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Comparative Analysis of the Effect of Replacing Central System Heating and Cooling with VRF Technology on Energy Efficiency

Merkezi Sistem Isıtma ve Soğutmanın VRF Teknolojisi ile Değiştirilmesinin Enerji Verimliliği Üzerindeki Etkisinin Karşılaştırılmalı Analizi

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ABSTRACT

In today's landscape, where energy efficiency and environmental impact are paramount in heating and cooling systems, Variable Refrigerant Flow (VRF) technology emerges as a compelling alternative to traditional systems. This article thoroughly evaluates the benefits of VRF technology, emphasizing its flexibility, efficiency, and cost-effectiveness.

VRF systems, with their dynamic refrigerant flow control, offer superior energy efficiency compared to fixed-speed traditional systems. This adaptability to varying heat demands enhances operational efficiency and reduces energy consumption, making VRF technology a sustainable choice.

Financial analysis further supports the case for VRF technology, demonstrating significant long-term cost savings. A case study of a student dormitory in Mersin illustrates the practical application of VRF, with detailed heat loss and gain calculations informing equipment selection.

Comparing selected Fan Coil Units (FCU) with VRF systems reveals a substantial 28% reduction in operating costs with VRF. Consequently, transitioning to VRF systems presents both economic and environmental advantages, as demonstrated by the successful implementation in the dormitory project.

In summary, this study highlights the transformative potential of VRF technology in improving energy efficiency, reducing costs, and enhancing sustainability in heating and cooling systems. Aimed at industry professionals and engineers, this analysis serves as a valuable guide in adopting more efficient and environmentally friendly solutions.

Keywords: VRF, Fan Coil, Conventional Water Systems, Energy Consumption.

ÖZ

Günümüzde enerji verimliliği ve çevresel etkinin ısıtma ve soğutma sistemlerinde ön planda olduğu bir dönemde, Değişken Soğutucu Akışkan Debisi (VRF) teknolojisi, geleneksel sistemlere kıyasla cazip bir alternatif olarak öne çıkmaktadır. Bu makale, VRF teknolojisinin esneklik, verimlilik ve maliyet etkinliği gibi faydalarını ayrıntılı bir şekilde değerlendirmektedir.

VRF sistemleri, dinamik soğutucu akışkan debi kontrolü ile sabit hızlı geleneksel sistemlere göre üstün enerji verimliliği sunar. Değişen ısı taleplerine uyum sağlama yeteneği, işletim verimliliğini artırır ve enerji tüketimini azaltır, bu da VRF teknolojisini sürdürülebilir bir seçenek haline getirir.

Mali analizler, VRF teknolojisinin uzun vadede önemli maliyet tasarrufları sağladığını göstermektedir. Mersin'deki bir öğrenci yurdu örneği, VRF'nin pratik uygulamasını, ısı kaybı ve kazancı hesaplamalarıyla detaylandırarak ekipman seçiminde nasıl bir yol izlendiğini ortaya koymaktadır.

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Seçilen Fan Coil Üniteleri (FCU) ile VRF sistemlerinin karşılaştırılması, VRF ile işletme maliyetlerinde %28'lik önemli bir azalma olduğunu göstermektedir. Sonuç olarak, VRF sistemlerine geçiş hem ekonomik hem de çevresel avantajlar sunmakta, yurt projesindeki başarılı uygulama bunu kanıtlamaktadır.

Özetle, bu çalışma, VRF teknolojisinin enerji verimliliğini artırma, maliyetleri düşürme ve ısıtma ve soğutma sistemlerinde sürdürülebilirliği artırma konusundaki dönüştürücü potansiyelini vurgulamaktadır. Sektör profesyonelleri ve mühendisler için hazırlanan bu analiz, daha verimli ve çevre dostu çözümlerin benimsenmesi konusunda değerli bir rehber niteliğindedir.

