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ECONOMICAL EVALUATION OF %100 FRESH AIR HVAC SYSTEM FOR HOSPITAL OPERATING ROOM: A CASE STUDY FOR 4 DIFFERENT CLIMATE ZONES

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ABSTRACT

The yearly energy consumption of heating, ventilation and air conditioning (HVAC) system for an operating room (OR), placed in four different countries such as Adana in Turkey, Astana in Kazakhstan, Mosul in Iraq and Dushanbe in Tajikistan have been performed in this study. This study aimed to economically evaluate the use of a 100% fresh air HVAC system in countries with different climate types in identical operation room. Moreover, 10 year's life span has been calculated using Life Cycle Cost (LCC) method for the considered countries. As a result, energy consumption of system is lower in regions with a cold climate type such as Astana in Kazakhstan with 6.58 kW and Dushanbe in Tajikistan with 7.15 kW while is higher in hot climates, such as Adana in Turkey with 12.87 kW and Mosul in Iraq with 9.256 kW. The annual and hourly cooling load for Mosul in Iraq are higher, but the total cooling load and total energy consumption are 40.6% less than these of Adana in Turkey because the fact that the wet-bulb temperature of Mosul in Iraq is lower than it of Adana in Turkey. The HVAC system's energy consumption is in direct proportion to the LCC value of the system. For this reason, Astana in Kazakhstan, which has a cold climate type, has the lowest LCC value with $116324.332. In conclusion, the %100 fresh air HVAC system can be used for analyzed countries but it is more economical in cold climates and countries with low wet-bulb temperatures.

Keywords: HVAC system, economic evaluation, energy consumption, Life Cycle Cost, Net Present Value.

Nomenclature

AHU	Air Handling Unit
ASHRE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CFD	Computational Fluid Dynamics
COP	Coefficient of Performance
EA	Exhaust Air
ELFT	Evaporator Leaving Fluid Temperature
EU	Exhaust Unit

HPHXS	Heat Pipe Heat Exchangers
HRU	Heat Recovery Unit
HVAC	Heating, ventilation and air conditioning
HX	Heat Exchanger
IDC	Internet Data Center
IU	Induction Unit
LCC	Life Cycle Cost
LS	Life Span
MPC	Model Predictive Control
NPV	Net Present Value
OR	Operating room
PCMs	Phase Change Materials
PD	Power Demand
PLP	Part Load Ratio
PV	Present Value
SA	Supply Air
SCAV	Self-Contained Air Cooled Vertical
SLP	Systematic Literature Review
TSA	Temperature Swing Adsorption

1. INTRODUCTION

Air conditioning and refrigeration is the process of adjusting the temperature, humidity and fresh air movement of a space in accordance with human health. In commercial and residential buildings, most importantly in places where there should be a clean and hygienic, such as a hospital, it is important to properly perform air conditioning and refrigeration. Usually, the system of HVAC uses to providing air conditioning and cooling in commercial and residential buildings. HVAC system includes ventilation, air conditioning and heating and using in living spaces such as hospitals, factories, shopping center and places where energy consumption is intensive. Since cooling and air conditioning directly affect human health, especially in the OR departments of hospitals, the cooling and air conditioning system is great importance. For this reason, many of studies have been conducted on this case. The case studies have been summarized below.

Anka et al. [1] through empirical observation researched the wield of the united coefficient of performance (COP) technique to making it optimal the amount of refrigerant load of an Internet Data Center refrigeration system. The test equipments were used in this study. The performance of the suggested technique was obtained from the use of alternative cooling systems through the experiment devices and experiment conditions. The refrigerant load was determined under the test conditions, so it was concluded that the degradation may be greater in different IDC refrigeration systems.

Taheri et al. [2] conducted extensive research on model predictive control (MPC) control systems. In the developed method, control systems were used to form an estimate of the characteristics of the MPC and how it can be used, what kind of optimization methods are proper, what kind of buildings are get used as test beds, measurements of performance were incorporated with the occupancy method. Although there were numerous studies on creating MPC models, only a few studies were used more complex algorithms, such as deep learning approaches, to find more hidden patterns in the relevant datasets. It was also observed that most of the previous research has focused on MPC control systems in residential or office buildings.

In the study, a large part of the MPC control system were examined only in the sense of thermal comfort and energy efficiency. That's why, their achievements from different viewpoints, for example managements of demand response were not sufficiently looked over in the other studies.

Wang et al. [3] proposed an incorporate frame for provide actual time optimization of HVAC setting values to ensure the thermal comfort of passengers. There were three main elements of the frame: a vision-based camera for sensing, estimated HVAC thermal and energy comfort models, and an HVAC temperature setting value optimizer. In conclusion, the use of that type of frame was found to effectively reduced energy consumption of HVAC and increased the thermal satisfaction of passengers. It was observed that future studies should concentrate improving the accuracy of predictive model and empirical observation that confirms the advantages of using this framework.

Ala'raj et al. [4] conducted a Systematic Literature Review (SLR) focus on data-driven methods to provide detailed information the main problems specifically, the most contradictory issues and current trends in modeling, controlling and optimizing HVAC systems. The main consequences of SLR users avoiding their use by increasing their energy efficiency while maintaining inadequate comfort levels and the importance of taking into account the needs of users when modeling, controlling and optimizing HVAC systems were emphasized.

Ozyogurtcu et al. [5] assayed the HVAC system's consumption for 4 different system operating rooms at the annual period in 5 cities. When the implementation of the standard was allowed, the mixing unit and heat recovery were recommended for the studied HVAC systems. Heat recovery and mixing units were found to significantly reduce not only the energy consumption of the system, but also the LCC value for cities with low latent load. At the end of the research, it was concluded that the HVAC system to be used should be selected after the annual energy analysis was performed.

