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Techno-economic Assessment of Retrofitting Heating, Ventilation, and Air Conditioning System – Case Study

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ABSTRACT

Retrofitting heating, ventilation, and air conditioning (HVAC) systems in existing buildings and applying energy-efficient technologies can significantly reduce energy consumption and greenhouse gases emissions. In this work, two options of HVAC retrofitting were proposed and discussed for the existing heating system of school of engineering at the University of Jordan as a case study. The experimental tests showed that only one of the three diesel boilers work normally while the other two boilers are not efficient, with actual efficiency of 25%. The first retrofitting was to upgrade the existing heating system to a liquefied petroleum gas (LPG) boiler system with estimated annual saving of 29,757 Jordanian dinar (JOD), and a payback period of 3.9 years. The second option for retrofitting was a new HVAC system for the building including heating and air conditioning with a variable refrigerant flow (VRF) system and heat pump chiller. The estimated cost showed that the VRF system was the lowest one in running cost in winter. The diesel boilers had the highest greenhouse gas emissions with an average value of 377.3 tons of CO_2 per year, while LPG boilers achieved the second highest emissions of around 279 tons of CO_2 per year, whereas the heat pump chiller in winter produced 199 tons of CO_2 and the VRF system emitted 180 tons in winter. The LCCA economic analysis was performed for the proposed systems, showing that the LPG boilers system was more feasible than the diesel boilers system, while the VRF system was more feasible than the heat pump chiller system.

Keywords: retrofitting HVAC, boilers system, LCCA analysis, GHG emissions, VRF system, energy audit.

INTRODUCTION

Buildings (commercial, public and residential) account for about 60% of Jordan's total electricity consumption (Tawalbeh, 2019). The consumption is the outcome of a variety of activities, including cooling, heating, lighting, and the operation of electrical equipment. Jordan faces two major challenges in its energy sector, namely growing energy consumption and limited domestic resources to meet the needs of the country (Ministry of Digital Economy and Entrepreneurship, 2018). It is widely acknowledged that improving the energy efficiency of heating ventilation and air conditioning (HVAC) systems, accounts for about half of a building's total energy consumption, is important (Yang et al., 2014). Retrofitting existing buildings or applying energy-efficient technologies to new designs can significantly reduce energy consumption and greenhouse gases emissions (Ma et al., 2012). The retrofit process involves removing, installing, relocating, or replacing one or more components of the system. (Jagarajan et al., 2017). Energy retrofit solutions are viable approaches to reducing energy use in existing buildings (Song et al., 2019).

Kim et al. (2017) evaluated the performance of VRF and RTU-VAV systems in a simulation environment using EnergyPlus software, the modeling findings demonstrate that VRF systems save 15–42% and 18–33% for HVAC site and source energy usage, respectively.

Using the eQuest energy software (Ligade and Razban, 2019) performed energy-efficient retrofits for the Purdue University. The existing dual-fan dual-duct (DFDD) system is 41 years old, and its energy utilization index (EUI) is greater than the national average for similar building types.

According to simulations and research, the single duct VAV with chilled water and electric reheat was the most energy-efficient, saving 28% in utility expenses.

Zanetti et al. (2019) conducted a retrofit case study on space heating (SH) and domestic hot water (DHW) systems. The suggested solution combines existing gas boilers with phase change material storage (PCM) and a direct current air source heat pump, which is supported by a grid-connected solar system (PV). TRNSYS software was utilized for dynamic simulations and to help with the retrofit layout implementation. In the best-case scenario, annual primary energy savings are more than 30% when PV energy is sold to the grid and roughly 11% when just self-consumption is included, with a pay-back period of around 10 years when considering EU28 economic conditions and a 20% overall discount for the renovation system.

Hamida et al. (2021) introduced a BIM-based technique to evaluate Energy Conservation Measures (ECMs) in a typical government-built educational building in Dammam, Saudi Arabia. The energy audit found many inefficiencies in the building construction and operation and four ECMs were proposed and simulated. It was found that annual energy consumption can be reduced by 22.7% in the educational building, and the investment for the ECMs is paid back in 2.7 years only.

VRV system is better than other HVAC systems at part load. On the basis of the data collected during summer a comparison study was conducted by Im et al. (2016) for the full and part-load performance of a VRF system vs a rooftop unit variable air volume system for a multi-zone building. The energy savings of the VRF system in the cooling season was 29%, 36%, and 46%, and the average cooling COP for the VRF system was 4.2, 3.9, and 3.7, and 3.1, 3.0, and 2.5 for the RTU system under 100%, 75%, and 50% of load conditions, respectively.

Schibuola et al. (2017) presented the set of technologies implemented in the framework of the renovation of a historical construction in Venice to reduce energy consumption. The study confirmed the energy savings by comparing the actual energy consumption against building energy simulations for baseline HVAC system configurations. The authors make use of the comprehensive building management system (BMS) that was installed and can record detailed data regarding flow rates (of air and water), temperature, and humidity for all the HVAC system's main units. When compared to a standard baseline HVAC system, a global primary energy savings of 36% have been computed.

Atallah and Tarlochan (2021) presented a life cycle cost analysis to an existing office building located in Qatar to find the economic feasibility of constant refrigerant flow (CRF) and the variable refrigerant flow (VRF) system by using detailed cooling load profiles, as well as initial, operating, and maintenance costs. The findings show that, while the VRF system's initial cost is 23% more than the CRF system, the VRF system's current worth cost is substantially lower than the CRF systems at the end of its lifetime due to lower operating costs. When comparing the VRF to the CRF, are considerable energy savings of 27%.

This study aimed to fill the knowledge gap for reducing HVAC energy consumption in educational buildings in Jordan by retrofitting HVAC systems, and economic evaluation using the life cycle cost analysis for several different HVAC systems for educational buildings in Jordanian climate. This work includes data collection, re-calculating of the heating load for the building, the amount of annual fuel consumption, and O&M costs. The experimental work part included measurements of water temperatures, flow rate, analysis of the combustion gases for each boiler, indoor temperature rooms in the building and investigating the insulation of water lines in boiler room as well. Then, an upgrade of the existing diesel boiler system to LPG boilers was proposed. The new proposed HVAC system was based upon calculating cooling and heating load using Carrier's Hourly Analysis Program (HAP) software. A VRF system and heat pump chiller were also proposed as another option. Technical and financial comparison between the new proposed systems was carried out including data analysis, calculations of initial costs, O&M, CO_2 emissions, overall yearly efficiency, and life cycle cost analysis.

