



**MARMARA UNIVERSITY**  
**INSTITUTE FOR GRADUATE STUDIES**  
**IN PURE AND APPLIED SCIENCES**



# **ANALYSIS OF HVAC SYSTEMS FOR A SAMPLE BUILDING**

HALMYRAT TOKGAYEV

**MASTER THESIS**

Department of Mechanical Engineering

**Thesis Supervisor**

Assoc. Prof. Dr. Candemiz SEÇKİN

ISTANBUL, 2020



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## ACKNOWLEDGEMENT

I express my sincere gratitude to my supervisor Assoc. Prof. Dr. Candemiz SEÇKİN for her advice and encouragement throughout my research and this dissertation. I would also like to acknowledge Beta Teknik Ltd. family for sharing valuable experience, data and their understandings. I sincerely thank Mr. Onur KARAÖZ for his useful comments on calculations and the HVAC system design. Finally, I warmly thank my family for their understanding, endless patience and continuous support during this period.

Halmyrat TOKGAYEV

Istanbul 2020

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## ÖZET

Günümüzde günden güne artan enerji talepleri dünyadaki enerji kaynaklarının tükenme riskini ve küresel ısınmayı beraberinde getirmektedir. Tüketilen toplam enerjinin yaklaşık %40'ı binalarda ve hizmet sektöründe harcanmaktadır [1]. Türkiye'de son on sene içinde binalarda ve hizmet sektöründe harcanan enerji miktarı 23.172 kGW'dan 36.013 kGW'a yükselerek bir buçuk katının üzerine çıkmıştır [2]. Devamlı artan bu enerji talebi karşısında en etkin çözümler, enerji verimliliği daha yüksek sistemler kullanmak ve yenilenebilir enerji kaynaklarından yararlanmak olacaktır.

Bu çalışmada, İstanbul'da bulunan örnek bir otel binası seçilerek, üç ayrı HVAC sistemlerinin ekonomik ve enerji tüketimi açısından karşılaştırılması yapılmıştır. Bu sistemler: A) VRF+Kazan, B) Chiller+Kazan, C) Absorpsiyonlu Isı Pompalarıdır. Çalışmada sırasıyla, ilgili standartlara göre ısı yalıtımı ve taze hava değişimleri hesaplandıktan sonra, Carrier HAP bilgisayar programı yardımı ile cihaz boyutları belirlenmiştir. Daha sonra, üretici kataloglarından cihaz seçimleri yapılmış ve model bina üzerinde yıllık simülasyonu gerçekleştirilmiştir. Proje mimarisi üzerinde üç ayrı sistemin çizimi ve dizaynı yapılarak mekanik projelerin keşif listeleri ve maliyetleri çıkartılmıştır.

Ekonomik açıdan değerlendirildiğinde, Sistem B en ucuz ve Sistem C en pahalı kurulum maliyetine sahip olduğu görülmüştür. İşletme giderlerinde ise en yüksek olan Sistem A, en uygunu Sistem C olmuştur. Bugünkü değer yöntemi (BDY) ile tesisat ömrü boyunca nakit akışı hesabı yapılmıştır. Çıkan sonuçlarda, Sistem C'nin kurulumunun en pahalısı olmasına rağmen, yedinci seneden sonra Sistem A'ya göre daha ucuz sistem konumuna geleceği görülmüştür.

İncelenen sistemlerin birincil enerji tüketimi ve emisyon değerleri de hesaplanmıştır. Yıllık salgılanan eşdeğer karbondioksit (CO<sub>2</sub>) miktarları incelendiğinde, Sistem A ve B'nin birbirine çok yakın, Sistem C'nin sonuçlarının ise diğerlerine göre önemli ölçüde azaldığı, kullanılması durumunda 0,06 CO<sub>2</sub> kg/kWh tasarruf edileceği görülmüştür.

## **ABSTRACT**

Nowadays the increasing of energy demands day by day, causes the risk of depletion of energy resources and global warming in the world. Approximately 40% of the total energy is consumed by buildings and service sectors [1]. In Turkey, through the last ten years the amount of energy in buildings and service sectors consumption has reached one and half times, increased from 23.172 kGW to 36.013 kGW [2]. The most effective solutions against to this constantly increasing energy demand is to apply of higher energy efficient systems and to benefit from renewable energy sources.

In this study, by selecting a sample hotel building in Istanbul, three different HVAC systems are compared in terms of economical aspect and energy consumption. These systems are: A) VRF+Boiler, B) Chiller+Boiler, C) Absorption heat pumps based HVAC systems. After calculating of heat insulation and fresh air changes according to the related standards, device dimensions are determined by means of Carrier HAP computer program. Then, device selection part is performed by means of from manufacturer catalogs and annual simulation is carried out for model building. By drawing and designing of three different systems on the architectural project, bills of quantity lists of mechanical projects and costs are calculated.

From the economic perspective, System B is found as the cheapest system and System C the most expensive one to install. In operating expenses, the most expensive one is System A and the most affordable System C. With the present value method (NPV), cash flow calculations are calculated throughout the life of installation. In the results, it is seen that although the installation of System C is the most expensive one, it is been more profitable than System A within seven years.

Primary energy consumption of the analyzed systems and emissions are also presented. In terms of annual amount of equivalent carbon dioxide (CO<sub>2</sub>) emission, System A and B are very close to each other, but in System C, significantly decreases with regard to the others systems and 0.06 CO<sub>2</sub> kg/kWh saving is determined.

## **ABBREVIATIONS**

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers.

HVAC – Heating, Ventilation and Air Conditioning.

Absorption Machines - Refers to both absorption chillers and absorption heat pumps.

HAP – Hourly Analysis Program.

FCU – Fan Coil Unit.

VRF – Variable refrigeration flow.

AHU – Air Handling Unit.

BS – Branch Circuit.

DX – Direct Expansion Refrigerant Evaporator.

COP - Coefficient of Performance.

EER - Energy Efficiency Ratio.

SEER - Seasonal Energy Efficiency Ratio.

DHW - Domestic hot water.

VCC - Vapor compression cycle.

VAC - Vapor absorption cycle.

GAHP - Gas Absorption Heat Pump.

ErP - Energy Related Products.

NPV – Net Present Value.

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# 1 INTRODUCTION

## Thermal Comfort for Human Body

The human body produces heat as a result of the digestion, and loses it continuously. It has ways to adjust (increase or decrease) its heat loss. The heat lost from human body occurs with the help of conduction, convection, radiation and evaporation. The human feels thermal comfort when the environment, the clothes and the lost heat are in equilibrium (Figure 1.1). As the optimum conditions for human health and comfort range from 20 to 24 °C and 40 to 50% relative humidity [3]. The human thermoregulation and comfort have not changed through the history. However, the environments and conditions in which they consume their lives have changed. Most of the facilities where humans occupied are air conditioned now. The ratio is even higher in the commercial buildings. Therefore, air conditioning systems have an important part in the modern life.

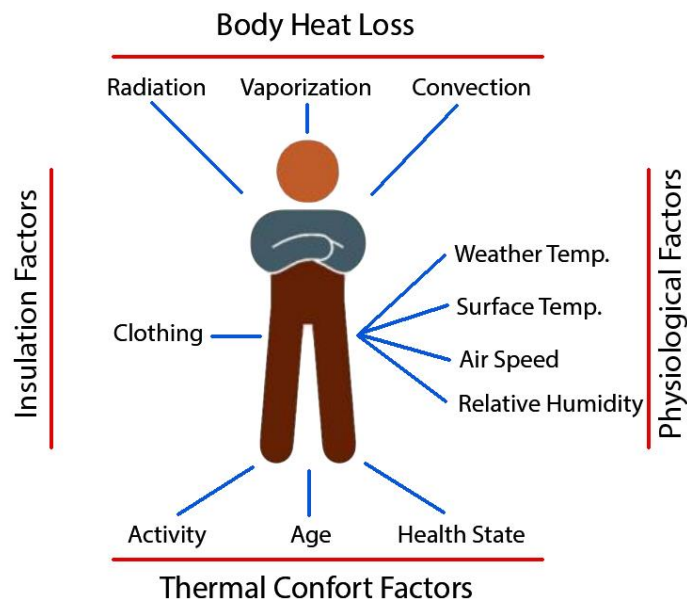
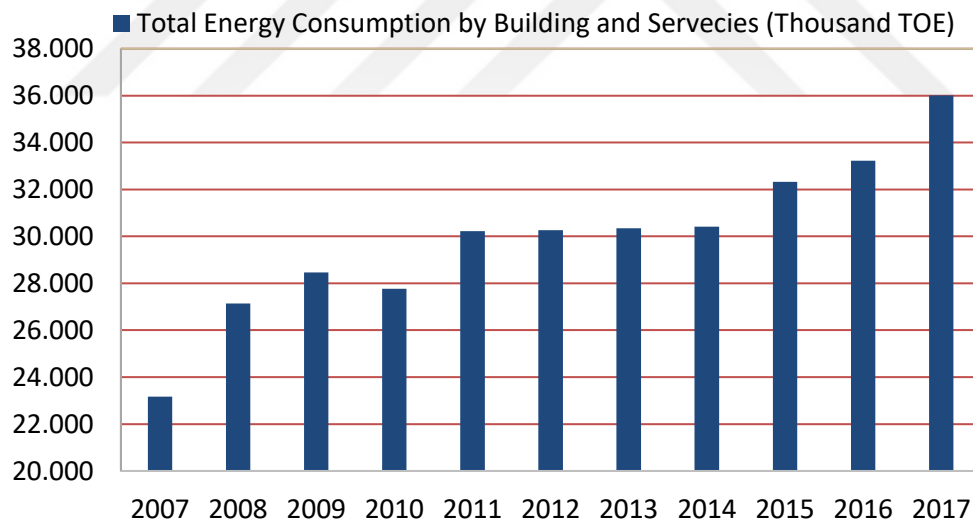


Figure 1.1 Human Body and Environment Heat Interaction Models

## Energy consumptions of the buildings

World energy demand increases in time. Due to both of the increasing of population and the need of more comfortable spaces, the requirement of air-conditioning in the buildings is also growing. As a result, the importance of using clean and renewable energy sourced systems in buildings is rising every day. In the HVAC sector, there is going to be approximately 1% growth per year till 2035 and the energy used by households is estimated to be 60% of primary energy production [4]. At the present time, the energy used in buildings is approximately 41% and 70% of it is consumed for heating and cooling [1].

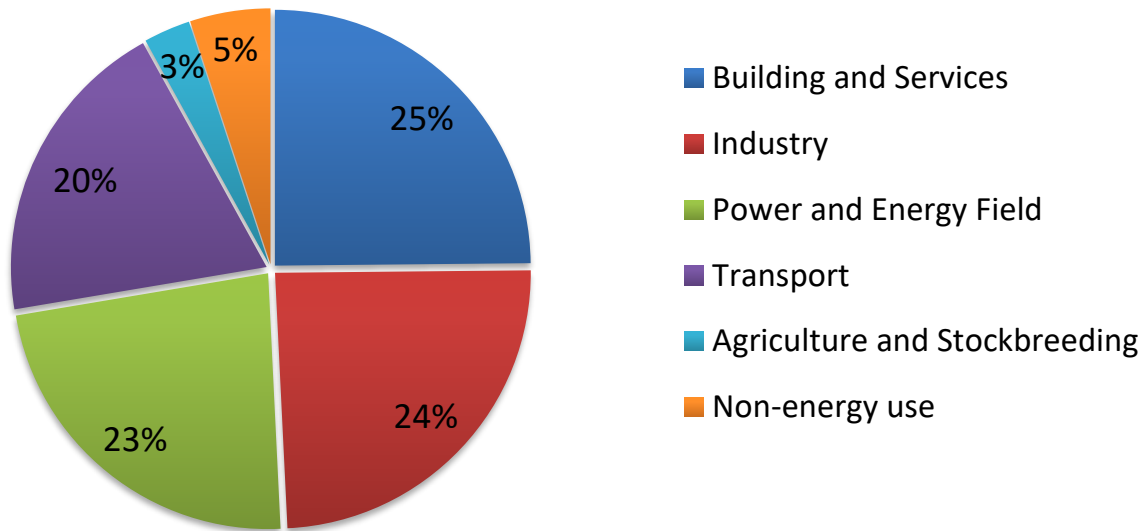
In order to decrease the energy consumption, new legislations are enacted and exist legislations are updated continuously. According to a 2015 USA government survey, 87% of the buildings in the United States use air conditioner and 65% of those homes have central air conditioning [5].



**Figure 1.2 Total energy consumption by buildings and services in Turkey by years**

The total energy consumption percentage of buildings and services in the last ten years are given at Figure 1.2 [2]. The country's total energy demand has increased %36 over

the last decade. Therefore, the use of alternative energy in the future is inevitable both economically and environmentally.



**Figure 1.3 Total Energy Consumption Distribution by Sectors in 2017**

Total energy consumption distribution by sectors in 2017 is shown at Figure 1.3 [2]. Energy consumption by residential and industrial area is around 72% of the total consumption. In these sectors, where energy is used intensively and hence, alternative energies come to the fore. New emerging systems for saving measures can reduce the energy consumption rate. In recent decades, many new HVAC technologies such as chilled beam and underfloor air distribution have been invented to reduce energy consumption without sacrificing indoor thermal comfort and air quality.

One of the highest energy consumptions is seen in hotel buildings. Together with offices and retails, hotels are the most energy consuming facilities, typically 50% of the total energy consumption in UK, 64% in US, and 85% in Spain [6].

Energy end uses	USA (%)	UK (%)	Spain (%)	Hong Kong (%)	Vietnam (%)
Lighting	22	17	33	17	10
Equipment	13	5	10	-	19
HVAC	48	55	52	45	54
Lift	-	-	-	7	17
Others	21	23	5	31	-

**Table 1.1 The comparisons of end-use energy consumptions for hotel buildings [6]**

The aim of this study is to prepare a source material to select the right heating, cooling and air conditioning systems for hotels which operates all day long with accompanying high energy consumption. Annual hourly dynamic energy simulation for selected three different cooling and heating systems is performed for Istanbul climate. It must be also highlighted that gas absorption chillers are not commonly used in Turkey; hence, this study can provide a deeper understanding for gas absorption chiller application in air conditioning.

## 1.1 Literature Review

Human always searching for more efficient alternative ways of doing a work. The ever-growing positive science and technology provide opportunities to examine innovative ways of doing a work with less power. In the literature, there are many studies about comparison of different heating and cooling systems for different applications by using with various simulation computer programs.

Alkan Fatih. (2017) compared by using energy analyze models for 5 common HVAC systems for a building. The first system is the existing system which is Variable air flow

system (VAV) + radiator, the other four systems are water source heat pump, heat recovery VRF / VRV, heat pump VRF / VRV + Radiator and 4 pipe Fan coil system respectively. In all 5 systems, energy consumption, initial investment cost, operation and maintenance costs were compared and according to the results optimum systems were proposed for short, medium and long terms. [7]

Existing cultural and social building which has total 8852 m<sup>2</sup> a heating and cooling area, investigated to compare conventional HVAC system with VRF by Ozahi E. vd (2016). They analyzed in thermodynamic and economic perspectives after measured actual data from existing system in the building. By assessing the heating and cooling capacity, initial, operation and maintenance costs, it was found that the VRF system is more economic and efficient such that the VRF system is found to have 44% cost profit when compared with the conventional HVAC system. [8]

Gazinga F. vd. (2016) investigated solar heat driven absorption chiller. They examined the option of operational the absorption chiller by solely relying on solar heat energy. They focused on minimizing the life cycle cost of a solar heat driven absorption chiller through optimizing the size of all of its main components. The system was named the standalone solar heat fired absorption chiller (SA-SHF-ABS-CH) sized to sufficiently meet the space conditioning demands, both heating and cooling, of a typical Australian 6 star home. For the aims of this research, TRNSYS17 software was used in modelling and dynamically simulating the integrated system, while GenOpt software was used to carry out the optimization. The economic assessment on the most optimally sized system component configuration showed, firstly, the twenty-year lifecycle cost of the system with the most minimized cost is AU\$ 53,387 in Brisbane, AU\$ 51,639 in Adelaide and AU\$ 32,816 in Melbourne. These investment costs in each of these cities appeared higher than those incurred if the householder were to instead install a standard efficient inverter, ducted, reverse cycle air conditioner (IRC-AA-HP) powered by grid electricity; as follows: Brisbane at 77%, Adelaide at 58% and Melbourne at 28%. Secondly, the payback period was found to be longer than the twenty-year system service life, which is far too long to justify the investment on such solar air-conditioner. However, when compared with IRC-AA-HP, in Adelaide and Melbourne, SA-SHFABS-CH consumed at least 50% less power, meaning it offsets half of

the carbon dioxide emissions. [9]

Jignesh M. Barot (2014) designed a heating, ventilating, and air conditioning (HVAC) system to satisfy the environmental requirements of comfort or a process, in a specific building or portion of a building and in a particular geographic locale. Efficient design of heating, ventilating and air-conditioning (HVAC) systems was a primary concern in building projects. The HVAC system design and equipment selection for a commercial building (376 TR) was included as a case study in this paper. The outcomes of that paper were efficient design of HVAC system with minimum energy consumption and equipment selection based on operating and life cycle cost analysis. [10]

Özkan Gökhan (2013) presented an assessment of absorption cooling system's energy efficiency on sample application. He has done the theoretical and practical examination of the hotel that has 60 rooms has been done. The hotel is located in the town of Aliğa, Izmir. It provides for the needs such as hot water, heating and cooling with the help of absorption heat pumps and chillers which are located at the roof. Four units of absorption cooling machines are participated in the hotel. The cooling capacity of a machine is 17.72 kW. The cooling machines operate with the ammonia-water solution. The chillers are connected in series to each other and cooling is provided with fan coils. The absorption cooling systems were compared with the other cooling systems for this sample application. The payback period was calculated by the economic analysis of the system and found 5 years. [11]

Yenice Merve (2010) studied the selection of appropriate heating, cooling and ventilation systems in publicly used buildings. Advantageous and disadvantageous sides of the systems were examined and comparisons were made between them. Heating, cooling and ventilation systems were examined during the construction of the building. It was evaluated which heating, cooling and ventilation systems to be used in terminal stations and similar buildings considering the criteria of comfort, maintenance and operation easiness, investment cost, operation cost and environmental factors. [12]

Bekir Erdiç Boz (2010) compared two kind of system for a hotel building in Istanbul. Alternative 1 was four piped Fan-coil system for cooling and heating. VAV system

in convention facilities, floor heating and dehumidification air handling unit was used in swimming area. As alternative 2, VRF was used instead of Fan-Coil used spaces, AHU cooling requirement was supplied from an air cooled group and heating needs was supplied from 4 pieces 92kW cascade systems. First investment prices and summer, winter operating prices also calculated and compared. Alternative 1 was found cheaper and convenient system in that year. Moreover, trigeneration loads calculated and it's report presented as energy supply system [13].

Gustafsson vd. (2011) presented a paper, dynamic simulation was used to compare the energy performance of three innovative HVAC systems: (A) mechanical ventilation with heat recovery (MVHR) and micro heat pump, (B) exhaust ventilation with exhaust air-to-water heat pump and ventilation radiators, and (C) exhaust ventilation with air-to-water heat pump and ventilation radiators, to a reference system: (D) exhaust ventilation with air-to-water heat pump and panel radiators. System A was modelled in MATLAB Simulink and systems B and C in TRNSYS 17. The reference system was modelled in both tools, for comparison between the two. All systems were tested with a model of a renovated single family house for varying U-values, climates, infiltration and ventilation rates. It was found that A was the best system for lower heating demand, while for higher heating demand system B would be preferable. System C was better than the reference system, but not as good as A or B. [14]

Liu and Hong (2010) promoted with the current movement towards net zero energy buildings, many technologies with emphasis on their superior energy efficiency. The variable refrigerant flow (VRF) and ground source heat pump (GSHP) systems were investigated. In their article, a preliminary comparison of energy efficiency between the air-source VRF and GSHP systems was presented. The computer simulation results show that GSHP system is more energy efficient than the air-source VRF system for conditioning a small office building in two selected US climates. In general, GSHP system is more energy efficient than the air-source VRV system, especially when the building has significant heating loads. For buildings with less heating loads, the GSHP system could still perform better than the air-source VRF system in terms of energy efficiency, but the resulting energy savings may be marginal.[15]

Nikoli vd. (2010) reported on a simulation appraisal of energy consumption, energy

costs and environment impact of three systems used for space heating, and space cooling of an office building in Kragujevac, Serbia. Three investigated systems were (1) a system with a natural gas boiler and convective baseboard heaters for water space heating and window air conditioners for air space cooling; (2) a system with a natural gas boiler and individual air reheaters for air space heating and a chiller plant for air space cooling; and (3) an air-to-air heat pump for air space heating, and cooling. The systems are modelled and simulated by using EnergyPlus software. After simulations, it is found that the first investigated system has the highest energy efficiency, the best economy, and the lowest environmental impact. That is because of the fact that the first system has water as a heating medium and uses predominantly natural gas as fuel [16].

Elamin and Kamal designed and constructed a lithium bromide–water (LiBr-H<sub>2</sub>O) absorption cooling system with a nominal capacity of approximately 1 TOR driven by solar energy which uses Lithium Bromide as absorbent and Water as refrigerant. The proposed absorption cooling system comprises a roof-mounted vacuum tubes solar collector, a single-effect LiBr–H<sub>2</sub>O absorption chiller (generator, a solution heat exchanger, an evaporator, a condenser, and an absorber), fan coil unit, a cooling tower, pumps, flow throttling and controlling valves. A thermodynamic analysis of the absorption cooling cycle has been performed to study the effect of various operating conditions on the thermal performance. Results from experimental work carried out in Khartoum City during October 2015 show that the COP of the absorption cooling system ranged from 0.57 to 0.64 while the Chilled water temperatures mostly ranged between 17°C to 19.5°C. Condensation and absorption temperatures were under 45°C while the maximum temperature of the driving water is 83°C. The results also show that the generator temperature had a great effect on the performance of absorption and solar collector systems.[17]

## **2 HVAC SYSTEMS**

One of the main reasons why we live in closed spaces is the thermal comfort. Natural environment is not eligible for human's biological comfort most of the time during a year. Therefore, we live in closed air-conditioned spaces. In order to keep the spaces at the comfort conditions, several complex tools and devices, in other word HVAC systems are used.

There are standards set by local authorities regarding efficiency and safety of devices and systems used in HVAC systems. These standards are updated from time to time to control the use of more energy efficient and environmentally preferable devices.