Ono et al. [6] carried out an optimization of simulation propped up using data-based personal comfort models to represent personnel thermal and air movement choices. The results were showed that more than half of passengers could be collected in a zone comfort model. On the other hand, it was concluded that it is very important to take into account the thermal choice as well as the air movement choice, especially for upgraded air movement systems with more supernal occupancy resolution. It was concluded that a purposeful thermal comfort model that contributes to the development of building performance from a passenger-centered vista would be the basis for the selection of HVAC controls.

Maddalena et al. [7] conducted an investigation into the polyzonal HVAC control of an industrial facility responsible for the cooling and air conditioning of a hospital OR. In order to guarantee thermal comfort and reduce consumption of electricity, a nonlinear regression technique which called statistical nonparametric Gaussian processes was used in the approach adopted. As predicted, the system's performance intimate was approached the HVAC facility limits and achieved austerity of electricity energy up to 4.76% compared to common techniques of controlling.

The present condition and importance of clean systems of air conditioning in various ORs and the implementations of environmental technology for controlling in the OR were investigated by Kang et al. [8]. It was noticed that the features of the air in the OR will impact the consequences of the surgery. That's why, it was concluded that ensuring air features in the OR is one of the significant situations for the surgery.

Zhai and Osborne [9] conducted a study describing the evaluation of the feasibility of developing climate conditions in a OR. The study was found that removing the laminar flow diffusers areas to the highest level was solved this problem and providing lower pollution level. In addition, the study was showed that compliance with the specifications related to the sizing of air curtain and laminar flow diffusers may not result in a better indoor environment than the basic model.

Ji et al. [10] aimed to integrate Direct Air Capture with a vapor compression refrigeration cycle to make the most of the condensation heat in the desorption process of CO2 capture. According to the results obtained; considering both the TSA cycle and the refrigeration cycle, the coalescence of Mg-MOF-74 and R134a was the best selection in terms of actual working capacity and COP. In addition, Zeolite 13X&R134a was showed the best energy utilization performance when the temperature is between 35°C and 55°C in the practical air conditioning system of buildings.

Hegazi et al. [11] conducted comprehensive parametrical research of a heat exchanger (HX) with named earth-air, which revealed the best elements for reducing the price of centralized climatization in a dry and cold climate condition. According to the study, when the number and lengths of the pipe were increased, the temperature of outlet was decreased. The optimum pipe diameter for any pipe's number in that system was found to be 0.35 m. It was observed that as the number of pipes were decreased, the power saving was increased and then decreased. It was seen that the optimal lengths of pipe concern to the number of pipes and reduces when the pipe's number enhances.

Faruk et al. [12] investigated the idea of using phase change materials (PCMs) to reduce power demand (PD) in the HVAC system for five locations in Saudi Arabia. When annual analyses were examined, it was found that the best performance was in A27 and A29 PCMs. In addition, it was observed that PCM is suitable for each location in this study.

Lu et al. [13] studied the applicability of the recommended radiant convective stratum air distributed room air conditioner in the heating conditions of the indoor thermal environment. With the proposed air conditioner, thermal utilization effectiveness was reduced and thermal comfort and energy efficiency were increased. The proposed air conditioner was provided an inhomogeneous thermal environment. Also, thermal comfort was found to depend on as well as output of heat and distribution of air.

Yang and Wan [14] worked on predictive control of a model based on machine learning with momentary linearizing for management of buildings energy. According to the data obtained, it was found that using momentary linearization for model prediction control depend on machine learning could significantly reduce the computational load. There was no significant performance decrease in the sense of energy conservation and thermal comfort.

Ahmadzadehtalatapeh and Yau [15] conducted to research examining the impact of heat pipe heat exchangers (HPHXS) on the hospital room's present system of air conditioning in Malaysia. The possibility of improving the air of supply indoor and duct with the assistance of the HPHXS was researched. Simulation results showed that system performance was improved by using HPHXS in the air conditioning system. In addition, the consequences showed that indoor and nutrition air states to the help of eight sequacious HPHXS were the healthiest and most favorable, since the conditions closest to those proposed by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for hospital rooms.

Glicksman and Thumb [16] performed to simplistic modelling for the thermal environment constituted by the HVAC system of passenger controlled and the passenger's actions. The study with passenger sensors, it was found that the energy use of HVAC is 13% less compared to a conventional HVAC system. In addition, the simulations doing for various climates were found to show savings ranging from 5% to 16%.

Dela'c et al. [17] developed an integrated structure to reduce the electricity usage cost of present commercial areas and to improve the water and air side system of HVAC. A technique for multi-purpose enhancing of the building casing and system of HVAC was offered. The technique was on the basis of coupling dynamic simulation models constituted in software of Trnsys with non-dominated sorting genetic algorithm with the aimed to reduce primary energy consumption and global cost. The proffered work demonstrated that the space between the nearly zero energy building norm and optimization of cost was an implication of raised investment costs.

Papakostas and Slini [18] searched the impact of urban heat island and climate change on energy demand for 2 provinces. According to the research, it was found that the latent and sensible energy necessities for the ventilation load in buildings shown a diminishing trend during the heating period and a rising trend during the cooling period. The highest increase was seen at night in the cooling period. The total energy demand of the heating and cooling period also were diminished.