Anahtar kelimeler: VRF, Fan Coil, Geleneksel Sulu Sistemler, Enerji Tüketimi

Introduction

The negative effects of fossil fuels (coal, oil, etc.) on human life and our planet continue. In this context, efforts are ongoing to increase energy efficiency and improve comfort parameters in devices and systems used for heating and cooling. Variable Refrigerant Flow (VRF) and Fan Coil Unit (FCU) applications stand out as systems reflecting these efforts. VRF systems, with their flexible architectural and geometric compatibility features, can be used in various structures, from schools to hospitals, providing energy-saving capabilities by performing heating and cooling processes.

FCU systems can be configured as 2-pipe or 4-pipe. While a 2-pipe system can only perform heating or cooling, a 4-pipe system can operate in both heating and cooling modes simultaneously, depending on user preferences and space requirements. System equipment, determined according to the needs of the space, can provide either heating or cooling in a 2-pipe system, while in a 4-pipe system, spaces can use both heating and cooling modes simultaneously. Schematic diagrams of the FCU System and VRF systems are shown in Figure 1 and Figure 2.

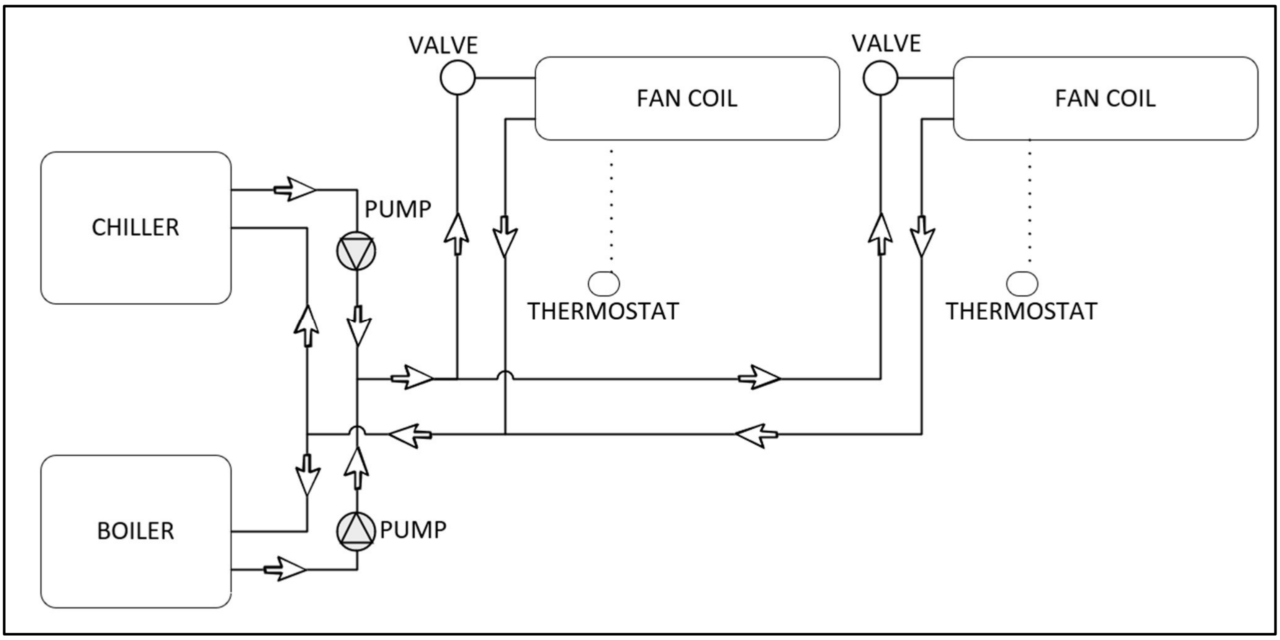

Figure 1.
FCU System Schematic Diagram

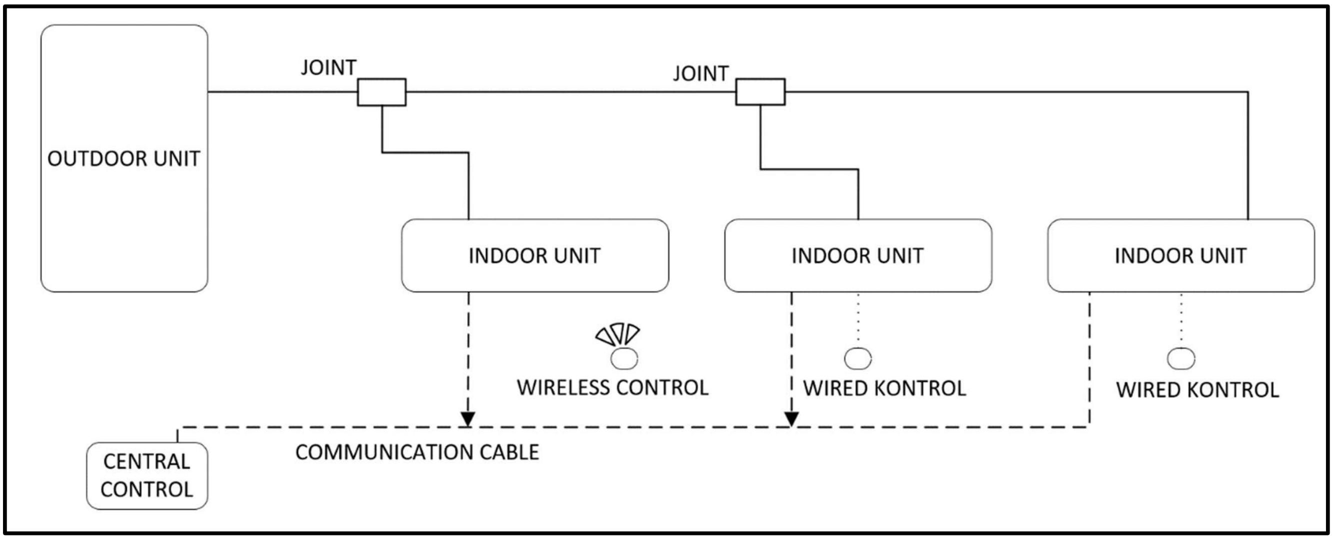

Figure 2.

VRF System Schematic Diagram

Extensive research has been conducted on VRF and FCU systems, and these studies continue. The findings obtained from examining these studies are summarized below.

Aynur et al. (2006) a study on VRF systems involving an office application, showed that the individual control mode provided more effective thermal control and higher thermal efficiency compared to the general control mode.