DATA COLLECTION

The considered case study is the building of the School of Engineering – The University of Jordan. The building is located in Amman with a latitude 32° 00' 30.00" N and a Longitude: 35° 52' 13.19" E, with diesel boilers heating system; it consists of five floors basement, ground, first, second, and the third floor, the basement floor is served by another heating system on other floors. The second-floor plan was available and, accordingly, the second floor with a total area of 2392 m² was chosen as a sample floor to calculate the heating load for the building.

Calculate heating load for building

Since the building is old and there is no available data about the construction material, the calculation of heating loads was based on the worst-case scenario for the space for the overall heat transfer coefficient (U). Table 1 shows the U values assumption.

Outside design conditions equaled 0 °C, and inside design conditions amounted to 21 °C. The equation used for the calculation of conduction heat loss to the outdoor through the roofs, exterior walls, windows, and doors are following:

$$Q = U * A * (Tin - Tout) \tag{1}$$

where: Q – the rate of heat loss by conduction (W);
U – overall heat transfer coefficient (W/m² °C);
A – area of the surface (m²);
Tin – the inside temperature (°C);
$Tout$ – the outside temperature (°C).

This equation can be used for the calculation of conduction heat loss to the adjacent through the ceiling, interior partition walls, and floors by using T(partition) instead of T(out).

The heat loss due to infiltration is calculated as the below equation.

$$Qinf. = ACH * place\ volume * * Cp * (Tin - Tout)/(3600 * v) \tag{2}$$

where: ACH – no. of air change per hour;
$Cp\ air$ – 1000 J/kg°C;
v – specific volume for air (0.78 m³/kg).

The heat loss for the second floor is shown in Table 2.

From the table above, the total heating load from the second floor is 355 kW, which will be considered also the load for other floors (ground, first and third). Thus, the total load for the building will be 1420 kW.

Data collection for the existing system

There are three boilers serving offices and classrooms in the school of engineering, the newest one was installed in 2013. The boilers lacked heat recovery systems such as economizers. The control system for the boilers was old control, which was difficult to operate and set for varied parameters. Table 3 describes the existing system and Figure 1 shows the boilers in the boiler room.

Diesel consumption

Diesel consumption for the diesel boilers was collected from the Central Supplies Department at the University of Jordan to provide the data for the years 2018, 2019, 2020, and 2021. Despite the start of the coronavirus crisis in early 2020 and most classes were held online, the data showed an increase in diesel consumption. The increase in

Table 1. U values assumption

Description	U (W/m².°C)
Ground	2.8
Roof	1.2
Glass	5.6
Door	5.6
Wall	1.2
Partition	2.8

Table 2. Heat loss for the second floor

Specifiction	U (W/m²·°C)	Area (m²)	Tin -Tout (°C)	Q (W)
Ground	2.8	2,392	10	66,976
Glass	5.6	621	21	73,030
Door	5.6	7	21	823
Wall	1.2	1,746	21	43,999
Partition (wall)	2.8	338	10	9,464
Partition (Ceiling)	2.8	2,392	10	66,976
Infiltration				61,534
Q total (with 10%)				355,082

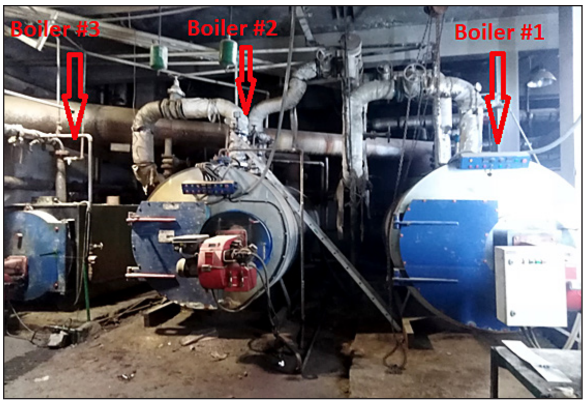

Figure 1. Existing diesel boilers

Table 3. Boiler data collection

Boiler number	1	2	3
Brand	METALCO	METALCO	ALSALAM
Model	FHW 1680	FHW 1680	SM1
Capacity (kcal/hr)	1,680,000	1,680,000	1,000,000
System	Three pass Fire tube	Three pass Fire tube	Fire tube
Year manufactured	2013	2009	2005
Burner model	Blowtherm (MKSF 250)	Blowtherm (MKSF180)	Unknown
Burner nozzle number	3 nozzles	3 nozzles	3 nozzles
Diesel tanks	Primary 55,000 L, secondary 4,000L		

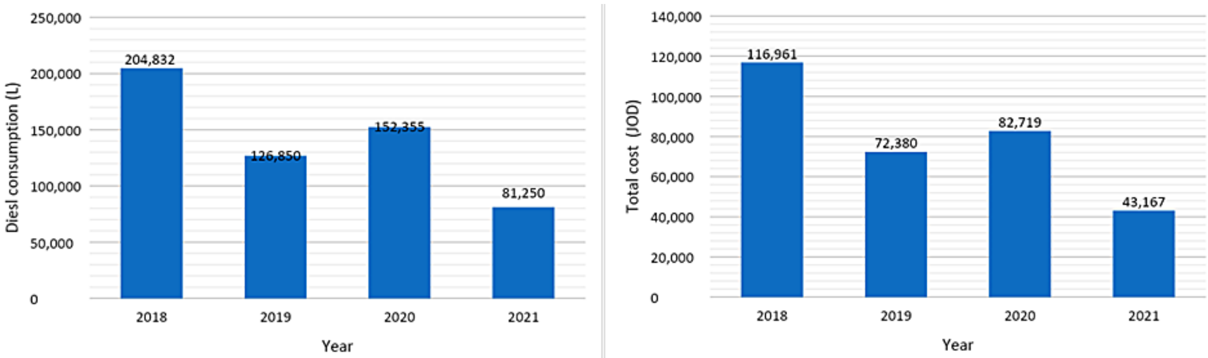

Figure 2. Diesel consumption and the cost paid for four years

fuel consumption brings additional costs that affect the financial situation of universities. Figure 2 shows the total cost for the consumption of diesel. The university has paid around 315,235 JOD for diesel costs only in four years.

According to Jordan Petroleum Refinery (Jopetrol, 2020) which is the authorized entity for listing fuel prices in Jordan, the diesel fuel prices in Jordan have ranged between 0.53 and 0.60 JOD/L between the years 2018 and 2021.