Luongo et al. [19] summarized epidemiological studies that address the relationship of at least one HVAC system-related parameter with airborne disease transmission in buildings. It was generally accepted that various parameters related to HVAC, including humidity, outdoor- indoor supply air ratios, or control technologies such as UV antiseptic lamps, or filter type and degree, can be changed, and HVAC system factors can affect airborne pathogen transmission. Therefore, it was concluded that quantitative relationships between HVAC factors and airborne pathogen transmission are necessary for the operation and design of HVAC systems.

Zulkafli et al. [20] modeled the entire chiller-AHU system consisting of the cooling tower system, chiller network, and air handling units taking into account different ambient conditions. The proposed optimization model for the Chiller-AHU system includes 17 air handling units, 2 chillers and 2 cooling towers. As a result of the study, it was shown that the performance of the existing chiller-AHU system in the building can be further improved by about 7-10%. It was concluded that the chilled water temperature for the chiller and the return air temperature for the AHU can be adjusting in the building management system or on-site facility by making the most appropriate decisions in order to achieve the optimal COP.

Although there are many studies regarding with HVAC system for different zones. Comparison of climatic conditions on operating rooms HVAC system for different countries have not been conducted yet. In this study, the effect of climate conditions of four different countries on the HVAC system for the operating room has been examined both systemically and economically. The economic analysis of the system has been carried out comprehensively using LCC analysis and NPV method with the data obtained from the examination. Along with this study; the effects of the HVAC system used in different climate types and the evaluation of the lifetime costs of the system, such as installation and operation, have been presented and has been predicted that it will shed light on future studies.

2. MATERIAL AND METHODS

2.1 HVAC design parameter and representation of the system for hospital operating room

ORs are usually inserted in the middle of the building to minimise heat gain and loss. Even when the operating room is closed, the HVAC system should provide conditioned and filtered air to the operating room. Therefore, the system of HVAC should work during 24 hours in an operating room. Temperature, fresh air velocity, relative humidity, number of grains, sort of microorganism, pressure difference between the operating room and neighboring blanks, feed rate OR air distribution in should be paid attention to account during the HVAC design of an operating room. A benchmarking of these characteristics recommended by certain guidelines and standards for a hospital operating room has been made and reported in the literature [5, 24, 25]. Table 1 has been showed the proposed design temperature, air distribution and relative humidity values for ORs according to particular guidelines and standards. The temperature of the OR has a significant impact on the thermal comfort of the patient and surgical staff. The effects of temperature on microorganism growth and the patient's immune system must have considered when determining the OR temperature. [5, 26]. So, temperature of the operating room should be kept at a low temperature constantly to prevent microorganism enhancing. A temperature ranges of 20 to 24 °C has been advised by most of the references. The level of relative humidity should not adversely affect the comfort of the surgical staff and patient and should not cause microbial increase. A range of 30% to 60% has been usually recommended for relative humidity. Many revised guidelines and standards advise laminar flow air supply. In addition, a low air velocity has been opted in operating rooms. So, the range of the supply air velocity for the operating room has been determined by certain standards [5].

Based on the brief description described above about the HVAC excogitation characteristics of an operating room, it can be decided that the design of an OR's system of HVAC is hinged on the standard used. The DIN 1946/4 standard is the most widely applied HVAC standard for OR's in Turkey [13]. Many project planners in Turkey choose to use HVAC systems that use one hundred percent fresh air to eliminate dangerous infections in the air.

Other project planners prefer to use the AHU mixing units as permitted by DIN 1946/4. The standard of DIN 1946/4 permits also the wield of a heat recovery unit. For this reason, there are also HVAC systems that use HRU’s in operating room implementations in Turkey. The HVAC system of hospital operating room has been designed for four countries with four different climates (Turkey, Kazakhstan, Tajikistan and Iraq) in this study. ASHRE standards have been applied for the accounts in the study [23]. The study has been conducted for a 1-year period. HVAC system of the operating room has been designed for 24 h a day. The equipment class has been used CW AHU in the study. The air system type has been "SCAV". The number of zones of the operating rooms have been 1, in total floor area consisted of 41 m2 and total quantity of occupants was 7. Lighting loads have been accepted 207W. Figure 1 has been demonstrated the view of the using system for the analysis of energy in this case. Because of heat generation, gain and loss of operating rooms are not changed to much, it has been supposed that the operating room is supplied with air with a temperature of dry bulb is 16 °C and a humidity of relative is 55% throughout the year to keep the OR temperature at 20°C and relative humidity at 50%. By creating a variation thereamong the exhaust air (EA) and supply air (SA) flow rates, the positive pressure in the operating room air have been obtained. In the system, it has been accepted that the exhaust unit (EU) operates at a constant air volume rate of 2200 m3/h, and the air flow rate of the supply AHU is constant at 2400 m3/h.

The air conditioning of the operating room has been performed with EU and supply AHU. In addition, the EU and supply AHU of system has been worked at a semi-

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airflow rate during the off-period of OR. To regulating the AHU and EU provide flow rates, electric motors have been fitted with a frequency converter or double-speed electric motors have been used. HRU has been settled among the EU and the AHU. Thus, heat transfer between the supply and exhaust air in the system have been ensured. The HRU has been decreased the temperature of the outdoor air in the summer months before flowing in the cooling coil. Also in winter, the outdoor air supplied to the operating room has been preheated using the heat of the recovered EA. In addition, it should refferred that air heating in the air conditioning systems of operating rooms has been performed using only a heating coil in an air handling unit, and a humidifier has been used [5].

