Turkish Journal of Science & Technology
20(1), 209-224, 2025

Research Paper
https://doi.org/10.55525/tjst.1556618

The Effects of Installation Faults of Air Conditioning Systems on Carbon Emissions

Ruveyda Ergen[1] and Mert Gürtürk[2*]
[1,2]Department of Energy Systems Engineering, Technology Faculty, Fırat University, 23100 Elazig, Turkey
[1]ruveydaergen@gmail.com, [2]m.gurturk@gmail.com

(Geliş/Received: 26/09/2024; Kabul/Accepted: 29/01/2025)

Abstract: In this study, the effects of installation faults of condenser of Air Conditioning (AC) systems on emissions were investigated and Life Cycle Climate Performance (LCCP) analysis was carried out according to the scenario of installation faults of the condenser unit of the AC system for 12 countries. The heat taken by the evaporator units of the ACs is transferred to the condenser unit via the system. This thermal energy is transferred to the surrounding air via condenser. The surrounding air cannot pass through the condenser unit in desired amounts and causes more electricity consumption of the system due to installation faults. The rates of increase of the LCCP values change from 0.02% to 29.6% because of installation faults. The LCCP value was calculated as 19692 – 19858 kg·CO_{2e} with the closing of the air inlet because of installation faults for Turkey. Considering the installation faults of the condenser, the LCCP value was calculated as 21284 - 21505 kg·CO_{2e} for Japan.

Keywords: LCCP, Air-conditioning, Emissions, Global Warming.

Klima Sistemlerinin Montaj Hatalarının Karbon Emisyonlarına Etkileri

Öz: Bu çalışmada, Klima (AC) sistemlerinin yoğuşturucu montaj hatalarının emisyonlara olan etkileri araştırılmış ve 12 ülke için AC sisteminin yoğuşturucu ünitesinin montaj hataları senaryosuna göre Yaşam Döngüsü İklim Performansı (LCCP) analizleri yapılmıştır. Klimaların buharlaştırıcı üniteleri tarafından alınan ısı sistem üzerinden yoğuşturucu ünitesine aktarılır. Bu ısıl enerji yoğuşturucu üzerinden çevre havaya aktarılır. Montaj hataları nedeniyle çevre havası yoğuşturucu ünitesinden istenilen miktarda geçemez ve sistemin daha fazla elektrik tüketmesine neden olur. LCCP değerlerinin artış oranları montaj hataları nedeniyle %0,02 ile %29,6 arasında değişmektedir. Türkiye için montaj hataları nedeniyle hava girişinin kapatılmasıyla LCCP değeri 19692 – 19858 kg·CO_{2e} olarak hesaplanmıştır. Kondenserin montaj hataları da göz önüne alındığında Japonya için LCCP değeri 21284 - 21505 kg·CO_{2e} olarak hesaplanmıştır.

Anahtar Kelimeler: LCCP, Klima, Emisyonlar, Küresel Isınma.

1. Introduction

With global warming, the importance of AC systems has been increasing. Cooling systems are encountered in many application areas such as improvement of comfort conditions in buildings [1] and the transfer or storage of food. The environmental effects of these systems are also important parameters when compared to many studies aimed at increasing the efficiency of these systems [2–5]. Countries and societies taking a more sensitive stance on global warming have researched the effects of many engineering systems on emissions according to The Paris climate agreement [6] and the Glasgow climate summit [7]. In addition, the war between Russia and Ukraine has seriously affected energy prices. Serious price increases due to natural gas prices, especially in the European region, have caused countries to announce a series of measures for energy efficiency and savings. AC systems have a significant share in energy consumption in buildings. Considering the energy performance of Air Conditioning (AC) systems, a review study was carried out with a statistical approach. In that study, when the data obtained from many data centers and the studies in the literature are examined, it is seen that most of the systems do not work at sufficient efficiency values. The electricity consumption rate of those systems is 38% [8]. Considering the articles in the literature examining the effects of cooling systems on emissions, studies examining the effects of refrigerants in particular stand out. In one of those studies, the effects of using five HydroFluoroCarbons (HFC) with low Global Warming Potential (GWP) in AC systems on system efficiency was investigated. Using alternative refrigerants to R410a having high GWP value was evaluated by making thermodynamic analyses [9]. Studies on the effects of HCFs on emissions are dominant in the literature. When the literature is examined, the use of alternative refrigerants to R410a and the effects of the AC system on efficiency and environmental factors were examined [10]. In a similar study, when HFCs having low GWP values were used in the AC system, their effects on emissions were investigated with different analysis methods. It was observed that the review study focused on the results obtained from Total Equivalent Warming Impact (TEWI) and Life

* Corresponding author: m.gurturk@gmail.com. ORCID Number of authors: [1] 0000-0001-7909-7770, [2] 0000-0003-0380-5704

Cycle Climate Performance (LCCP) analyses of different refrigerants. The refrigerant compared as a reference is R410a. As a result, alternative refrigerants have been evaluated to reduce or prevent the use of HFCs having high GWP [11]. Taking into account many factors that affect the operating efficiency of the AC, LCCP and Life Cycle Assessment (LCA) analysis of the system were made by the researchers. The results obtained from the analysis show that the parameters that negatively affect the Seasonal Energy Efficiency (SEER) value have serious effects on the emission values [12]. The AC systems are used for many purposes and application areas. For this reason, some variations can be observed in the designs of the AC. One of them is mobile AC systems. Researchers have studied the effects of different HFCs (R134a, R152a, R1234yf and R744) in mobile AC systems on emissions [13]. Thermodynamic analysis of environmental friendly refrigerants (HFO-1234yf) used in mobil AC systems was carried out [14]. The LCCP analyses of AC systems according to the climate conditions of South Korea were carried out and it is found that the increase in the system efficiency according to the working conditions decreased the emission values [15]. In another study, exergy and environmental assessment analyses of ACs sold in Turkey were carried out. In that study, Exergy Efficiency Factor (EER) and MTEWI value were analyzed. Similar to other studies, the effects of R410a and R22 refrigerants on EER and MTEWI values were investigated [16]. In another study, the Ozone Depletion Potential (ODP) and GWP values of the refrigerants in the AC system, depending on the location, were estimated at a certain time interval. The LCA method was used to estimate ODP and GWP values [17]. The LCCP is the most preferred method today to examine the effects of AC systems on emissions. Successful LCCP analyses of AC systems can be found in the literatüre [18]. Using the LCCP method, the researchers analyzed five different cycle options and seven different low-GWP refrigerants [19]. In another study, life cycle Carbon Footprints (CFP) analyses were performed with the assumption that the AC system was operated for 10 years and 2 hours per day. As a result of the research, the preference for refrigerants having low-greenhouse gas emission values, especially in the destruction process of AC, made a big difference [20]. A review study examining the effects of cooling systems on climate change and global warming focused on refrigerants. The refrigerants have a serious effect on global warming. The effects of refrigerants were examined. That study includes the analyses made within the scope of TEWI [21]. Life Cycle Climate Performance is a method by which HVAC&R (heating, ventilation, AC and refrigeration industry) systems can be evaluated for global warming impact. A lot of valuable studies were examined the environmental effects of refrigerants used in the AC system cycle [20–22]. The literature review described so far consists of studies examining the contribution of air conditioning systems to emissions. Although these studies are very comprehensive and detailed studies, it seems that detailed data are not obtained within the scope of LCCP analysis for installation faults. It is seen that very few studies have been done in the literature examining the effects of installation faults of air conditioners. For example, studies were carried out for air conditioners and heat pumps in the United States for installation faults. Unnecessary energy consumption values caused by the installation faults have been evaluated [23,24].

When the above studies are examined, many academic/scientific studies have been carried out that will improve the performance of AC systems and have positive effects on emissions (CO_2). However, even if today's best technology, equipment or strategy are applied in AC systems, problems caused by the installation faults cause the systems to operate at very low performance. This situation has the potential to contribute significantly to emissions (CO_2) and unnecessary energy consumption due to installation faults. The main purpose of this study is to examine the effects that occur as a result of installation faults of the condenser units of AC systems on LCCP. In the installation of AC systems, researchers have found that there are serious problems. In particular, the air inlets in the condenser section of the AC system are partially or completely closed due to installation faults. This situation makes it difficult to transfer the energy in the refrigerant of the AC system to the environment.

2. Research Methodology

In this part of the study, the installation faults of the air conditioning system is examined experimentally. In the experimental setup, the air inlet sections of the condenser were closed at different rates. Detailed information about the experimental setup is presented in the following lines.