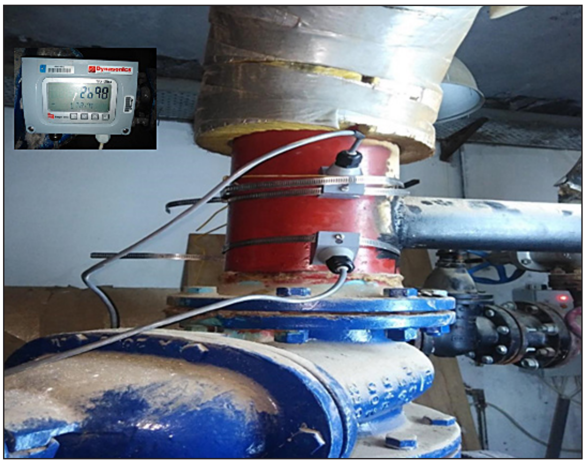

Figure 3. Ultrasonic flow meter installation and water flow rate reading

EXPERIMENTAL WORK

Measuring water flow of the system

To determine the efficiency of the boiler, the amount of water flow into the boiler network was determined using a flow meter. An ultrasonic flow meter was used, which was clamped to the outside of pipes with the diameter of 8 inches. The device is Dynasonics type with flow accuracy of ±0.5 of reading. Figure 3 shows the installation of the flow meter at the main supply pipe of the system.

Analysis of the combustion gases

The device model used was Kane 255 Combustion Flue Gas Analyzer, it can calculate O_2, CO ppm, CO_2 ratio, and exceed air for combustion. The device probe must be placed in the chimney. Figure 4 shows the installation of this device.

Data results for each boiler are shown in table 4. It can be seen that the flue gas temperature from boiler number 2 is very low and the excess air ratio is very high, part of the fuel does not burn. This partially burned fuel produces smoke and pollutes the environment. The unburned fuel may also be a significant source of energy waste (Bhatia, 2012). Moreover, the CO ppm and flue

Table 4. Flue Gas Analyzer data for each boiler

Description	Boiler #1	Boiler #2	Boiler #3
O2 %	3.6	12.8	1.7
CO_2 %	12.8	5.9	14.2
CO ppm	26	5	2641
Flue temperature °C	194.4	90.4	502.9
Excess air %	20.7	158.9	8.9

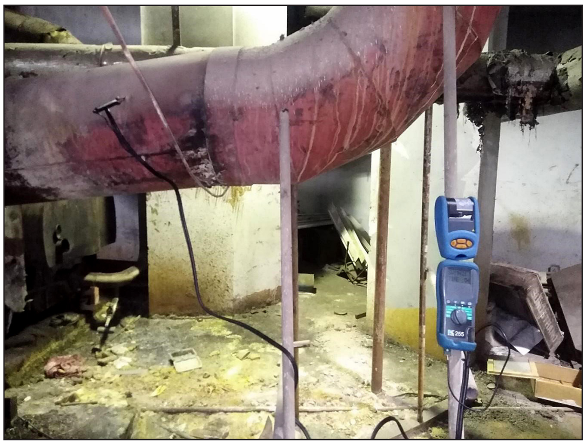

Figure 4. Flue Gas Analyzer installation

temperature from boiler number 3 are very high. CO is a sensitive indicator of incomplete combustion, with levels ranging from zero to 400 ppm by volume. The presence of a large amounts of CO in the flue gas is a sure cause of a lack of air supply (Bhatia, 2012).

Measuring the supply and return water temperature from boilers

A data logger thermometer device (type TES 1384 with accuracy ±0.5°C) has been installed to monitor the supply and return water temperatures

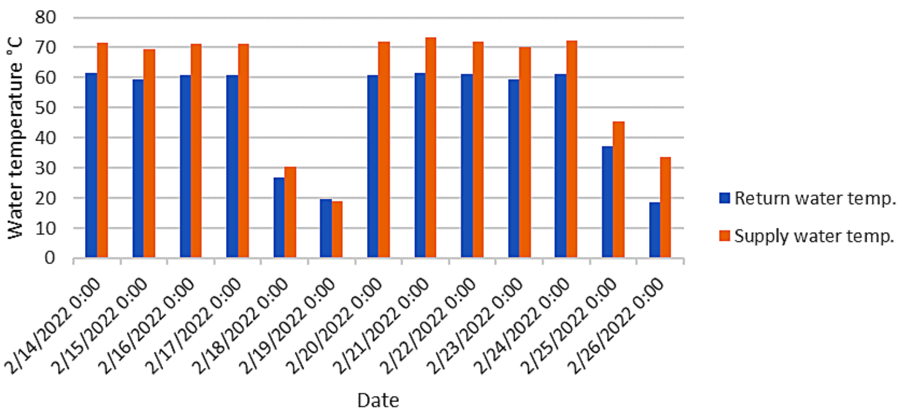

Figure 5. Boilers supply and return water temperatures

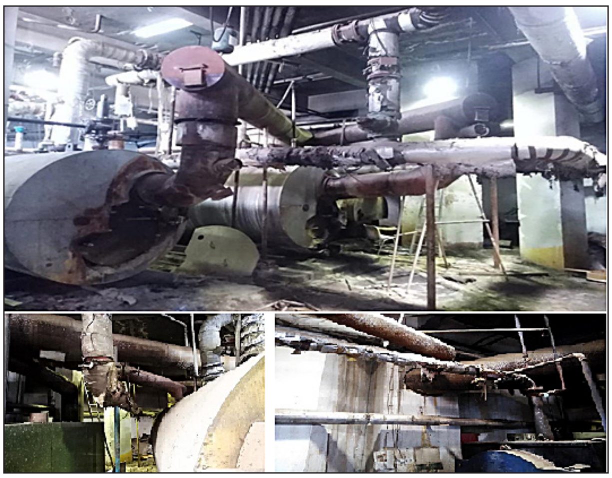

Figure 6. Pipe insulations evaluation

from boilers. The temperatures that were measured are shown in the Figure 5.

At steady state, the temperature difference between the water supply and the water return is about 10 degrees Celsius. The days 18, 19, 25, and 26 are the university's weekly vacation days.

According to the continuous observation of the boilers room, some problems were found in pipe insulation, worn-out pipes, and pipes that need to be re-insulated. Figure 6 shows the pipe insulation problems.