Table 1. Ventilation design paramater for ORs. [23]

Space's Function	**Pressure relationship to Adjacent areas**	**Minimum outdoor ACH**	**Minimum total ACH**	**All room air exhaust directly to outdoors**	**Air recirculated by means of room unit**	**Relative Humidity**	**Design temp. (℃/F)**
CRITICAL CARE AND SURGERY							
Class B and C operating room	Positive	4	20	N/R	No	20-60	20-24/68-75
Surgial cystospic /Operating room	Positive	4	20	N/R	No	20-20	20-24/68-75
Delivery room/Caesarean	Positive	4	20	N/R	No	20-60	20-24/68-75

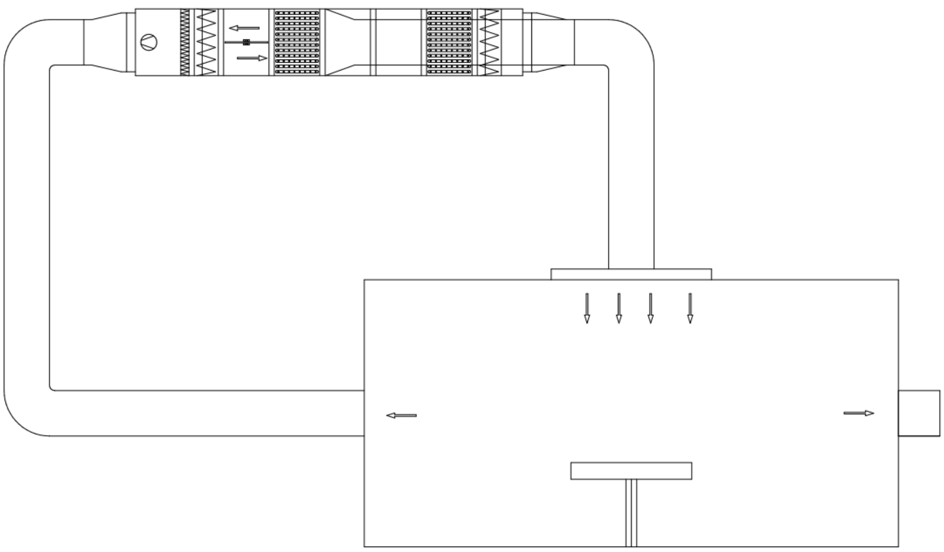

Figure 1. Schematic representation of the studied HVAC system

2.2 Determination of thermal loads and calculation of energy consumption of systems

As already mentioned, it is supposed that the relative humidity and SA temperature have been fixed along the year at 16 °C and 50%. Portion of the energy consumed by the system has been used to maintain the temperature at the value of requested. The remaining part of the energy consumed has been also used to organise the humidity level. For this reason, total heat value has been considered and showed individually. The relative humidity and outdoor temperature datum for four countries have been ensured by the meteorological service of each country. Calculation of hourly based has been used to define thermal loads. The ratio of relative humidity determinated on rooms have been transformed to the ratio of specific humidity by putting to use thermodynamic connections [5, 22]. While the total thermal load has been found, the absolute values of latent and sensitive thermal loads have been added. The connections have been used to determine heat loads of total, latent and sensible in the operating room. [5, 24]. In addition, the following other formulas have been also used to calculate loads.

$$\dot{Q}_{sensible} = \dot{m}\ C_p\ (T_{supply} - T_{out}) \tag{1}$$

$$\dot{Q}_{sensible} = 1.08\ x\ cfm\ x\ \Delta T \tag{2}$$

$$\dot{Q}_{latent} = C_p\ ((wh)_{supply} - (wh)_{out}) \tag{3}$$

$$\dot{Q}_{latent} = 0.68\ x\ cfm\ x\ \Delta W \tag{4}$$

$$\dot{Q}_{total} = |\ \dot{Q}_{latent}\ | + |\dot{Q}_{sensible}| \tag{5}$$

$$Total\ heat\ consumption = \frac{Qtotal}{COP}\ \ (COP=2.8) \tag{6}$$

According to equations 1,2,3, and 4; Cp and ṁ are the specific heat constant and flow rate of air mass, in turn, ΔT is the outdoor and supply temperature difference, w is the moisture content of the air, h is the saturated waters in specific entahlpy, and cfm is volume of air transition along the heat exchange coil, in cubic feet per minute. Equations 5 and 6 demonstrate the total heat charges and the total heat consumption, respectively. When the calculation has been performed, the latent and sensible heat charges could be negative and positive. It has been shown that the positive value of the sensitive heat load indicates that the outdoor temperature is fewer than the supply temperature, and the system works in mode of heating. In addition, it has been shown that the negative value of the sensitive heat load indicates that the outdoor temperature is more than the supply temperature, and the system works in mode of cooling. Alike, the latent heat load's positive value implies a bigger specific humidity of the supply air analogized to the outdoor air, and therefore the system works in mode of the humidification. Alike, the latent heat load's negative value means the mode of siccation process. The efficiency of the HRU has been used in the system varies from 40 to 60%, and the efficiency of the HX belongs to the supply and exhaust air temperatures. For ease of calculation, it has been accepted in this case that the efficiency of HRU was 40% during the year. The temperature and specific humidity of the air at the outlet of the mixing unit has been procured from connections [5, 22].