It has been determined by the authors that serious problems occur in the installation of AC systems. Meetings were held with the dealers and technical services of AC systems. The AC manufacturers organize training for their dealers and technical services on the installation of AC systems. In those training, information is shared on how to install to wall the condenser section. However, some of the condenser units of the ACs are not installed according to the information given in those training. The AC manufacturers also inform the AC users with materials such as user guides. When the information on how to install the condenser section of the AC companies is examined, it is stated that a 30 cm space should be left at the back and side (air inlets) in the installation of the condenser units of the ACs. It is stated that 60, 60 and 200 cm spaces should be respectively from the top, right and finally the front of the condenser. The installation procedure is not taken into account by some dealers and technical services. The main purpose of the installation procedure is that the air inlet and outlet of the condenser are not blocked. This information in the user guide is not read enough by some users. While the AC system is being installed by the dealer or technical service personnel, it is encountered that the trained personnel are not sent to the installation of AC, or the technical personnel who do not participate in the training practices are sent to the installation. At the same time, users can sell the AC system which they purchased for various reasons. It has been observed that the installation of the AC system, which was purchased secondhand, was carried out by untrained technical personnel. Technical service, dealers or the AC manufacturers are not the only responsible for the wrong applications in the installation of the AC. It is also seen that the users force the technical personnel to make the installation faults for various reasons. The authors designed the experimental setup in Fig. (1) to experimentally examine the installation faults of the condenser section. Fig. (1) shows the experimental setup used in this study.

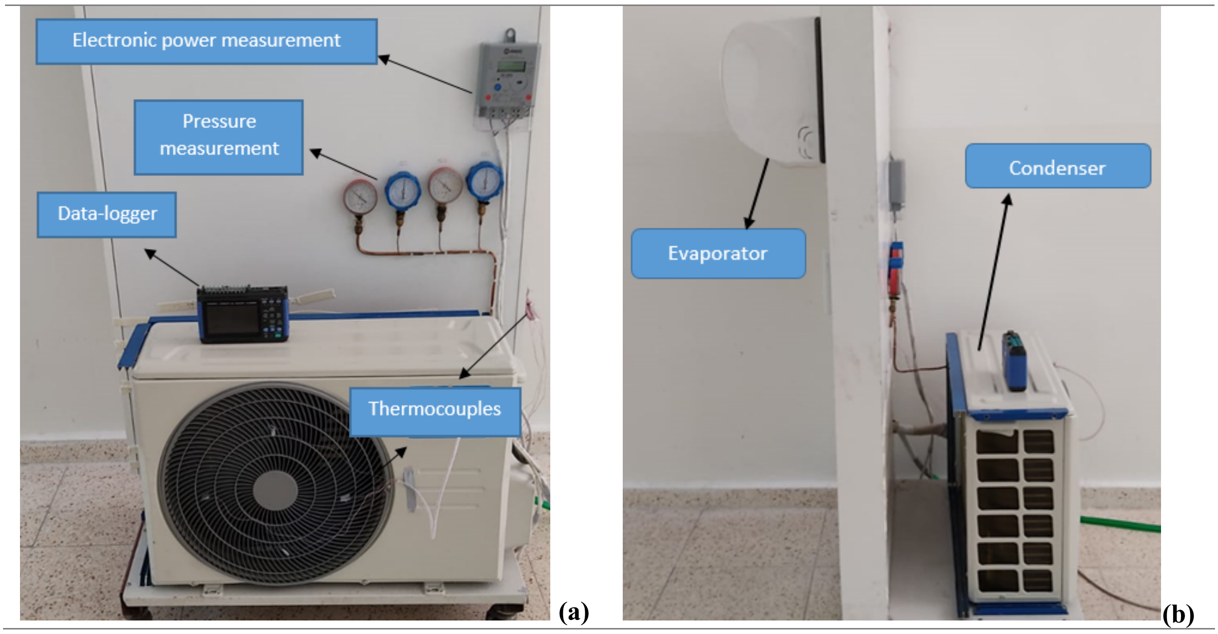

Figure 1. Experimental setup (experiment set view: (a) - front, (b) - side).

Fig. 1-(a) shows the measurement devices used in the experimental study. T-type thermocouples were used in the study. Measurements were made from different points of the air conditioning system with a 10-channel data logger. Pressure measurement and electronic power measurement are also among the measurement devices used. Fig. 1-(b) shows the evaporator and condenser sections of the air conditioning system. They are separated by a partition to prevent the airflow in both units from affecting each other. A split type AC system was used in the experiments. The working fluid used in the cycle of the system is R32. While the cooling capacity of the system is 12000 BTU/h, the seasonal efficiency value is 6.1 in the AC system cooling mode. The experimental process consists of two parts. In the first part, the AC was installed in accordance with the installation procedure of the authorized service and then the system was operated. The energy consumption values of the AC, which was installed in accordance with the installation procedure of the authorized service, were calculated. The values obtained from this analysis are for reference or comparison parameters. In the second part, installation faults was created. Barriers are placed in the air inlets of the condenser section. In the condenser section of the AC, the air is passed from two different sections. The air inlets are made from the back and side of the condenser. The air inputs from the back and side were gradually closed. The stages were formed by closing 25% - 50% - 75% and 94% of the air inlet area. During the experiments, the set value of the AC was kept constant (set value 16 °C). The ambient temperature was taken as 27 °C and the experiments were carried out in the laboratory in summer. The evaporator unit airflow of the AC was worked under different operating conditions. The evaporator unit fan speed was operated at 20%-40%-60%-100% and the measurements were obtained according to this experimental procedure.

Significant studies have been conducted investigating the environmental impact of AC systems. It is very important to examine the effects of cooling systems on climate change. One of the main reasons for this is that the greenhouse gas effect of the refrigerant used in cooling systems is quite high. There are many parameters that contribute to environmental pollution and climate change, such as the gas emission to the atmosphere as a result of leakage, maintenance and repair in 15 years of use, the polluting effects of the production of these gases, the cycle life of the gases, and the disposal of these gases. However, the analyses show that the negative effects of cooling systems on the environment occur especially in the case of use. A lot of valuable studies have been done examining and compiling the environmental effects of gases used in the AC system cycle [20–22]. Discussing the effects of gases on the environment is beyond the scope of this study. Many of the parameters used in LCCP analyzes are obtained from various sources. Among these parameters, it is claimed that the values of Adp.GWP for some gases are controversial [25]. The most challenging parameter in the LCCP analysis of air conditioners is the Annual Energy Consumption (AEC) value of the system and the CO_{2e} value. The AEC value varies according to the climatic conditions of the location where the AC is used, the purpose of use and the structure in which the system is used. Researchers have developed different approaches using different methods for this situation such as field test method, temperature bin method, simulation-based method and data-driven methods. In another review study examining the effects of cooling systems on global warming, TEWI and LCCP analyzes were compared. TEWI and LCCP analyses of domestic refrigeration, supermarket refrigeration, AC systems, mobile AC, heat pumps and transport refrigeration systems were reviewed and compared [26]. Each emission factor is calculated separately. In Fig. (2), the carbon emission categories that affect the system during the LCCP calculation process are shown.

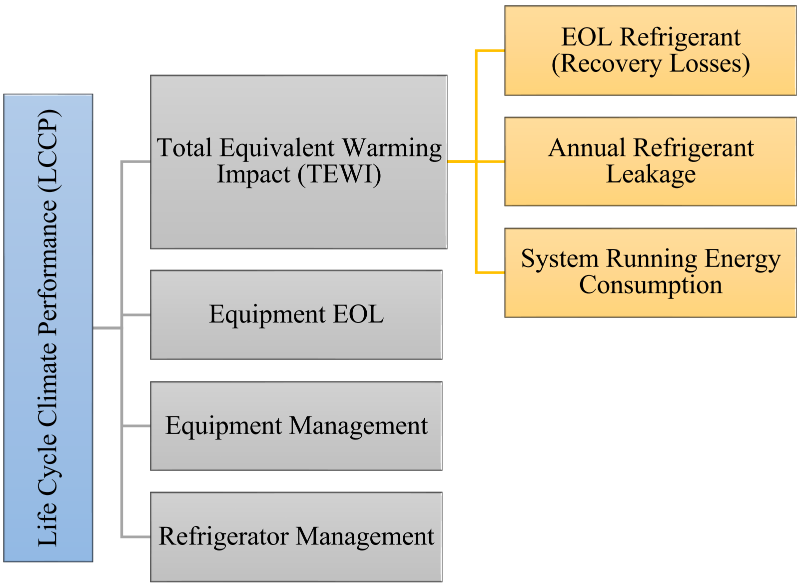

Figure 2. Comparison of the LCCP and TEWI [26].