As mentioned in the introduction chapter, heating, ventilation and cooling of buildings are responsible for 30-40 % of total energy consumption in buildings and hence, significant amount of CO<sub>2</sub> emission [1]. Each building must have an energy certificate and regular inspections of HVAC. As a result, energy efficiency in HVAC systems and related certification attempts have received great attention from scientists, researchers, and engineers in the last decades. The most known certificates are: energy performance and green building certifications that evaluates the buildings from various aspects with life cycle approach. It is becoming increasingly common for clients to require green building certification for selected projects. The other well-known certification systems developed and implemented by different countries are BREEAM (Building Research Establishment Environmental Assessment Method), LEED (Leadership in Energy and Environmental Design), DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen eV), IISBE (International Initiative for Sustainable Built Environment), Greenstar (Environmental Rating System for Buildings), Casbee (Comprehensive Assessment System for Built Environment Efficiency) [18].

### **Heating**

In HVAC, heating process is transferring thermal energy to air which fills the conditioned zone, i.e. heating is increasing the sensible temperature of the air. Since the

controlled fire for heating, during the history humans have been in search of more effective and efficiency way of heating. In 1894, the American Society of Heating and Ventilating Engineers (ASH&VE) was established and central heating was highly developed [19]. In general, by burning the fossil fuel sources thermal energy is employed for the heating purpose. Last year, in 2018 ErP regulation was introduced and it was made compulsory to produce small size (<400 kW) combi boilers with condensation in Turkey [20].

## **Cooling**

Air conditioning is the process that removing heat (thermal energy) from the air in the occupied space.

In the 18th century, certain mixtures were used to lower the temperature. In 1851, John Gorrie received US Patent for a refrigeration machine that produces cold air and ice by using compressed air in an open loop. In 1851, Ferdinand Carre designed the first ammonia absorption unit. After ammonia, ether was the first refrigerant used in mechanical compressors. In the 1920s, the use of electrical power and the development of small refrigeration systems led to the development of residential vapor compression systems. In the 1980s, environmental problems, ozone depletion and greenhouse effects associated with full halogen refrigerants led the industry to struggle for alternative refrigerants [22, 23].

In 1902, Carrier achieved significant respectability by reducing the humidity of the air and keeping it at a certain level. This achievement is written in history as the birth of known true environmental control [23]. Air conditioning and refrigeration industry started in 1950s and has developed rapidly in Turkey [24].

### **2.1 System Selection and Designing**

There are various cooling and heating devices combination systems in the market today. In large buildings, central system solutions instead of local systems are advantageous in many respects such as: diversity factor can be applied and generally cheaper to install. Hotels are highly energy consuming facilities and possible HVAC system parts are presented in Table 2.1.

Heating Devices	Cooling Devices
<ul style="list-style-type: none"> <li>• Natural Gas Boilers</li> <li>• Absorption heat pumps</li> <li>• Solar thermal collectors</li> </ul>	<ul style="list-style-type: none"> <li>• Air Source Chiller</li> <li>• Water Source Chiller</li> <li>• Absorption Chiller</li> </ul>
<ul style="list-style-type: none"> <li>• Air Source Heat Pumps <ul style="list-style-type: none"> <li>○ Split air conditioner</li> <li>○ Three Pipe VRF</li> <li>○ Two Pipe VRF</li> </ul> </li> <li>• Water Source Heat Pump</li> <li>• Ground Source Heat Pump</li> <li>• Gas Engine Driven Heat Pump</li> </ul>	

**Table 2.1 Applicable Heating and Cooling Device Types for the Sample Building**

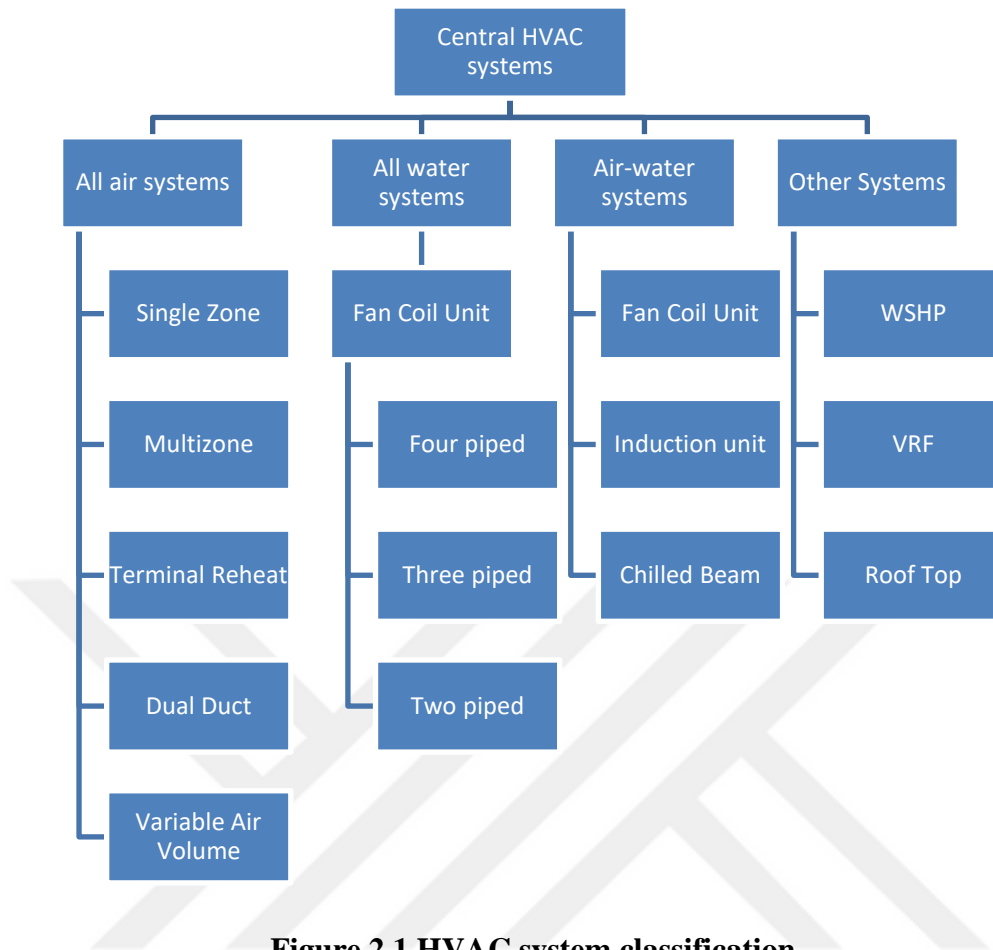
Gas Engine Driven Heat Pump is a newer technology compared to electric and gas absorption heat pumps, thus, knowledge about the system is limited. A gas engine heat pump mainly consists of two parts: a vapor compression heat pump circuit (composed by an open compressor, a condenser, an expansion valve and an evaporator) and a gas fueled internal combustion engine directly driving the compressor. Relative to electric heat pumps, gas engine driven heat pumps provide the advantage of reduction in energy conversion and transport losses because fuel conversion process occurs close to the place where energy is used. Today, in the market, commercially available gas engine heat pump units are produced by limited number by manufacturers.

There are various air condition alternatives which can meet the same requirements. System selection criteria are related to questions such as: what the factors that affect the selection are, what the expectations from the system and the requirement are. It is possible to align the main system selection criteria as follows:

- Structure of the building and the demands of the landlord
- Building's purpose of use
- Installation costs
- Management costs
- Capacity
- Performance
- Place requirement
- Credibility
- Ease of service maintenance
- Indoor air quality
- Thermal comfort
- Noise factor
- Environment factor
- Fire protection and smoke control

The cost and price of a facility is the sum of the first investment costs and the operational expenses throughout its usage life. In addition, management expenses also comprise several costs and the investment costs may be reduced during operation. Thus, the total capital cost can be found by calculating depreciation and profitability.

HVAC systems' classifications can be made in several ways. Figure 2.1 shows the classification for mechanical heating, cooling and ventilation which is conducted based on the fluid types. The thermal energy transfer medium can be air (all-air systems) or water (all-water systems) or both (air-water systems). Also, central systems include water-source heat pumps and heating and cooling panels.



**Figure 2.1 HVAC system classification**

## 2.2 VRF

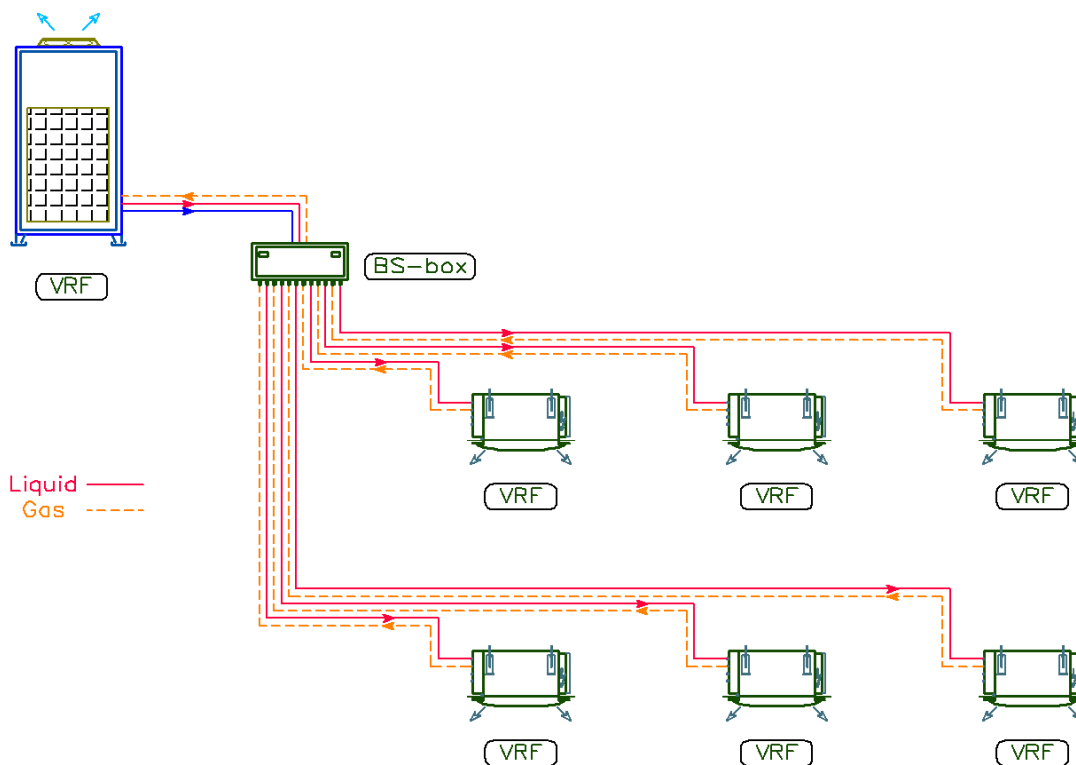
Second law of thermodynamics tells that the natural flow of heat is from the high-temperature source to the low-temperature one. Heat pump is a device that pumps heat to a higher temperature environment from one of a lower temperature. They use a refrigerant fluid to accomplish that process. The refrigerant is gone through a lower temperature source and boils by absorbing heat. Usually, heat pumps need compression to work and is powered by electricity. Variable refrigerant flow (VRF) type heat pump devices are one of the most used in air conditioning of buildings. All VRF devices provide cooling but may not heat. Models that can reverse the cooling cycle, can heat. In this study, VRF models providing both heating and cooling are used.

VRF is an air-condition system configuration where there is one outdoor condensing

unit and multiple indoor units. The term variable refrigerant flow refers to the ability of the system to control the amount of refrigerant flowing to the multiple evaporators (indoor units), enabling the use of many evaporators of differing capacities and configurations connected to a single condensing unit. The arrangement provides an individualized comfort control, and simultaneous heating and cooling in different zones.

VRF systems are grabbing a greater share of the market in moderate climates. However, they are not widely implemented in cold climates because they typically lose capacity and efficiency at low ambient temperatures. To overcome this barrier, VRF systems may be supplemented by an additional heat source. Alternately, they can be upgraded to water or ground source systems that are not subject to ambient temperatures.

As for the types of VRF system: two piped VRF systems can provide either cooling or heating to all of the zones while three pipe systems can provide heating and cooling at the same time. Heat recovery application enables to receive heat from cooled zones and use this heat in the zones that require heating. Therefore, VRF systems are suited to buildings which has multiple and varying heating and cooling demand zones. Heat recovery causes an increase in capital cost but it lowers operating costs of HVAC system.



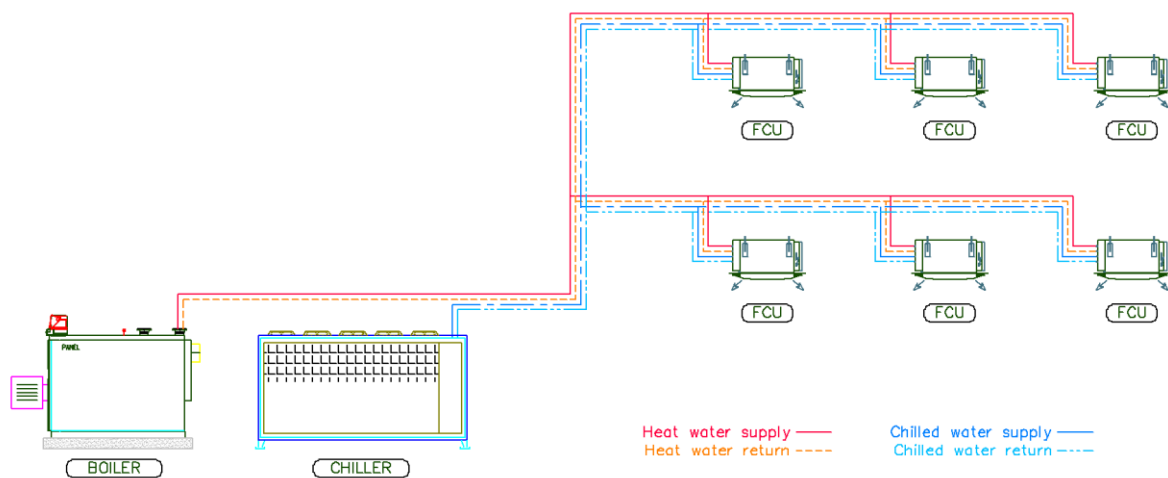
**Figure 2.2 Three pipe VRF system diagram**

### 2.3 FCU

FCU is used in a water circuit system. Hot or cold water produced by boiler and chiller (water cooling group) in a heat center, is connected to fan coil indoor units (Figure 2.3). These systems are generally used in buildings such as offices, shopping and commercial centers. In order to meet the heating requirements in winter and cooling requirements in summer in the rooms, a quadruple pipe FCU system + Primary air system shall be used and on/off valves on the FCU, are controlled via the command received by the room thermostats to be located in the places in order to change the indoor temperature. FCU air condition system is a system composed of the boiler on the heating side and the water-cooled chillers unit and water-cooling tower on the cooling side. In two piped FCU system, it is not possible to provide heating and cooling together to the building at the same time. However, four piped FCU system, when necessary, each FCU unit can do heating or cooling independent from each other. For this, an electronic control valve in the inner unit suitable for the changing of

the load in the service area, which is used to change the fluid flow of the cooler, must be located. Thus, a flexible system depending on the purpose and duration of the work is composed.

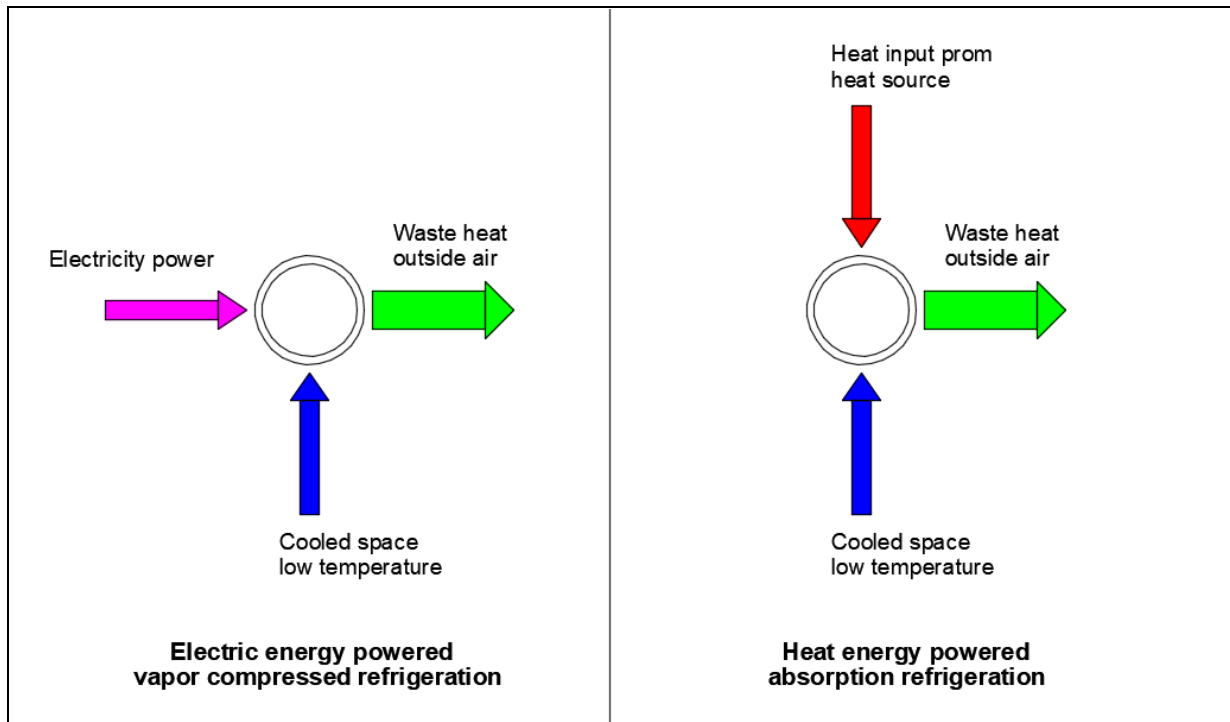
FCUs consist a fan, heating and cooling elements. Generally, they are not connected to ductwork. Recirculate the internal air through heat exchanger coil. In the case of the fresh air is provided to the space, ventilation system can be connected to the FCU, thus the fresh air is mixes with the FCU's recirculated air.



**Figure 2.3 Boiler, Chiller and FCU system diagram**

## 2.4 Air Source Chiller

Chillers are the major cooling equipment used in central cooling plants. They remove heat from the working medium, which is then distributed throughout the buildings. Chillers vary in type and applications, and fall into two major categories: vapor compression refrigeration cycle chillers, and absorption cycle chillers. Figure 2.4 shows two kind cycles' energy flows.



**Figure 2.4 Heat flow in electrical and heat powered refrigeration**

In compression systems, to absorb heat from water that returning from the building used a refrigerant which has a low boiling point. Then, in an evaporator the liquid refrigerant boils to a gas form. After the evaporation, to increase its temperature further, the gas is compressed. After that, the gas releases its rejected heat to the outside and condenses. Then the cycle repeats again.

Absorption chiller works with the similar principle. There is a refrigerant which boils at under pressure and low temperature. However, this time, there is an absorbent solution instead of compression within the device. The solution absorbs the liquid refrigerant in absorber and the mix of liquids are pumped to the generation. They are heated together, heated liquid refrigeration starts to get evaporate while absorbent stays liquid. Then the refrigerant goes to condenser separated from absorber, and condenses here by rejecting its latent heat to the ambience.

## 2.5 Boiler

A boiler is a significant part of technical apparatus that fuels are oxidized to generate thermal energy in it, which is delivered to water or steam. Boilers are typically used to heat water to feed heating systems or to provide hot water or both of them.

A boiler is an enclosed vessel that water is heated and circulated in it, either as hot water, steam or superheated steam according to the purpose of heating, powering or producing electricity. The fuel and air are introduced to combust from the furnace of the boiler. Normally, air and fuel mixtures are introduced to the furnace by using burners, so the flames are occurred there. The occurred hot gases move through a series of heat exchanges, where heat is transferred to the water flowing through them. Finally, the combustion gases removed from the system and release to the atmosphere by the stack of exhaust section of the boiler.

There is a numerically examined building that we have and for heating of water circulations we use a gas fuel boiler. The initial cost of the boiler is just a little part of the total costs compared with its lifelong. Hence the most important thing is its efficiency. The thermal efficiency of a boiler demonstrates that the effectiveness of the heat exchanger of the boiler which is using for to transfer the heat energy from fire side to water side. The total boiler efficiency is not just depending on combustion and thermal efficiency parameters. These parameters are ON-OFF losses, radiation losses, convection losses, blow down losses and many other parameters. "Direct method" is most commonly used method to find out boiler efficiency:

$$\eta(\text{efficiency}) = (\text{Energy output}) / (\text{Energy input}) \times 100$$

As a result of combustions in boilers, all of the generated heat cannot be used transferred to the fluid. Some of the heat is discharged from surfaces of the boiler and the others is thrown to the atmosphere with flue gas. The size of the heat that cannot be used is an important parameter affecting the boiler efficiency.

## 2.6 Absorption Machines

Absorption chiller system was invented for the first time in 1858 by French scientist Ferdinand Carre. The original design consists of water and sulfuric acid. Later in 1887, the developments in this area gained momentum with the first absorption chiller machine of Pontifex and Wood companies in England. After 1920s, especially in countries such as America, Germany, Italy, England, Belgium, Netherlands, Russia, studies on absorption cooling were continued. The largest absorption chiller plant manufactured on these dates and that had a cooling capacity of 4190 kW. After the 1950s, with the low cost of electricity and the use of compressors of different sizes and capacities, steam compression mechanical systems gained priority. In the 19th century, many processes were replaced by NH<sub>3</sub>-H<sub>2</sub>O [25].

The most commercial absorption chillers are operating with driving temperatures in the range of 90–100°C basis on single-effect chillers. COPs (normally) values are up to 0.8, as shown in Table 2.2. Theoretically, further increases in the driving temperature would increase the COP of a single-effect cycle even more. Currently, as a result of high costs, there are no reported double-effect commercial systems for small scale applications. Furthermore, to make COPs in the range of 1.4, double-effect chillers need higher driving temperatures, as high as 140–160°C. Triple-effect chillers which can rise the COP up to 1.7. that have been developed at lab scale. However, the fact that their need for driving temperatures of 200°C and high system complexity has excluded their commercial competitiveness for now [28].