Measurement of the diesel consumption for each boiler

Diesel consumption was measured separately for each boiler using a simple method. The tank directly feeding the boiler is a secondary tank located in the boiler room with a capacity of 4,000 liters, it contains a tube that indicates the level of diesel in the tank. The diesel level was determined in the start of experiment and switched off the diesel pump that pumps from the large primary tank – which is outside the boiler room – to the secondary tank. Then the timer was turned on and each boiler was turned on to know how many millimeters were consumed in an hour. Results are shown in Table 5.

It should be note from the Table 5 that Boiler #3 is the smallest boiler, but its consumption is higher than all boilers, and Boiler #1 also consumes less than all boilers. The burner of Boiler #3 needs repair or replacement. Table 6 shows the errors related to measuring instruments.

Upgrade of the existing diesel boilers to LPG gas boilers system

The first retrofitting objective of the study is to convert the existing heating system to a boiler gas system. Accordingly, it was studied to replace the old boilers and install a newer LPG boiler. Liquefied gas, often known as LPG, is a type of energy carrier made composed of liquefied hydrocarbon gases C3-C4 (propane and butane). It is classified as an alternative fuel. LPG is used in over 1000 diverse applications, including industry, civil engineering, community economy, agriculture, housing, and transportation. LPG demonstrates high dynamics of production and consumption due to simplified logistics of transportation providing supply diversity, availability of sources, and, most importantly, environmental issues (Paczuski et al., 2016).

LPG boilers

The Liquefied Petroleum Gas (LPG) boiler is the heating device, where gas has burned the heat generated by combustion is transmitted to the water that circulates throughout the heating system via a heat exchanger. When the water has absorbed enough heat, it runs through the system to the end-points, which can be radiators mounted in the space to provide the heat (Costa et al., 2012). LPG boilers emit lesser amounts of greenhouse gases than other alternative fuels like diesel, making them a more environmentally responsible central heating option. They're also usually quieter than diesel boilers when they're running. According to Jopetrol, LPG fuel prices

Table 5. Diesel consumption from each boiler

Boiler number	Experiment time (min)	ΔH tank (mm)	Total diesel consumption (m^3/hr)
Boiler # 1	16	14	0.21
Boiler # 2	16	18	0.27
Boiler # 3	16	28	0.42

Table 6. Error of instrument measurement

Instrument	Accuracy	Range	Error (%)
Ultrasonic flow meter	± 0.5 gpm	0-5000 gpm	0.01
Flue gas analyzer (flue temperature)	± 0.5 °C	0-600 °C	0.08
Flue gas analyzer (Carbon Monoxide)	± 3 ppm	0-2000 ppm	0.15
Flue gas analyzer (Carbon Dioxide)	± 0.3% volume	0-20%	1.5
Flue gas analyzer (Oxygen)	± 0.3% volume	0-21%	1.4
Data logger thermometer	± 0.5 °C	-50 to +200 °C	0.2

Table 7. Suggested new gas boiler brand

Type	Model	Qty.	Heating capacity (kW) for one unit	Price for one unit (JOD)
Ferroli	Energy top W80	4	73.5	3168
	Energy top W125	12	113.7	3600

have ranged between 450-881 JOD/ton between January 2018 and October 2021. Taking the average LPG prices for the same period shows that it equals 637 JOD/ton.

Selection and installation of new LPG boilers

The Table 7 shows the suggested new gas boiler based on design capacity. To make a zoning system in the building, four boilers will be connected for each floor.

The system will include two LPG tanks, each with a capacity of 5000 liters, one evaporator for converting liquefied LPG to LPG in its vapor phase, and two stages of gas pressure regulators for controlling gas pressure at the tank level. After inspecting the site by the gas tanks installation company, the location of the tank was suggested in front of the boiler room so that the place would guarantee the standards required of the tanks by the Civil Defense. The total LPG gas tank installation is 27,600 JOD including fittings and tanks.

Installation work for new piping and pumps

The best, easiest and cheapest way to make a zoning system in new gas boilers is separate the boilers (four boilers) for each floor, every four boilers have one pump covering one floor, and by achieving this, the operator can turn on or turn off heating for each floor. Only new 4 pumps with new pipes are needed in the mechanical shaft, separate the main pipes for the old system and then connect new pipes for the new system. The cost of new pumps, new pipes, and new installation pipework was estimated at approximately 13,000 JOD. The price of new gas boiler units does not include the installation of them, the estimated price for installing the new units is 20,000 JOD including the dismantling of the old units.

New boilers operating and maintenance

New LPG boilers have lower operating and maintenance costs than diesel boilers. This is because they are new and equipped with all the necessary equipment, faults and failures are almost non-existent, especially during the first few years of operation. The primary operational costs for LPG boilers will be the cost of LPG fuel, energy used for pumps and modulating burners. The system is covered by a two years manufacturer's warranty.

DESIGN AND SELECTION OF NEW HVAC SYSTEM

The new design includes the building's heating and cooling system. Second floor loads were calculated using the Carrier Hourly Analysis Program (HAP) air conditioning design program. The program meets American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standards. It can be used for the evaluation and design of air conditioning systems. The load is rated to meet the expected building load at the set point temperatures. The space area, space orientation, doors, windows, partitions, lighting, occupancy rates, and electrical devices are all considered load variables at a building.

Table 8. VRF system indoor units design for the second floor

Ref.	Total cooling load (kW)	Heating load (kW)	Qty.
FCU-01 to FCU-8	29.3	20.2	8
FCU-09 to FCU-17	70.7	43.8	9
FCU-18 to FCU-33	72.9	47.8	16
FCU-34 to FCU-42	67.8	42.7	9
FCU-43 to FCU-52	68.7	43.3	10
FCU-53 to FCU-64	182.4	105.2	12

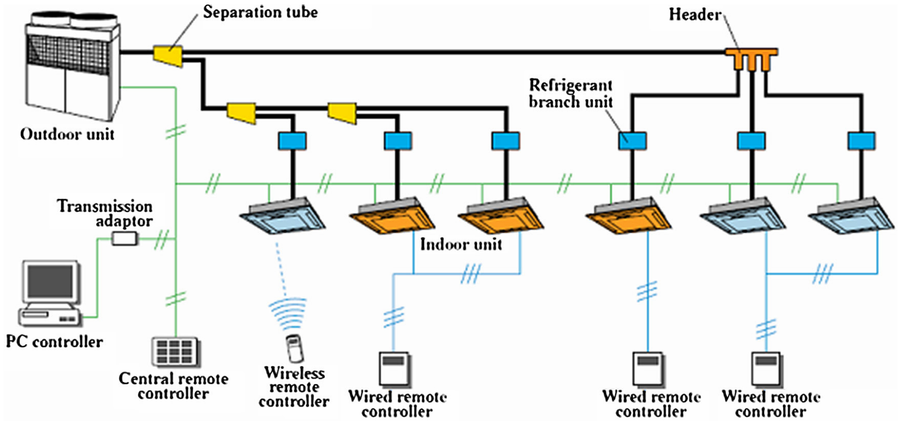

Figure 7. Components of VRF systems (Alahmer and Alsaqoor, 2017)