Fig. (2) shows the comparison of LCCP and TEWI. Another review study examining the effects of cooling systems on climate change and global warming focused on heat transfer or working fluid. The gases used also have a serious effect on global warming. In the study, the effects of gases used in a wide framework were examined. The scope of the study includes the analyzes made within the scope of TEWI [21]. Life Cycle Climate Performance is a method by which HVAC&R (heating, ventilation, AC and refrigeration industry) systems can be evaluated for global warming impact throughout their entire lifecycle. With LCCP analysis is calculated as the sum of the direct and indirect emissions produced over the life of the system. Direct emissions include all effects resulting from the release of refrigerants into the atmosphere over the life of the system. This includes annual leakage and losses during disposal of the unit. Indirect emissions include emissions from the manufacturing process, energy consumption and disposal of the system [25]. The LCCP consists of direct emissions and indirect emissions. The Eq. (1) is calculated in kg units as [25].

$$\text{LCCP} = \text{Direct Emissions} + \text{Indirect Emissions} \tag{1}$$

Direct emissions consist of refrigerant emission effects released to the atmosphere during and after the life of the unit.

- Annual refrigerant loss due to gradual leaks during use,
- Losses in disposal of the unit at the end of its life,
- Large losses during the operation of the unit,
- Atmospheric reaction products from the decomposition of the refrigerant in the atmosphere

These four categories are calculated using the refrigerant leakage rate multiplied by the refrigerant charge and the global warming potential (GWP) of the refrigerant [25]. Eq. (2) is used to calculate direct emissions.

$$\text{Direct Emissions} = C \times (L \times ALR + EOL) \times (GWP + Adp.GWP) \tag{2}$$

C used in Eq. (2) shows the refrigerant charge amount (kg). L is equipment lifetime (years). ALR is the annual leak rate (%). EOL is the end-of-life refrigerant leakage rate (%). GWP indicates global warming potential (kg CO_{2e}/kg). Adp.GWP shows the GWP of atmospheric degradation products of refrigerant (kg CO_{2e}/kg) [25,27].

Indirect emissions include emissions from energy consumption during AC system operation, materials manufacturing, cooler manufacturing, cooler and system recycling [22]:

• Emissions from electricity generation

• Emissions from the manufacture of materials

• Emissions from the production of refrigerants

• Emissions from the disposal of the unit

$$\text{Indirect Emissions} = L \times AEC \times EM +$$

$$\sum(m \times MM) + \sum(mr \times RM) + C \times (1 + L \times ALR) \times RFM + C \times (1 - EOL) \times RFD \tag{3}$$

Eq. (3) is used to calculate indirect emissions. Here, AEC is annual energy consumption (kWh). EM shows electricity generation emission value (kg CO_{2e}/kg). m is the mass of the refrigeration unit (kg). MM indicates material production emission value (kg CO_{2e}/ kg). mr is mass of recycled material (kg). RM shows the emission value of the recycled material (kg CO_{2e}/ kg). RFM is refrigerant production emission (kg CO_{2e}/kg) and RFD shows the emission value (kg CO_{2e}/ kg) [25]. The fixed parameters used in the above equations were determined by considering the studies in the literature and the characteristics-catalogue values of the air conditioning system used in the experimental study. The parameters used in the LCCP analysis are shown in the Table (1).

The time of AC usage increases in hot climatic conditions. Due to the increase in energy prices, countries announce some measures in the use of ACs. The Spanish government stated that ACs should be used at ambient temperatures above 27 ºC [28]. The authors examined the environmental temperature values in various parts of the world by taking this value as a reference. The capitals of 12 countries were taken into consideration as a location. Table (2) was created by taking the hourly average values of the ambient temperature values in 2019, 2020 and 2021 as a reference to the environmental temperature values taken from NASA POWER Web [29].

Table 1. Fixed parameters used in LCCP analysis [18,20].

Fixed parameters	Values
C (kg)	0.55
GWP (R32)	675
L (year)	10
ALR (%)	2.5
EOL (%)	15
m (kg)	7.9
MM (kg CO_{2e}/kg)	2.25
mr (kg)	3.95
RM (kg CO_{2e}/kg)	0.5
RFM (kg CO_{2e}/kg)	7.2

Table 2. Average hourly values of the capitals of 12 countries in 2019, 2020 and 2021 where the ambient temperature is above 27 ºC [29].

Country	Capital	Annual hourly the AC operation period in which 3-year average ambient temperature values are above 27 ºC (hour)	EM electricity generation emission value (kg CO_{2e}/kWh)
Canada	Ottawa	190	0.029
China	Beijing	1034	0.623
England	London	52	0.269
France	Paris	170	0.055
Germany	Berlin	276	0.301
India	New Delhi	4056	1.4
Japan	Tokyo	860	0.492
Mexican	Mexico City	148	0.423
Spain	Madrid	913	0.019
Sweden	Stockholm	56	0.013
Turkey	Ankara	570	0.555
United States of America	Washinton DC	896	0.373

LCCP analyses were carried out separately for each country by taking into account the values in Table (2). The results of the installation faults of the condenser of the AC are evaluated from different perspectives.

3. Results and Discussions

The results obtained within the scope of the study were examined under several headings. Within the scope of the LCCP analysis, considering the capitals of 12 countries, the effects on emission values were examined with the assumption that similar installation faults was made in these countries. Installation faults causes much more serious problems, especially in countries that use fosil fuel-based energy sources in energy production. Installation faults of the AC system has an effect on indirect emission values. The main reason for this is the variability in electricity consumption values (AEC). This variability is due to the fact that the heat energy taken from the evaporator unit in the cooling cycle cannot be discharged to the environment if the air inlet sections of the condenser unit are blocked. Since the heat energy cannot be discharged to the environment, it is stored in the refrigerant and its elements. In these systems, which work with the inverter system, the compressor power is increased automatically, since the heat in the system cannot be discharged to the environment. This situation increases the electricity consumption values of the AC system and has a negative effect on the indirect emission values. When the results obtained from the analyses for the capitals of the 12 countries considered within the scope of the study are examined, the contribution of the AC system to carbon emissions due to installation faults of condenser has increased significantly in some countries. Fig. (3) shows the values obtained for Ankara.

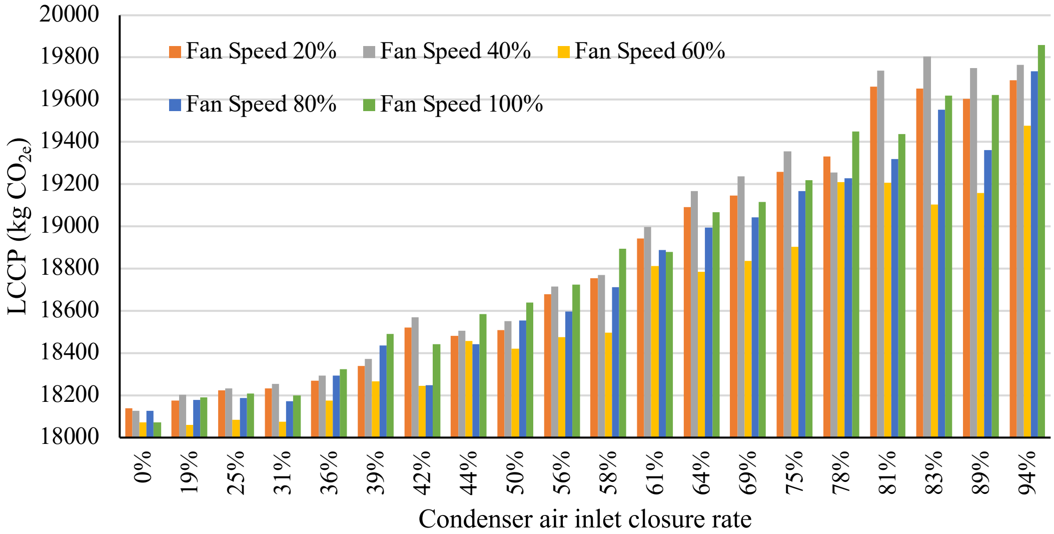

Figure 3. Effect of installation faults on emissions (Ankara).

