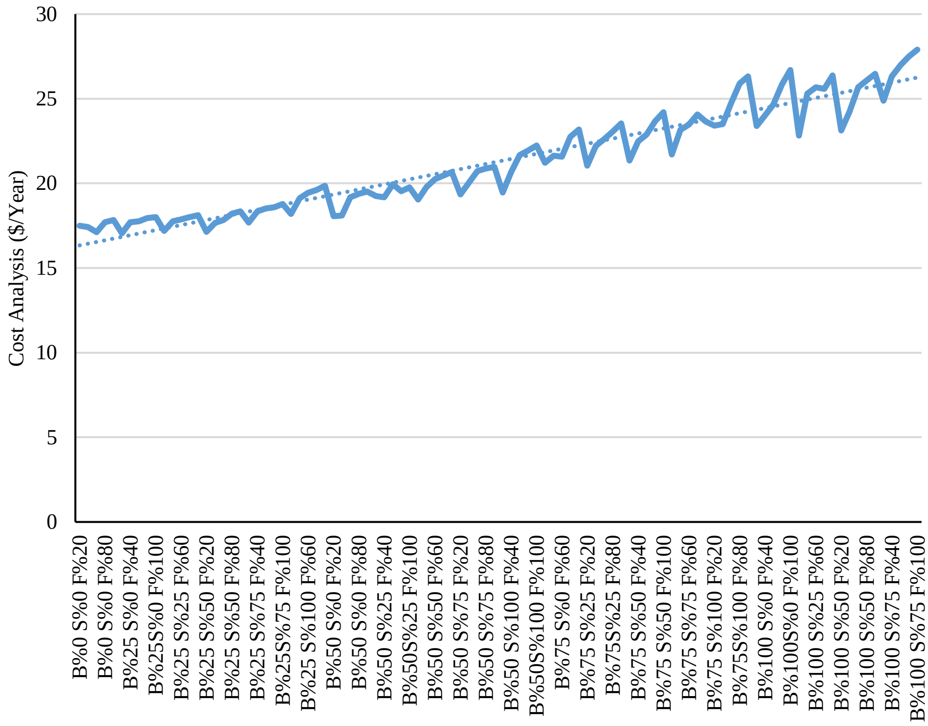

Figure 10. Effect of Wrong Montage on Electricity Consumption (London)

For London, an average of 52 hours of air conditioning usage per year is taken into account. The unit electricity consumption price of England was taken as 0.332 $/kWh and the cost analysis was made accordingly. It is seen that the air inlet of the condenser is not blocked and the cost analysis values considered as reference values vary between 17.12-17.84 $/year. As a result of the gradual closure of the air inlet of the condenser, it is seen that the electricity consumption cost increases up to 24.88-27.89 $/year. Although England has the lowest air conditioner usage time among 12 countries, the effect of incorrect installation on electricity consumption costs is clearly seen. Fig. (11) presents the values obtained for Sweden.