The method used to find the total cost of the system is life cycle cost (LCC). LCC includes beginning, maintaining and operating costs. The purpose of performing a life cycle cost method is to estimate how much an asset will cost over its lifetime. The life cycle cost method associates the relationship between time and money by assembling ownership and maintenance costs. In the LCC method, the system assesses on a long-term basis. When determining the LCC of a system, several approaches like, net present value NPV uses for the analysis of financial survivability in the investment. In this case, NPV approach has been used to evaluate the HVAC system economically. By using NPV approach, the profit and cost of the system for every country have been transformed into the present value (PV) and the greatest NPV has been found. The mathematical representation of the net present value has been shown as:

$$\text{Net Present Value} = \sum_{n=k+1}^{t} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{k} \frac{C_n}{(1+i)^n} \quad (7)$$

where B_n and C_nare profit and cost worthiness corresponding to systems life span (LS) (n means years), in turn. The yearly interest rate is shown by (i). In view there is no cash input to the system in the study, the profit section in Eq. 7 the following item;

$$\frac{B_n}{(1+i)^n}$$

has been omitted. Therefore, an economic evaluation has been made for the system using the other side of equation 7. The major expenditure arguments have been sales cost of the all system include set up, beginning, cost of electricity for operating the system and maintenance and repair cost through the LS of system. The evaluated system LS, (n), has been accepted as 10. It has been important to determine the yearly interest rate (i) in present value (PV) calculations. That's why, the yearly interest rate has been kept fixed at 10% in this study. After calculations, the smallest cost choice for the operating room has been evaluated.

3. RESULTS and DISCUSSION

3.1 Technical results for four cities

The using the data supplied by Meteorological Service of each country, the alterations of hourly peak cooling load progression and annual peak cooling load progression throughout a year for different cities have been calculated and contrast with one others. During the period when the operating room has been not operated, it has been assumed in the calculation that the system is operating with a half-air volume ratio. A HRU has been utilized to transmit the heat of exhaust to the supply air. The comparison consequences for four countries as Adana Turkey, Dushanbe Tajikistan, Mosul Iraq and Astana Kazakhistan have been presented in Fig. 2 and 3, showing the change of hourly and annual peak cooling load progression for four countries throughout a year, respectively. As could be seen these figures, annual peak cooling load of the Dushanbe and Mosul does not drop below 0W, while the peak cooling load could be observed under − 7000W in some months for Astana. The annual peak cooling load of Mosul has been generally higher than other cities in both winter and summer periods. The total heat loads and energy consumption of HVAC system for the four cities have been demonstrated in Table 2.

Also, Fig. 4 has been shown the comparison of total heat loads for each cities. The total heat load of Astana has been similar to Dushanbe. The trenchment of total heat load has been decreased the overall energy expenditure. Adana with 36.052 kW has greatest total heat load while the least load has Astana with 18.426 kW. On the other hand, the comparing of HVAC system's energy consumption for each city have been shown in Fig. 5. It has been calculated that Adana has a maximum total energy consumption of 12.87 kW, while Astana has a minimum energy consumption of 7.15 kW. Although the annual and hourly cooling load is higher in Mosul, it has been found that the total cooling load and total energy consumption are less than Adana due to the fact that the wet bulb temperature is lower than Adana. As a result, as the total heat load value has been increased, the energy consumption value also increases. When total heat load has been decreased also energy consumption value decreased.