Manufacturer (Country)	Model	Working Pair	Capacity (kW)	COP (-)
AGO (Germany)	Congelo	NH <sub>3</sub> -H <sub>2</sub> O	50–150	0.51
Baelz	Bee/Bumblebee	H <sub>2</sub> O-LiBr	50/160	0.8
Broad Air Conditioning Co. (China)	BCT	H <sub>2</sub> O-LiBr	16–500	1.1
Carrier Corporation (USA)	16LJ	H <sub>2</sub> O-LiBr	90–4,000	n/a
	16TJ	H <sub>2</sub> O-LiBr	350–2,500	n/a
	16NK	H <sub>2</sub> O-LiBr	352–4,652	n/a
Century Corporation (South Korea)	AR-D	H <sub>2</sub> O-LiBr	98–193	n/a
ClimateWell AB (Sweden)	ClimateWell Solar Chiller	LiCl-H <sub>2</sub> O	7	0.7
Colibri B.V./Stork B.V. (Netherlands)	ARP	NH <sub>3</sub> -H <sub>2</sub> O	100->2,500	Up to 0.8
EAW (Germany)	Wecagral SE	H <sub>2</sub> O-LiBr	15–200	0.71–0.75
En-Save (Germany)	En-Save Cold	NH <sub>3</sub> -H <sub>2</sub> O	30–100	n/a
Heinen & Hopman (Netherlands)	SWM60-SWM1200	H <sub>2</sub> O-LiBr	150–5,000	Up to 0.8
Helioclim (France)	(pilot plant)	NH <sub>3</sub> -H <sub>2</sub> O	10	n/a
Jiangsu Huineng (China)	RXZ	H <sub>2</sub> O-LiBr	10–175	0.70
Krloskar Pneumatic Company (India)	KVAC-SA/DA	H <sub>2</sub> O-LiBr	211–2,400	n/a
LG A/C (South Korea)	WCDH	H <sub>2</sub> O-LiBr	350–5,275	1.51
	WCMH	H <sub>2</sub> O-LiBr	98.4–3,587	0.80
Meibes System-Technik (Germany)	n/a	H <sub>2</sub> O-LiBr	5	n/a
Phoenix (Germany)	n/a	H <sub>2</sub> O-LiBr	10	0.74
Pink (Austria)	PC19	NH <sub>3</sub> -H <sub>2</sub> O	19	0.63
Robur (Italy)	GA ACF	NH <sub>3</sub> -H <sub>2</sub> O	17.7	Up to 0.9
Rotartica (Spain)	Solar 045	H <sub>2</sub> O-LiBr	11	0.67
Sakura (Japan)	SHL	H <sub>2</sub> O-LiBr	10.5–176	0.71–0.80
Slarice GmbH (Germany)	n/a	NH <sub>3</sub> -H <sub>2</sub> O	25–several MWs	n/a
Thermax (India)	LT 1/2/3/5	H <sub>2</sub> O-LiBr	35–171	0.78
World Energy Europe (Ireland)	S050-S1500 (single effect)	n/a	176–5,274	Up to 0.81
	SWHH100-1500 (double effect)	n/a	352–5,274	Up to 1.48
Yazaki (Japan)	WFC SC	H <sub>2</sub> O-LiBr	17.6–175.8	0.70
York (USA)	YIA	H <sub>2</sub> O-LiBr	422–4,840	

**Table 2.2 Overview of the Absorption Chiller Market [26]**

Absorption chillers manufacturers across the world are as shown in Table 2.2. Medium- and larger-scale commercial absorption chillers have been available for many years, while smaller-scale chillers have become a field of intense focus in recent years. In the EU, there are already about 45000 gas absorption heat pumps installed. [27] As is evident from

Table 2.2, commercial absorption chillers are mostly available at cooling capacities higher than 10 kW. The main challenge at the moment is to expand the market for smaller, domestic-scale applications, and thus develop cost-efficient directly fired absorption chillers.

The cycle of absorption heat pump work on the same principle compressor heat pump cycle. Schematic view of a small capacity (17 kW cooling and 35 kW heating) absorption heat pump model is shown in Figure 2.5. This model can supply heating or cooling by reversing the cycle. This cycle is called sing effect.

This kind of small capacity air cooled absorption heat pumps use  $\text{NH}_3\text{-H}_2\text{O}$  working fluid pair. Here, ammonia ( $\text{NH}_3$ ) is refrigerant gas and water ( $\text{H}_2\text{O}$ ) is absorbent solution. Unlike  $\text{LiBr-H}_2\text{O}$ , there is no the risk of crystallization in this fluid pair. Both of the  $\text{NH}_3\text{-H}_2\text{O}$  and  $\text{LiBr-H}_2\text{O}$  have not ozone depleting gas (ODG) or a global warming potential (GWP) gas effect. But they are toxic and flammable hence the absorption is generally located outside. The appearance of the outside installation of GAHP units are shown in Figure 2.6.

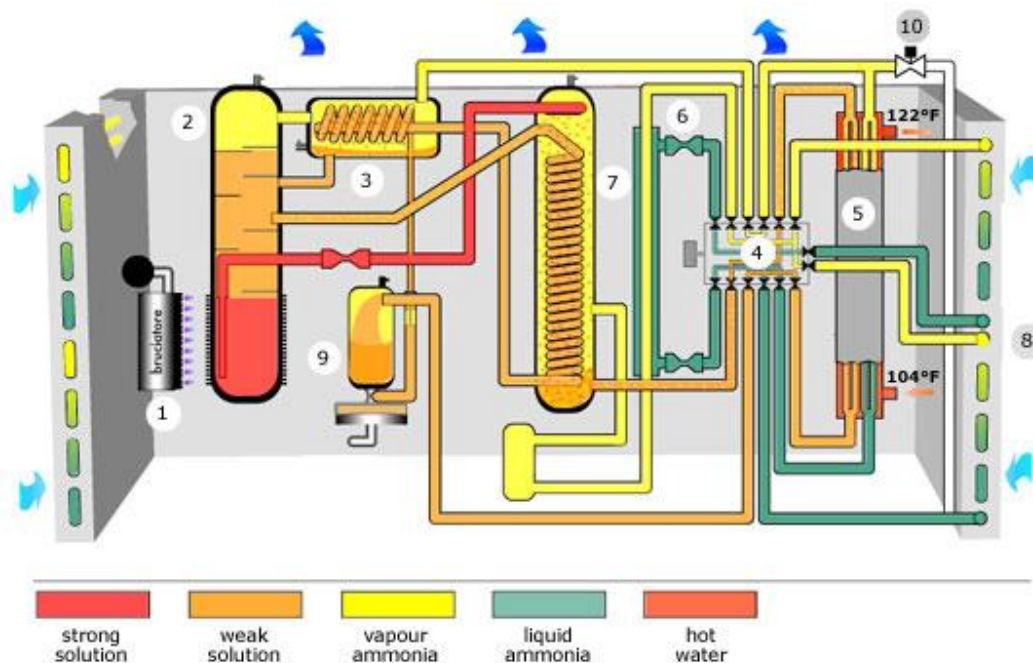
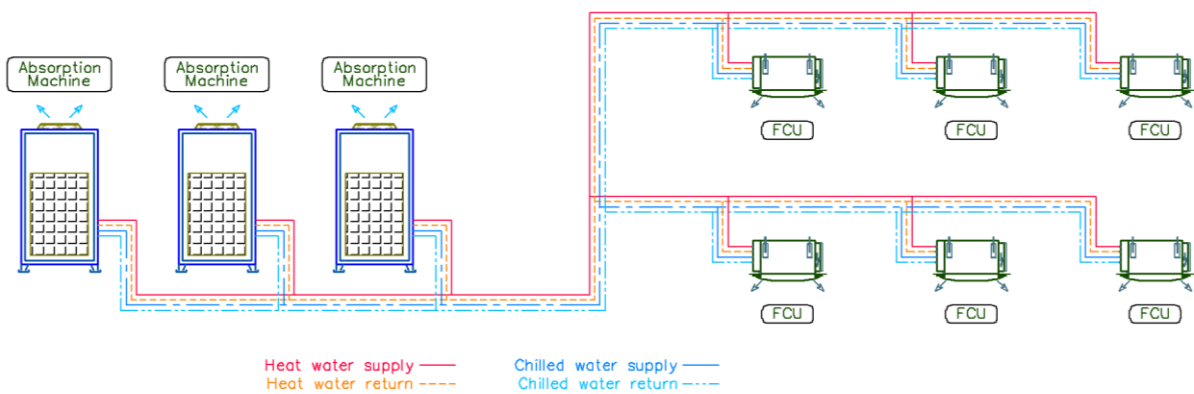


Figure 2.5 Gas Absorption heat pumps schematic view [28]



**Figure 2.6 GAHP units outside installation view**

These small-scale absorption devices are connected as in series to each other. This type of connection is called cascade system. Thus, necessary part load capacity is provided by turning on needed number of devices, so they can always be operated at maximum efficiency. Figure 2.7 shows typical absorption heat pumps systems diagram.



**Figure 2.7 Absorption heat pumps systems diagram**

## 2.7 Building Energy Performance Simulation Tools

Building energy performance simulation computer softwares became engineers' the most effective tools design and decision. With the help of these programs, a small mathematical model of buildings is created in a virtual environment. Different outdoor and indoor conditions can be easily tested in different fuel consumed devices. Lots of commercial and freeware programs are available and each has its own features. Therefore, coupling of the programs and co-simulation between them, is more appropriate to use strengths each of them in some situations. HAP Carrier E20-II program is in widespread use in Turkey. In this study HAP carrier software is used.

**HAP Carrier** - Energy and operating cost analysis can be carried out full 8760 hours-per-year. Dynamic heating, cooling and miscellaneous loads are calculated using the ASHRAE®1-endorsed Transfer Function load method. This is commercial program. Renewably energy sources and importing or exporting any drawn geometry of building are not supported.

**Energy Plus** includes innovative simulation capabilities including time steps of less than an hour. It can be used for simulations of many common HVAC types, naturally ventilated buildings, buildings with day lighting control, double facades, advanced solar shading strategies etc.

**Revit** is a 3d geometric modeling Autodesk program. Architectural, mechanical, electrical and static project's drawings can be done in BIM project modeling environment. For HVAC systems dynamic energy analysis and life cycle assessments can be carried out.

**DOE-2** covers all major building systems including lighting daylighting, HVAC, water heating and the building envelope. Hourly results are available for detailed analysis.

**eQUEST** is a freeware sophisticated, yet easy to use building energy use analysis tool which provides professional-level results with an affordable level of effort. This is accomplished by combining a building creation wizard, an energy efficiency measure (EEM) wizard and a graphical result display module with an enhanced DOE-2-derived building energy use simulation program.

**ESP-r** is a freeware created by University of Strathclyde. It is possible to model thermal, visual and acoustic performances of the modeled building. This has more flexible in modeling building physics. This capable cooperate with TRANSYS.

**TRANSYS** is a commercial useful tool in the fields of renewable energy engineering and building simulation for passive as well as active solar design. The developer of this program is University of Wisconsin-Madison.

**TRACE** is presented by TRANE company. Windows based program is used to construct a virtual building, calculate its air conditioning loads, and simulate its hourly operation through a year. It can perform a life cycle cost analysis.

**IDA** – is also commercial simulation engine. It is introduced in 1998 by EQUA Simulation AB, SE. Widely use in Sweden and Finland. Dynamic renewable energy sources and importing of drawing from CAD programs are supported.

### 3 SISTEM DISCRIPTIONS

In this study, three different heating and cooling systems are analyzed for a sample hotel building and comparison of the results are presented in terms of cost, energy consumption and emission production of the systems. The analysis is conducted at Istanbul city climate conditions. These systems are selected from manufacturer catalogue with all other ancillary equipment. The configuration of the systems and system names are listed in Table 3.1. System A and System B are widely used and are ubiquitous. However, System C is rarely encountered in application (the reasons are extensively discussed in conclusion chapter).

Cases	Heating Plant	Cooling Plant	Delivery
System A	VRF + Boiler	VRF	VRF
System B	Boiler	Chiller	FCU
System C	Absorption Heat Pump	Absorption Chiller	FCU

**Table 3.1 Selected Heating and Cooling Systems**

The first System A case is designed as VRF + Primary air system in order to supply the heating load demands in winter and the cooling in summer in the rooms. All guest rooms are mechanically ventilated with pre-conditioned fresh (outdoor) air supply and extract ventilation, which operate on a continuous basis with no local control by the occupants. The pre-conditioned fresh air is ducted to the supply side of the VRF units and are connected separately to the supply diffuser. Fresh air and extract air ventilation main ductwork are located within the ceiling space of guestroom corridors and shafts on each floor.

The building is designed in CAD drawing environment in AutoCAD computer program. Whole mechanical designs and systems are drawn one by one on the architectural plan. Riser schemes are also drawn. Otherwise the survey list's calculations would not be possible without drawing its mechanical plan.

Load calculations and device selections are made in Excel Microsoft and HAP Carrier programs. The design and calculation stages can be listed in the following steps:

- Determining the sample building's insulation values for all partitions for Istanbul climate zone.
- Entering all conditioned spaces to the HAP with all details (internal loads, air change rates etc.).
- Creating HVAC systems in the HAP.
- Creating cooling and heating plants for the built systems.
- Drawing the mechanical design plan.
- Sizing the systems and selecting from manufacturers' catalogue.
- Calculating materials and labor prices.
- Annual simulation of the building.
- Analyzing and comparing of the reports.

### **Sample Building Description**

The selected case study building is a typical hotel building located in Istanbul. Total area of hotel building is 16.454 m<sup>2</sup> and has 6 floors, 150 guestrooms. The analyzed sample building geometric view and architectural drawing of a guest rooms floor is shown in Figure 3.1 and Figure 3.2. The main departments of the hotel are listed below:

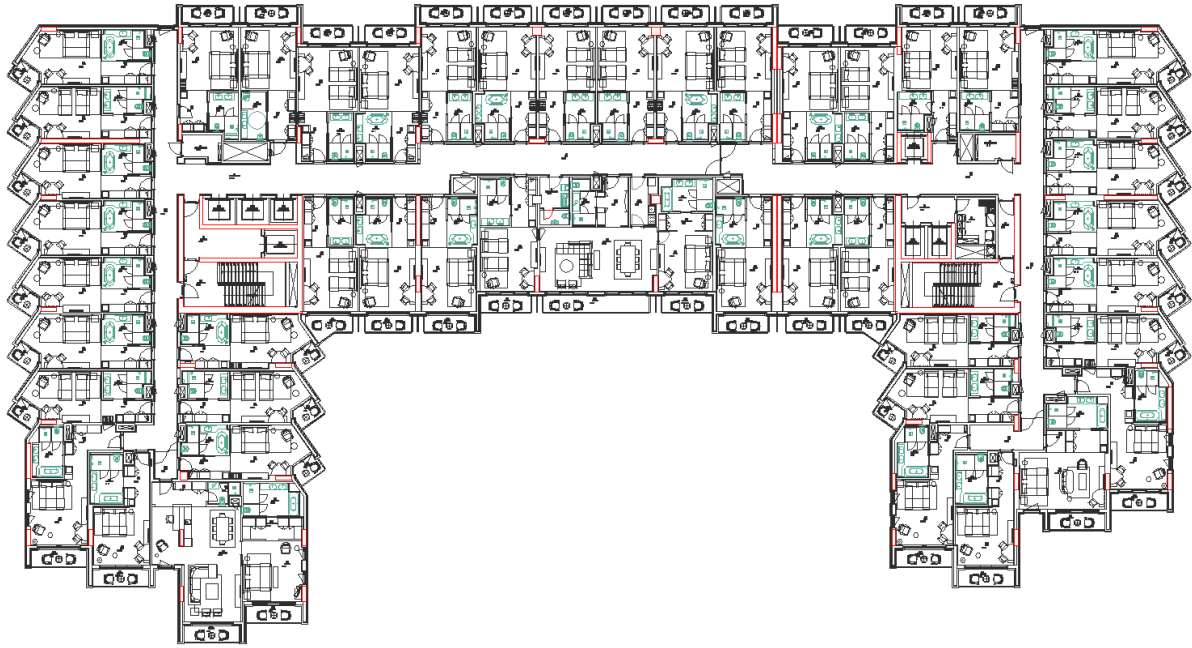
- 2nd Basement Floor;  
Technical Areas, Carpark, Storages.
- 1st Basement Floor;  
Main Kitchen, Laundry, Office Areas, Technical Areas.
- Ground Floor;

Lobby, Lobby Lounge Bar, Restaurant, Entertainment Bar, Hall, Offices, Children and Youth Activity Area, Fitness Center, Meeting Rooms, Foyer, Pool Area, Spa Area, Changing Rooms

- 1st-3rd Floors;  
Guest Rooms, Corridors, Lounge, Halls.



**Figure 3.1 3D view of the analyzed sample building**



**Figure 3.2 First floor plan**

## **Standards and Building Design Criteria**

Standards and regulations are the main limiting factors in HVAC system selections. Local and international standards and regulations are used to be able to control the energy efficiency and safety in buildings. These standards also play an active role in system selection by limiting device efficiencies.

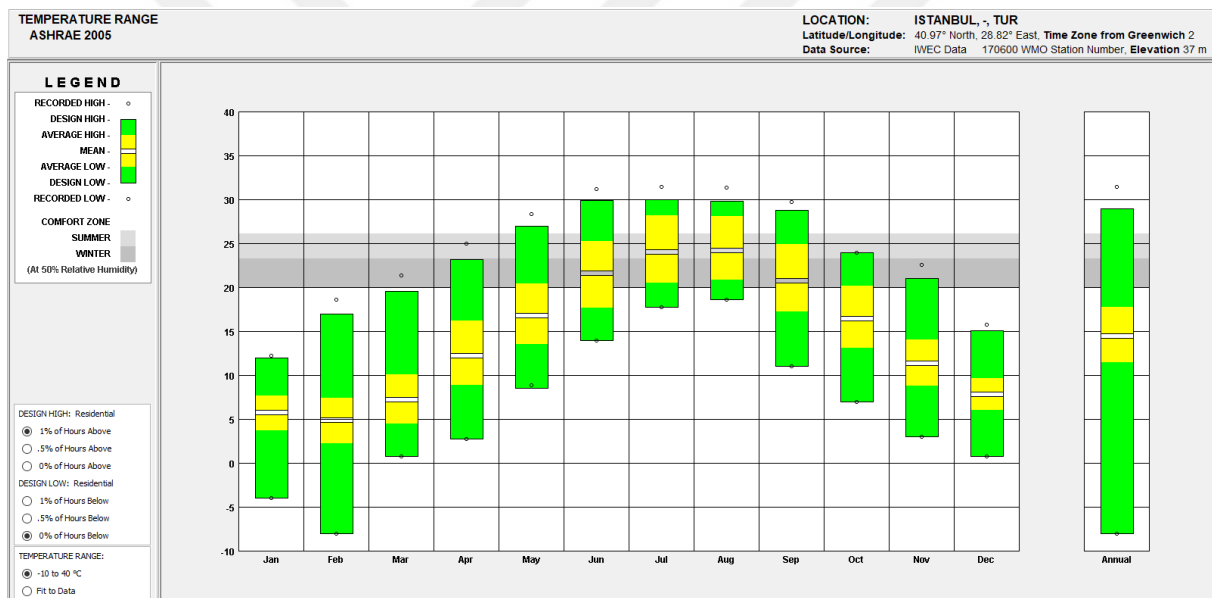
Design and drawing of the project, building license are obtained from local authority to construct the building. In this study all the design stages are made to correspond to given standards and regulations, regarding the design of the mechanical installation systems (air condition, ventilation, heating, cooling, automatic control system).

### **3.1 Outdoor and Indoor Air Conditions**

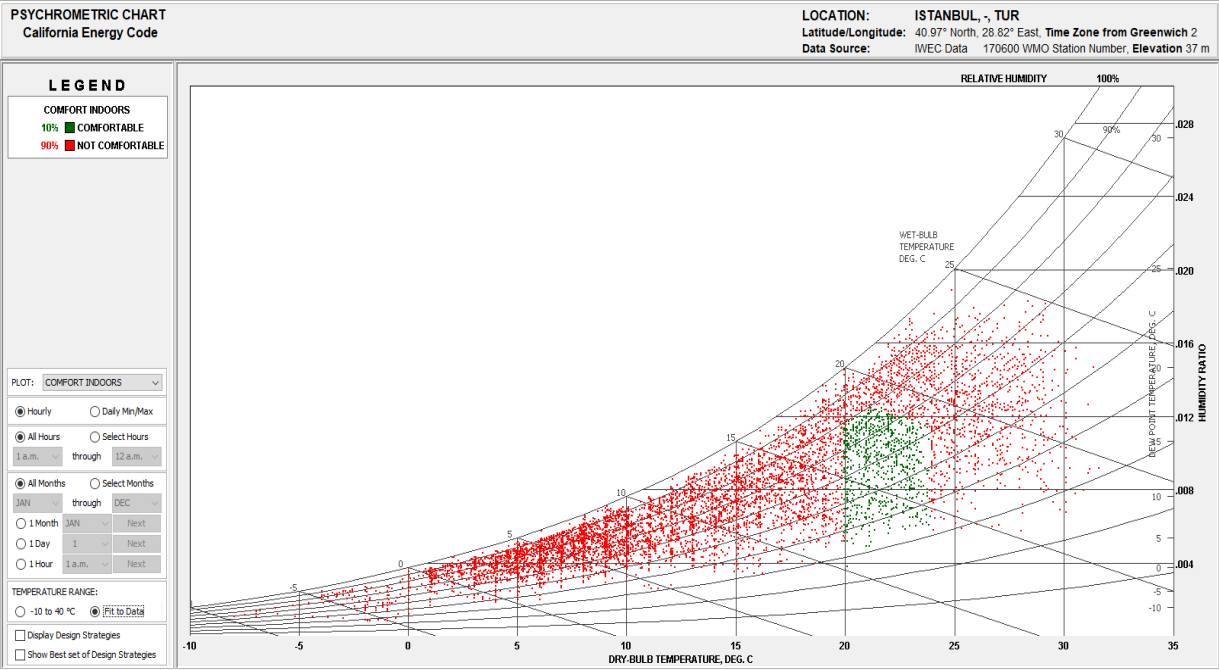
Istanbul has a heating dominated weather. Figure 3.3 shows monthly temperature ranges through a year. Figure 3.4 shows hourly psychrometric chart of Istanbul. Each point

on it, shows a day's represented climate conditions. Green dots are the days that do not require air conditioning, which corresponds to the comfort zone. As it seen in the figure, the climate of this city is comfortable to human body only in transition seasons. In other months, air-conditioning is strongly required in zones to supply thermal comfort.

While calculating the heating-cooling values of the structure, applied outdoor air properties are presented in Table 3.2. These values are reported in TS 3419/9.1 (Turkish Standard: Ventilation and Air Conditioning Installation - Requirements of Project) standard. Outdoors's design temperature is taken as -3 °C for winter condition, and 33 °C dry bulb, 24 °C wet bulb temperatures for summer. Indoor air properties are seen in Table 3.3. All the HVAC devices and system sizes are selected according to this critic temperatures.