In their study on a VRF system with two indoor units, Park et al. (2001) studied how well a VRF system with electronic expansion valves worked and stressed how important it is to make the right adjustments to get the best performance out of the system.

Xia et al. (2002) in his study on a VRF system with five indoor units and a three-pipe structure, demonstrated that using two compressors in tandem increased the system's performance.

Masuda et al. (1991) by developing a new control methodology for a two-indoor-unit VRF system, stated that the independent control of indoor units increased energy efficiency.

Hai et al. (2006a) in his experimental studies on a 3-pipe VRF system with a 30 kW rated capacity, found that the system had high Coefficient of Performance (COP) values in simultaneous heating and cooling mode.

Hai et al. (2006b) in his research on a VRF system with a storage tank for ice, stated that integrating an ice storage tank increased energy efficiency by 25% and calculated a return on investment within 3 years considering electricity prices in Shanghai.

Özsoy et al. (2019) by examining the differentiation of air velocities and air distribution in fan coil systems, revealed that using an optimally designed distributor could contribute to achieving a more homogeneous air distribution.

Material and Methods

The General Features of the Building

The mentioned "1000-Person Male Student Dormitory" is located at Mersin University's Yenisehir campus in Mersin (Figure 3). The mechanical installation reports for the premises have been obtained from the Ministry of Youth and Sports of the Republic of Turkey.