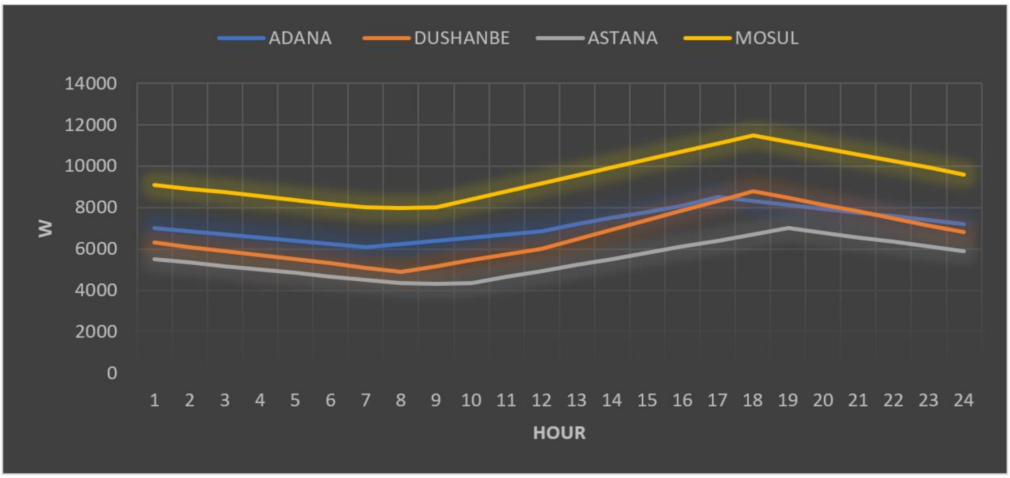

Figure 2. Comparison of hourly peak cooling loads of for 4 different cities

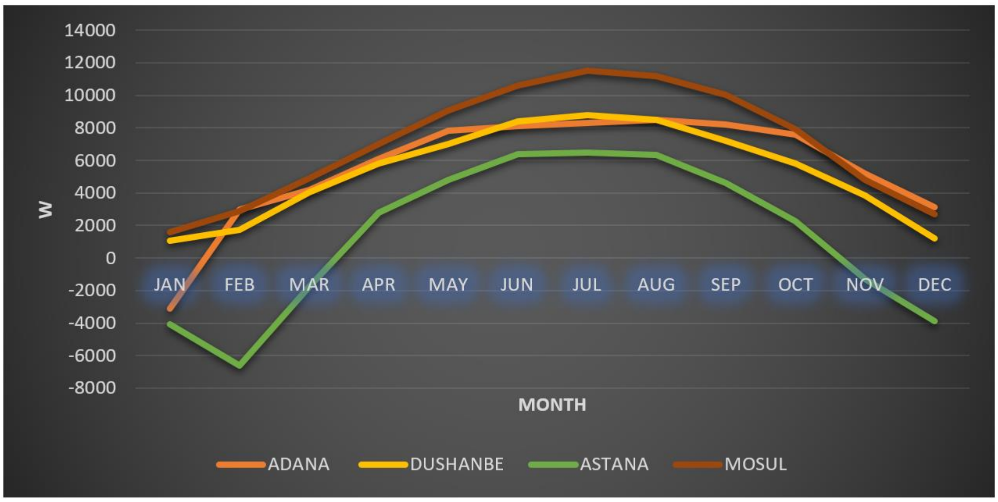

Figure 3. Comparison of annual peak cooling loads of for 4 different cities

Table 2. Total heat loads (Q_{total}) for the 4 different cities

City/ Country	Energy Consumption (kW)	Total Loads (kW)
Adana	12.87	36.052
Astana	6.58	18.426
Dushanbe	7.15	20.028
Mosul	9.156	25.637

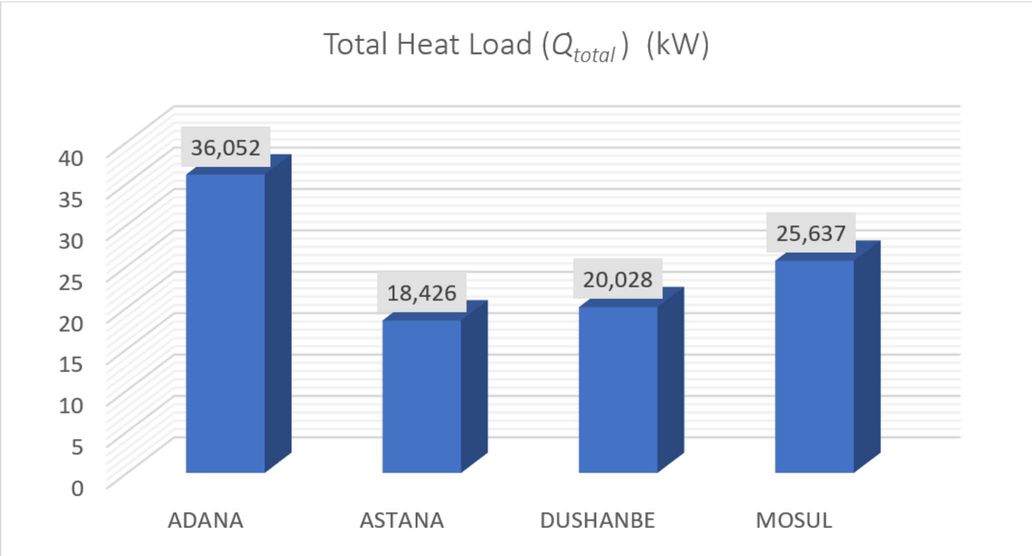

Figure 4. Comparison of total heat loads for 4 different cities

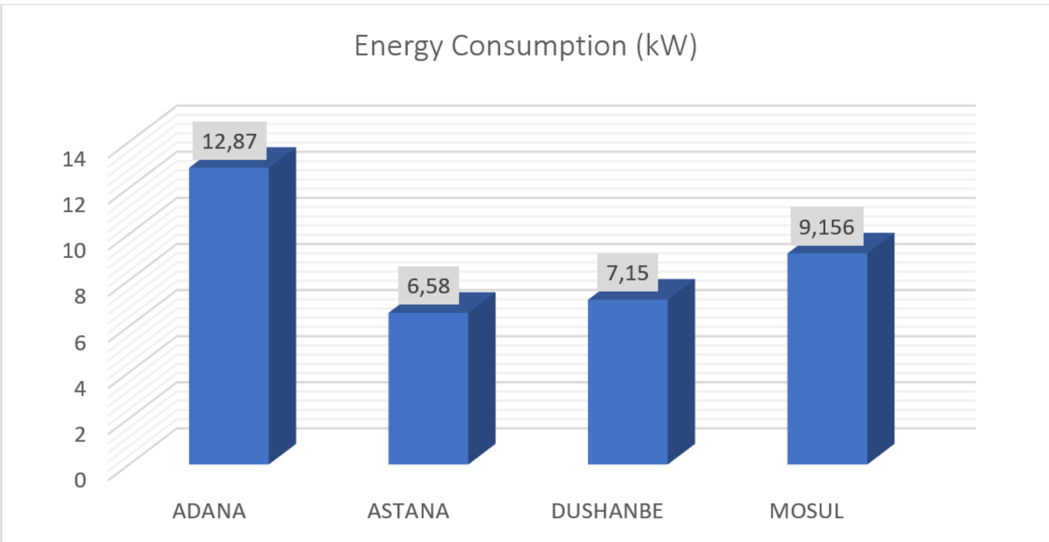

Figure 5. Comparing the HVAC system's energy consumption for cities in four different countries