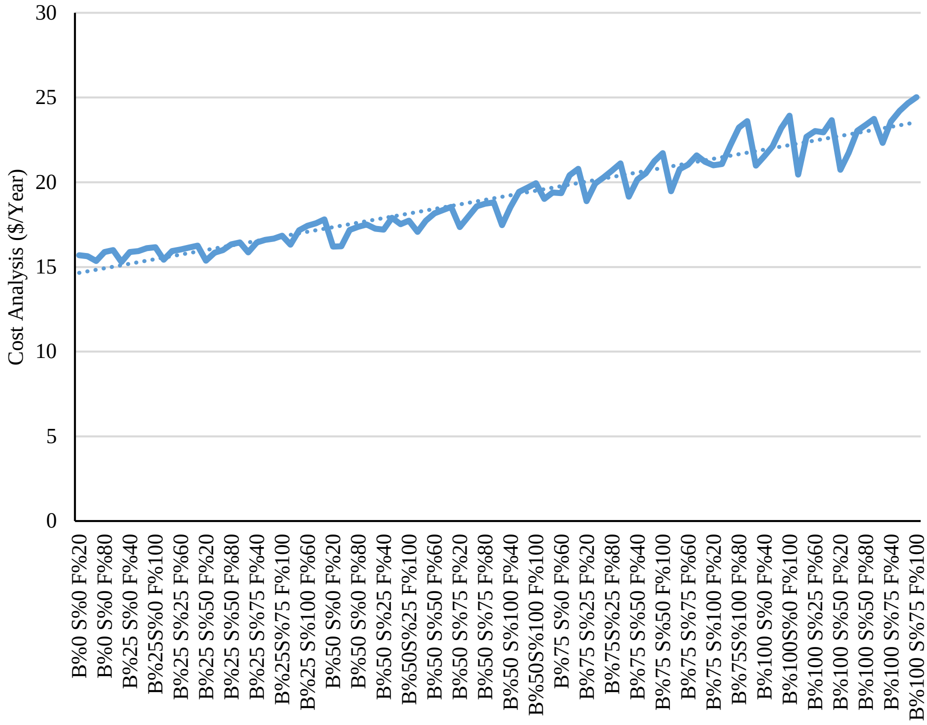

Figure 11. Effect of Wrong Montage on Electricity Consumption (Stockholm)

An average of 56 hours of air conditioning usage per year is calculated for Stockholm. For Sweden, the unit electricity consumption cost for March 2022 is taken as 0.280 $/kWh. It is seen that the reference values for cost analysis vary between 15.35-15.99 $/year. As a result of the gradual closure of the air inlet of the condenser, it is seen that the electricity consumption cost increased to 22.31-25.01 $/year. Fig. (12) presents the values obtained for the United States.

With global warming, it is expected that the rate of air conditioning usage in the USA will increase by 59% in homes and 17% in commercial areas by 2050. It has been said that air conditioners account for 12% of energy bills in homes in the United States. [19]. The total air conditioner usage time in the USA is 896 hours, and the electricity consumption cost is taken as 0.162 $/ kWh. It is seen that the reference values for cost analysis vary between 142.17-148.10 $/year. According to the wrong installation scenario of the condenser, the electricity consumption cost increases up to 206.54-231.59 $/year. Fig. (13) shows the values obtained for Canada.

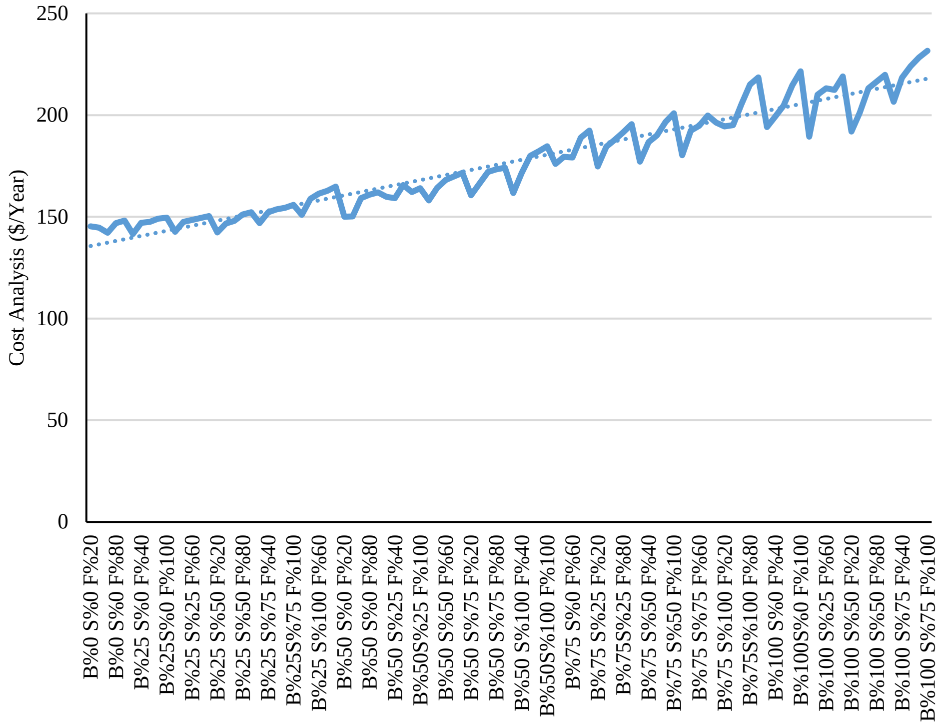

Figure 12. Effect of Wrong Montage on Electricity Consumption (Washington DC)