Table 9. VRF system outdoor units design for the second floor

Total cooling/heating capacity (kW)	Ambient temperature cooling/heating (°C)	Total heating capacity (kW)	Note
492/310	38/0	310	Heat pump with inverter compressor and R410A refrigerant

Variable refrigerant flow

A variable refrigerant flow (VRF) system is a modern air conditioning system, it consists of outdoor units, indoor units, and pipework. Figure 7 shows the main components of VRF system. A report from the HAP program on VRF design is summarized in the Tables 8 and 9.

The Table 10 shows the suggested brand with technical data. The system price is 188,855 JOD. Tables 11 and 12 show the selected indoor unit and outdoor units.

The VRF system price presented above includes the price of network pipes and installation of units and pipes. The ductwork was priced by the contractor at an estimated price of 56,700 JOD according to the supplier's duct design.

Table 10. Suggested VRF system with technical data for the second floor

Type	HITACHI
Model	VRF RAS
Indoor unit Qty.	81
Outdoor unit Qty.	7
Indoor units type	Ducted
Total actual cooling capacity (W) for outdoor unit	527
Total actual cooling capacity (kW) for indoor unit	552
Total actual heating capacity (kW) for outdoor unit	542.1
Total power consumption cooling mode (kW)	189.28
Total power consumption heating mode(kW)	187.95
Design ambient temperature for cooling (°C)	38
Design ambient temperature for heating (°C)	0

Table 11. selected VRF indoor units

Model	Air flow (m^3/min)	Nominal cooling capacity (kW)	Nominal heating capacity (kW)	Qty.
RPIM-0.8HNAUNQ	10	2.2	2.8	2
RPIM-1.3HNAUNQ	12	3.6	4.2	3
RPIM-1.5HNAUNQ	12	4.3	4.9	19
RPIM-1.8HNAUNQ	16	5	5.6	4
RPIM-2.3HNAUNQ	20	6.3	7.5	10
RPIM-2.5HNAUNQ	20	7.1	8.5	2
RPIH-3.0HNAUNQ	30	8.4	9.6	4
RPIH-3.3HNAUNQ	30	9	10	5
RPIH-4.0HNAUNQ	30	11.2	13	9
RPIH-5.0HNAUNQ	35.5	14.2	16.3	3
RPIH-6.0HNAUNQ	41	16	18	20

Table 12. Selected VRF outdoor units

Model	Nominal Cooling Capacity (kW)	Nominal Heating Capacity (kW)	Power input at Nominal condition for cooling (kW)	Power input at Nominal condition for heating (kW)	Qty
RAS-160HNCEL(R)WS	44.8	50	11.8	11.35	1
RAS-360HNCEL(R)WS	100.8	114	24.82	25.35	4
RAS-380HNCEL(R)WS	106.4	120	26.08	26.27	2

The civil and electrical works for VRF system design were estimated at 28,330 JOD.

Heat pump chiller system design and selection

The heat pump chiller system consists of outdoor units, indoor units, water pumps, ductworks, and a water pipe network. Figure 8 shows the main components of heat pump chiller system. Reports from the HAP program for chiller system design is summarized in the Tables 13 and 14. Tables 15, 16 and 17 show the suggested brand heat pump chiller system with a total price of 257,930 JOD.

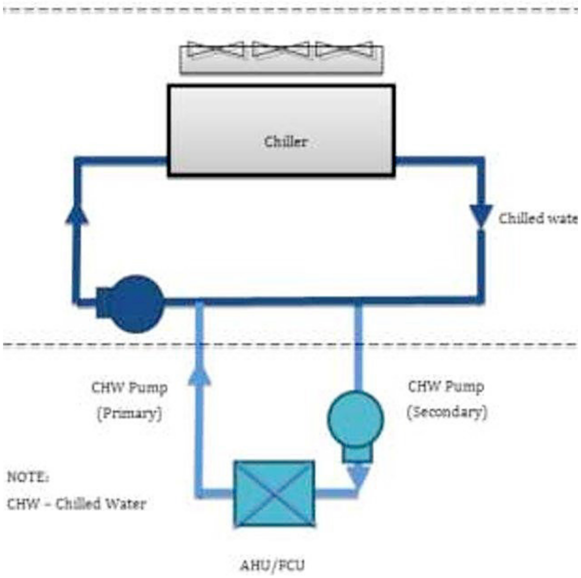

Figure 8. Schematic diagram of air-cooled chiller system (Muhammad et al., 2019)

The heat pump chiller system requires pumps, pipes, fittings, valves and ductwork for indoor units. All installation works including all devices (pumps, valves, and fitting) were priced by the contractor with an estimated price of 128,965 JOD. The ductwork price was estimated at 56,700 JOD, and the civil and electrical works for the heat pump chiller system were estimated at 38,700 JOD.

RESULTS AND DISCUSSION

Diesel boilers vs LPG gas boilers

As previously mentioned, the historical data for the diesel boilers covers four years and the data are reflected to compare diesel and gas boilers. The Table 18 and 19 show the estimated needed LPG, the average LPG price from 2018 to 2021, and the corresponding costs based on this. Knowing that the diesel fuel has a calorific value

Table 13. Heat pump chiller system indoor units cooling design for the second floor

Ref.	Total cooling load (kW)	Heating load (kW)	Qty.
FCU-01 to FCU-08	29.1	23.3	8
FCU-09 to FCU-17	69.4	52.2	9
FCU-18 to FCU-33	71.2	57.3	16
FCU-34 to FCU-42	66.2	51.2	9
FCU-43 to FCU-52	67.2	51.8	10
FCU-53 to FCU-64	176.1	125.4	12

Table 14. Heat pump chiller system outdoor unit design for the second floor

Cooling capacity (kW)	Water in / out temp. (cooling) (°C)	Ambient temp. for cooling (°C)	Heat pump capacity (kW) at Δ T = 5 °C	Note
479.2	12 /7	38	361	Heat pump with VSD compressor