The capital of Turkey experiences 4 seasons as a location. Locations considered in the analysis: Latitude 39.9659 Longitude 32.9524. It was calculated how many hours the temperatures were above 27 ºC in the relevant location. When the average of the three-year temperature values is taken as 570 hours. This value shows AC usage per year. The LCCP values, which are considered reference values and where the air inlet of the condenser is not blocked, vary between 18073 and 18140 kg·CO_{2e}. According to the installation faults scenario of the condenser, a serious increase in the LCCP value occurs as a result of the gradual closing of the air inlet. The LCCP value increased up to 19692 – 19858 kg·CO_{2e} values with the closing of the air inlet as a result of installation faults. In Fig. (4), the values obtained for Tokyo are presented.

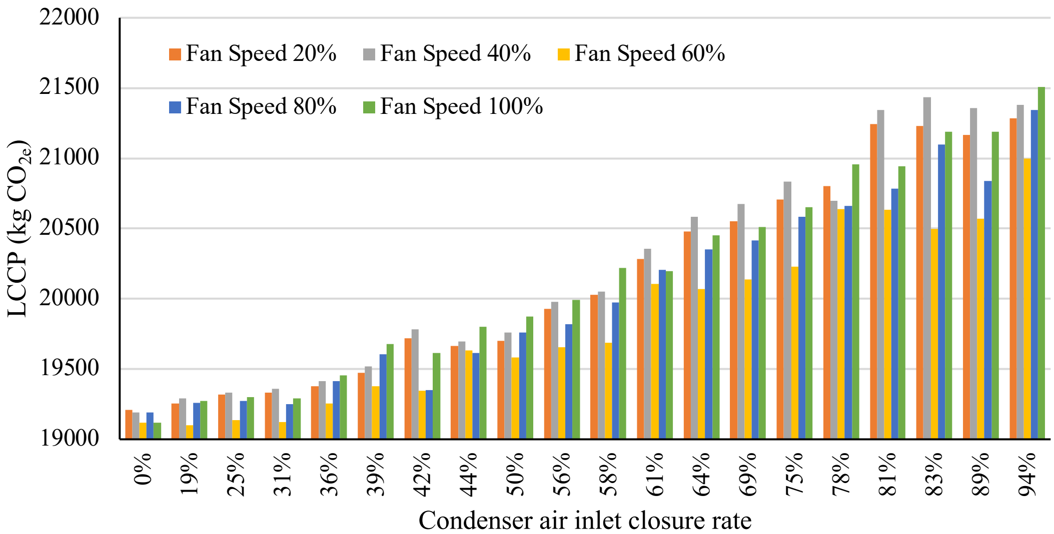

Figure 4. Effect of installation faults on emissions (Tokyo).

Japan is a country where AC usage is intense. Locations considered in the analysis: Latitude 35.7754 Longitude 139.7679. For Tokyo, an average of 860 hours of AC usage per year is taken into account. The LCCP values considered as reference vary between 19180 and 19208 kg·CO_{2e}. As a result of the gradual closing of the air inlet of the condenser, the LCCP value increases up to 21284 - 21505 kg·CO_{2e} values. The values obtained for Benjing can be examined in Fig. (5).

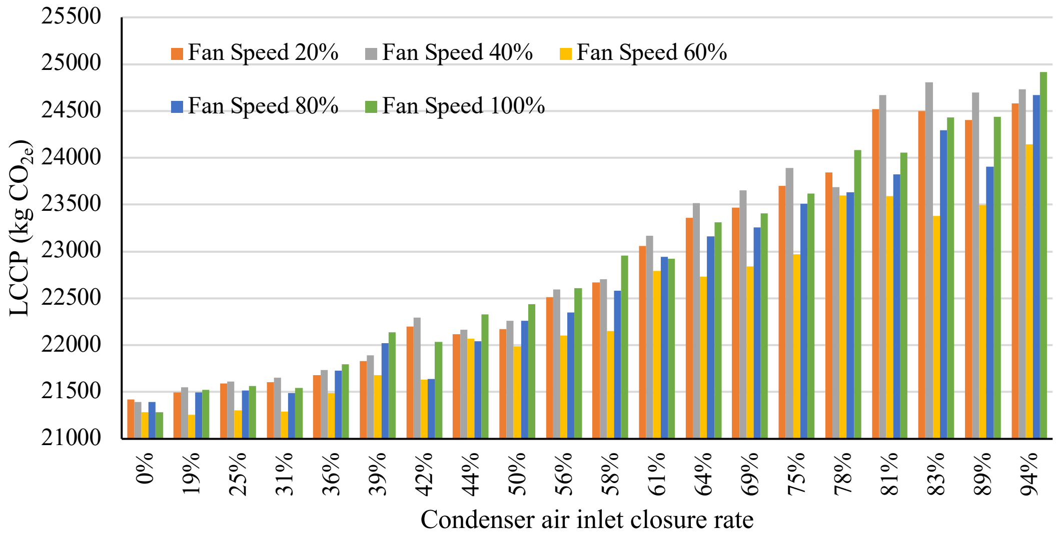

Figure 5. Effect of installation faults on emissions (Benjing).

China is one of the countries where fossil fuel consumption is high in electricity generation. China's EM value has the second highest value among the countries considered in the study. At the same time, assuming that AC is used at an ambient temperature of 27 °C, China stands out as one of the high hourly value of AC usage. The LCCP values are also quite high in parallel with the high values in the EM value and the AC usage time. An average of 1034 hours of AC usage per year is calculated for Beijing. Reference values for LCCP range from 21420 to 21284 kg·CO_{2e}. As a result of the gradual closing of the air inlet of the condenser, the LCCP value increased to 24581 – 24918 kg·CO_{2e}. The figures obtained for New Delhi are given in Fig. (6).

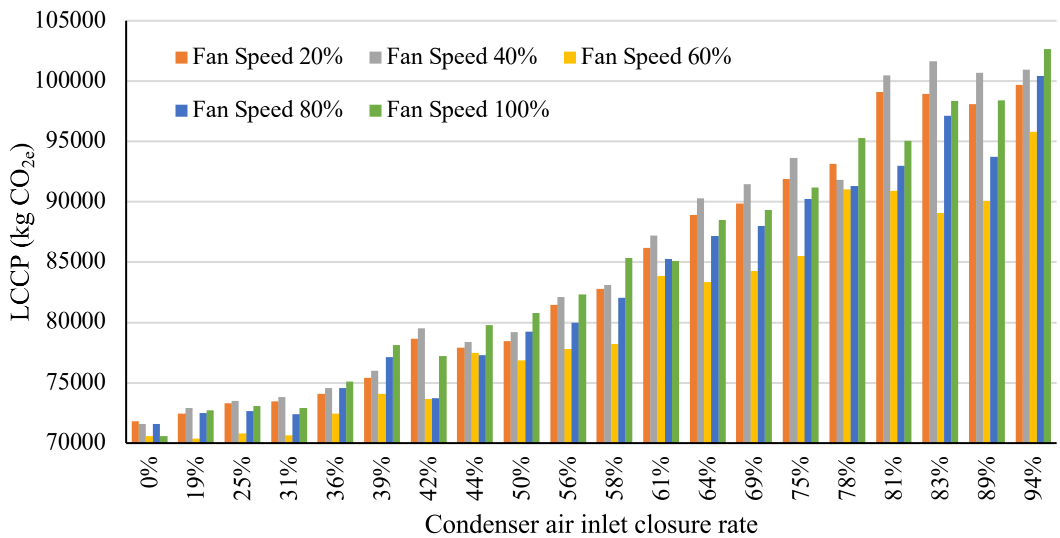

Figure 6. Effect of installation faults on emissions (New Delhi).

India has both the highest EM value and the highest AC usage hours among the countries considered in the study. The main reasons for this are the fact that it has a hot climate as a location, and the use of fossil fuels in energy production is quite high. India's EM value is 1.4 kg·CO_{2e}/kWh and total the AC usage time is 4056 hours. Locations considered in the analysis: Latitude 28.687 Longitude 77.1719. Reference values for LCCP range from 70601 to 71800 kg·CO_{2e}. According to the scenario of installation faults of the condenser, the LCCP value increased up to 99663-102630 kg·CO_{2e}. When compared by taking the average of the LCCP analyses obtained as a result of the reference and installation faults, there is a 29.6% increase in the LCCP value. In Fig. (7), the values obtained for Madrid are presented.