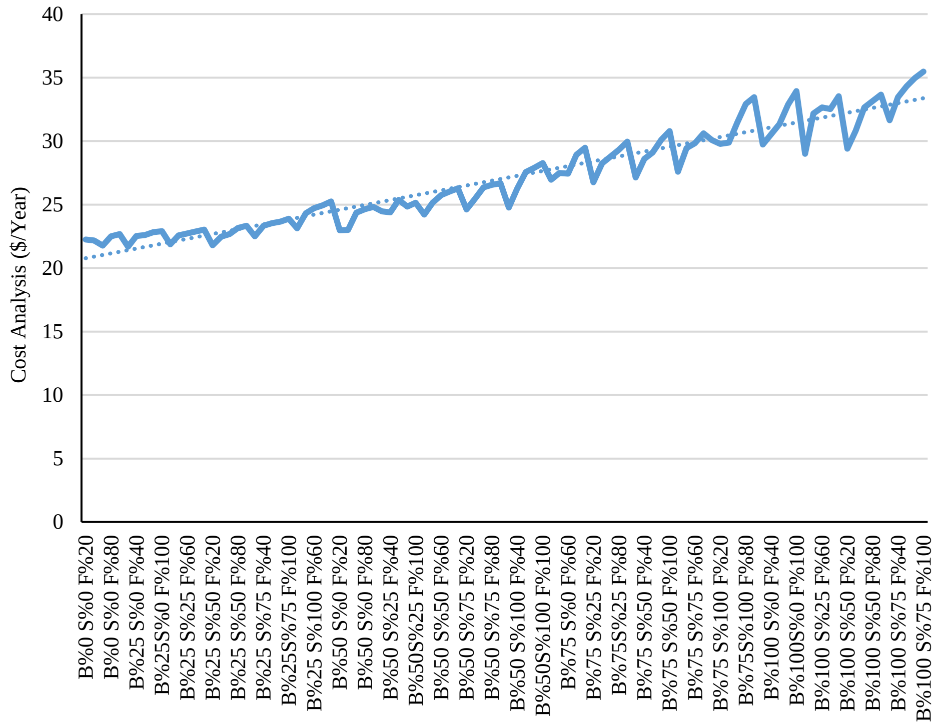

Figure 13. Effect of Wrong Montage on Electricity Consumption (Ottawa)

In the Canadian climate, summers are mild and winters are cold and harsh. However, with the effect of climate change, heat waves have been seen in the summer months in recent years. As a result, it can be predicted that there will be an increase in the use of air conditioners and the associated electricity consumption in the coming years. The total air conditioner usage time for Canada is 190 hours and the unit electricity consumption cost is determined as 0.117 $/kWh. It is seen that the reference values for cost analysis vary between 21.77-22.68 $/year. According to the wrong installation scenario of the condenser, as a result of preventing the air inlet, the cost of electricity consumption rises to the values of 31.63-35.46 $/year. The values obtained for Mexico can be seen in Fig. (14).