Table 15. Suggested heat pump chiller system

Type	FCU units Qty.	Chiller unit Qty.	Total cooling capacity	
			for chiller (kW)	for FCU units (kW)
DAIKIN	73	1	456.7	667.9

Table 16. Selected fan coil units

Model	Cooling capacity (kW)	Qty.	Power consumption for one unit (kW)
CN 02 DA	2.37	2	0.106
CN 04 DA	3.72	7	0.106
CN 05 DA	4.25	15	0.106
CN 06 DA	4.84	4	0.192
CN 08 DA	7.32	14	0.294
CN 09 DA	8.18	8	0.294
CN 10 DA	8.8	2	0.294
CN 12 DA	10.55	5	0.294
CN 16 DA	13.46	1	0.441
EUSW040D-4	16.1	7	0.662
EUSW050D-4	23.7	8	0.992

Table 17. Selected heat pump chiller

Model	Cooling / heating capacity (kW)	Qty.	Power consumption at cooling / heating (kW)
EWYD460BZSS	456.7/475	1	161.5/163.8

of 36.9 MJ/liter and one kg of LPG fuel has a calorific value of 46 MJ/kg (Liquefied Petroleum Gas (LPG) - energypedia.info, 2020). Also, assuming the diesel boiler efficiency and new LPG gas boiler efficiency are 80% and 98% respectively. Figure 9 shows the difference between the actual diesel costs and the estimated LPG costs during four years.

To calculate the efficiency of the existing boilers will be used the below equation by dividing the thermal output of the system over diesel consumption, the mass flow rate value is constant and it has been read through an ultrasonic flow meter, the value was 2700 liter/minute (45 kg/s), assuming a constant return water temperature of 60 °C and a water supply temperature of 70 °C,

Table 18. Estimation of the needed LPG

Year	Diesel consumption [L]	Used diesel heating energy [MJ]	Desired LPG heating energy [MJ]	Equivalent LPG mass [kg]
2018	204,832	6,046,641	6,046,641	134,131.34
2019	126,850	3,744,612	3,744,612	83,065.93
2020	152,355	4,497,520	4,497,520	99,767.52
2021	81,250	2,398,500	2,398,500	53,205.41

Table 19. Average yearly prices and estimated fuel cost

Year	Diesel cost paid [JOD]	Equivalent LPG mass [Ton]	LPG average price [JOD/Ton]	Cost for LPG [JOD]	Total savings [JOD]
2018	116,961	134.13	680	91,156	25,805
2019	72,380	83.07	592	49,192	23,188
2020	82,719	99.77	566	56,443	26,276
2021	43,167	53.21	714	37,971	5,196

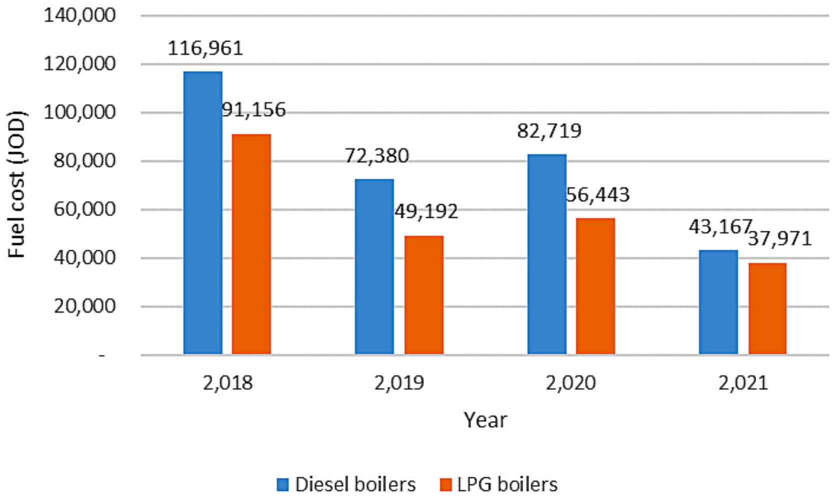

Figure 9. Comparison between diesel and LPG fuel costs paid

at steady state. The isobaric specific heat capacity (cp) of water is assumed to be 4,186 J/kg°C.

$$Performace = \frac{Desired\ output}{Required\ input} = \tag{3}$$
$$= \frac{Q_{Output}}{Diesel\ consumption}$$

$$Q_{Output} = \dot{m}\left(\frac{kg}{s}\right) * cp\left(\frac{J}{kg.C}\right) * \Delta T(°C) =$$
$$= (45 * 4{,}186 * (70 - 60)) = 1{,}883.7\ \text{kW}$$

The thermal output at full load from the boilers system can be calculated using the equation, below, knowing that one liter of diesel fuel has a calorific value of 36.9 MJ/liter (Differences Between Diesel and Petrol. ACEA - European Automobile Manufacturers' Association, 2016) and assuming that the combustion efficiency for all boilers is 80%.

$$Q_{diesel} = Diesel\ calorific\ value\left(\frac{J}{Litre}\right) *$$
$$* diesel\ consumption\left(\frac{Litre}{second}\right) * \tag{4}$$
$$* combustion\ efficiency =$$
$$= 36{,}900{,}000 * 0.249 * 0.80 = 7{,}350.48\ kW$$

$$Overall\ \eta = \frac{Q\ output}{Q\ Diesel} = \tag{5}$$
$$= \frac{1{,}883.7}{7{,}350.48} = 25.6\ \%$$

At full load, the thermal efficiency of the boilers system is very low. To calculate the efficiency of the new LPG gas boilers, the previous equation can be used by dividing the thermal output of the system over gas consumption. Q output from new LPG boilers is 1658.4 kW, the gas consumption of the selected units is 5.87 kg/hr for model (Energy top W80 with quantity 4) and 9.08 kg/hr for model (Energy top W125 with quantity 12), one kg of LPG fuel has a calorific value of 46 MJ/kg; then, the efficiency of the new system can be calculated as below.

$$Overall\ \eta = \frac{Q\ output}{Q\ LPG\ gas} = \tag{6}$$
$$= \frac{1658.4}{46000 * 132.44/3600} = 98\ \%$$

The university has consumed about 565,287 L of diesel in four years, while the recent average price of diesel fuel is 0.615 JOD/L. Therefore, the yearly diesel costs will be estimated as 86,912.8 JOD. The power consumption of the boiler room corresponds to the operating cost of the LPG boiler including new pumps and new boiler burner, calculated from the nominal power of burners and pumps, the daily average power consumption for operation days is 196.68 kWh. Assuming that the price of electricity is 0.12 JOD for each kWh, the boiler's monthly average electricity cost is 519.2 JOD (based on 22 working days monthly). Thus, it can be estimated to be 2,596.2 JOD/ year (based on 5 months of working yearly).