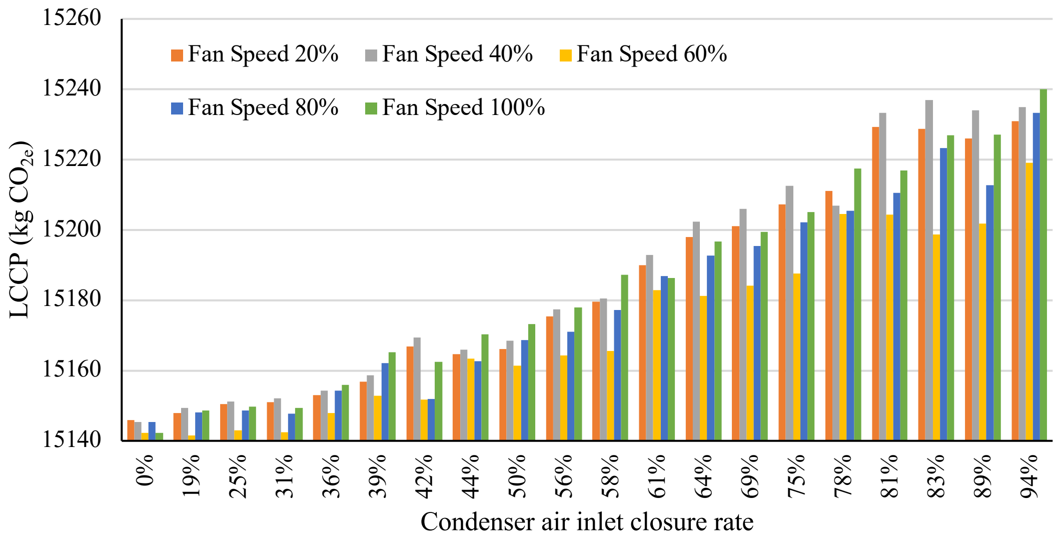

Figure 7. Effect of installation faults on emissions (Madrid).

The EM value for Spain is 0.019 and the total the AC usage time is 913 hours. For Spain, EM and the AC usage time allow good comparison data to be obtained. Spain provides an opportunity to examine the effects of incorrect condenser installation on emissions for a location with low EM but high AC usage. Reference values for LCCP range from 15145 to 15142 kg·CO_{2e}. According to the scenario of installation faults of the condenser, it was calculated that the LCCP value increased to 15239 kg·CO_{2e} by blocking the air inlet. The values obtained for Washington DC are presented in the Fig. (8).

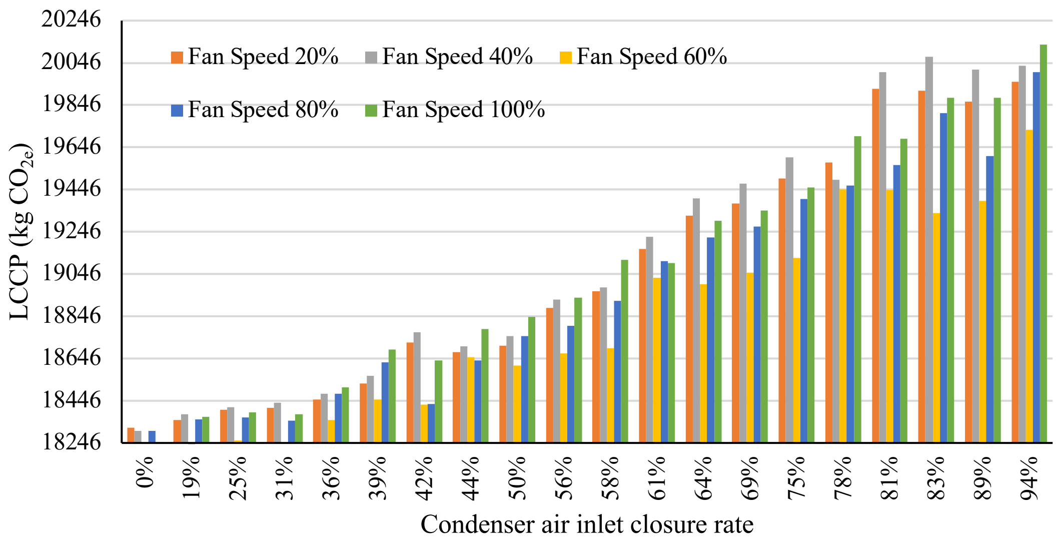

Figure 8. Effect of installation faults on emissions (Washington DC).

The EM value of USA is 0.373 and the total the AC usage time is 896 hours. Reference values for the LCCP range from 18316 to 18246 kg·CO_{2e}. According to the installation faults scenario of the condenser, the LCCP value increased up to 19956- 20131 kg·CO_{2e} values. When compared by taking the average of the LCCP analyses obtained as a result of the reference and installation faults, there is an 8.7% increase in the LCCP value. It can be said that the differences between the values obtained for the other countries covered in the study are very small. The main reason for this is the low air conditioner usage times in these countries. Fig. (9) shows the values obtained for Paris.

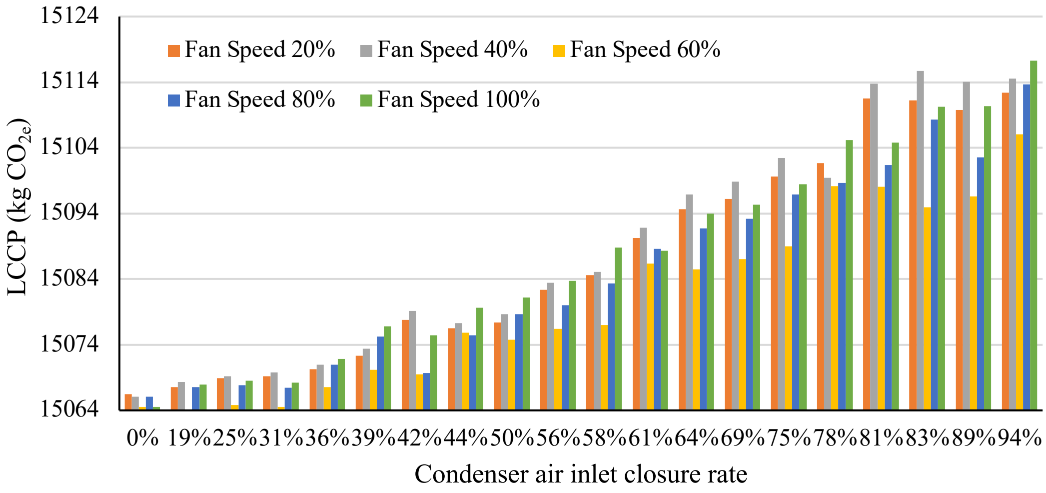

Figure 9. Effect of installation faults on emissions (Paris).

France is a country that heavily benefits from nuclear energy in electricity generation. This situation makes a positive contribution to the EM values of France. It also has a low value in terms of the hourly average of the AC usage. The annual average AC time has been determined as 170 hours. However, with the effects of global warming in Europe, it can be predicted that there will be an increase in the AC usage time. Locations considered in the analysis: Latitude 48.8763 Longitude 2.2868. Reference values for the LCCP range from 15066 to 15064 kg·CO_{2e}. According to the scenario of installation faults of the condenser, the maximum LCCP value is calculated as 15117 kg·CO_{2e}, with the air inlet blocked. The figures obtained for Berlin are given in Fig. (10).

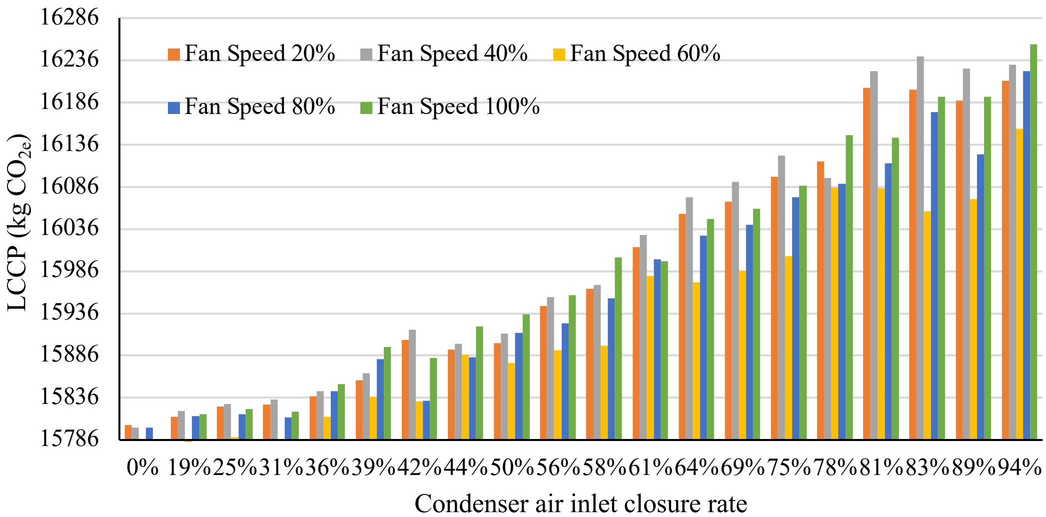

Figure 10. Effect of installation faults on emissions (Berlin).