**Figure 3.3 Monthly temperature range**



**Figure 3.4 Hourly psychrometric chart of Istanbul [29]**

<b>Istanbul</b>	<b>Climate conditions</b>
Altitude Above Sea Level:	40 m
Wind:	Summer: KD13
	Winter: KD13
<b>Winter Conditions:</b>	
Outdoor air temperature:	-3 °C
According to the warm	
<b>Summer Conditions:</b>	
Dry Bulb Temperature:	33 °C
Wet Bulb Temperature:	24 °C
Daily Temperature	10.50 °C
Humidity Rate:	48%
Moisture Content:	15.20 gr/kg
Enthalpy:	72.4 kJ/kg

**Table 3.2 Outdoor air conditions**

<b>Indoor</b>	<b>Summer</b>		<b>Winter</b>
	<b>KT Temp. (°C)</b>	<b>RH (%)</b>	<b>KT Temp. (°C)</b>
Hotel – Bedrooms	23	45-55	22
Hotel – General Areas	23	45-55	21
Hotel – Offices	24	45-55	22
Kitchens	27	45-55	18

**Table 3.3 Indoor air conditions**

### 3.2 Insulation

TS 825 standard regarding the “Heat Insulation Regulations in the Buildings” which entered into force in June 2008 provides considerable advantages in terms of energy saving. Increasing the capacity of heat storage in the building is important due to the increasing energy costs today. Storage capacity depends on the mass and specific heat of the building component.

Aim of the TS 825 standard is to provide energy saving in heating and cooling process of buildings being constructed in Turkey. In order to provide energy saving in the aforementioned sample hotel building, TS 825 heat insulation standards are applied in this study. Heat transmission factors of Istanbul (U factor) are presented in Table 3.4 [30].

Components	U values (W/m <sup>2</sup> K)
External Wall Details: Aerated Concrete Wall	0,36
External Wall Details: Reinforced Concrete Wall	0,55
External Wall Details: Soil Contact Wall	0,56
Internal Wall Details: Aerated Wall	0,77
Internal Wall Details: Reinforced Concrete Wall	1,95
Internal Floor Details: Heated and non-heated	0,98
Roof Details	0,34
Door	3,50
Window	1,80

**Table 3.4 Heat transmission factors (U) of Istanbul**

### 3.3 Domestic Hot Water Calculation

Domestic Hot Water						
Lavatory	262	x	7,5	=	1.965	lt/h
Lavatory General	20	x	30	=	600	lt/h
Shower	167	x	250	=	41.750	lt/h
Sink	5	x	70	=	350	lt/h
					44.665	lt/h
Coefficient of Utilization:					0,25	
Coefficient of Storage:					0,80	
	V =	44.665	x	0,2	=	<b>9.000 lt/h</b>
Water Inlet Temperature			10	°C		
Water Outlet Temperature			50	°C		
Heating Load: ...l/h x (1h/3600s) x 4.18kJ/kgK x 1 kg/L x dT K						
Load per hour =						<b>420,0 kW</b>
Kitchen and Laundry						
Kitchen and Laundry	1	x	10000	=	10.000	lt/h
Coefficient of Utilization:					0,25	
Coefficient of Storage:					0,80	
	V=	10.000	x	0,2	=	<b>2.000 lt/h</b>
Water Inlet Temperature			10	°C		
Water Outlet Temperature			60	°C		
Heating Load: ...l/h x (1h/3600s) x 4.18kJ/kgK x 1 kg/L x dTK						
Load per hour=						<b>120,0 kW</b>

**Table 3.5 Energy Calculations of Hot Water Supply**

Domestic hot water (DHW) constitutes an important part of total energy consumption. As seen in Table 3.5, heat demand for DHW calculation is calculated by applying the diversity factor after determining the hot water needs of all the spaces using hot water.

Temperature of DHW is 60 °C at the exit of the central heating unit. Storage and recovery capacity of DHW supply system is large enough to maintain design temperature of water at all peak usage hours including laundry and kitchens.

### 3.4 Internal Heat Gain Assumptions

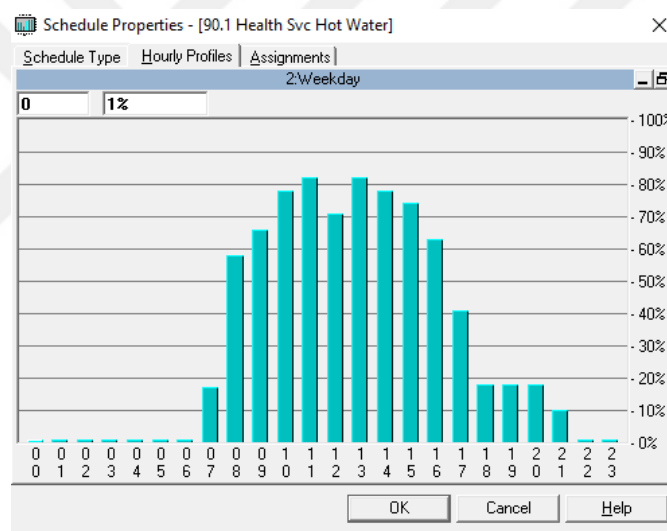
In the performed analysis, weather properties of Istanbul and annual solar radiation data are loaded from the computer program's library. Ventilation outdoor air (fresh air) rates and occupancies are applied based on ASHRAE 62.1-2010. According to the standard's requirements, different functions of spaces require a different rate of ventilation for the occupants[31]. First two columns of Table 3.6 lists the input data of ventilation rates, occupancies and taken internal loads of the simulation models. Last two columns of Table 3.6 show the input parameters of lighting power density and the equipment power density for different spaces in the energy model.

Name	Outdoor Fresh Air Rate-Person l/s - person	Occupancy Person/ 100m <sup>2</sup>	Lighting loads (W/m <sup>2</sup> )	Other loads (W/m <sup>2</sup> )
Offices	2,5 l/s-person	20	25	25
Lobby	3,8 l/s-person	30	30	5
Lobby Lounge Bar	3,8 l/s-person	30	30	15
Entertainment Bar	3,8 l/s-person	30	30	15
Restaurant	3,8 l/s-person	70	30	15
Guest Room	33,0 l/s	2 per room	25	15
Corridor	0,0 l/s-person	10	15	5
Foyer	5,0 l/s-person	50	30	5
Meeting Rooms	2,5 l/s-person	50	30	15

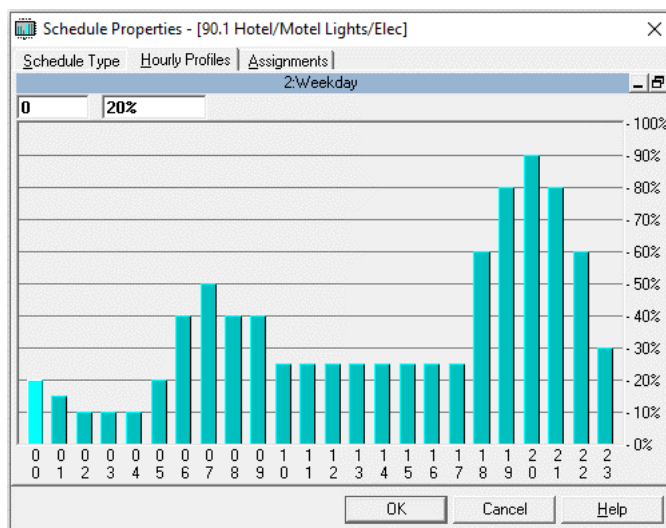
**Table 3.6 Ventilation rates, occupancies and lighting loads**

### 3.5 Operating Schedules

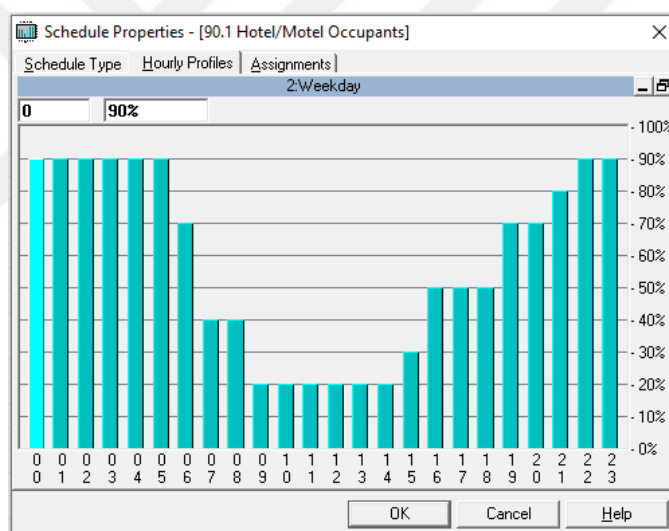
Energy simulation are carried out for hourly. Internal heat loads and occupancy is not constant, they are dynamic in a day. Thus, in the applied energy model, operational schedules are composed by considering a typical hotel building. ASHRAE’s fractional schedules for hotels/motels which contains data for 24-hour period are used in the annual simulation. This may have led to slightly higher results in terms of energy consumption. However, because of the same load and the same schedule are applied to all the three considered HVAC configurations (System A, B and C), it does not impair the accuracy of the results in comparison of the systems. Figure 3.5 show the occupancy, lighting, equipment, and how water schedules of a typical operating workday. The 100% in schedules means the highest density.



**Figure 3.5 Service Hot Water Schedule**



**Figure 3.6 Lighting Schedule**



**Figure 3.7 Occupancy Schedule**

### 3.6 Designing and Drawing of the Systems

At the design stage, diversity is not applied to any total loads or total device sizing. It might be applied for big facilities which have different function zones.

The pressure of the system components is an important factor for service life of the systems. For this reason, installations with working fluid in high structures are divided into

vertical zones. Heat exchangers are used between them. Since the examined building is a four-floor building, approximately 1,4 bars of static pressure occur in pipes. This pressure is a low-pressure level in installation applications and there is no strain on the system components. Therefore, all system design is conducted based on single zone operation and a single circuit is used for water pipes.

### **3.6.1 System A**

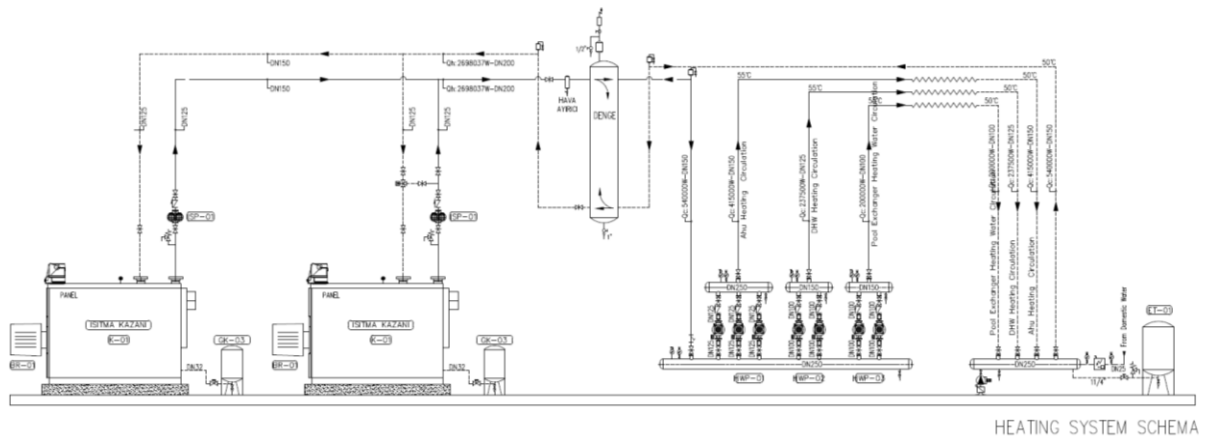
#### **Three pipe VRF system + Gas boiler.**

The building is heated and cooled by three piped VRF system. AHU cooling demand is supplied by an air-cooled group DX battery. On the other side, hot water preparation and AHUs heating are provided by 2.800 kW boiler system to be installed in the structure. VAV system in the meeting rooms, underfloor heating in the pool area, pool dehumidification plant is used.

All guest rooms, service and entertainment areas are equipped with VRF indoor units. The indoor units are divided in 19 zones and each of them is connected to a BS controller (shown as appendix 7.2). Grouping of the indoor units are conducted in terms of heat recovery capacity. EN 378 and ASHRAE 15 standards determine the limitations of refrigerants. Accordingly, when the system is designed with refrigerant, the maximum size of outdoor units is considered.

A natural gas boiler is used for AHU heating demands. Hereby water heating coils are used in heating part of AHUs. On the other side, air cooled (DX coils) are selected with an outdoor unit in order to supply cooling demands for AHUs.

Restaurant, kitchen, lounge, meeting rooms, pool area, and laundry zones are designed with all air systems. For these zones eight AHUs are projected with CAV or VAV systems. Similarly, these ventilation systems (AHU, CAV, VAV, duct elements etc.) are used in other two systems, too. Therefore, these common equipment are excluded from the comparison when the systems' installation cost calculated.



**Figure 3.8 Diagram for System A**

### 3.6.2 System B

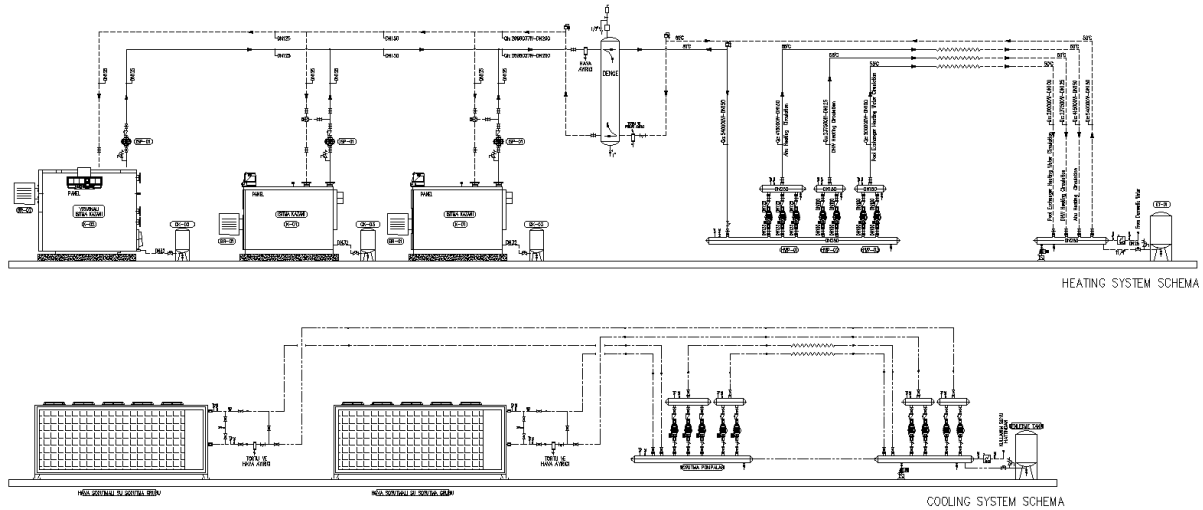
#### **System B: Air Source Chiller + Gas Boiler.**

In this case, the structure is heated and cooled by a 4-pipe fan-coil system. VAV system in the meeting rooms, underfloor heating in the pool area, pool dehumidification plants are used. The kitchen and laundry air conditioning systems are designed as all air systems and are heated/cooled with air.

Four piped Fan-Coil Units are installed in all hotel rooms and side spaces in this system. The reason why the four piped system has been selected instead of two piped, is that heating and cooling can be supplied simultaneously for different spaces if needed.

There are two air source chillers and three gas boilers to supply the whole building's heating and cooling demand. These central main devices are located in mechanical room at the first basement floor. "All air systems" zones are remained same as in System A. Only VRF indoor units are replaced with FCU indoor units. These are connected with water pipes to the chillers and boilers. There is one common manifold for each heating and cooling systems in mechanical room, and all heating and cooling lines are connected to the same central line. There are separate pump groups in each system's circuit.

DHW heat loads and timetable are the same again in System B and are added to boilers' heat loads. Additionally, two sides of AHU which are for cooling and heating coils have water exchangers unlike System A.



**Figure 3.9 Diagram for System B**

### 3.6.3 System C

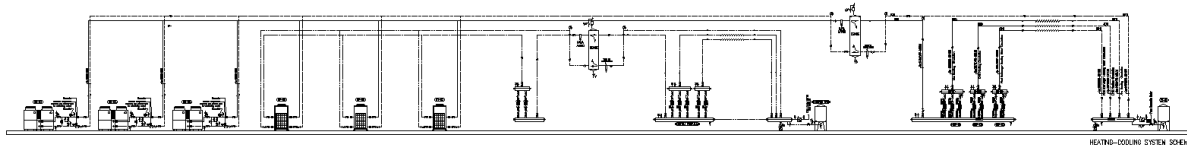
#### Absorption Chiller + Absorption Heat Pump

System components and system installation are similar to System B. Only difference is: heating and cooling supply devices are replaced with absorption machines. Thermal loads are transferred by water as the working fluid. Four piped water lines are connected to FCUs which placed in the ceiling in each conditioned space. In this case, GAHP heating source water's temperature (60-50°C) is slightly lower than that of natural gas boiler in System B. This may affect FCU units' models if heating and cooling coils are not the same in the unit. In this study, the indoor units are assumed to remain the same for boiler and GAHP situations.

All absorption machines, heat pumps and chillers are located outside. Since they reject heat to or gain it from atmosphere air. These devices consume heat produced by combustion

of natural gas instead of electricity power.

Similar to System B, there is one common manifold for each heating and cooling systems in the mechanical room, and all heating and cooling lines are connected to the same central line. There are separate pump groups in each systems circuit. DHW and AHU heating and cooling pipe lines are connected to the main common manifold.



**Figure 3.10 Diagram for System C**

### **3.7 Simulation**

Hourly Analysis Program (HAP) version 5.1 is used for building energy simulation of System A, B and C. As a building energy analysis tool, HAP can simulate and precisely calculate all 8760 hours load for a year and energy consumption of a building. Additionally, corresponding carbon dioxide emission of consumed energy by the systems are calculated by the software.

The analysis focuses on the energy consumptions, operating and initial costs for System A, B and C, which depends on the heating and cooling demand of the building model. The primary building load is related to the climate, insulation, layout, and indoor heat generation rate of the considered building. After setting the building model, envelope materials, room functions, indoor heat densities and schedules; HAP can calculate the heating and cooling load for the building model in a particular climate condition.

The following values are taken into account to perform annual energy simulation:

- The electricity price for business in one-time tariff excluding taxes in Istanbul is taken to be 0,717103 TL/kWh [32].

- The Greenhouse Gas Coefficient is assumed to be 2,06 kgCO<sub>2</sub>/m<sup>3</sup> for natural gas and 0.6 kgCO<sub>2</sub> /kWh for electricity [33].
- The natural gas price for business excluding taxes is taken to be 1,820689 TL/m<sup>3</sup> [34].
- The ratio of TL/Euro equals to 6,45 [35].
- The heat rejection energy consumption is taken as zero CO<sub>2</sub>.

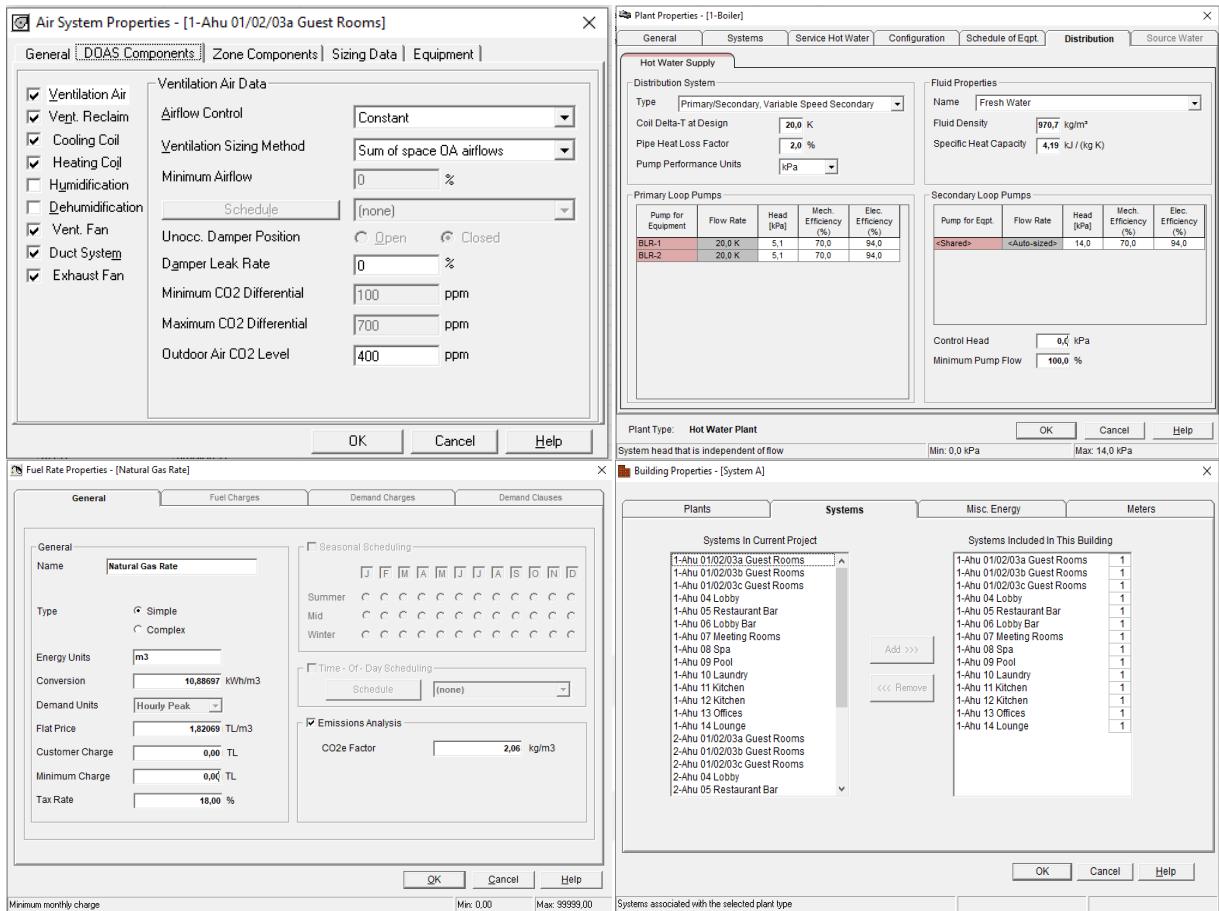
### 3.7.1 Modeling of the systems in HAP program

In this study, both of the system design and energy analysis features of the HAP program are used. Separate systems are used for each zone by collecting of the spaces.