LPG consumption and prices are averaged for one year based on four years, from 2018 to 2021. Taking an average diesel consumption from four years of 141,322 liter per year, the needed LPG consumption will be 92.54 tons. For LPG prices, an average of 638 JOD/ton will be taken based on Jopetrol historical prices of four years, this would have cost the school around 59,041 JOD. Cleaning the new boilers is easier than cleaning the old diesel boilers. The boiler system will be covered by the manufacturer's two-year warranty. Other maintenance expenditures, such as human error breakdowns or any other required maintenance, are estimated to cost 2,000 JOD per year. On the basis of the above, the estimated annual saving will be 29,757.2 JOD/year, then the estimated payback period for the new LPG gas boilers system will be 3.9 years.

Life cycle cost analysis

Life Cycle Cost Analysis (LCCA), based on present value method (PWC), is an economic analysis that includes initial costs, operating costs, maintenance costs, replacement costs and residual values, and is a useful tool for economic analysis of different systems (Murugavel, V., & Saravanan, 2010). LCCA is important when project options that meet the same performance criteria but have different initial and operating costs need to be compared to select the one that optimizes net savings (Fuller, 2006). LCCA calculation is based on PWC with the following formula:

$$\begin{aligned}Present\ Worth\ (PW) = -\text{Capital Cost} - \\ -[(\text{Maintenance cost} + \text{Running cost})\text{X}\ (\text{P/A}, \text{i}, \text{n})] + \\ +[\text{Salvage value X}\ (\text{P/F}, \text{i}, \text{n})]\end{aligned} \tag{7}$$

where: i – interest rate; n – lifetime; the factors (P/F and P/A) are available in compound interest factor, using an interest rate of 10% and a lifetime of 15 years.

CO_2 emission

According to Annex 5 and the European Commission's Task 3a results (Annex 5: Subsidy level indicators for the case studies, 2009), around 2.67 kg of CO_2 are produced per liter of diesel burned. The boiler system will therefore emit between 216 and 546 tons of CO_2 per year from 2018 to 2021. For GHG emissions produced by new boilers, each kilogram of LPG produces 3.01 kg of CO_2, according to reliable website information (Engineering ToolBox, 2009). Between 2018 and 2021, the new boilers generated 1,114 tons of CO_2. Figure 10 shows a comparison of CO_2 emissions from diesel and LPG boilers.

To calculate the coefficient of performance (COP) at full load of a selected VRF system and heat pump chiller, the following formula can be used, dividing the Q output of the system over power consumption.

$$COP\ (cooling) = \frac{Nominal\ cooling\ capacity}{Power\ consumption\ in\ cooling} \tag{8}$$

$$COP\ (heating) = \frac{Nominal\ heating\ capacity}{Power\ consumption\ in\ heating} \tag{9}$$

The COP values for VRF are 4.05, 4.51 for cooling and heating respectively, and 2.83, 2.9 for heat pump chiller for cooling and heating respectively. To find the real running hours for the new systems will be used the Degree Days approach (DD) as the below equation.

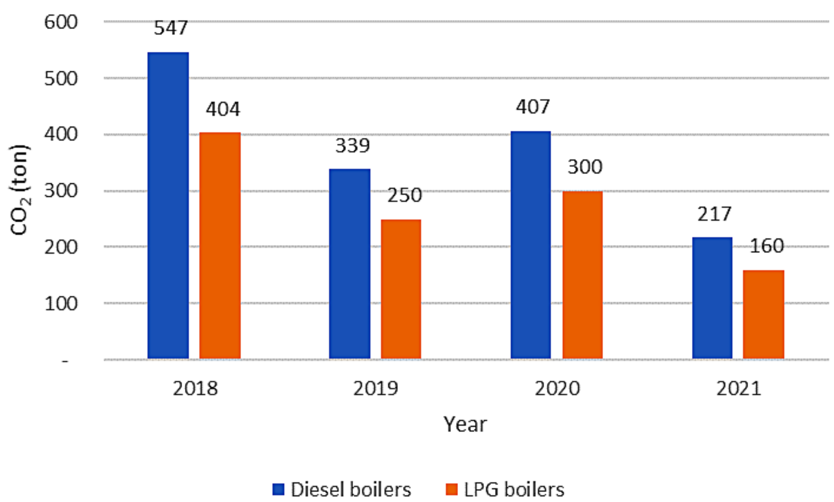

Figure 10. Difference between diesel and LPG boilers in CO_2 emissions

$$E\ (cooling) = \frac{P\ (cooling) * 8\frac{hours}{day} * 24\frac{days}{months} * 4\frac{months}{year} * DD\ cooling}{(To\ - Ti\ )} = \frac{P\ (cooling)\ * 768\frac{hours}{year} * DD\ cooling}{(To\ - Ti\ )} \quad (10)$$

where: $E\ (cooling)$ – energy consumption at degree days method for cooling;
$P\ (cooling)$ – air conditioning system power consumption for cooling;
$DD\ cooling$ – average summer months' temperatures – 18.3, the average summer temperature for the university of Jordan was taken from (Alsaad and Hammad, 2011) from June to September, 18.3 is the balance point temperature value;
Ti – desired inside temperature;
To – desired outside temperature.

For the winter season, the equation will be as below:

$$E\ (heating) = \frac{P\ (heating) * 8\frac{hours}{day} * 24\frac{days}{months} * 5\frac{months}{year} * DD\ heating * Cv}{(Ti\ - To\ )} = \frac{P\ (heating) * 960\frac{hours}{year} * DD\ heating * Cv}{(Ti\ - To\ )} \quad (11)$$

where: $E\ (heating)$ – energy consumption at degree days method for heating;
$P\ (heating)$ – air conditioning system power consumption for heating;
$DD\ heating$ – 18.3 – average winter months' temperatures, the average winter temperature for the university of Jordan was taken from (Alsaad and Hammad, 2011) from November to March, 18.3 is the balance point temperature value;
Ti – desired inside temperature;
To – desired outside temperature,;
Cv – correction factor = 0.77 (Alsaad and Hammad, 2011).