3.2 Economical evaluation

The initial investment of the HVAC system has been the same for the four cities examined in this study. This investment has been made up of the costs of chiller, AHU, laminar flow unit, EU and other equipments and devices. Also, the labor cost for the assembly has been involved in the calculation. The capability of the devices has been defined according to the loads of highest heating and cooling in the winter and summer eras in case, the same HVAC devices have been used. The comparing of LCC of each cities has been showed in Fig. 8. The values of LCC have been calculated by using Eq. (4). These values showed that the overall expenditure of the HVAC system has been based on the current values. The using electricity price has been accepted as 0.115 $/kWh, which is the mean selling value of electricity in Turkey. The yearly energy consumption amounts have been calculated for each city. The HVAC system's annual energy consumption datas have been demonstrated in Table 3. The comparison of annual energy consumption amounts has been showed in Fig. 6. Adana and Astana have the highest and lowest annual energy consumption amounts as 112.741 kWh/year and 57.640,8 kWh/year. Fig. 7 has been demonstrated comparison of the annual energy costs consumed for each city. The maximum annual energy consumption cost of Adana has been calculated as $12965. Also, the renovation and maintaining cost has been accepted as 800$/year. The cost of the HVAC system for the specified LS has been involved the beginning, maintaining, operating and renovation. The investment of beginning has been received for the first year. The operating, maintaining and renovation costs for the future 10 years have been taken into account. As given in Fig. 8, the least LCC belongs to Astana with $116324.332, whereas Adana has the maximum LCC with $143197.4727, resulting from the Astana's cold climate condition. The second city with a minimum LCC is Dushanbe with a continental-mediterranean climate. The LCC of Dushanbe has been calculated at $118759.6744 for the considered life span. The reduction of LCC and energy consumption has been depended on also climatic conditions. It has been determined that the LCC and energy consumption values are low in the countries with the cold climate type studied. It has been found that it is more economically feasible to use the system in regions with a cold climate type. Since the system has been used in all climate types, it can also be used in hot climates.

Table 3. The HVAC system’s annual energy consumption datas for cities in four different countries

City/Country	Annual Energy Consumption (kW/year)
Adana/ Turkey	112.741
Astana/ Kazakhstan	57.640,8
Dushanbe/ Tajikistan	62.634
Mosul/ Iraq	80.260,6

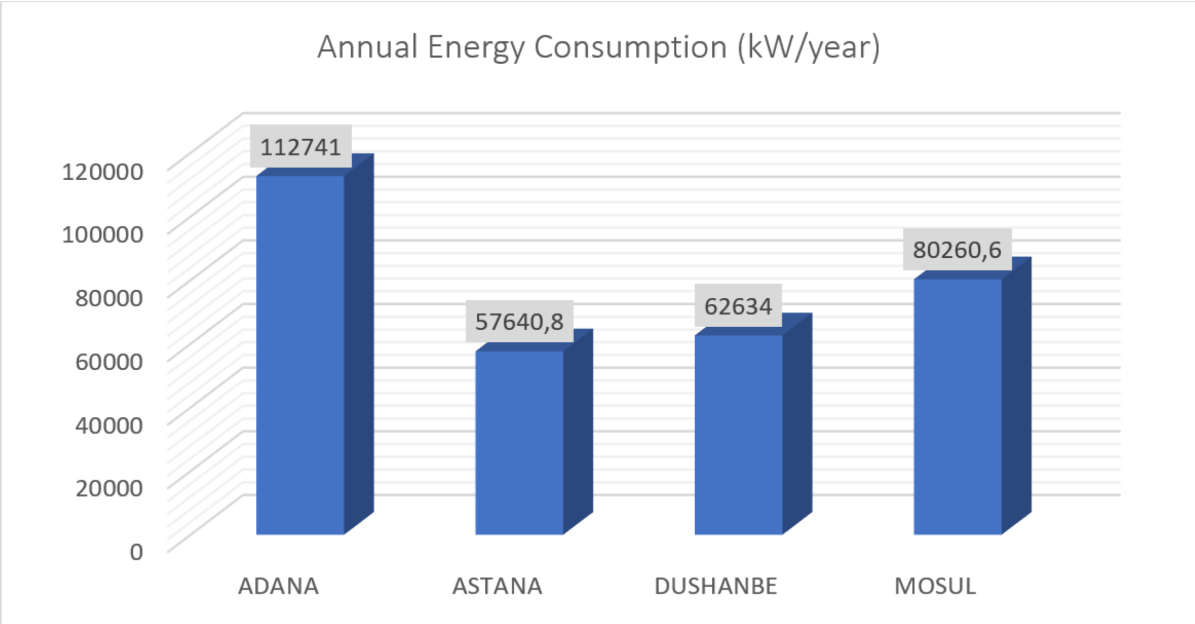

Figure 6. Comparison of annual energy consumption for four different cities.