Locations considered in the analysis: Latitude 52.5203 Longitude 13,383 for Berlin. It was calculated how many hours the temperatures were above 27 °C in the relevant location. When the average of the three-year temperature values is taken as 276 hours. The LCCP values, which are considered reference values and the air inlet of the condenser is not blocked, vary between 15786 and 15803 kg·CO_{2e}. According to the installation faults scenario of the condenser, a serious increase in the LCCP value occurs as a result of the gradual closing of the air inlet. The LCCP value increases up to 16211 – 16254 kg·CO_{2e} values. In Fig. (11), the values obtained for London are presented.

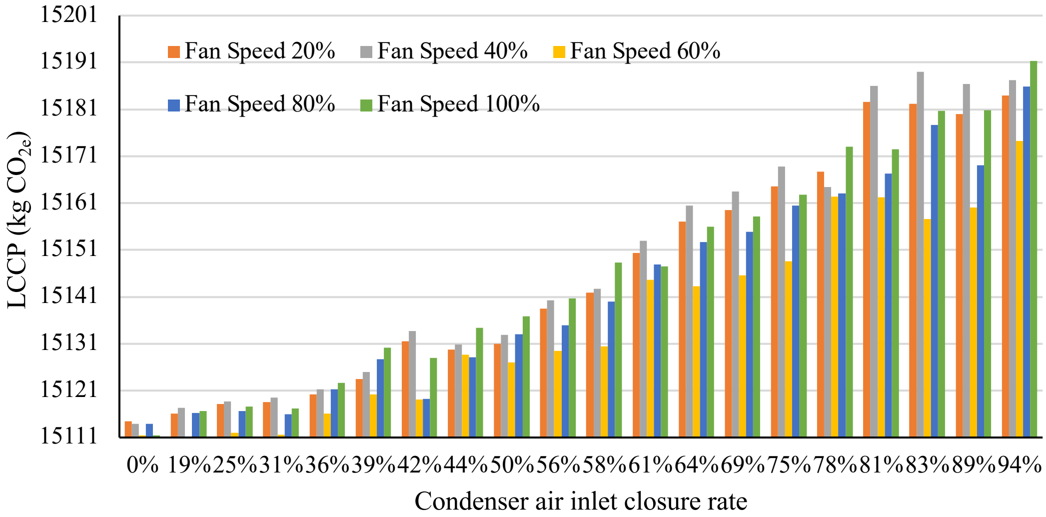

Figure 11. Effect of installation faults on emissions (London).

It cannot be said that England is a country where the use of AC (for cooling) is intense. For London, an average of 52 hours of AC usage per year is taken into account. The LCCP values, where the air inlet of the condenser is not blocked and considered as reference values, vary between 15114 and 15111 kg·CO_{2e}. As a result of the gradual closing of the air inlet of the condenser, the LCCP value increased up to 15191 kg·CO_{2e} values. The values obtained for Stockholm are presented in the Fig. (12).

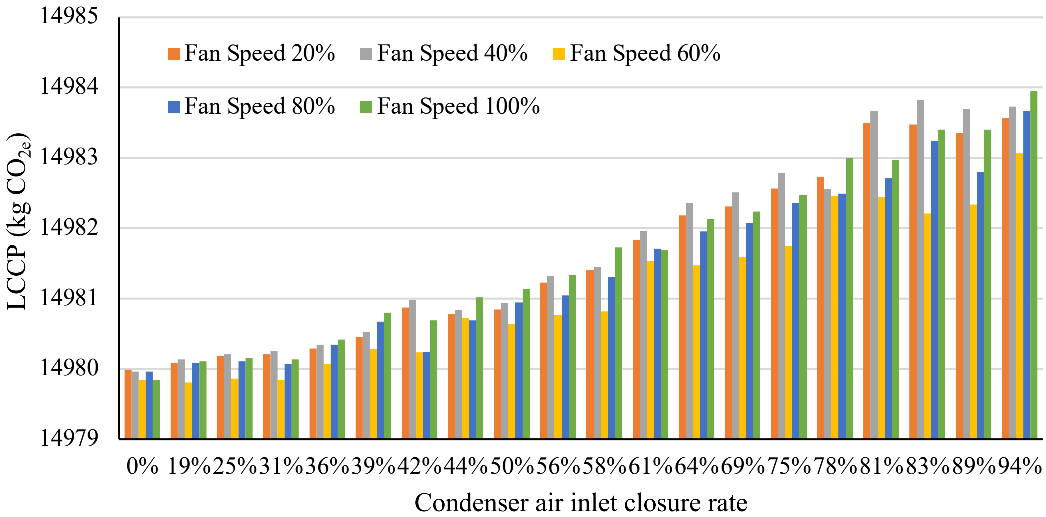

Figure 12. Effect of installation faults on emissions (Stockholm).

Sweden is one of the countries with the lowest fossil fuel consumption in electricity generation. Sweden's EM value has the lowest value among the countries considered in the study. At the same time, Sweden is the second country with the lowest hourly value of AC use, assuming that AC is used at an ambient temperature of 27 °C. Parallel to the low values in EM value and the AC usage time, the LCCP values are also quite low compared to other countries. Locations considered in the analysis: Location: Latitude 59.3863 Longitude 18.0394. An average of 56 hours of AC usage per year is calculated for Stockholm. The reference value for LCCP was calculated as 14979 kg·CO_{2e}. As a result of the gradual closing of the air inlet of the condenser, the LCCP value was calculated to be 14983 kg·CO_{2e}. The values obtained for Ottawa are given in the Fig. (13).

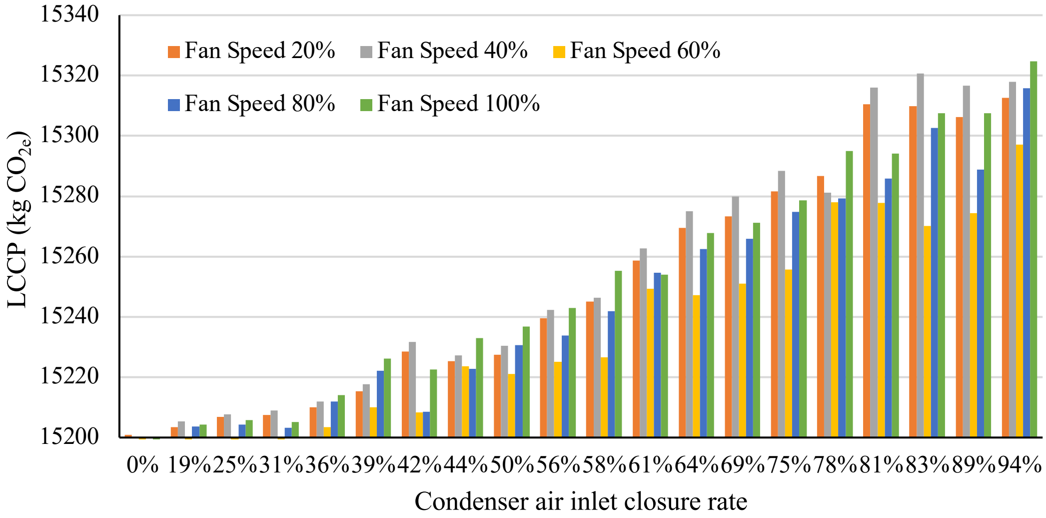

Figure 13. Effect of installation faults on emissions (Ottawa).

The EM value for Canada is 0.029 and the total the AC usage time is 190 hours. When EM and the AC usage time are evaluated for Canada, it can be said that they are relatively low values. Locations considered in the analysis: Location: Latitude 45.3936 Longitude -75.692. Reference values for LCCP range from 15196 to 15200 kg·CO_{2e}. According to the scenario of installation faults of the condenser, it was calculated that the LCCP value increased to 15324 kg·CO_{2e} by blocking the air inlet. The values obtained for Mexico City can be seen in Fig. (14).