By taken into account the calculated conduction coefficient U values, the project library of materials, is created. This library contents dates from schedules, walls, roofs, doors and windows and other components of the building. The spaces are composed by the library's components. After that, zones and systems are created by collecting the spaces. Finally, the plants are built from the systems, in another words indoor units and air systems are connected to a main HVAC device. Sample views of entering information for a heating group are presented in Figure 3.11.

For energy simulation, a “building” in building menu should be generated which compose created plants and systems. It is possible that creating more than one building from same systems and simulating them at the same time. Finally, results can be seen in the same tables and can be compared easily.

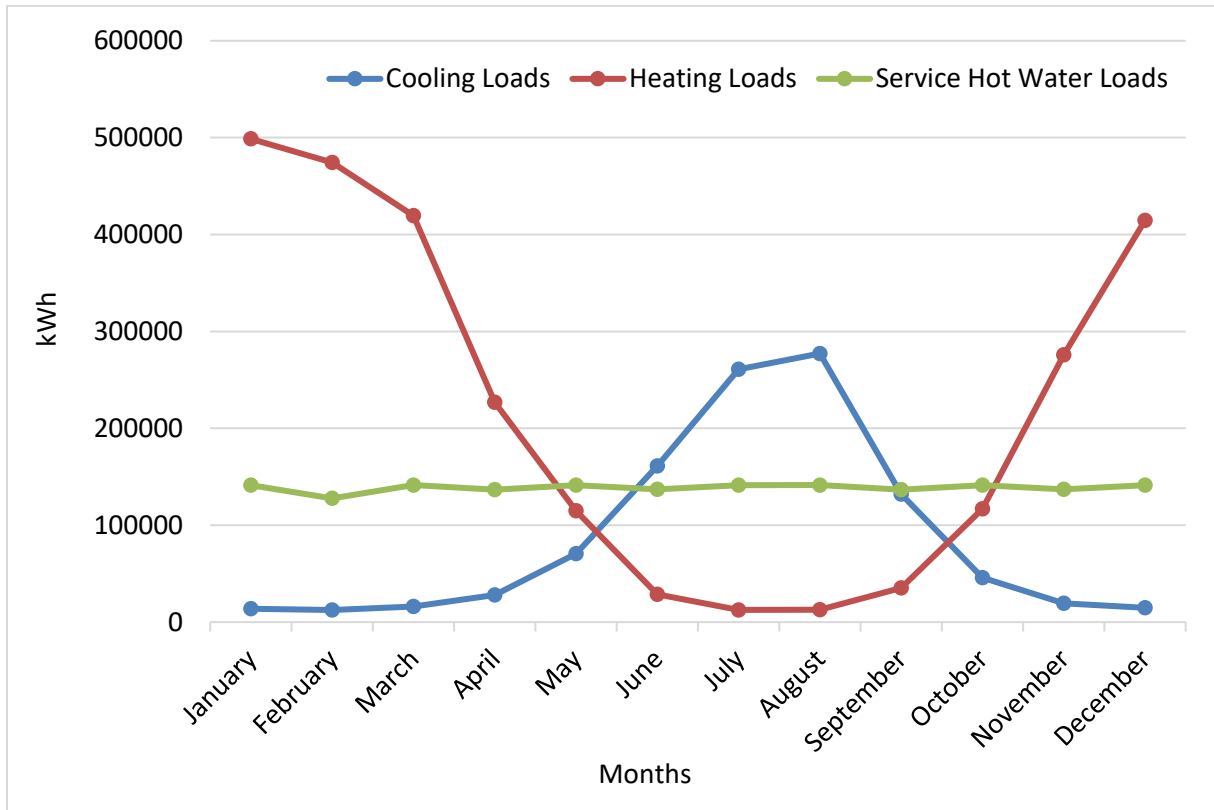
For the absorption system, there are not direct fired water to air cooling and heating for sorption cycles in the program. Absorption heat pumps for the building's heating and cooling purpose are not widely used in the last decades. Therefore, computer HVAC design and simulation softwares do not have this kind of ready packet devices in their library of the program yet. For this reason, absorption machines had to be created by collecting from different components that already exist in program's library.



**Figure 3.11 Entry information of System A heating group in HAP program**

### 3.7.2 Building Load Simulation Results

Istanbul has a heating dominant climate through a year-round. The annual total heating load of the model is 4.299.625 kW, while the annual cooling load of the building is 1.029.228 kW. Figure 3.12 and Table 3.7 report the monthly heating, cooling and service hot water heating loads. As represented in Table 3.8, heat gain (1.668 kW) is 24% less than the heat loss (2.192 kW) in this building. HVAC device's selections for compared systems are performed by considering calculated peak demands. Heat pumps, pipes, circulation pumps etc. are chosen according to their peak cooling load demand.



**Figure 3.12 Monthly Heating and Cooling Loads**

In the investigated sample hotel building, only about 45% of total cooling and heating loads belong to the guest rooms. The other 55% loads belong to the entrance, service, entertainment areas and DHW. Simulation outputs indicate that approximately 38% of the annual heating load of the hotel belongs to the energy requirement of DHW production.

Month	Plant Cooling Load (kWh)	Plant Heating Load (kWh)
January	15378	640387
February	13728	602516
March	17521	561212
April	29367	364102
May	72189	256698
June	162837	165802
July	262697	154249
August	278841	154495
September	133672	172429
October	47423	258496
November	20923	413046
December	16174	556196
<b>Total</b>	<b>1.070.751</b>	<b>4.299.625</b>

**Table 3.7 Monthly Heating and Cooling Loads**

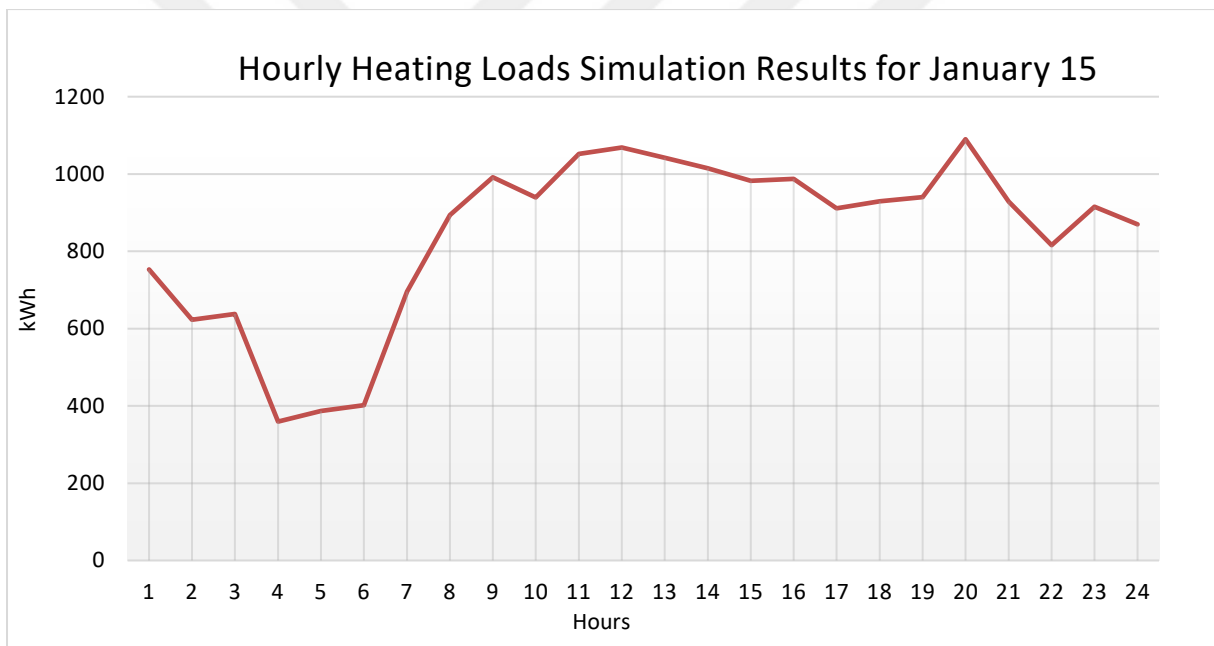
	Heating Plant Sizing Data	Cooling Plant Sizing Data
Maximum Plant Loads	<b>2.192,0 kW</b>	<b>1.668,6 kW</b>

**Table 3.8 Cooling and heating peak loads**

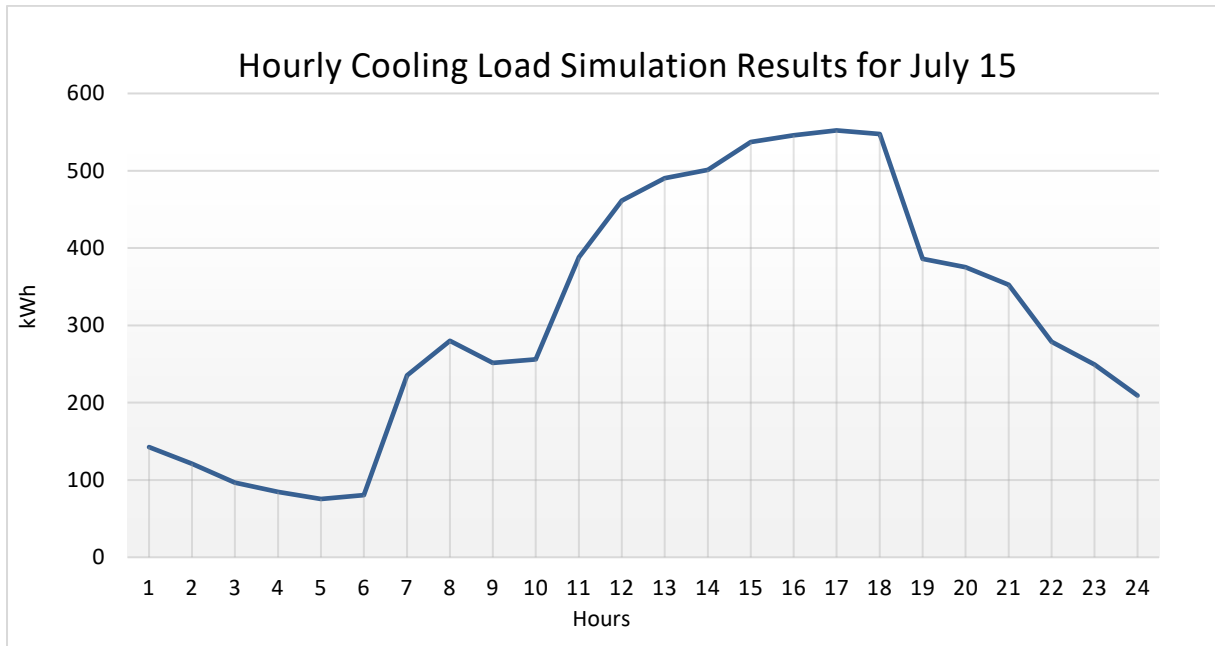
Figure 3.13 shows hourly maximum heating loads simulation results through a day. That day is usually lived in the middle of winter in Istanbul. If we look broadly, loads during the peak days in the winter do not hourly change considerably like the cooling load in the summer. This means that the devices operate at an uninterrupted and close to full capacity

load when peak loads occur. But a substantial decrease occurs in heat loss in early morning hours.

Figure 3.14 illustrates that the cooling load during the cooling season is very various with respect to hours. As expected, the highest point of heat gain with 1668,6 kW is in middle day hours. It rises regularly like a wave and decreasing in the evening again. At early morning hour, at five o'clock the cooling need is 531,1 kW. That means cooling load changes in day and night about 3 times a day. Therefore, in order to provide cooling in terms of operational cost, the partial load efficiency of the device we choose is of great importance. Not only in terms of energy expenditure, but also in terms of service life, the low load of the devices is an important factor.



**Figure 3.13 Hourly Heating Loads Simulation Results for January 15**

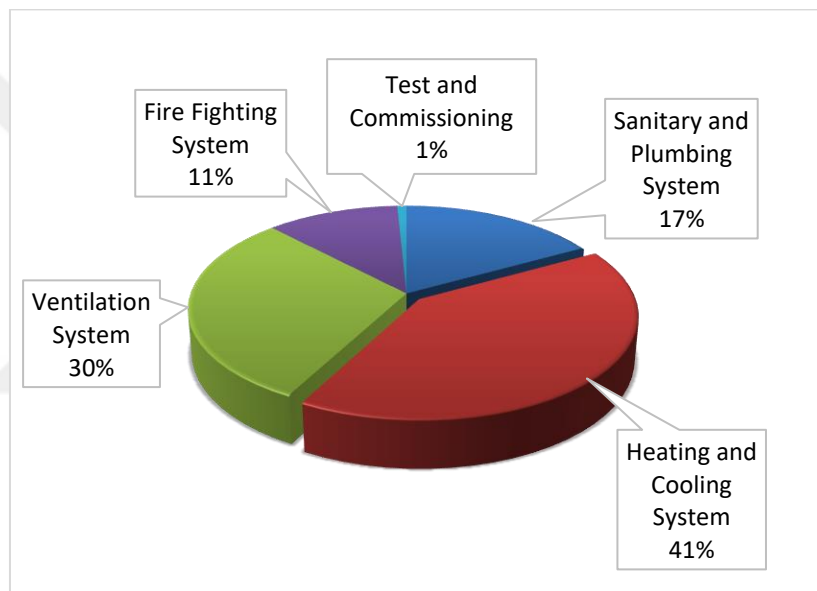


**Figure 3.14 Hourly Cooling Load Simulation Results for July 15**

## 4 ECONOMICAL AND ENERGY ANALYSIS

### 4.1 Capital Cost of the Systems

HVAC system investment cost distribution for a typical hotel building under the five-star category is shown in the Figure 4.1. Heating and cooling systems' cost is about 41% of total mechanical installations for the building.



**Figure 4.1 Investment Cost Distribution**

To obtain accurate initial investment cost and a fair result, prices are calculated according to “Construction and Installation Unit Prices 2019” report which is published by “Ministry of environment and urbanization of Turkey” [36]. Additionally, if the price of an equipment is needed in the analysis which is not available in the report, the price is obtained from manufacturer companies by direct contact (details of the prices are presented in Appendices 7.5 and 7.6). Ventilation systems and other HVAC components, which are used in the Systems A, B and C, are excluded in the calculation of the installation costs, such as AHU, air ducts, CAVs and VAVs.

List of indoor and outdoor devices is extracted from the output reports of the HAP program. In appendix 7.4, space lists, loads and VRF/FCU indoor units' selection report are presented. After the report received, HVAC devices are installed into the systems and the system is drawn on sample building architectural drawing. In appendix 7.3 drawing of first floor and mechanical room in System A are presented to view example drawings of the analyzed systems.

Table 4.1 reports the list of prices for investigated system components and installations. As seen in the table, mechanical cycle systems' installation cost is lower than that of the absorption system. One of the reasons for this is that absorption heat pump systems are not widely used [11]. If we look closer to the Systems, BS (Branch selector) boxes (~ %10) and copper pipes (~ %7) prices constitute a significant fraction of the System A capital cost. All the system components except the main heating and cooling devices are the same in System B and C. The main difference between System B and C is because of the high price of the absorption devices in System C.

Material Type	System A		System B		System C	
	Quantity	Total Price	Quantity	Total Price	Quantity	Total Price
<b>VRF outdoor units</b>	33 pc	429.000 €	-	-	-	-
<b>VRF indoor units</b>	261 pc	193.225 €	-	-	-	-
<b>BS units</b>	22 pc	133.072 €	-	-	-	-
<b>Boiler</b>	2 pc	50.000 €	3 pc	90.000 €	2 pc	7.000 €
<b>Chiller</b>	-	-	2 pc	270.000 €	-	-
<b>Absorption Heat Pump</b>	-	-	-	-	35 pc	346.500 €
<b>Absorption Chiller</b>	-	-	-	-	61 pc	380.640 €
<b>FCU indoor units</b>	-	-	261 pc	169.650 €	261 pc	169.650 €
<b>Expansion tanks</b>	3 pc	1.332 €	6 pc	7.500 €	8 pc	10.000 €
<b>Piping and insulation</b>	12160 mt	166.554 €	15000 mt	315.000 €	16000 mt	336.000 €
<b>Valves</b>	272 pc	44.590 €	290 pc	27.550 €	310 pc	29.450 €
<b>Circulation Pumps</b>	10 pc	32.561 €	15 pc	24.000 €	17 pc	27.200 €
<b>Boiler Flue</b>	2 pc	7.000 €	3 pc	10.500 €	-	-
<b>Natural gas installation</b>	1 pc	136.000 €	1 set	136.000 €	1 set	150.000 €
<b>Automatic control systems</b>	Various	40.000 €	Various	35.000 €	Various	35.000 €
<b>Total Cost</b>		<b>1.233.334 €</b>		<b>1.085.200 €</b>		<b>1.491.440 €</b>

**Table 4.1 Bill of quantities**

## 4.2 Operating Costs

Hotels are all-day operating facilities with high operational costs. Annual operational cost of analyzed HVAC systems (System A, B and C) is presented in Table 4.2.

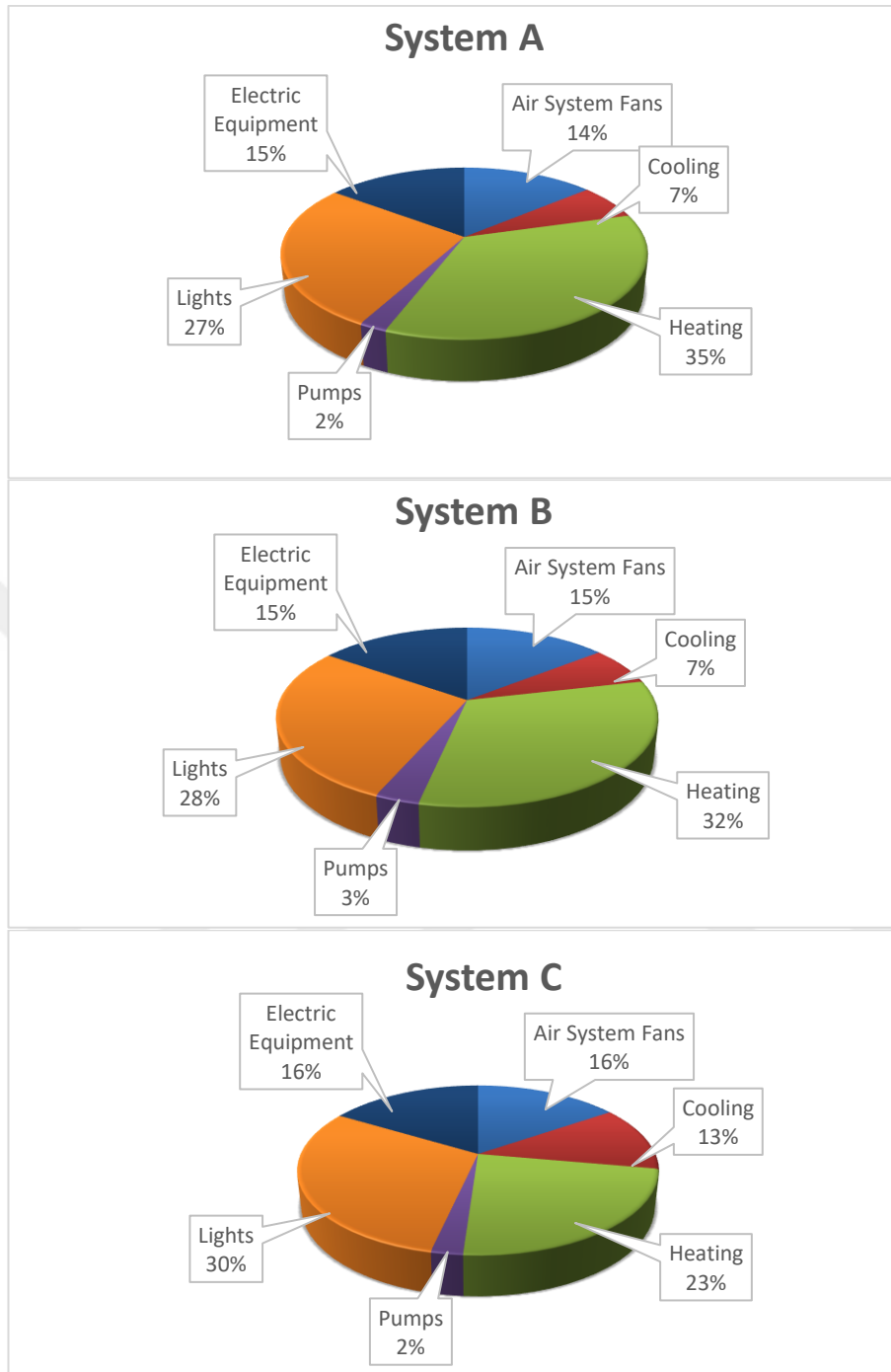
Cost of HVAC system energy consumption for System A, B and C are given in “HVAC Sub-Total” row of the Table 4.2. The costs are 249.114 € and 234.509 € for System A and B, respectively. These results show that System A (VRF and DX batteries), display better performance than chiller for cooling in Istanbul climate conditions. Regarding the heating costs, System B (consumes natural gas for heating), has lower cost than that of System A (consumes electricity for heating). In addition, pumping expense is the lowest among the others for System A.

<b>Component</b>	<b>System A (€)</b>	<b>System B (€)</b>	<b>System C (€)</b>
Air System Fans	59.607	59.628	59.628
Cooling	27.318	28.804	48.116
Heating	153.290	132.617	90.104
Pumps	8.898	13.460	9.087
Heat Rejection Fans	0	0	0
<b>HVAC Sub-Total</b>	<b>249.114</b>	<b>234.509</b>	<b>206.935</b>
Lights	116.457	116.457	116.457
Electric Equipment	63.248	63.248	63.248
Misc. Electric	0	0	0
Misc. Fuel Use	0	0	0
<b>Non-HVAC Sub-Total</b>	<b>179.705</b>	<b>179.705</b>	<b>179.705</b>
<b>Grand Total</b>	<b>428.819</b>	<b>414.214</b>	<b>386.640</b>

**Table 4.2 Annual cost for the systems**

There are two remarkable features about small GAHP models used in System C. First, it provides ~40% cost reduction relative to the other two systems. Second, in cooling mode, it enables to supply hot water supply for domestic usage. The absorption system has a higher operating cost when it is used only for cooling purposes. For the analyzed building in this study, operating cost is 48.116 € for System C. It is ~ %42 higher than the cost of the other systems. Thereby, if both of cooling and hot water are needed, absorption systems can be more profitable in summer as well. These results are similar to the studies of A. A. Baig and A. S. Fung at Ontario city in Canada about “The potential benefits of a natural gas-fired absorption heat pump”. That study also emphasizes only heating mode savings of the GAHP devices [37].