In the current project, a traditional water heating and cooling system was preferred. To explain the traditional system, in the traditional system, boilers are used to heat the water and chillers are used to cool the water.

Boilers generally work with fuel (natural gas, fuel oil, biofuel, etc.) or electricity. The boiler produces heat by heating or evaporating water. This heat provides heating to the building or facility through a heating system. Boiler systems use energy from the combustion process to heat water and generally transfer heat by circulating the water in a loop.

Chillers are generally used in ventilation, air conditioning and cooling systems. Chillers cool an environment, usually using water or another refrigerant. Chillers work by circulating the refrigerant and allowing this fluid to exchange heat. Depending on the cooling load, chillers can use the condensation principle to cool the cooling water (with the help of a cooling tower) or use compressors to cool the cooling liquid.

AutoCAD project drawings, on the other hand, have been acquired from the project author. In the project, the selections for Fan Coil Units (FCU) have been made, and the selections for Variable Refrigerant Flow (VRF) devices are conducted in this study. The total enclosed area of the building is approximately 35000 square meters, comprising a total of 418 premises.

Operation calculations have been performed, taking into account both summer and winter conditions, as well as seasonal transitions.

Figure 3.
1000-Person Male Student Dormitory

VRF Indoor Unit Selection
The VRF device selections were made using a Daikin Xpress selection program. The device type selections were made as concealed ceiling type and cassette type of the same kind as the selected fan coils. Depending on the number of devices within the premises, one or more individual control selections were made. Since the FCU system in the project is two-pipe, for the sake of comparison and preference, the VRF system was also preferred as a two-pipe system. This means the system can operate in either heating or cooling mode simultaneously. Figure 4 and Figure 5 show the indoor unit types of VRF systems.

Figure 4.
Ducted Type VRF Indoor Unit

VRF Outdoor Unit Selection
During the selection of the outdoor units, the diversity ratio was taken into consideration in the system. However, due to the nature of the existing structure being a dormitory rather than a residential building, the diversity ratio was preferred to be minimal. The outdoor units have been selected according to the two-pipe system (Figure 6). The planned location for the outdoor units is in unused spaces at the top of the building.

Figure 5.
Cassette Type VRF Indoor Unit

Figure 6.
VRF Outdoor Unit

Determination of the Location of Copper Pipe Installation
In a VRF system, unlike the FCU system, there are specific rules for piping. The most crucial rule is that the copper pipe distance from the first indoor unit separation to the last indoor unit should not exceed 40 meters. Therefore, zoning has been implemented within each section of the building. Due to the limited number of indoor units that can be connected to each outdoor unit, zoning has also been implemented between floors.

Heat Loss and Gain Calculation, and Heating-Cooling Group Selections
The selections of the boiler chiller group, made based on the building's heat loss and gain charts and received from the project author, have been organized and presented in Table 1 and Table 2.

Table 1.

Boiler Capasity Selection

Boiler Capacity (Q_b)		
Heating zone 1	46300	kcal.h^{-1}
Heating zone 2	51950	kcal.h^{-1}
Heating cone 3	46150	kcal.h^{-1}
Zone 1 FCU installation	98550	kcal.h^{-1}
Zone 1 FCU installation	92300	kcal.h^{-1}
Zone 1 FCU installation	112750	kcal.h^{-1}
Kitchen fresh air AHU	35000	kcal.h^{-1}
Boiler installation (Q)	1700000	kcal.h^{-1}
Total heating requirement	2183000	kcal.h^{-1}
Safety factor	5	%
Device capacity	2292150	kcal.h^{-1}

3 quantity premix burner condensing boilers with 800000 kcal.h-1 capacity were selected. 2 quantity air-cooled water chillers with a cooling capacity of 800 kw have been selected. (It will be able to meet the needs in the climatic conditions of the region.)

Table 2.