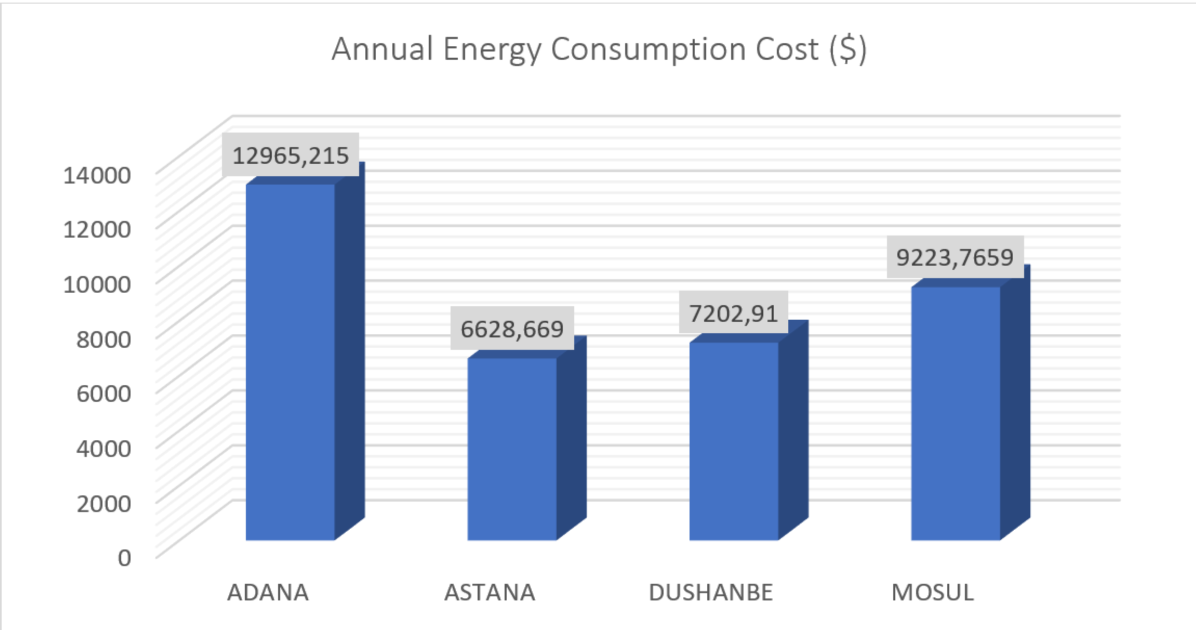

Figure 7. Comparison of annual energy consumption costs for different cities.

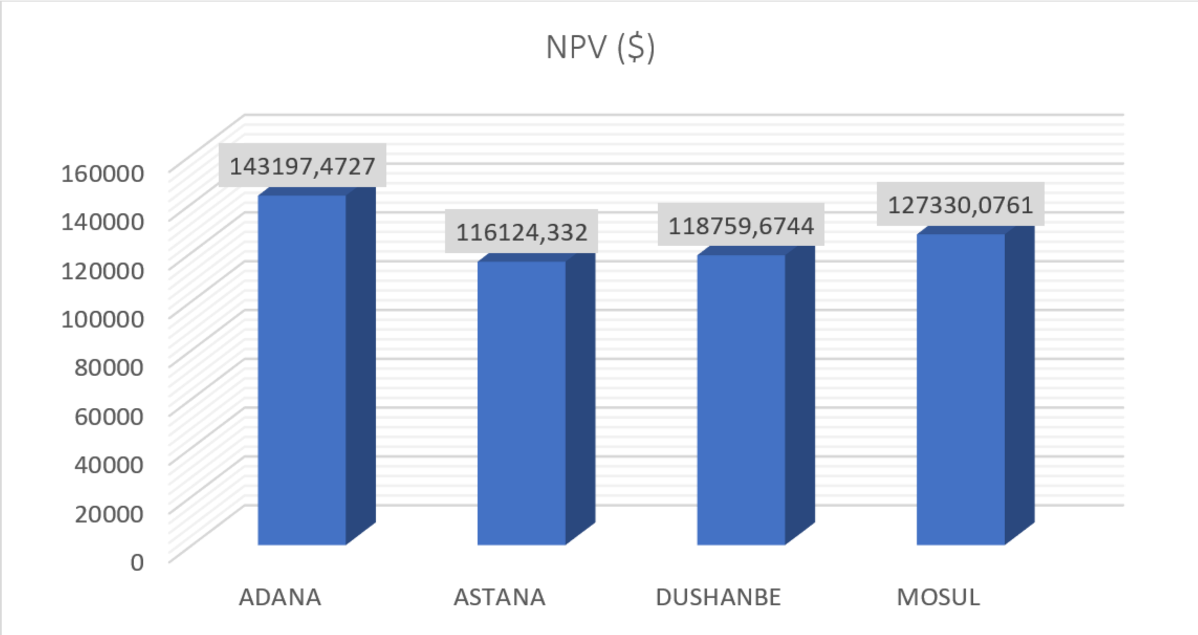

Figure 8. Comparing the NPV of the system for cities in four different countries

4. CONCLUSION

A study on energy expenditure of the HVAC system that uses a percent fresh air and works with half the air volume ratio during the night period with HRU for single operating room equaled to different climate conditions has been performed to investigated the economical evaluation for each country. The use of 100% fresh air in the system has been preferred because it prevents the risk of infection and the increase of microorganisms. Thermal analysis has been performed for each country using identical devices in the designed operating room. Thermal analyses have been performed for each country using the LCC and NPV methods, and the thermal load values of the system has been calculated and evaluated economically.

According to the data obtained from the study, the following results can be accomplished:

- Although the annual cooling load is high, it has been found as a result of calculations that a low wet-bulb thermometer temperature will reduce energy consumption.
- As a result of the calculations, it has been determined that there is the direct proportion between the total heat load values and the energy consumption values. In other words, as the total heat load value has been increased, the energy consumption value also increases. When total heat load has been decreased also energy consumption value decreased.
- The highest heat load belongs to Adana, which has a hot climate, so it also has the highest energy consumption. Although Mosul has a warmer climate than Adana, it has a lower energy consumption value than Adana because its wet-bulb temperature is low.

- Since the lowest heat load belongs to Astana with a cold climate, Astana also has the lowest energy consumption.
- Since the same devices has been used in the system, the highest LCC value belongs to Adana, which has the highest energy consumption.
- The use of the HVAC system used in the study in countries with cold climate type and low wet-bulb temperature has been energy consumption. The system could be used in countries with all climate types, but the energy efficiency of the system has been higher in cold climates.
- The reduction of LCC and energy consumption has been depended on also climatic conditions. It has been determined that the LCC and energy consumption values are low in the countries with the cold climate type studied. It has been found that it is more economically feasible to use the system in regions with a cold climate type. Since the system has been used in all climate types, it can also be used in hot climates.

In future research, economic evaluation of different types of HVAC systems could be made for countries with different climate types.

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