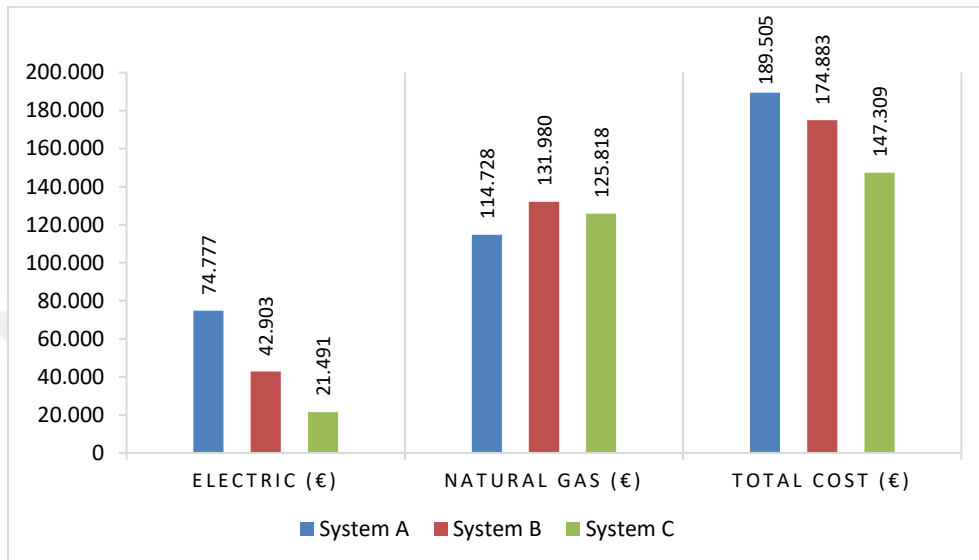
Energy consumption costs of total components are seen in Figure 4.2 . Energy cost of HVAC systems constitute ~55% of annual cost for all the considered systems. Heating components’ energy consumption is the largest part of system energy expenditure. Ratio of cooling and heating expenses is close to unity in System A and B. However, the cost of cooling is higher than that of heating in System C. But, total operational cost of System C is lower than System A and B as seen in Table 4.1.



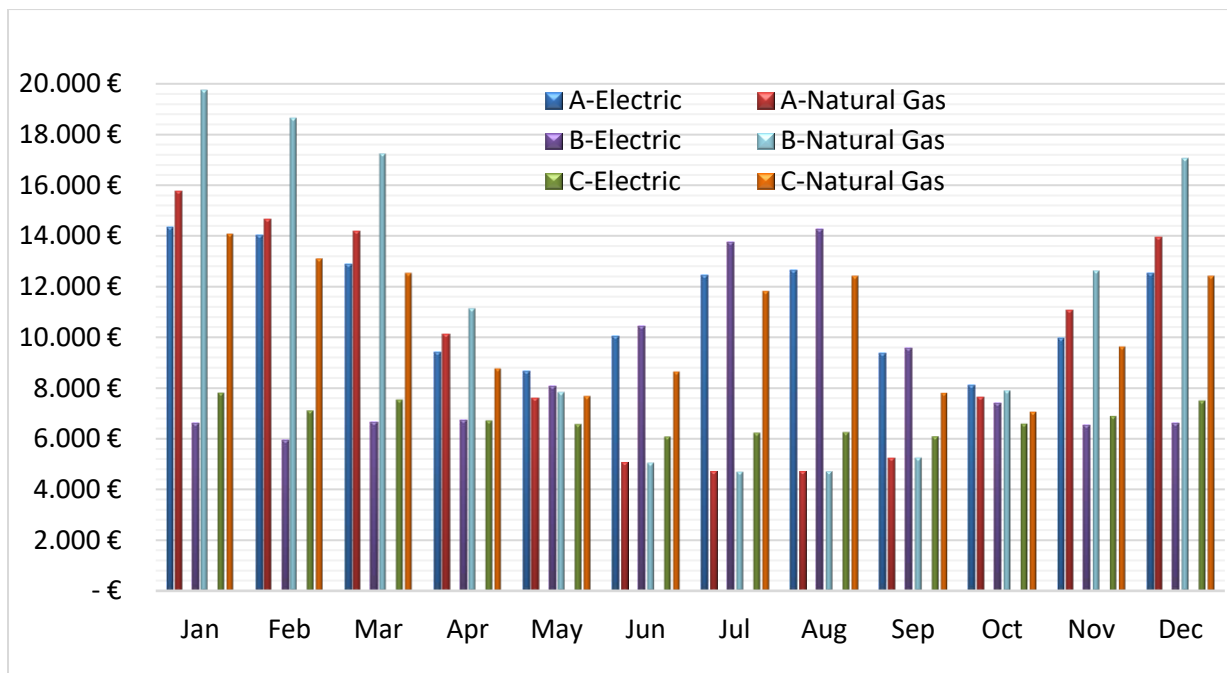
**Figure 4.2 Annual component costs**

All the considered systems in this study provide heating and cooling by consuming electricity and natural gas. The summary of the annual and monthly computed energy costs for heating and cooling systems are given in Figure 4.3 and Figure 4.4 respectively. As it is

seen in the bar graph that, System A has the highest electrical cost and the lowest natural gas consumption cost. Since the price of electricity is high, the highest annual operational cost belongs to the System A. On the other hand, the absorption machines which use the natural gas in its modules have lowest operational cost in System C.

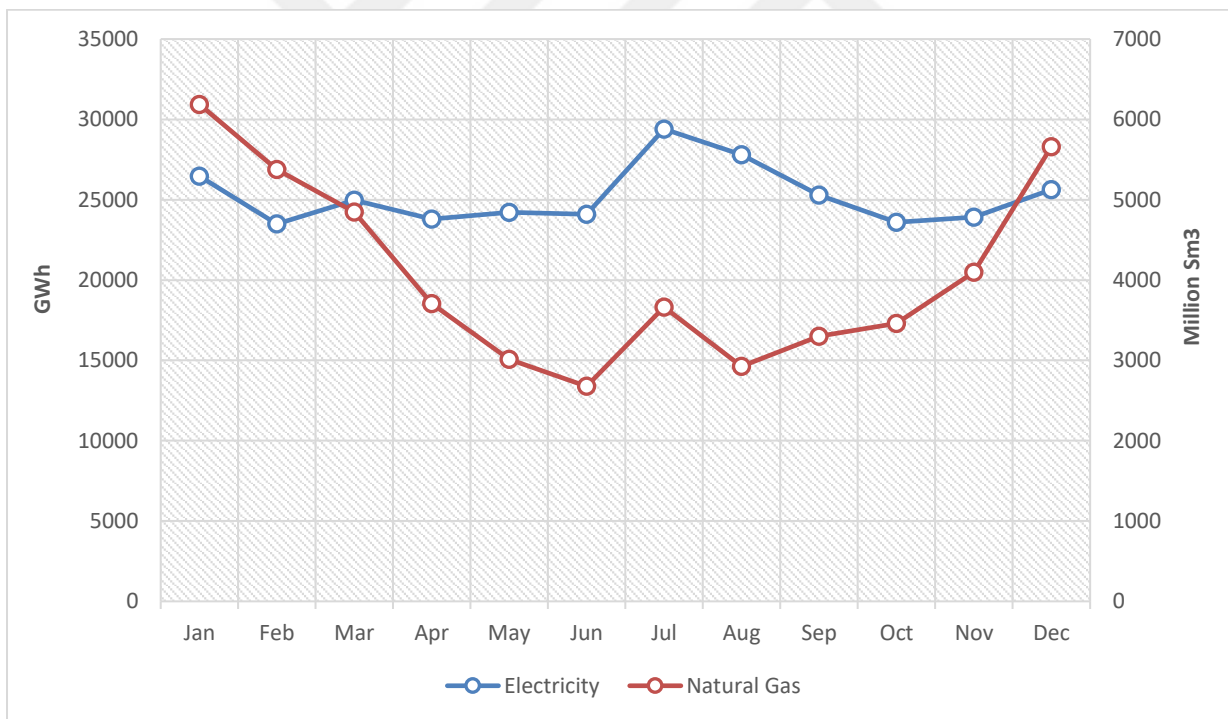


**Figure 4.3 Annual consumed energy costs for heating and cooling supplies**



**Figure 4.4 Monthly HVAC energy costs**

In Turkey, maximum electricity and minimum natural gas consumptions are seen in summer (Figure 4.5) [42, 43]. If the natural gas is used for cooling too, seasonal waves in annual energy consumption would be balanced and, consequently, it is able to mitigate investment for upgrading of electricity infrastructure capacity. It is possible by using GAHP devices. They consume 40% less electricity than VRF units over a year. Reduction in natural gas consumption is possible by integrating the gas absorption machine with solar collector. Hot water at required temperatures can be supplied to GAHP models' generator from thermal solar collectors. For high capacities, using solar thermal energy as the heat source in absorption cycles has been investigated over decades. However, solar assisted absorption machine is not highly preferred due to its high initial installation costs. These days, the number of solar collector manufacturers increases and the price of solar systems decreases, besides energy prices rises. Hence, it is expected to see solar assisted absorption machine applications in the near future.



**Figure 4.5 Electricity and Natural Gas consumptions in 2018**

### 4.3 Payback Period of the Systems

Life time of the materials used in heating and cooling installations differs from one to one. Some of material life times are available in Appendix 7.1 according to ASHRAE. Majority of heating and cooling equipment can provide minimum 15 years of life time. Therefore, in this study, it is assumed that the lifespan of the analyzed models is 15 years.

The net present value method is adopted as a tool for calculating the life cycle cost values for each system's installation and operational costs. The net present value method (NPV) uses a discount rate to compute the value of money over a period of time. If it is assumed that the defined discount rate is constant the equation can be expressed as Equation 4.1 [38].  $NPV$  is net present value,  $n$  is time period,  $r$  is discount rate and  $C$  is outlay cost.

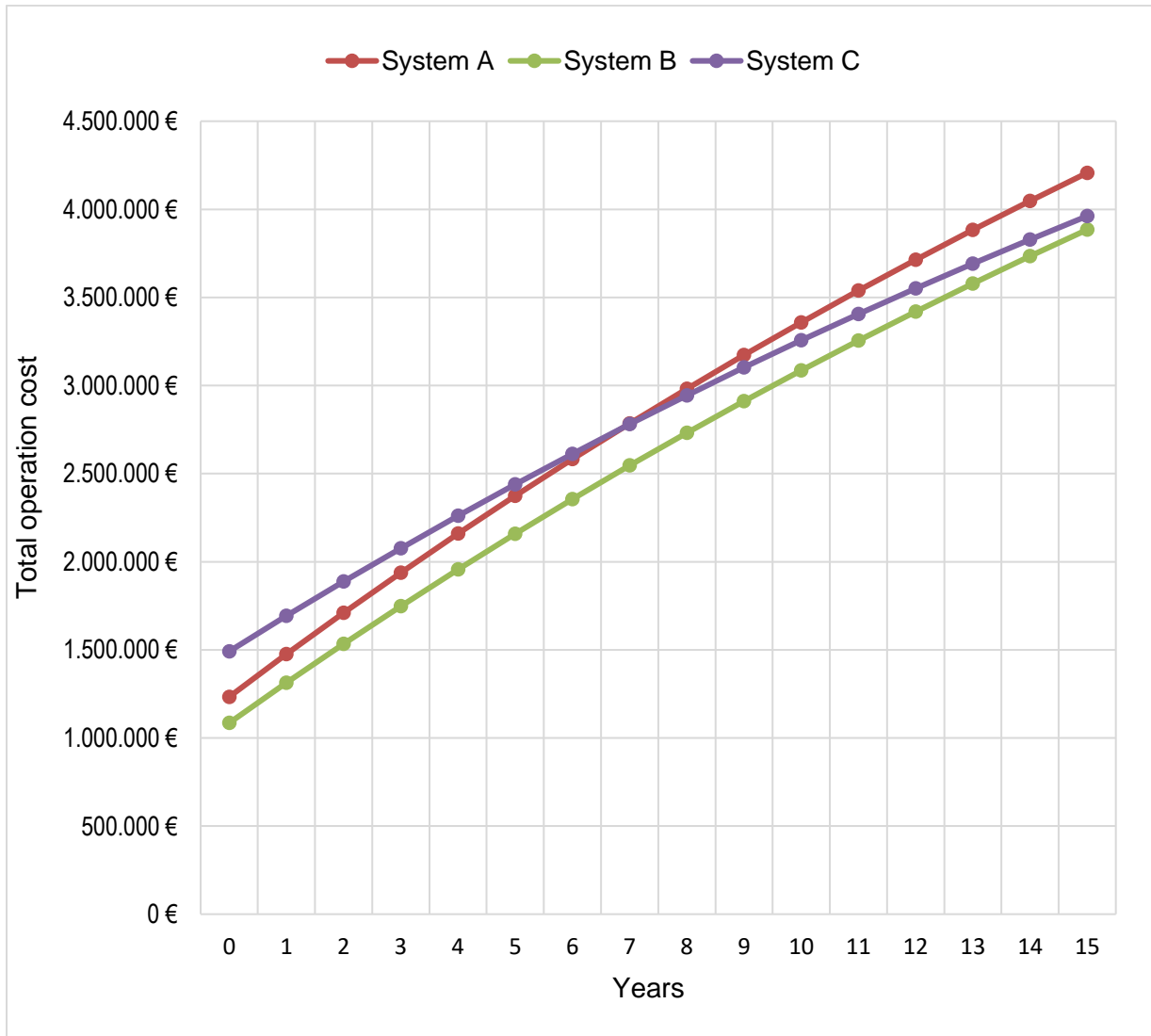
$$NPV_n = \frac{C_n}{(1+r)^n} \quad (4.1)$$

A cash flow calculation is made by taking into account the initial investment cost and operating cost throughout the life cycle. Long term maintenance cost and repair cost data is always difficult to obtain, especially for complex systems. For small scale absorption machines, practical data is not available. For this reason, maintenance and repair costs are excluded from calculations. It is assumed that annual discount rate is 4% for € over 15 years. Table 4.3 and Figure 4.6 shows the variation of NPV by years.

NPV results in Table 4.3, it is seen that although the installation cost of System C is the highest, it is more profitable than System A since the total operational cost of System C get equals to get off System A in seven years. Like the initial cost, the operation cost of VRF system in System A is higher than the others. Even the System C has the lowest operational cost, its amortization time is longer than System B. Therefore, economically System B is found more profitable than two others.

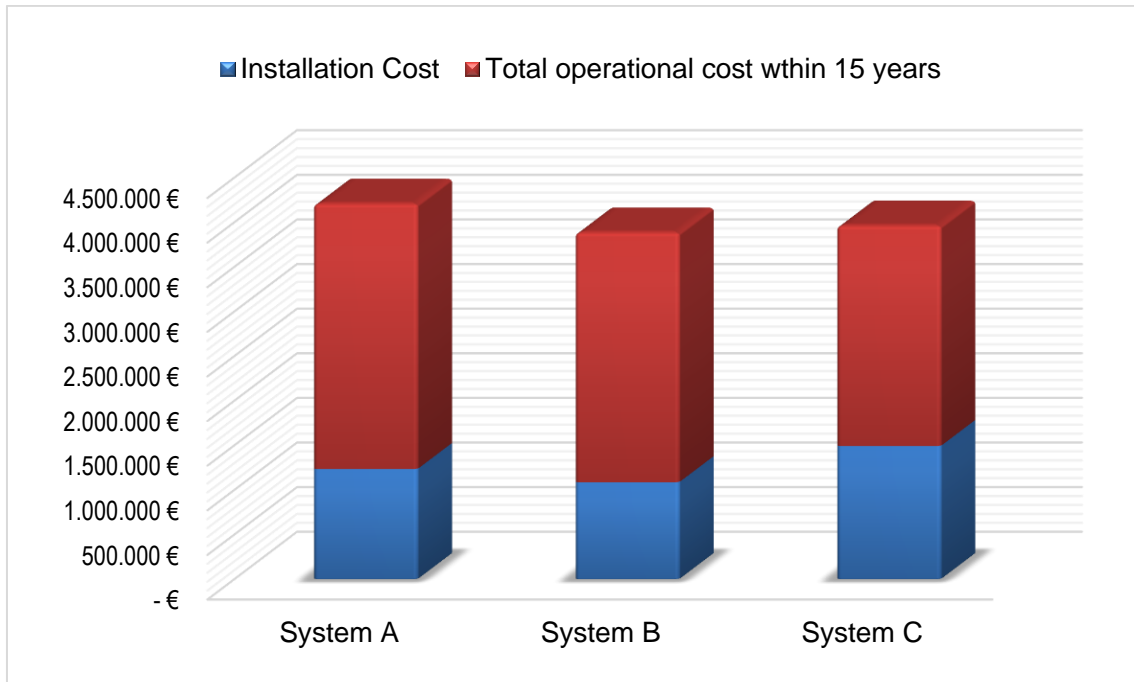
Years	System A (€)	System B (€)	System C (€)
1	1.475.193	1.312.879	1.692.348
2	1.710.006	1.533.926	1.887.404
3	1.937.981	1.748.535	2.076.779
4	2.159.316	1.956.893	2.260.638
5	2.374.204	2.159.183	2.439.142
6	2.582.833	2.355.580	2.612.447
7	2.785.385	2.546.257	2.780.704
8	2.982.038	2.731.381	2.944.060
9	3.172.963	2.911.113	3.102.658
10	3.358.327	3.085.609	3.256.638
11	3.538.293	3.255.024	3.406.132
12	3.713.016	3.419.504	3.551.272
13	3.882.651	3.579.193	3.692.184
14	4.047.344	3.734.231	3.828.993
15	4.207.241	3.884.753	3.961.817

**Table 4.3 Net present values variation with time**



**Figure 4.6 Accumulate cash flow for the systems**

Figure 4.7 shows the importance of operational costs through the life cycle of an investment. At the end of the analyzed period, the operational costs are two to three times greater than the initial investment cost.



**Figure 4.7 NPV of the initial and operational costs**

#### 4.4 Emissions Analysis

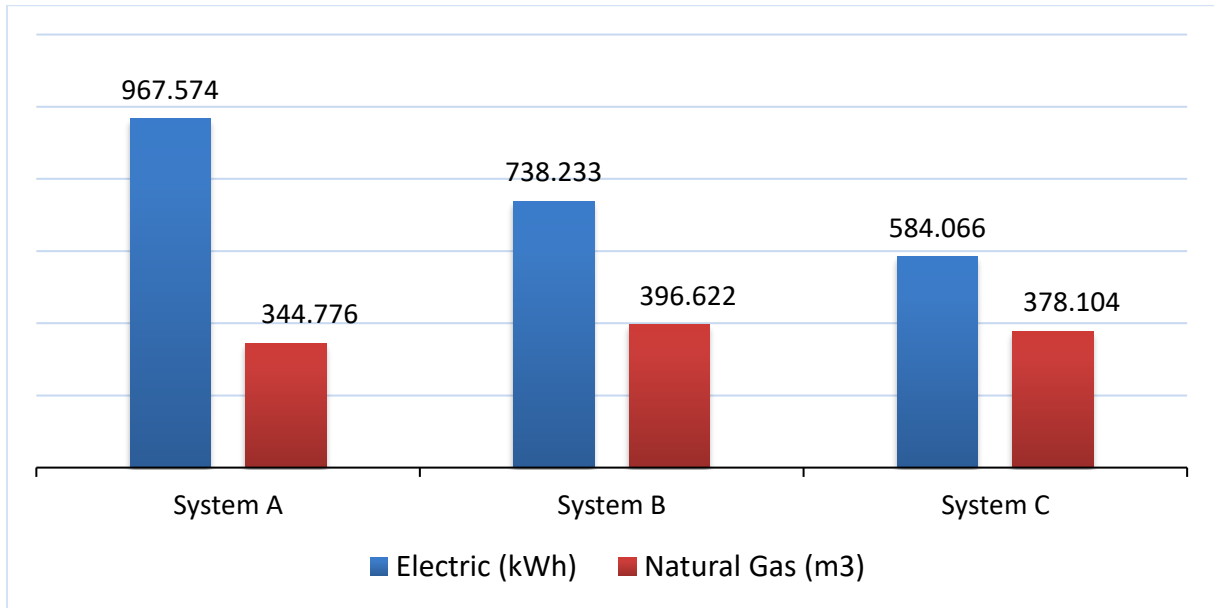
Increase of human-induced greenhouse gas accumulation in the atmosphere has continued since the Industrial Revolution. Especially when CO<sub>2</sub>'s accumulation in the atmosphere and life span are considered, greenhouse gases started to receive considerable attention. Moreover, it is increasing rapidly according to scientific observations. At the end of the 1950s, the annual average CO<sub>2</sub> accumulation, which was around 315 ppm, reached 380 ppm in recent years, exceeding the natural level of the last 650 thousand years [39]. Increase of greenhouse gas accumulation have weakened the cooling process of the earth by long wave radiation and the phenomenon we call global warming has emerged.

Month	System A		System B		System C	
	Electric (kWh)	Natural Gas (m <sup>3</sup> )	Electric (kWh)	Natural Gas (m <sup>3</sup> )	Electric (kWh)	Natural Gas (m <sup>3</sup> )
Jan	103.178	47.358	47.693	59.335	55.982	42.239
Feb	101.063	44.051	42.903	56.038	51.045	39.327
Mar	92.671	42.686	47.915	51.814	54.080	37.617
Apr	67.787	30.380	48.404	33.454	48.184	26.319
May	62.365	22.874	57.982	23.578	47.215	23.086
Jun	72.203	15.188	75.164	15.229	43.688	25.945
Jul	89.496	14.168	98.918	14.168	44.752	35.473
Aug	91.070	14.190	102.604	14.191	44.884	37.261
Sep	67.601	15.774	68.843	15.838	43.714	23.459
Oct	58.391	22.977	53.210	23.744	47.256	21.223
Nov	71.652	33.218	47.064	37.962	49.427	28.900
Dec	90.097	41.912	47.535	51.270	53.838	37.254
<b>Totals</b>	<b>967.574</b>	<b>344.776</b>	<b>738.233</b>	<b>396.622</b>	<b>584.066</b>	<b>378.104</b>

**Table 4.4 Monthly energy consumptions of the HVAC systems**

So, when an investment is analyzed and compared the different energy source systems, not only economic perspective, but also environmental facts should be considered. In this study, investigated three different HVAC systems have two kinds of energy sources: electricity and natural gas. Consumption in both of the sources vary depending on the considered system. Most of the electricity is produced by burning natural gas in Turkey. Therefore, if we look behind of the produced electricity, the primary source is again the natural gas. Because of that, equivalent primary energy and carbon footprint is high for

electricity. Hence, absorption cycled systems which use natural gas for cooling is expected to be more environment friendly. Table 4.4 and Figure 4.8 represents monthly and annually energy consumptions of the HVAC systems, respectively. The difference in natural gas consumption is not considerable among the System A, B and C, but in electricity consumption, the difference is quite noticeable. GAHPs consume 40% less electricity in System C than VRF units in System A over a year.