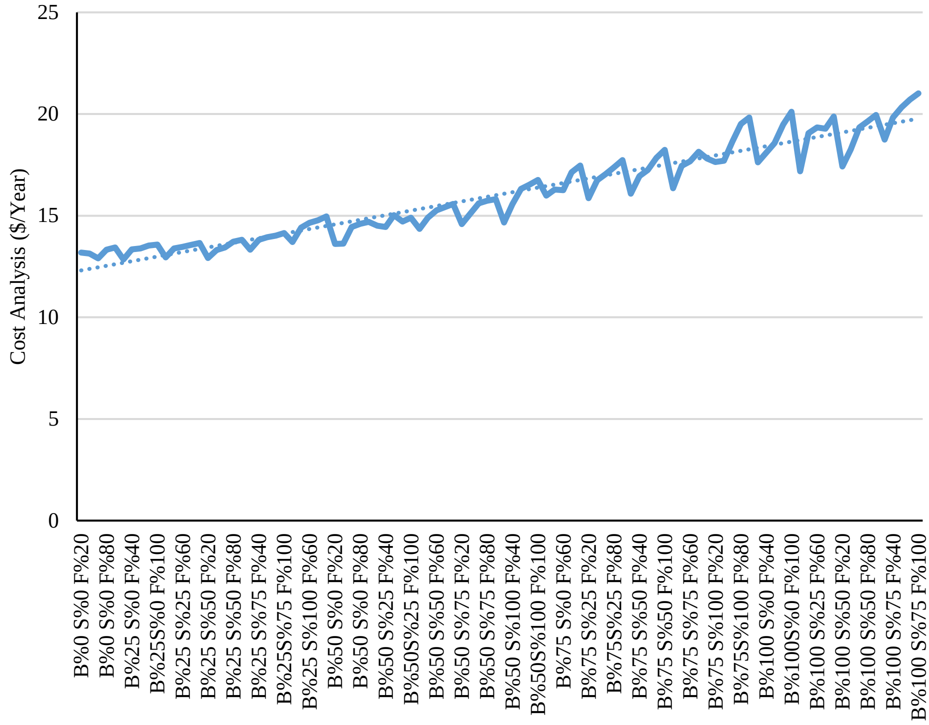

Figure 14. Effect of Wrong Montage on Electricity Consumption (Mexico City)

The average annual air conditioning usage time for Mexico has been determined as 148 hours. The unit electricity consumption cost to be used in the cost analysis has been taken as 0.089 $/kWh. It is seen that the reference values for cost analysis vary between 12.90-13.44 $/year. According to the wrong installation scenario of the condenser, the electricity consumption cost varies between 18.74-21.01 $/year because of preventing the air inlet.

4. Conclusion

Many studies have been made and will continue to be done on increasing temperatures with global warming, widespread use of air conditioners and increasing energy prices around the world. Within the scope of this study, it was determined that the condenser unit of the air conditioning systems was installed incorrectly or the air inlets were blocked. The effect of these incorrect installation situations on the electricity consumption cost has been discussed for 12 different countries. The results obtained as a result of the analysis can be summarized as follows.

- Inadequate air inlet as a result of incorrect installation of the condenser unit of the air conditioning systems increases the electricity consumption of the air conditioning system, which leads to an increase in the electricity cost of the system.
- Assuming that the mistakes made during the installation will remain the same throughout the lifetime, it can be predicted that the electricity consumption costs will increase because of the changing climatic conditions and the increasing air conditioner usage times.
- Due to high unit electricity prices in countries with low air conditioner usage periods due to climatic conditions, increases in electricity consumption costs have been observed as a result of incorrect installation of the

condenser. For example, due to the fact that England has the third highest unit electricity price among 12 countries, although the air conditioner usage time is short due to climatic conditions when the values obtained according to the 100% fan speed of the reference and incorrect installation scenario are examined, it is observed that the electricity consumption cost has increased by approximately 56%.

- As a result of incorrect installation practices of air conditioning systems in Turkey, it has been observed that annual electricity bills are approximately 56-62.78 $. The results show that the cost of incorrect installation of the condenser increases the costs associated with electricity consumption, between 49% and 51% in all countries considered in this study.

- When the graphs obtained for 12 different countries are examined, it has been observed that the annual electricity consumption cost has increased significantly due to the closure of the air inlets as a result of incorrect installation of the condenser unit.

Acknowledgements

This study was produced from the master thesis titled "Investigation of the possible effects of incorrect montage of AC systems on the performance values of the system". Authors thank to Fırat University Project Support Unit with the project number TEKF.22.07. The historical temperature data used in this study were obtained from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program.

We undertake that in the article we submitted for publication, no study requiring ethics committee approval, was conducted.

There is no conflict of interest between the authors.

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