According to the United States Environmental Protection Agency (Environmental Protection Agency, 2022) by using the Greenhouse Gas Equivalencies calculator, energy data can be converted to the corresponding quantity of carbon dioxide (CO_2) emissions.

The VRF system is covered with five years warranty for compressors and a one-year warranty for the whole unit, the estimated other maintenance assumed by the rate of 20 JOD/Ton, will be around 3,000 JOD for the second floor and 12,000 JOD for the whole building. The heat pump chiller system is covered with a one-year warranty for the whole unit, the estimation of other maintenance assumed by the rate of 30 JOD/Ton, will be around 3,897 JOD for the second floor and 15,588 JOD for the whole building (Table 20 and 21). Figures 11–13 show the comparison between all systems.

Table 20. Comparison table between the existing diesel boilers system and upgrading the system with LPG boilers

Description	Diesel boilers	LPG boilers
LCCA based on PW [JOD]	-710,357.8	-598,823.5
Capital cost [JOD]	Zero	116,472
Yearly operation costs [JOD]	89,394.4	61,637.2
Yearly maintenance costs [JOD]	4,000	2,000
GHG emissions [ton of CO_2/year]	377.3	279
Efficiency	25%	98%

Table 21. Comparison table between new design systems VRF and heat pump chiller

Description	VRF system	Heat pump chiller system
LCCA based on PW [JOD]	-1,946,395	-2,856,015
Capital cost [JOD]	1,105,540	1,929,180
Yearly operation costs [JOD]	100,639.3	109,911
Yearly maintenance costs [JOD]	12,000	15,588
GHG emissions [ton of CO_2/year]	362	396
COP	4.05 in summer 1.83 in winter	2.83 in summer 2.9 in winter

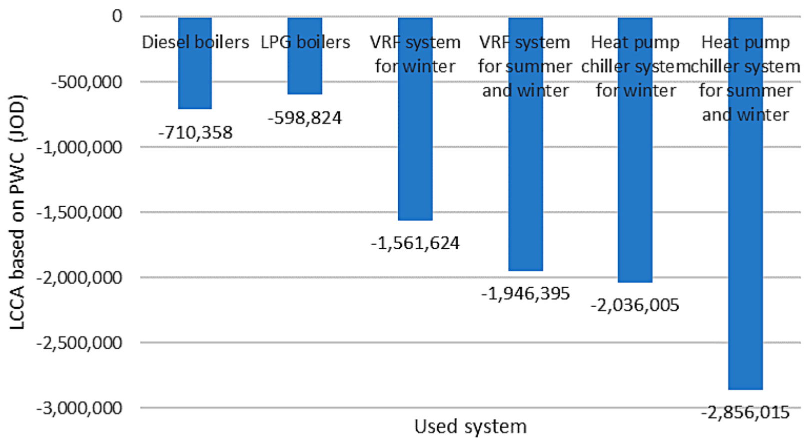

Figure 11. LCCA comparison

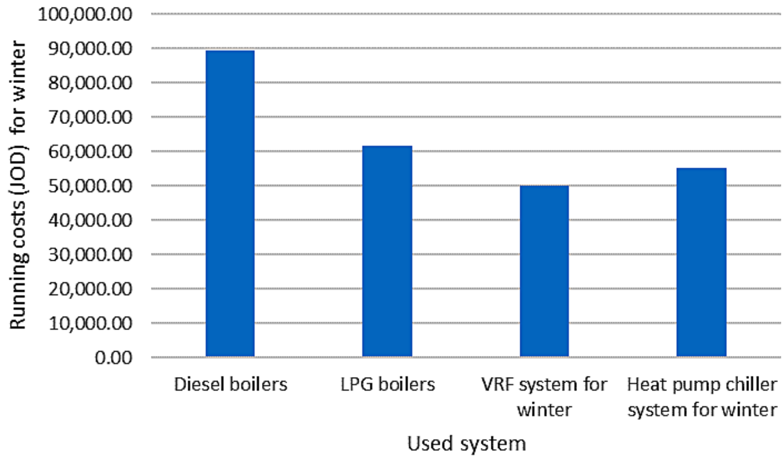

Figure 12. Running cost for winter for all systems

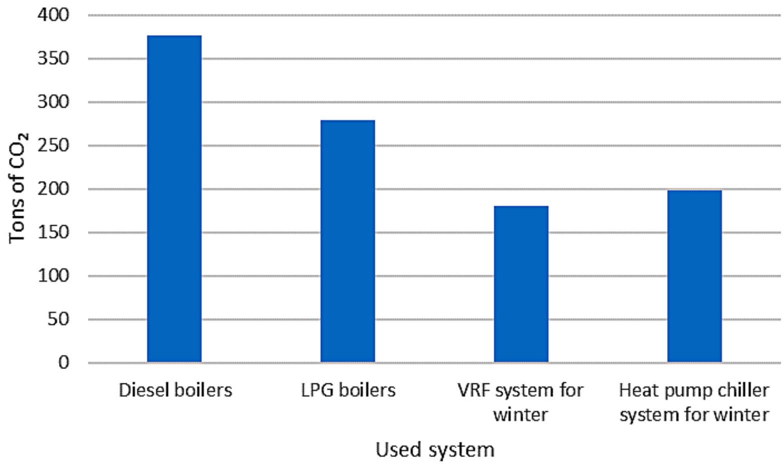

Figure 13. CO_2 yearly emissions for each system

CONCLUSIONS

Retrofitting HVAC systems in existing buildings and applying energy-efficient technologies can significantly reduce energy consumption and greenhouse gases emissions. The efficiency of the proposed new LPG Boiler system was 98%, while the efficiency of existing system was 25%. The amount of savings in operation and maintenance costs will be better in the new LPG boilers system.

The estimated annual saving from new LPG boilers will be 29,757.2 JOD, and the estimated payback period for the new LPG gas boilers system will be 3.9 years. The LPG boilers system is more feasible than the diesel boilers system.

The COP of the VRF system is higher than the heat pump chiller in cooling and heating. The COP at the full load of the VRF system was 4.05 for cooling and 4.51 for heating, while the heat pump chiller system was 2.83 for cooling and 2.9 for heating. The initial and running cost of the VRF system was better than a heat pump chiller. The VRF system is more feasible than the heat pump chiller system. It is the lowest running cost rather to other systems in the winter season.

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