Chiller Capacity Selection

Chiller Capacity(Qc)		
Zone 1 FCU installation	469650	kcal.h^{-1}
Zone 2 FCU installation	540950	kcal.h^{-1}
Zone 3 FCU installation	559150	kcal.h^{-1}
Total cooling requirement	1569750	kcal.h^{-1}
Coincident time factor	85	%
Device capacity	1334288	kcal.h^{-1}

The list of devices specified in the project for the VRF system is shown in Table 3.

VRF System Zoning Plan

Zoning and outdoor unit (OU) selection capacities are provided in Table 4.

Ground floor plan zones are shown in Figure 7 and outdoor units are shown in Figure 8. Figure 9 shows an overview of the building.

Results

FCU and VRF System Operational Costs

After the selection of VRF system outdoor units, the one-year operational cost based on space requirements, seasonal COP and seasonal efficiency (SEER) values is shown in Table 5.

Based on the selections made for the boiler, chiller, and circulation pump in the project, the electricity consumption and natural gas consumption for the gas-fired floor-standing boiler are calculated and the one-year operational cost is shown in Table 6-12.

The calculations do not take into account the electricity consumption of the indoor units in the systems, as they are significantly low compared to external factors. The calculations assume no consumption for 2 months, each representing the transition between the summer and winter seasons. The unit price of natural gas is considered 6.07 TLm^{-3}, and the unit price of electricity is considered 4.62 TLkWh^{-1}. It is anticipated that instead of 3 units of 800000 kcal.h^{-1} floor-standing natural gas boilers, 1 unit of 688000 kcal.h^{-1} capacity floor-standing natural gas boiler will be used for hot water usage. The percentage-wise comparison of VRF operating costs is shown in Table 13.

Table 3.

Device Selection List

Description	Capacity(kW)	Quantity
4 way cassette	1.7	50
4 way cassette	2.2	8
4 way cassette	2.8	48
4 way cassette	3.6	25
4 way cassette	4.5	58
4 way cassette	5.6	18
4 way cassette	7.1	22
M.S.P hidden ceiling	2.8	14
M.S.P hidden ceiling	3.6	200
M.S.P hidden ceiling	4.5	95
M.S.P hidden ceiling	5.6	3
Outdoor unit	52	2
Outdoor unit	78.5	1
Outdoor unit	90	2
Outdoor unit	102.4	4
Outdoor unit	123.5	4
Outdoor unit	130	2
Outdoor unit	135	1
Outdoor unit	140.4	2
Outdoor unit	145.8	1
Outdoor unit	151.2	1
Joint		295
Joint		114
Joint		91
Joint		26
Expansion valve		2
Expansion valve		3
Expansion valve		5
Outdoor unit 2-joint		7
Outdoor unit 3-joint		11
Wired control		445
Central control		7

Table 4.

Zones and Capacities

Unit	HP	Location	Capasity(kW)	Unit	HP	Location	Capasity(kW)
OU-1	50	Ground floor left	63.8	**OU-10**	32	5th floor middle	46.6
		1st floor Left	79.7			6th Floor Middle	46.6
		Total	**143.5**			**Total**	**93.2**
OU-2	46	2nd floor left	69.4	**OU-11**	38	7th floor middle	46.6
		3rd floor left	64			8th floor middle	61.2
		Total	**133.4**			**Total**	**107.8**
OU-3	44	4th floor left	64	**OU-12**	32	1st basement floor right	91.4
		5th floor left	64				
		Total	**128**			**Total**	**91.4**
OU-4	44	6th floor left	64	**OU-13**	52	Ground floor right	69.6
		7th floor left	64			1st floor right	82.5
		Total	**128**			**Total**	**152.1**
OU-5	28	8th floor left	76.4	**OU-14**	48	2nd floor right	71.3
						3th floor right	65.9
		Total	**76.4**			**Total**	**137.2**
OU-6	54	2nd basement floor middle	19.7	**OU-15**	44	4th floor right	65.9
		1st basement floor middle	131.2			5th floor right	65.9
		Total	**150.9**			**Total**	**131.8**
OU-7	38	Ground floor middle	108.9	**OU-16**	46	6th floor right	65.9
		Total	**108.9**			7th floor right	65.9
OU-8	38	1st floor middle	109.7				
		Total	**109.7**			**Total**	**131.8**
OU-9	50	2nd floor middle	52	**OU-17**	28	8th floor right	79.2
		3rd floor middle	46.6				
		4th floor middle	46.6				
		Total	**145.2**			**Total**	**79.2**