**Figure 4.8 Annual energy consumptions of the systems**

	System A	System B	System C
CO <sub>2</sub> Equivalent (kg)	2.067.126	2.036.306	1.737.532

**Table 4.5 Annual Emissions**

As it is seen in Table 4.5, multi-storey buildings cause annually hundreds of tons carbon dioxide emissions. With this gas absorption heat pump system, every year 298.3 tons of CO<sub>2</sub> emissions are saved, which are equivalent to those absorbed by 11600 trees or those produced by 1400 green cars. In another words, 0,06 kg CO<sub>2</sub> is reduced for each kW energy consumption.

## 5 CONCLUSION

The goal of this research is to prepare a help source material to select the right heating and cooling systems. Three different HVAC systems in a four-storey hotel building are compared from economic and environmental perspectives at Istanbul climate conditions:

- 1) Initial installation cost,
- 2) Energy cost of operation through the system lifetime,
- 3) Carbon dioxide emission.

These systems are: A) VRF+Boiler, B) Chiller+Boiler, C) Absorption heat pumps, respectively. Ventilation systems and the other components which are remained the same in three systems are excluded from the comparison. Gas absorption heat pumps is not a commonly encountered system in Turkey. Hence, this study can provide a deeper understanding for GAHP application in air conditioning. Computations of the annual energy consumption are carried out by Carrier HAP energy modeling analysis software.

	System A	System B	System C
Installation Cost	1.233.334 €	1.085.200 €	1.491.440 €
Operation Cost	249.114 €	234.509 €	206.935 €

**Table 5.1 Capital and operational cost summary**

In the capital cost comparison, the most expensive one is the System C (GAHP system), then System A (VRF) and System B (Chiller+Boiler) in an order (Table 5.1). From operational cost aspect, System B is the most economical system. However, it is seen in Figure 4.6 that, total operational cost of System C is equalized to that of System A in seven years and to that of System B in twenty years, due to the low operational cost of System C. Critical point about GAHP devices (System C) is that, they provide advantage at energy consumption only in heating mode. Cooling with these devices is more expensive than that

with chillers and VRFs. In system C, significant reduction occurs for boiler room's area, transformer and generator capacity. Moreover, utilizing a natural refrigerant, ammonia, in a factory sealed circuit, gains building certification credits and provides exemption from F-Gas regulations.

In the VRF system selection (in System A), due to losses in copper pipes, the VRF outdoor units' capacity are selected 26% larger than requested total loads. Another notable result about VRF system is: three piping system provides only 5% save in electricity consumption compared to that of double pipe system.

Carbon dioxide emissions of System A and B are close to each other. System C, however, produces 298.3 tons less carbon dioxide than System A and B.

In this study, three different air conditioning systems are numerically modelled and analyzed. Results of the numerical analysis and comparison of the analyzed systems in terms of capital, operational costs and system CO<sub>2</sub> equivalent emissions are presented. These findings of the study can be regarded as a guide to HVAC system designers to improve system selection. The next steps of this research can include practical, maintain and repair analysis by using the illustrated methodology to select HVAC system.

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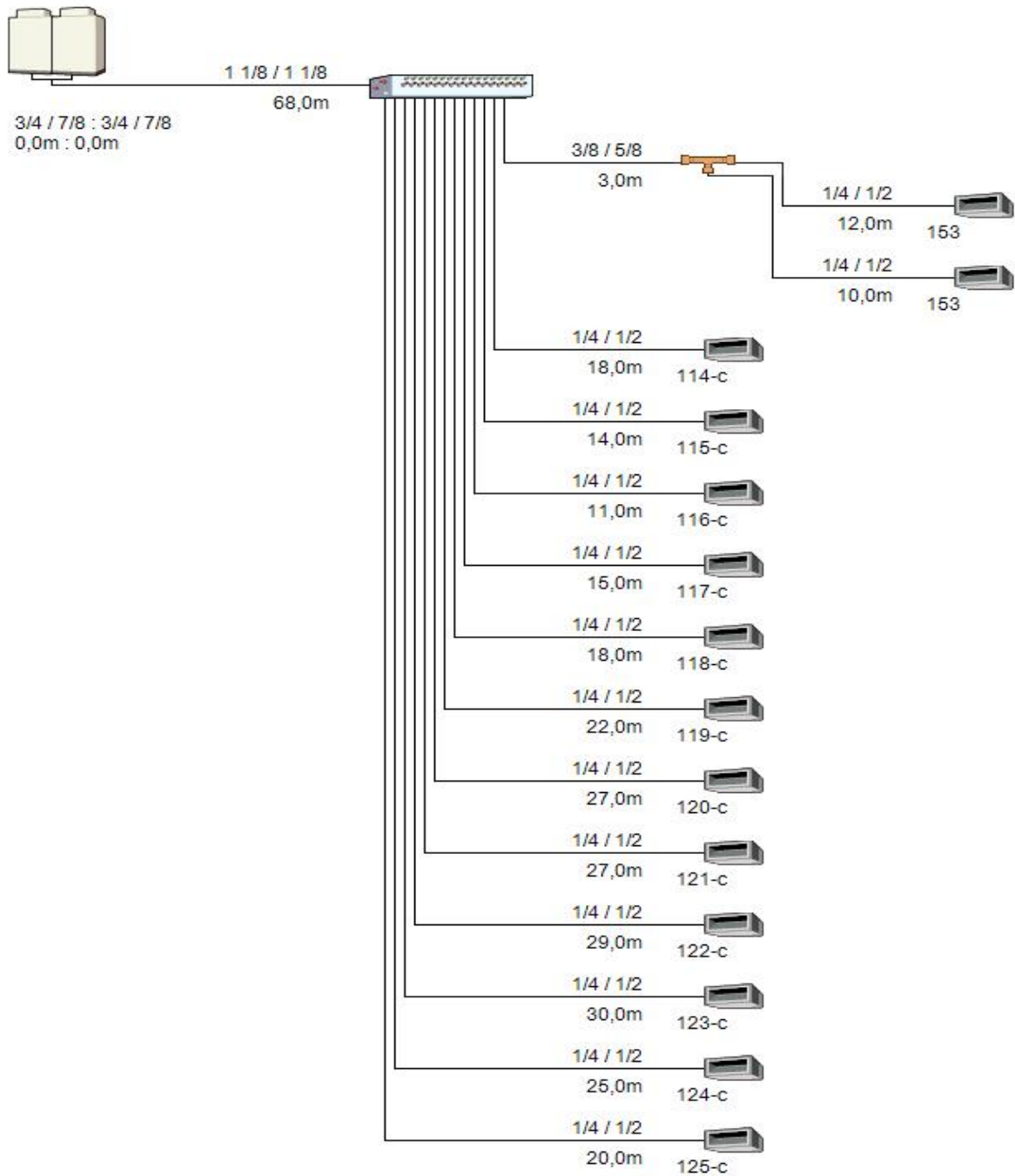
## 7 APPENDICES

### 7.1 Comparison of Service Life Estimates [42]

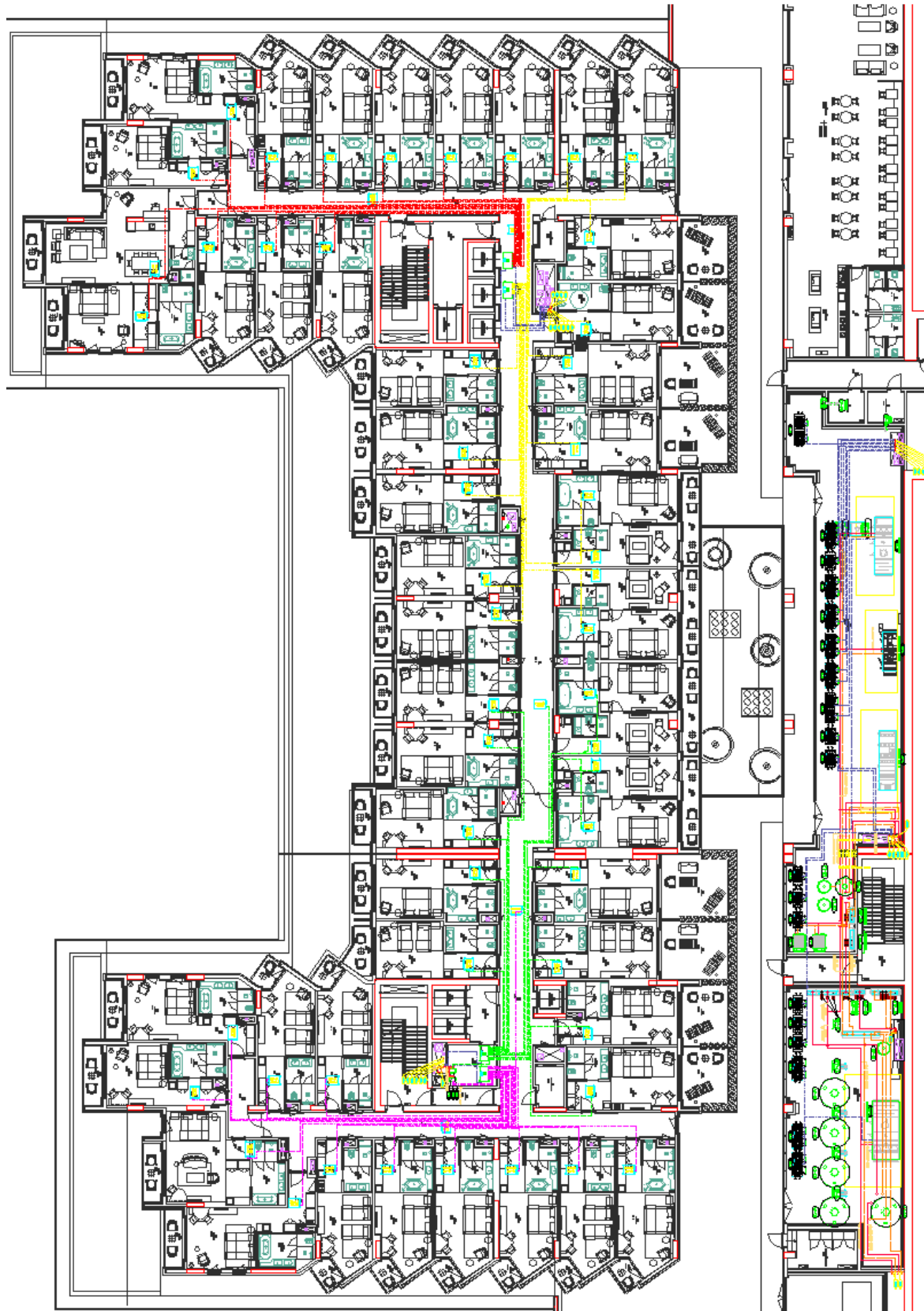
Equipment Item	Median Service Life, Years		Equipment Item	Median Service Life, Years		Equipment Item	Median Service Life, Years	
	Abramson et al. (2005)	Akalin (1978)		Abramson et al. (2005)	Akalin (1978)		Abramson et al. (2005)	Akalin (1978)
<b>Air Conditioners</b>			<b>Air Terminals</b>			<b>Condensers</b>		
Window unit	N/A*	10	Diffusers, grilles, and registers	N/A*	27	Air-cooled	N/A	20
Residential single or split package	N/A*	15	Induction and fan-coil units	N/A*	20	Evaporative	N/A*	20
Commercial through-the-wall	N/A*	15	VAV and double-duct boxes	N/A*	20	<b>Insulation</b>		
Water-cooled package	>24	15	<b>Air washers</b>	N/A*	17	Molded	N/A*	20
<b>Heat pumps</b>			<b>Ductwork</b>	N/A*	30	Blanket	N/A*	24
Residential air-to-air	N/A*	15 <sup>b</sup>	<b>Dampers</b>	N/A*	20	<b>Pumps</b>		
Commercial air-to-air	N/A*	15	<b>Fans</b>	N/A*		Base-mounted	N/A*	20
Commercial water-to-air	>24	19	Centrifugal	N/A*	25	Pipe-mounted	N/A*	10
<b>Roof-top air conditioners</b>			Axial	N/A*	20	Sump and well	N/A*	10
Single-zone	N/A*	15	Propeller	N/A*	15	Condensate	N/A*	15
Multizone	N/A*	15	Ventilating roof-mounted	N/A*	20	<b>Reciprocating engines</b>	N/A*	20
<b>Boilers, Hot-Water (Steam)</b>			<b>Coils</b>			<b>Steam turbines</b>	N/A*	30
Steel water-tube	>22	24 (30)	DX, water, or steam	N/A*	20	<b>Electric motors</b>	N/A*	18
Steel fire-tube		25 (25)	Electric	N/A*	15	<b>Motor starters</b>	N/A*	17
Cast iron	N/A*	35 (30)	<b>Heat Exchangers</b>			<b>Electric transformers</b>	N/A*	30
Electric	N/A*	15	Shell-and-tube	N/A*	24	<b>Controls</b>		
<b>Burners</b>			<b>Reciprocating compressors</b>	N/A*	20	Pneumatic	N/A*	20
<b>Furnaces</b>			<b>Packaged Chillers</b>			Electric	N/A*	16
Gas- or oil-fired	N/A*	18	Reciprocating	N/A*	20	Electronic	N/A*	15
<b>Unit heaters</b>			Centrifugal	>25	23	<b>Valve actuators</b>		
Gas or electric	N/A*	13	Absorption	N/A*	23	Hydraulic	N/A*	15
Hot-water or steam	N/A*	20	<b>Cooling Towers</b>			Pneumatic	N/A*	20
<b>Radiant heaters</b>			Galvanized metal	>22	20	Self-contained		10
Electric	N/A*	10	Wood	N/A*	20			
Hot-water or steam	N/A*	25	Ceramic	N/A*	34			

\*N/A: Not enough data yet in Abramson et al. (2005). Note that data from Akalin (1978) for these categories may be outdated and not statistically relevant. Use these data with caution until enough updated data are accumulated in Abramson et al.

## 7.2 Schematic view of a VRF outdoor, indoor units and BS box connection



7.3 Drawing view of first floor and mechanical room in System A



## 7.4 Space lists, loads and VRF/FCU indoor unit selection report

Zone Name	Floor Area (m <sup>2</sup> )	Occupancy	Summer C	Summer RH	Winter C	Cooling System				Heating System		Ventilation		VRF/FCU Quantity	FCU Number	VRF Number	VRF/FCU Total Cooling Capacity (kW)	VRF/FCU Sensible Cooling Capacity (kW)	VRF/FCU Heating Capacity (kW)	VRF/FCU Electrical Power per Unit (kW)	
						Total Cooling Load (kW)	Sens. Cooling Load (kW)	Coil Entering (DB/WB) (°C)	Coil Leaving (DB/WB) (°C)	Time of Peak Coil Load	Heating Coil Load (kW)	Coil Leaving (DB/DB) (°C)	Fresh Air Ratio (m <sup>3</sup> /h)								Exhaust Air Ratio (m <sup>3</sup> /h)
*150/151/152 Hall	200	20	24	50	22	10.5	9	23.7 / 18.4	15.7 / 15.2	Aug 1500	11.4	21.3 / 31.5	270.0	0.0	2	FCU5	VRF 4	3.5	3.0	3.8	0.20
*159 Hall	120	12	24	50	22	6.5	5.6	23.7 / 18.4	15.7 / 15.2	Jul 1500	7.6	21.4 / 32.3	250.0	0.0	2	FCU5	VRF 4	3.5	3.0	3.8	0.20
*149-c Guest Room	28	2	24	50	22	3.2	2.8	23.7 / 18.2	15.6 / 15.0	Jul 1800	2.6	21.5 / 28.9	125.0	115.0	1	FCU5	VRF 4	3.2	2.8	2.6	0.20
*101-c Guest Room	28	2	24	50	22	3.2	2.8	23.7 / 18.2	15.6 / 15.1	Jun 1700	2.7	21.4 / 29.0	125.0	115.0	1	FCU5	VRF 4	3.2	2.8	2.7	0.20
*102-c Guest Room	28	2	24	50	22	3.2	2.8	23.7 / 18.2	15.6 / 15.0	Jul 1800	2.6	21.5 / 28.9	125.0	115.0	1	FCU5	VRF 4	3.2	2.8	2.6	0.20
*103-c Guest Room	28	2	24	50	22	3.2	2.8	23.7 / 18.2	15.6 / 15.0	Jul 1800	2.6	21.5 / 28.9	125.0	115.0	1	FCU5	VRF 4	3.2	2.8	2.6	0.20
*105-c Living Room	18	2	24	50	22	1.9	1.6	23.6 / 18.3	15.4 / 14.9	Jun 1800	1.3	21.6 / 28.2	125.0	115.0	1	FCU2	VRF 2	1.9	1.6	1.3	0.15
*105-d Guest Room	20	2	24	50	22	2.6	2.3	23.7 / 18.2	15.6 / 15.1	Jun 1700	2.5	21.6 / 30.3	125.0	115.0	1	FCU4	VRF 3	2.6	2.3	2.5	0.15
*106-c Living Room	18	2	24	50	22	1.9	1.6	23.6 / 18.3	15.4 / 14.9	Jul 1800	1.3	21.7 / 28.6	125.0	115.0	1	FCU2	VRF 2	1.9	1.6	1.3	0.15
*106-d Guest Room	20	2	24	50	22	2.6	2.3	23.7 / 18.3	15.7 / 15.2	Jun 1800	2.4	21.5 / 30.1	125.0	115.0	1	FCU4	VRF 3	2.6	2.3	2.4	0.15
*107-c Living Room	18	2	24	50	22	1.9	1.6	23.6 / 18.3	15.4 / 14.9	Jun 1800	1.3	21.6 / 28.2	125.0	115.0	1	FCU2	VRF 2	1.9	1.6	1.3	0.15
*107-d Guest Room	20	2	24	50	22	2.6	2.3	23.7 / 18.3	15.7 / 15.2	Jun 1800	2.4	21.5 / 30.1	125.0	115.0	1	FCU4	VRF 3	2.6	2.3	2.4	0.15
*108-c Living Room	18	2	24	50	22	1.9	1.6	23.6 / 18.3	15.4 / 14.9	Jul 1800	1.3	21.7 / 28.6	125.0	115.0	1	FCU2	VRF 2	1.9	1.6	1.3	0.15
*108-d Guest Room	20	2	24	50	22	2.7	2.4	23.6 / 18.2	15.4 / 14.9	Jun 1800	2.5	21.4 / 30.0	125.0	115.0	1	FCU4	VRF 3	2.7	2.4	2.5	0.15
*110-c Guest Room	28	2	24	50	22	3.2	2.8	23.7 / 18.2	15.6 / 15.0	Jul 1800	2.6	21.5 / 28.9	125.0	115.0	1	FCU5	VRF 4	3.2	2.8	2.6	0.20
*111-c Guest Room	28	2	24	50	22	3.2	2.8	23.7 / 18.2	15.6 / 15.0	Jul 1800	2.6	21.5 / 28.9	125.0	115.0	1	FCU5	VRF 4	3.2	2.8	2.6	0.20
*112-c Guest Room	25	2	24	50	22	3.0	2.7	23.8 / 18.3	15.7 / 15.1	Jun 1800	2.5	21.7 / 29.2	125.0	115.0	1	FCU5	VRF 4	3.0	2.7	2.5	0.20
*113-c Guest Room	28	2	24	50	22	3.2	2.8	23.7 / 18.2	15.6 / 15.0	Jul 1800	2.5	21.5 / 28.6	125.0	115.0	1	FCU5	VRF 4	3.2	2.8	2.5	0.20
*114-c Guest Room	26	2	24	50	22	2.8	2.5	23.6 / 18.2	15.4 / 14.9	Jul 1700	2.4	21.5 / 29.6	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.4	0.15
*115-c Guest Room	28	2	24	50	22	2.8	2.5	23.6 / 18.2	15.5 / 15.0	Jun 1600	2.5	21.5 / 29.7	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.5	0.15
*116-c Guest Room	28	2	24	50	22	2.8	2.5	23.6 / 18.1	15.4 / 14.8	Jul 1500	2.6	21.6 / 30.0	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.6	0.15
*117-c Guest Room	28	2	24	50	22	2.8	2.5	23.6 / 18.1	15.4 / 14.8	Jul 1500	2.6	21.6 / 30.0	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.6	0.15
*118-c Guest Room	28	2	24	50	22	2.8	2.5	23.6 / 18.1	15.4 / 14.8	Jul 1500	2.6	21.6 / 30.0	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.6	0.15
*119-c Guest Room	28	2	24	50	22	2.8	2.5	23.6 / 18.1	15.4 / 14.8	Jul 1500	2.6	21.6 / 30.0	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.6	0.15
*120-c Guest Room	33	2	24	50	22	4.1	3.7	23.8 / 18.2	15.6 / 15.1	Aug 1200	3.1	21.5 / 28.2	125.0	115.0	1	FCU6	VRF 5	4.1	3.7	3.1	0.20
*121-c Guest Room	37	2	24	50	22	4.6	4.2	23.7 / 18.1	15.5 / 14.9	Sep 1200	2.8	21.5 / 27.0	125.0	115.0	1	FCU8	VRF 6	4.6	4.2	2.8	0.20
*122-c Guest Room	28	2	24	50	22	3.5	3.1	23.7 / 18.1	15.5 / 14.9	Sep 1300	2.8	21.6 / 28.9	125.0	115.0	1	FCU5	VRF 4	3.5	3.1	2.8	0.20
*123-c Guest Room	33	2	24	50	22	4.4	4.1	23.7 / 18.1	15.5 / 15.0	Sep 1300	3.3	21.5 / 28.1	125.0	115.0	1	FCU8	VRF 6	4.4	4.1	3.3	0.20
*124-c Guest Room	27	2	24	50	22	3.1	2.8	23.7 / 18.2	15.5 / 15.0	Sep 1500	2.5	21.4 / 28.7	125.0	115.0	1	FCU5	VRF 4	3.1	2.8	2.5	0.20
*125-c Guest Room	27	2	24	50	22	3.1	2.8	23.7 / 18.2	15.5 / 15.0	Sep 1600	2.6	21.7 / 29.4	125.0	115.0	1	FCU5	VRF 4	3.1	2.8	2.6	0.20
*126-c Guest Room	27	2	24	50	22	3.2	2.9	23.8 / 18.4	15.8 / 15.3	Sep 1200	2.6	21.5 / 28.7	125.0	115.0	1	FCU5	VRF 4	3.2	2.9	2.6	0.20
*127-c Guest Room	27	2	24	50	22	3.2	2.9	23.8 / 18.4	15.8 / 15.3	Sep 1200	2.6	21.5 / 28.7	125.0	115.0	1	FCU5	VRF 4	3.2	2.9	2.6	0.20
*128-c Guest Room	27	2	24	50	22	3.4	3.0	23.7 / 18.1	15.5 / 14.9	Sep 1300	3.0	21.4 / 29.6	125.0	115.0	1	FCU5	VRF 4	3.4	3.0	3.0	0.20
*129-c Guest Room	28	2	24	50	22	3.3	3.0	23.7 / 18.2	15.5 / 15.0	Aug 1200	2.6	21.5 / 28.6	125.0	115.0	1	FCU5	VRF 4	3.3	3.0	2.6	0.20
*130-c Guest Room	28	2	24	50	22	3.3	3.0	23.7 / 18.2	15.5 / 15.0	Aug 1200	2.6	21.5 / 28.6	125.0	115.0	1	FCU5	VRF 4	3.3	3.0	2.6	0.20
*131-c Guest Room	28	2	24	50	22	3.3	3.0	23.7 / 18.2	15.5 / 15.0	Aug 1200	2.6	21.5 / 28.6	125.0	115.0	1	FCU5	VRF 4	3.3	3.0	2.6	0.20
*132-c Guest Room	28	2	24	50	22	3.3	3.0	23.7 / 18.2	15.5 / 15.0	Aug 1200	2.6	21.5 / 28.6	125.0	115.0	1	FCU5	VRF 4	3.3	3.0	2.6	0.20
*133-c Guest Room	28	2	24	50	22	3.3	3.0	23.8 / 18.3	15.7 / 15.2	Sep 1200	2.7	21.7 / 29.1	125.0	115.0	1	FCU5	VRF 4	3.3	3.0	2.7	0.20
*134-c Guest Room	26	2	24	50	22	3.3	2.9	23.7 / 18.1	15.5 / 14.9	Sep 1200	2.5	21.5 / 28.6	125.0	115.0	1	FCU5	VRF 4	3.3	2.9	2.5	0.20
*135-c Guest Room	26	2	24	50	22	3.2	2.9	23.7 / 18.3	15.7 / 15.1	Sep 1100	2.5	21.5 / 28.5	125.0	115.0	1	FCU5	VRF 4	3.2	2.9	2.5	0.20
*136-c Guest Room	28	2	24	50	22	2.8	2.5	23.7 / 18.2	15.5 / 15.0	Jul 1400	2.6	21.6 / 30.1	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.6	0.15
*137-c Guest Room	28	2	24	50	22	2.8	2.5	23.7 / 18.2	15.5 / 15.0	Jul 1400	2.6	21.6 / 30.1	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.6	0.15
*138-c Guest Room	28	2	24	50	22	2.8	2.5	23.7 / 18.2	15.5 / 15.0	Jul 1400	2.6	21.6 / 30.1	125.0	115.0	1	FCU4	VRF 3	2.8	2.5	2.6	0.15
*139-c Living Room	55	2	24	50	22	5.4	4.7	23.7 / 18.2	15.4 / 14.9	Sep 1300	3.9	21.7 / 28.4	250.0	230.0	1	FCU9	VRF 7	5.4	4.7	3.9	0.25
*139-f Bedroom	28	2	24	50	22	2.9	2.5	23.7 / 18.2	15.5 / 15.0	Jul 1400	2.8	21.5 / 30.6	125.0	115.0	1	FCU4	VRF 3	2.9	2.5	2.8	0.15
*140-c Guest Room	28	2	24	50	22	3.4	3.1	23.8 / 18.4	15.8 / 15.3	Sep 1200	2.8	21.7 / 29.0	125.0	115.0	1	FCU5	VRF 4	3.4	3.1	2.8	0.20
*141-c Guest Room	33	2	24	50	22	4.5	4.1	23.7 / 18.1	15.4 / 14.9	Sep 1500	3.3	21.4 / 28.0	125.0	115.0	1	FCU8	VRF 6	4.5	4.1	3.3	0.20
*142-c Guest Room	28	2	24	50	22	3.1	2.8	23.7 / 18.3	15.6 / 15.1	Sep 1600	2.6	21.6 / 29.2	125.0	115.0	1	FCU5	VRF 4	3.1	2.8	2.6	0.20
*143-c Guest Room	28	2	24	50	22	3.1	2.8	23.7 / 18.3	15.6 / 15.1	Sep 1600	2.6	21.6 / 29.2	125.0	115.0	1	FCU5	VRF 4	3.1	2.8	2.6	0.20
*144-c Guest Room	28	2	24	50	22	3.1	2.8	23.7 / 18.3	15.6 / 15.1	Sep 1600	2.6	21.6 / 29.2	125.0	115.0	1	FCU5	VRF 4	3.1	2.8	2.6	0.20
*145-c Guest Room	28	2	24	50	22	3.1	2.8	23.7 / 18.3	15.6 / 15.1	Sep 1600	2.6	21.6 / 29.2	125.0	115.0	1	FCU5	VRF 4	3.1	2.8	2.6	0.20
*146-c Guest Room	28	2	24	50	22	3.1	2.8	23.7 / 18.3	15.6 / 15.1	Sep 1600	2.6	21.6 / 29.2	125.0	115.0	1	FCU5	VRF 4	3.1	2.8	2.6	0.20