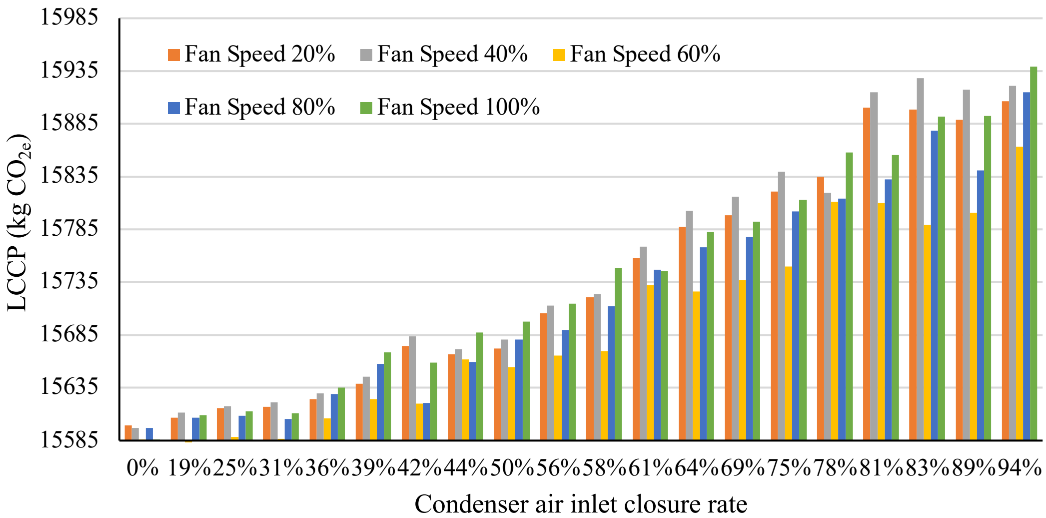

Figure 14. Effect of installation faults on emissions (Mexico City).

For Mexico, the AC has a low value in terms of hourly average usage. The average annual air-conditioning time has been determined as 148 hours. However, with the effects of global warming, it can be predicted that there will be an increase in the AC usage time. Locations considered in the analysis: Location: Latitude 19.4214 Longitude -99.129. Reference values for LCCP range from 15599 to 15585 kg·CO_{2e}. According to the scenario of installation faults of the condenser, the maximum LCCP value is calculated as 15938 kg·CO_{2e} by blocking the air inlet.

LCCP analyses are difficult to compare with results from other studies. The main reason for this is that different approaches are preferred in determining the operating times of the AC system. In addition, it is seen that there are serious differences on the capacity of the AC system considered in the study and the values obtained from the LCCP analysis in the refrigerat - material used. For example, the results obtained from the LCCP analyses of the AC system for an airport and campus in the United States were examined. The study was carried out by considering different refrigerants. According to the results obtained, it is seen that it varies between 60000 and 75000 kg·CO_{2e} [27].

When the graphs above are examined, an increasing trend is seen in the emission values depending on the installation faults. It can be said that the faults made during the installation will contribute to the emissions. In addition to the climatic conditions, the EM values of the countries cause serious variability in emissions. For example, there is no serious AC use in England. It cannot be said at first assessment that the effects of installation faults of the AC system will have serious effects in this country. However, ACs are not only used for the purpose of improving evaporator comfort conditions. ACs are also used to preserve food, medicine and many similar substances in certain temperature environments. In this case, it cannot be assumed that the AC is activated at temperatures above 27 ºC, which is considered within the scope of the study. There will be differences in the LCCP value if the AC is used for the purpose of cooling the warehouses. installation faults of ACs used for the cooling of warehouse environments can have a serious negative impact on the value of the LCCP analysis. For this reason, the operating hour's value of the AC will vary in the storage applications of the AC in countries where the effects of installation faults in the LCCP analysis are low (England, Sweden, Canada, France, Mexico and Germany). Longer operating hours in ACs used for storage will cause a direct increase in the AEC value. In this case, it can be said that there will be serious increases in the LCCP value of these countries presented in the study. The serious effects of installation faults on the LCCP value were seen in the experimental analysis. As a result of installation faults, the rates of increase of the LCCP values change from 0.02% to 29.6% as a result of closing the air inlets of the condenser unit. The effects of installation faults of the AC on the LCCP value increase in direct rate to the usage time of the AC. The effect on emission values can be clearly seen due to the increase in electricity consumption values as a result of installation faults. Installation faults will also have indirect effects on emissions. The maintenance and repair frequency will increase due to the strain of the AC system. At the same time, there will be a case of very frequent break down in the system. This will adversely affect the direct emission values in the LCCP analysis.

The obtained values can also be handled with a statistical approach. The use of air conditioners is intense in Japan, the United States and China [30]. Considering the number of air conditioners used in homes, it can be seen that the values obtained above have serious consequences. While the number of air conditioners used in homes in Japan is 131 million, this number is 331 million in the United States and 336 million in China [30]. The following Table 3 was obtained as a result of comparing the LCCP values obtained according to the closing rate of the condenser air inlet with the reference values. The values in Table 3 were created by considering the characteristics of the air conditioner (12000 Btu) used in this study. When comparing the values obtained for an AC unit in Table 3 according to countries, it can be interpreted that there are no significant differences. For example, the values obtained due to the installation faults of the condenser were compared with the reference values. For Japan, the amount of unnecessary emissions caused by installation faults of the condenser ranges from 15.58 kg·CO_{2e} to 1877,659 kg·CO_{2e}. For the United States, these values range from 12.3 kg·CO_{2e} to 1482.52 kg·CO_{2e}. Finally, the values obtained for China are 23.72 kg·CO_{2e} and 2858,468 kg·CO_{2e}. It cannot be said that these obtained values make a significant difference. However, when the number of air conditioner usage in countries is evaluated, it is revealed that there may be a very serious increase in emissions. When these numbers mentioned above are multiplied by the number of air conditioners, serious emission values are obtained. Considering the number of air conditioners used in Japan, emission values ranging from 2.04E+09 kg·CO_{2e} to 2.46E+11 kg·CO_{2e} are obtained. An optimistic approach can also be adopted. For example, these obtained values by assuming that only 1% of the air conditioners used in Japan are incorrectly installed in the condenser section. When 1% of the air conditioners used in Japan are evaluated, the number of air conditioners is 1.31 million. When this value is multiplied by the values in Table 3, the amount of unnecessary emission varies between 20,417,849 kg·CO_{2e} and 2.46E+09 kg·CO_{2e}. It is seen from the above evaluations that installation faults of condenser units of air conditioners contributes to a serious amount of emissions.

Table 3. Comparison of the values obtained according to the closure ratio of the condenser air inlet (Fan speed %60).

Compared parameters	Japan	US	China
LCCP(Ref*. – 1 AC unite)	19118.78 kg·CO_{2e}	18246.28 kg·CO_{2e}	21284.51 kg·CO_{2e}
LCCP(%25** – 1 AC unite)	19134.37 kg·CO_{2e}	18258.59 kg·CO_{2e}	21308.24 kg·CO_{2e}
LCCP(%50 – 1 AC unite)	19582.64 kg·CO_{2e}	18612.52 kg·CO_{2e}	21990.66 kg·CO_{2e}
LCCP(%75 – 1 AC unite)	20227.41 kg·CO_{2e}	19121.61 kg·CO_{2e}	22972.24 kg·CO_{2e}
LCCP(%94 – 1 AC unite)	20996.44 kg·CO_{2e}	19728.81 kg·CO_{2e}	24142.98 kg·CO_{2e}
LCCP(%25 – 1 AC unite) - LCCP(Ref. – 1 AC unite) amount of unnecessary emissions	15.58614 kg·CO_{2e}	12.30619 kg·CO_{2e}	23.72768 kg·CO_{2e}
LCCP(%50 – 1 AC unite) - LCCP(Ref. – 1 AC unite) amount of unnecessary emissions	463.8543 kg·CO_{2e}	366.2407 kg·CO_{2e}	706.152 kg·CO_{2e}
LCCP(%75 – 1 AC unite) - LCCP(Ref. – 1 AC unite) amount of unnecessary emissions	1108.627 kg·CO_{2e}	875.327 kg·CO_{2e}	1687.726 kg·CO_{2e}
LCCP(%94 – 1 AC unite) - LCCP(Ref. – 1 AC unite) amount of unnecessary emissions	1877.659 kg·CO_{2e}	1482.524 kg·CO_{2e}	2858.468 kg·CO_{2e}
Considering the number of air conditioners used in countries			
LCCP(%25) - LCCP(Ref) amount of unnecessary emissions	2.04×10^{9} kg·CO_{2e}	4.07x10 kg·CO_{2e}	7.97 x10 kg·CO_{2e}
LCCP(%50) - LCCP(Ref.) amount of unnecessary emissions	6.08×10^{10} kg·CO_{2e}	1.21×10^{11} kg·CO_{2e}	2.37×10^{11} kg·CO_{2e}
LCCP(%75) - LCCP(Ref.) amount of unnecessary emissions	1.45×10^{11} kg·CO_{2e}	2.9×10^{11} kg·CO_{2e}	5.67×10^{11} kg·CO_{2e}
LCCP(%94) - LCCP(Ref.) amount of unnecessary emissions	2.46×10^{11} kg·CO_{2e}	4.91×10^{11} kg·CO_{2e}	9.6×10^{11} kg·CO_{2e}

(*) Values where condenser air inlets are not closed
(**) Values obtained as a result of closing the air inlets of the condenser at different rates

4. Conclusion

Topics such as rising energy prices and global warming will continue to be hot topics on the agenda of governments and communities for years. Many research and development studies are carried out on systems that consume energy intensively, such as heating and cooling systems. However, the correct use of these systems has been shown to have serious effects on energy efficiency and their contribution to emissions. Within the scope of the study, it was observed that some condenser units of the AC systems were installed incorrectly. The effects of this installation faults on the emission values were examined and the results obtained for 12 different countries were discussed. In the following lines, the results obtained from the study can be summarized.