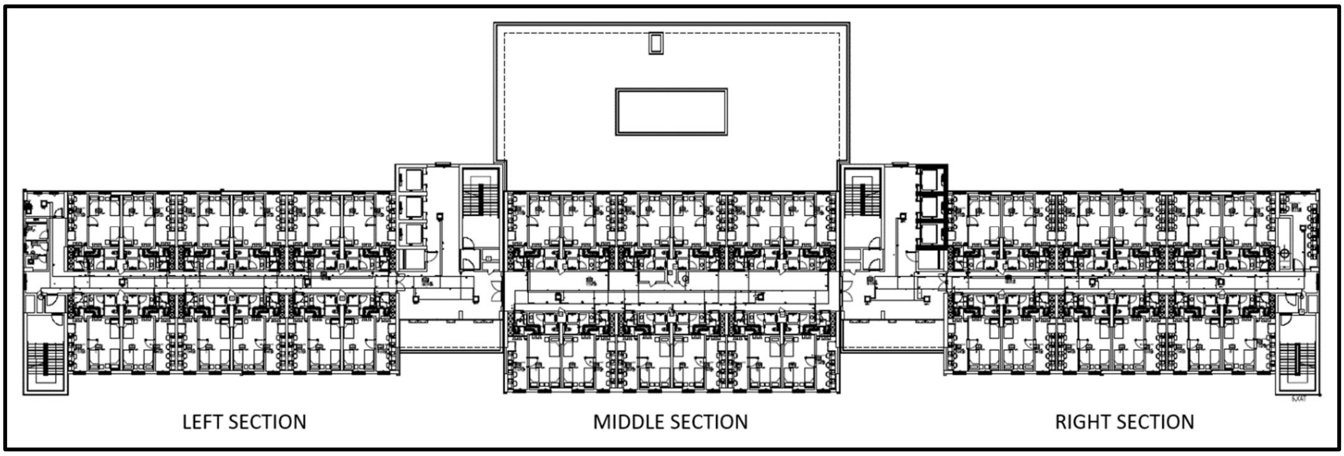

Figure 7.
Floor Plan Zones

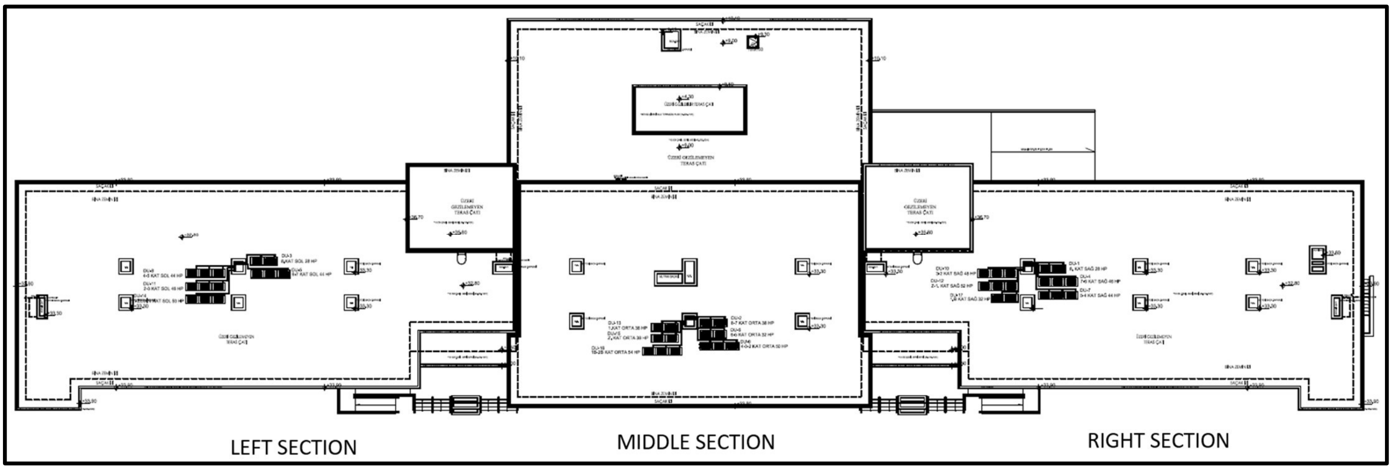

Figure 8.
Outdoor Unit Layout Plan

Figure 9.
Overview of and information about the building

Table 5.

Annual Operational Cost of the VRF System

Od unit name	SCOP	SEER	Cooling			Heating		
			Total capacity required (kW)	**Total working (hour)**	**Total consumption (kWyear^{-1})**	**Total capacity required (kW)**	**Total working (hour)**	**Total consumption (kWyear^{-1})**
DU-1	4.2	6.4	143.5	1200	26906.3	40.19	2100	20095
DU-2	4.1	6.4	133.4	1200	25012.5	40.18	2100	20580
DU-3	4.2	6.5	128.0	1200	23630.8	40.58	2100	20290
DU-4	4.2	6.5	128.0	1200	23630.8	41.49	2100	20745
DU-5	4.2	6.5	76.4	1200	14104.6	26.89	2100	13445
DU-6	4.3	6.4	150.9	1200	28293.8	22.20	2100	10841.9
DU-7	4.3	6.9	108.9	1200	18939.1	19.00	2100	9279.1
DU-8	4.3	6.9	109.7	1200	19078.3	21.80	2100	10646.5
DU-9	4.2	6.4	145.2	1200	27225	42.39	2100	21195
DU-10	4.2	6.4	93.2	8640	125820	28.65	2100	14325
DU-11	4	6.3	107.8	8640	147840	35.44	2100	18606
DU-12	4.3	6.4	91.4	1200	17137.5	25.57	2100	12487.7
DU-13	4.3	6.4	152.1	1200	28518.8	42.14	2100	20580
DU-14	4.1	6.4	137.2	1200	25725	41.09	2100	21046.1
DU-15	4.2	6.5	131.8	1200	24332.3	41.51	2100	20755
DU-16	4.1	6.4	131.8	1200	24712.5	41.71	2100	21363.7
DU-17	4.2	6.5	79.2	1200	14621.5	27.16	2100	13580
DX-1	4.0	5.9	57.0	1200	11593.2	10.0	2100	5250
DX-2	4.2	6.5	128.0	1200	23630.8	27.0	2100	13500
DX-3	4.0	5.9	0.0	1200	0.0	56.0	2100	29400
			Total electricity consumption (kWYear^{-1})		650752.6	Total electricity consumption (kWYear^{-1})		338010.9
			Total working time			Total working time		
			1 year	5	month	1 year	5	month
			1 month	30	day	1 month	30	day
			1 day	8	hour	1 day	14	hour

VRF installation heating & cooling annual energy cost (TL)	Total (kWyear^{-1})	Electricity unit price (TLkW^{-1})	Annual energy cost (TLyear^{-1})
	988763.5	**4.62**	**4568087.39**

Table 6.

Circulation Pumps Total Consumption (Heating)

	Flow (m^3h^{-1})	High pressing (mss)	Pump number (principal-reserve)	Pump power calculation (numberkW^{-1})	Pump power calculation (total kWh^{-1})
Boiler primary circuit	40	5	3P	1.00	3.00
Towel warmer	8	10	1P +1R	0.30	0.30
Fan coil	20	10	1P +1R	1.00	1.00
Ahu heating installation	2	10	1P +1R	0.30	0.30
Total consumption (kW)					**4.60**

Table 7.