- When compared by taking the average of the LCCP analyses obtained as a result of the reference and installation faults, there is a 29.6% increase in the LCCP value for India.
- Reference values for LCCP range from 15145 to 15142 kg·CO_{2e}. According to the scenario of installation faults of the condenser, it was calculated that the LCCP value increased to 15239 kg·CO_{2e} by blocking the air inlet for Spain.

- When compared by taking the average of the LCCP analyses obtained as a result of the reference and installation faults, there is an 8.7% increase in the LCCP value for the US.
- For Japan, the amount of unnecessary emissions caused by installation faults of the condenser ranges from 15.58 kg·CO_{2e} to 1877,659 kg·CO_{2e}. For the United States, these values range from 12.3 kg·CO_{2e} to 1482.52 kg·CO_{2e}. Finally, the values obtained for China are 23.72 kg·CO_{2e} and 2858,468 kg·CO_{2e}.
- Considering the number of air conditioners used in Japan, emission values ranging from 2.04E+09 kg·CO_{2e} to 2.46E+11 kg·CO_{2e} are obtained. When 1% of the air conditioners used in Japan are evaluated, the amount of unnecessary emission varies between 20,417,849 kg·CO_{2e} and 2.46E+09 kg·CO_{2e}.

Acknowledgments

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.

References

[1] Rusen, Eren S, Rusen A. A Sample Study for Determining Energy Consumption Values in Public Buildings: Central Anatolia Region. In: Gökçekuş H, Kassem Y, editors. Clim Chang Nat Resour Sustain Environ Manag, Springer; 2022, p. 100–9.

[2] She X, Cong L, Nie B, Leng G, Peng H, Chen Y, et al. Energy-efficient and -economic technologies for air conditioning with vapor compression refrigeration: A comprehensive review. Appl Energy 2018;232:157–86.

[3] Ruşen SE, Koç M. Araştırma Makalesi / Research Article Enerji Tüketim ve CO_2 Salınım Değerlerinin Analizi ; Bir Gıda Fabrikası Örneği Analysis of Energy Consumption and CO_2 Emission Values ; A Case Study of a Food Factory 2019;8:1478–88.

[4] Ener Rüşen S. Elektrik Motorlarının Verimlilik ve CO_2 Emisyon Analizi; Bir Gıda Fabrikası Örneği. Eur J Sci Technol 2019:564–9.

[5] Rüşen Eren S, Rüşen A. Bir Spor Kompleksinin Karbon Ayak İzinin Hesaplanması ve Enerji Kayıplarının Tespiti. 2. Bilsel Int. Korykos Sci. Res. Innov. Congr., Mersin/Türkiye: astana; 2024, p. 145–54.

[6] The Paris Agreement. United Nations Treaty Collect n.d. https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-7-d&chapter=27&clang=_en.

[7] Glasgow Climate Change Conference. United Nations Clim Chang n.d. https://unfccc.int/conference/glasgow-climate-change-conference-october-november-2021.

[8] Ni J, Bai X. A review of air conditioning energy performance in data centers. Renew Sustain Energy Rev 2017;67:625–40.

[9] Mishra P, Soni S, Maheshwari G. Exergetic performance analysis of low GWP refrigerants as an alternative to R410A in split air conditioner. Mater Today Proc 2022;63:406–12.

[10] Chen W. A comparative study on the performance and environmental characteristics of R410A and R22 residential air conditioners. Appl Therm Eng 2008;28:1–7.

[11] Guilherme ÍF, Marcucci Pico DF, dos Santos DDO, Bandarra Filho EP. A review on the performance and environmental assessment of R-410A alternative refrigerants. J Build Eng 2022;47.

[12] Li G. Investigations of life cycle climate performance and material life cycle assessment of packaged air conditioners for residential application. Sustain Energy Technol Assessments 2015;11:114–25.

[13] Zhiyi Y, Tianduo P, Xunmin O. Scenario Analysis on CO_2-equivalent Emissions from Alternative Mobile Air Conditioning Refrigerants in China. Energy Procedia 2017;142:2617–23.

[14] Golzari S, Kasaeian A, Daviran S, Mahian O, Wongwises S, Sahin AZ. Analyse selon le second principe d'un système de conditionnement d'air automobile fonctionnant au HFO-1234yf, frigorigène respectueux de l'environnement. Int J Refrig 2017;73:134–43.

[15] Choi S, Oh J, Hwang Y, Lee H. Life cycle climate performance evaluation (LCCP) on cooling and heating systems in South Korea. Appl Therm Eng 2017;120:88–98.

[16] Ziya Sogut M. Exergetic and environmental assessment of room air conditioners in Turkish market. Energy 2012;46:32–41.

[17] Wang Z, Song Q, You Y, Duan H, Yuan W, Li J. Identifying the lifecycle ODP and GWP effects of the refrigerants from household air-conditioners in Macau. Environ Impact Assess Rev 2021;90:106639.

[18] Wan H, Cao T, Hwang Y, Radermacher R, Chin S. Comprehensive investigations on Life Cycle Climate Performance

of unitary air-conditioners. Int J Refrig 2021;129:332–41.
[19] Lee H, Troch S, Hwang Y, Radermacher R. Évaluation du LCCP de diverses options de cycle à compression de vapeur et de frigorigènes à faible GWP. Int J Refrig 2016;70:128–37.
[20] Zhao L, Zeng W, Yuan Z. Reduction of potential greenhouse gas emissions of room air-conditioner refrigerants: A life cycle carbon footprint analysis. J Clean Prod 2015;100:262–8.
[21] Sarbu I. A review on substitution strategy of non-ecological refrigerants from vapour compression-based refrigeration, air-conditioning and heat pump systems. Int J Refrig 2014;46:123–41.
[22] Wan H, Cao T, Hwang Y, Radermacher R, Chin S. Comprehensive investigations on Life Cycle Climate Performance of unitary air-conditioners Études complètes sur les performances climatiques sur le cycle de vie des appareils de conditionnement d ' air monobloc. Int J Refrig 2021;129:332–41.
[23] Winkler J, Das S, Earle L, Burkett L, Robertson J, Roberts D, et al. Impact of installation faults in air conditioners and heat pumps in single-family homes on U.S. energy usage. Appl Energy 2020;278:115533.
[24] Hourahan GC, Baxter VD. Impact of Installation Faults on Heat Pump Performance. IEA Heat Pump Cent Newsl 2015;33:34–8.
[25] Guideline for Life Cycle Climate Performance January 2016, 2016. 1-26. 2016:1–26.
[26] Mota-Babiloni A, Barbosa JR, Makhnatch P, Lozano JA. Assessment of the utilization of equivalent warming impact metrics in refrigeration, air conditioning and heat pump systems. Renew Sustain Energy Rev 2020;129.
[27] Wan H, Cao T, Hwang Y, Radermacher R, Andersen SO, Chin S. A comprehensive review of life cycle climate performance (LCCP) for air conditioning systems. Int J Refrig 2021;130:187–98.
[28] Spanish government to allow flexibility on air-conditioning, but rules out U-turn on decree. Spain in English 2022. https://www.spainenglish.com/2022/08/08/spanish-government-to-allow-flexibility-on-air-conditioning-but-rules-out-u-turn-on-decree/.
[29] NASA. POWER | Data Access Viewer n.d. https://power.larc.nasa.gov/data-access-viewer/.
[30] The International Energy Agency (ıea). Percentage of households equiped with AC in selected countries 2022. https://www.iea.org/data-and-statistics/charts/percentage-of-households-equiped-with-ac-in-selected-countries-2018.