Natural Gas Consumption (Heating)

Boiler capacity (kW)	1990	Working days per month	30
Natural gas lower heating value (kcal.h^{-1})	8.250	Working months per year	5
Boiler efficiency (%)	85	Annual consumption (m^{3}year^{-1})	512504.81
Consumption (m^{3}h^{-1})	244.05	Natural gas unit price (TLm^{-3})	6.07
Daily working hour	14	Annual energy cost (TLyear^{-1})	3110904.21

Table 8.

Circulation Pumps Annual Energy Cost (Heating)

	Hourly pump consumption (kWh^{-1})	Daily working hours	Days worked per month	Month worked per year	Annual consumption (kWyear^{-1})	Electricity unit price (TLkW^{-1})	Annual energy cost (TLyear^{-1})
Circulation pumps total consumption	4.60	14	30	5	9660	4.62	44629.20

Table 9.

Circulation Pumps Total Consumption (Cooling)

	Flow (m^{3}h^{-1})	High pressing (mss)	Pump number (principal-reserve)	Pump power calculation (numberkW^{-1})	Pump power calculation (total kWh^{-1})
FCU	80	20	4P+1R	6.50	26
Chiller group	70	16	4P+2R	5.00	20
Total Consumption (kW)					46

Table 10.

Circulation Pumps Annual Energy Cost (Cooling)

	Hourly pump consumption (kWh^{-1})	Daily working hours	Days worked per month	Month worked per year	Annual consumption (kWyear^{-1})	Electricity unit price (TLkW^{-1})	Annual energy cost (TLyear^{-1})
Circulation pumps total consumption	46	8	30	5	55200	4.62	255024

Table 11.
Chiller Annual Energy Cost

Chiller capacity (kW)	1600	Month worked per year	5
Energy Efficient Ration (EER)	3.0	Annual consumption (kWyear^{-1})	640000
Consumption (kW)	533.33	Electricity unit price (TLkW^{-1})	4.62
Daily working hours	8	Annual energy cost (TLyear^{-1})	2956800
Days worked per month	30		

Table 12.
FCU System Annual Energy Cost

Consumption name	Annual energy cost (TLyear^{-1})
Natural gas consumption (heating)	3110904.21
Circulation pumps annual energy cost (heating)	44629.20
Circulation pumps annual energy cost (cooling)	255024
Chiller annual energy cost	2956800
Total energy cost	6367357.41

Table 13.
Annual Operating Cost Analysis for VRF and FCU Systems

VRF installation heating & cooling annual energy cost (TL)	FCU system annual energy Cost (TL)	Annual energy cost difference (TL)	With VRF system annual energy savings (%)
4568087.39	6367357.41	1799270.03	28%

Conclusions

VRF systems have a more professional structure with mass production and an extensive service network. The assembly processes are carried out by authorized services designated by the manufacturing companies, using copper pipes produced in factories. On the other hand, FCU system equipment and piping processes are also performed by authorized personnel. Labor in FCU systems requires more human skills compared to VRF systems, leading to a higher likelihood of manufacturing errors. This indicates that both systems have different assembly and production processes.

VRF systems tend to offer more advantageous prices in terms of initial investment costs since they have single-firm production. On the other hand, the components that make up the FCU system may face more time and cost challenges in material procurement during the operation process since they cannot be supplied by a single company. The higher number of components in the FCU system also requires more technical personnel. In FCU systems, the fresh air needs in the spaces can be met using a DX coil heat recovery device instead of a water coil heat recovery device. DX coil outdoor units are also selected for air handling units in this study.

When considering the annual operating expenses for both systems, the calculated annual operating cost for the VRF system is 4568087.39 TL, while for the FCU system, it is 6367357.41 TL. The calculated operational cost difference between the two systems is 1799270.03 TL annually.

Considering all these factors, it can be said that VRF systems are more efficient in terms of energy consumption and operational ease compared to central heating and cooling systems.

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