Zone Name	Floor Area (m <sup>2</sup> )	Occupancy	Summer					Cooling System					Heating System		Ventilation		VRF / FCU Quantity	FCU Number	VRF Number	VRF/FCU Total Cooling Capacity (kW)	VRF/FCU Sensible Cooling Capacity (kW)	VRF/FCU Heating Capacity (kW)	VRF/FCU Electrical Power per Unit (kW)
			Summer	Summer	Winter	Total Cooling Load (kW)	Sens. Cooling Load (kW)	Coil Entering (DB/WB) (°C)	Coil Leaving (DB/WB) (°C)	Time of Peak Coil Load	Heating Coil Load (kW)	Coil Leaving (DB/DB) (°C)	Fresh Air Ratio (m <sup>3</sup> /h)	Exhaust Air Ratio (m <sup>3</sup> /h)									
*G58 Hall	18	2	24	50	22	1.1	0.7	24.5 / 20.9	18.3 / 17.9	Aug 1400	1.3	21.1 / 33.1	0.0	0.0	1	FCU 1	VRF 2	1.1	0.7	1.3	0.15		
*G62 Staff Resting Room	14	4	24	50	22	1.6	0.7	24.1 / 21.3	14.4 / 14.3	Aug 0600	0.8	22.0 / 33.4	200.0	100.0	1	FCU 1	VRF 2	1.6	0.7	0.8	0.15		
*G63 Hall	7	1	24	50	22	0.5	0.5	24.0 / 21.5	21.1 / 20.6	Jul 1500	1.9	22.0 / 33.3	500.0	0.0	1	FCU 1	VRF 1	0.5	0.5	1.9	0.15		
*G64 Women Staff Chng	9	4	24	50	22	1.0	0.8	25.6 / 18.6	14.4 / 13.8	Aug 0600	0.6	21.5 / 29.3	0.0	0.0	1	FCU 1	VRF 2	1.0	0.8	0.6	0.15		
*G65 Men Staff Chng	9	4	24	50	22	1.0	0.8	25.6 / 18.6	14.4 / 13.8	Aug 0600	0.6	21.5 / 29.3	0.0	0.0	1	FCU 1	VRF 2	1.0	0.8	0.6	0.15		
G70 Spa Lounge	41	7	24	50	22	4.9	2.5	24.6 / 21.0	14.4 / 14.2	Jun 0800	1.9	21.9 / 29.5	500.0	0.0	1	FCU 4	VRF 3	4.9	2.5	1.9	0.15		
G71 Hall	34	4	24	50	22	1.9	1.2	24.2 / 21.5	19.6 / 19.4	Aug 1300	3.0	21.7 / 33.3	500.0	0.0	1	FCU 1	VRF 2	1.9	1.2	3.0	0.15		
G72 Spa Lead Office	9	3	24	50	22	1.8	1.3	24.5 / 19.9	17.0 / 16.5	Jun 1300	2.1	21.2 / 33.1	100.0	100.0	1	FCU 2	VRF 2	1.8	1.3	2.1	0.15		
G74-a Massage Room	18	2	24	50	22	1.7	0.9	24.5 / 20.5	14.7 / 14.4	Aug 0600	1.1	21.7 / 33.5	150.0	150.0	1	FCU 1	VRF 2	1.7	0.9	1.1	0.15		
G74-b Massage Room	18	2	24	50	22	1.5	0.9	24.4 / 20.7	16.9 / 16.6	Aug 1600	1.3	21.5 / 33.0	150.0	150.0	1	FCU 1	VRF 2	1.5	0.9	1.3	0.15		
G74-c Massage Room	17.5	2	24	50	22	2.5	1.6	24.8 / 19.6	14.4 / 14.0	Jun 0900	1.8	21.5 / 33.2	150.0	150.0	1	FCU 2	VRF 2	2.5	1.6	1.8	0.15		
G74-d Massage Room	16.8	2	24	50	22	1.5	0.8	24.4 / 20.6	16.1 / 15.8	Aug 1400	1.2	21.6 / 33.3	150.0	150.0	1	FCU 1	VRF 2	1.5	0.8	1.2	0.15		
G74-e Massage Room	15	2	24	50	22	2.7	1.8	24.8 / 19.4	14.4 / 14.0	Jun 0900	1.8	21.6 / 31.8	150.0	150.0	1	FCU 3	VRF 2	2.7	1.8	1.8	0.15		
G74-f Massage Room	17	2	24	50	22	2.7	1.8	25.0 / 19.5	14.4 / 14.0	Jun 0900	1.4	21.6 / 29.8	150.0	150.0	1	FCU 3	VRF 2	2.7	1.8	1.4	0.15		
G74-g Massage Room	27	2	24	50	22	3.0	1.8	25.1 / 20.2	14.4 / 14.0	Jun 0800	1.4	21.7 / 29.8	200.0	200.0	1	FCU 3	VRF 2	3.0	1.8	1.4	0.15		
G74-h Relaxing Area	42	6	24	50	22	10.7	8.6	24.8 / 18.6	14.8 / 14.2	Sep 1100	4.0	21.8 / 26.5	350.0	300.0	3	FCU 5	VRF 4	3.6	2.9	1.3	0.20		
G73 Spa Dispensary	7	3	24	50	22	1.9	1.3	24.8 / 19.1	14.4 / 13.9	Jun 0900	0.8	21.6 / 28.0	100.0	100.0	1	FCU 2	VRF 2	1.9	1.3	0.8	0.15		
*G75-a Family Room	9	2	24	50	22	1.1	0.5	24.1 / 21.3	15.0 / 14.8	Aug 0600	0.7	22.0 / 33.6	150.0	150.0	1	FCU 1	VRF 1	1.1	0.5	0.7	0.15		
Ahu 09 Pool																							
G32 Pool Area**	256	12	24	50	22																		
Ahu 10 Laundry																							
*B149-a Laundry	370		24	50	22																		
*B149-c Laundry Chef	10		24	50	22																		
*B149-d Clean Linen Stor	43		24	50	22																		
*B149-e Uniform	32		24	50	22																		
Ahu 11 Kitchen																							
*B136 Laundry Office	7	2	24	50	22																		
*B137-a Flower Prep	4	2	24	50	22																		
*B138-a Clean Corridor	44	5	24	50	22																		
*B138-b Can&Bottle Store	9	1	24	50	22																		
*B138-c Potato Store	8	1	24	50	22																		
*B138-d Vegetable pre.	16	2	24	50	22																		
*B138-h Dry Store	27	3	24	50	22																		
*B138-n Dry Store	30	3	24	50	22																		
*B139-a Clean Corridor	40	4	24	50	22																		
*B139-b Pastry&Bakery	54	4	24	50	22	10.2	8.4	25.2 / 18.5	14.4 / 13.8	Aug 0700	1.7	21.9 / 24.1	8500.0	0.0	3	FCU 5	VRF 4	3.4	2.8	0.6	0.20		
*B139-c Dry Store	9	1	24	50	22																		
*B139-f Potwash	13	1	24	50	22																		
*B139-g Pastry Chef	10	1	24	50	22																		
*B142-k Sample Room	10	1	24	50	22																		
*B142-l Chef Office	10	1	24	50	22																		
*B142-m/n Meat Poultry P	32	4	24	50	22	4.5	3.5	25.6 / 18.9	14.4 / 13.8	Jul 0700	0.6	21.9 / 23.8	950.0	0.0	1	FCU 6	VRF 5	4.5	3.5	0.6	0.20		
*B142-o Vegetable Prepar	26	3	24	50	22																		
*B141-a Garbage Corridor	62	7	24	50	22																		
*B141-b Trolley Parking	38	4	24	50	22																		
*B141-c Room Service	22	1	24	50	22																		
Ahu 12 Kitchen																							
*B139-h Hot Kitchen&Bang	75	4	24	50	22																		
*B139-i Cold Kitchen	46	3	24	50	22	8.7	7.1	25.2 / 18.4	14.4 / 13.8	Jul 0700	1.6	22.0 / 24.5	3500.0	0.0	2	FCU 6	VRF 5	4.4	3.6	0.8	0.20		
*B148-a/b Staff Dining R	92	40	24	50	22																		
*B140 Hall	32	5	24	50	22																		
*B139-k Staff Cant. Kitc	40	2	24	50	22																		
Ahu 13 Offices																							
*B166 Chief Engineer	19	3	24	50	22	2.1	1.5	24.6 / 19.2	14.4 / 14.0	Jun 0600	1.3	21.7 / 30.8	150.0	150.0	1	FCU 2	VRF 2	2.1	1.5	1.3	0.15		
B171-a/H Hall	48	5	24	50	22	3.2	1.7	24.3 / 20.3	14.4 / 14.1	Jun 0600	1.4	21.9 / 29.7	900.0	900.0	1	FCU 3	VRF 2	3.2	1.7	1.4	0.15		
B171-b HR Assistant	16	3	24	50	22	1.9	1.3	24.8 / 19.4	14.4 / 14.0	Jun 0600	0.7	21.8 / 27.4	150.0	150.0	1	FCU 2	VRF 2	1.9	1.3	0.7	0.15		
B171-c Meeting Room	36	18	24	50	22	5.9	4.1	24.7 / 19.1	14.4 / 13.9	Jun 0600	1.1	21.8 / 24.4	400.0	400.0	2	FCU 3	VRF 3	3.0	2.1	0.6	0.15		
B171-d Language Lab	21	10	24	50	22	3.5	2.4	24.5 / 19.1	14.4 / 14.0	Jun 0600	0.9	21.8 / 25.7	250.0	250.0	1	FCU 4	VRF 3	3.5	2.4	0.9	0.15		
B171-e HR Training Manag	10	2	24	50	22	1.2	0.8	24.7 / 19.5	14.4 / 14.0	Jun 0600	0.4	21.8 / 27.3	100.0	100.0	1	FCU 1	VRF 2	1.2	0.8	0.4	0.15		
B171-f HR Storage	10	1	24	50	22	0.5	0.4	27.1 / 19.2	14.4 / 13.7	Aug 0600	0.2	21.6 / 27.8	0.0	75.0	1	FCU 1	VRF 1	0.5	0.4	0.2	0.15		
B171-g Beverage	5	1	24	50	22	0.7	0.3	23.8 / 20.8	14.4 / 14.2	Jun 0600	0.2	22.0 / 27.1	100.0	100.0	1	FCU 1	VRF 1	0.7	0.3	0.2	0.15		
B171-h Ynterview Room	16	3	24	50	22	1.9	1.3	24.8 / 19.4	14.4 / 14.0	Jun 0600	0.7	21.8 / 27.4	150.0	150.0	1	FCU 2	VRF 2	1.9	1.3	0.7	0.15		
B174-a Revenue manager	11	2	24	50	22	1.3	0.9	24.8 / 19.4	14.4 / 14.0	Jun 0600	0.5	21.8 / 27.2	100.0	100.0	1	FCU 1	VRF 2	1.3	0.9	0.5	0.15		
B174-b Sales Manager	11	2	24	50	22	1.3	0.9	24.8 / 19.4	14.4 / 14.0	Jun 0600	0.5	21.8 / 27.2	100.0	100.0	1	FCU 1	VRF 2	1.3	0.9	0.5	0.15		
B174-c Director of Sales	11	2	24	50	22	1.3	0.9	24.6 / 19.3	14.4														

## 7.5 Price offer for the devices of System A

Model No	Tip	Soğutma Kapasitesi (kW)	Miktar	Birim Fiyat (USD)	Toplam Fiyat (USD)
<b>DIŞ ÜNİTELER</b>					
PUHY-P400YKB-A1	VRF HEAT PUMP Diş Ünite -16 HP	45,0	10	13.724,00	137.240,00
PUHY-P500YSKB-A1	VRF HEAT PUMP Diş Ünite - 20 HP (10+10)	56,0	8	17.176,00	137.408,00
PURY-P350YLM-A1	VRF HEAT RECOVERY Diş Ünite - 14 HP	40,0	3	13.430,00	40.290,00
PURY-P400YLM-A1	VRF HEAT RECOVERY Diş Ünite - 16 HP	45,0	2	15.350,00	30.700,00
PURY-P450YLM-A1	VRF HEAT RECOVERY Diş Ünite - 18 HP	50,0	4	17.270,00	69.080,00
PURY-P500YSLM-A1	VRF HEAT RECOVERY Diş Ünite - 20 HP (10+10)	56,0	5	19.180,00	95.900,00
PURY-P550YSLM-A1	VRF HEAT RECOVERY Diş Ünite - 22 HP (10+12)	63,0	2	21.100,00	42.200,00
PURY-P600YSLM-A1	VRF HEAT RECOVERY Diş Ünite - 24 HP (12+12)	69,0	3	23.020,00	69.060,00
<b>İÇ ÜNİTELER</b>					
PEFY-P15VMS1-E	DÜŞÜK STATİK BASINÇLI İNCE GİZLİ TAVAN TİPİ - (50 Pa)	1,7	33	940,00	31.020,00
PEFY-P20VMS1-E	DÜŞÜK STATİK BASINÇLI İNCE GİZLİ TAVAN TİPİ - (50 Pa)	2,2	20	960,00	19.200,00
PEFY-P25VMS1-E	DÜŞÜK STATİK BASINÇLI İNCE GİZLİ TAVAN TİPİ - (50 Pa)	2,8	8	970,00	7.760,00
PEFY-P32VMS1-E	DÜŞÜK STATİK BASINÇLI İNCE GİZLİ TAVAN TİPİ - (50 Pa)	3,6	59	990,00	58.410,00
PEFY-P40VMS1-E	DÜŞÜK STATİK BASINÇLI İNCE GİZLİ TAVAN TİPİ - (50 Pa)	4,5	113	1.030,00	116.390,00
PEFY-P50VMS1-E	DÜŞÜK STATİK BASINÇLI İNCE GİZLİ TAVAN TİPİ - (50 Pa)	5,6	16	1.060,00	16.960,00
PEFY-P63VMS1-E	DÜŞÜK STATİK BASINÇLI İNCE GİZLİ TAVAN TİPİ - (50 Pa)	7,1	3	1.100,00	3.300,00
PEFY-P20VMA-E	ORTA STATİK BASINÇLI GİZLİ TAVAN TİPİ - (150 Pa)	2,2	4	1.160,00	4.640,00
PEFY-P25VMA-E	ORTA STATİK BASINÇLI GİZLİ TAVAN TİPİ - (150 Pa)	2,8	1	1.180,00	1.180,00
PEFY-P40VMA-E	ORTA STATİK BASINÇLI GİZLİ TAVAN TİPİ - (150 Pa)	4,5	4	1.240,00	4.960,00
PEFY-P50VMA-E	ORTA STATİK BASINÇLI GİZLİ TAVAN TİPİ - (150 Pa)	5,6	4	1.280,00	5.120,00
PEFY-P63VMA-E	ORTA STATİK BASINÇLI GİZLİ TAVAN TİPİ - (150 Pa)	7,1	12	1.350,00	16.200,00
PLFY-P40VEM-E	KASETLİ TAVAN TİPİ - (950X950) - 4 YÖN	4,5	4	1.460,00	5.840,00
PLFY-P50VEM-E	KASETLİ TAVAN TİPİ - (950X950) - 4 YÖN	5,6	2	1.520,00	3.040,00
<b>KUMANDA SİSTEMLERİ</b>					
PAR-32MAA-J	KABLOLU KUMANDA		6	230,00	1.380,00
PAC-YT52CRA-J	BASİTLEŞTİRİLMİŞ KABLOLU KUMANDA		283	125,00	35.375,00
PAR-W21MAA-J	SICAK SU ÜRETİCİSİ KUMANDASI		31	330,00	10.230,00
AE-200E	DOKUNMATİK MERKEZİ KUMANDA WEB TARAMA (50 İç Ünite)		7	3.750,00	26.250,00
<b>BAĞLANTI ELEMANLARI</b>					
CMY-Y102S-G	BAĞLANTI ELEMANI - CMY 1		102	50,00	5.100,00
CMY-Y102L-G	BAĞLANTI ELEMANI - CMY 2		30	90,00	2.700,00
CMY-Y202-G	BAĞLANTI ELEMANI - CMY 3		24	95,00	2.280,00
CMY-R160-J	BAĞLANTI ELEMANI - BC BAĞLANTI ELEMANI		9	110,00	990,00
CMY-Y100VBK2	H. PUMP DIŞ ÜNİTE BAĞLANTI ELEMANI		8	150,00	1.200,00
CMY-R100VBK2	H. RECOVERY DIŞ ÜNİTE BAĞLANTI ELEMANI		10	380,00	3.800,00
<b>AKIŞ KONTROL ÜNİTELERİ</b>					
CMB-P1010V-G1	AKIŞ KONTROL ÜNİTESİ - 10 BRANŞMAN		1	6.340,00	6.340,00
CMB-P1016V-G1	AKIŞ KONTROL ÜNİTESİ - 16 BRANŞMAN		1	8.300,00	8.300,00
CMB-P1010V-GA1	AKIŞ KONTROL ÜNİTESİ - 10 BRANŞMAN		1	7.040,00	7.040,00
CMB-P1013V-GA1	AKIŞ KONTROL ÜNİTESİ - 13 BRANŞMAN		9	8.170,00	73.530,00
CMB-P1016V-GA1	AKIŞ KONTROL ÜNİTESİ - 16 BRANŞMAN		7	9.230,00	64.610,00
CMB-P108V-GB1	AKIŞ KONTROL ÜNİTESİ - 8 BRANŞMAN (YARD)		3	4.950,00	14.850,00
<b>HAVALANDIRMA CİHAZLARI</b>					
PAC-AH500M-J	KLİMA SANTRALİ DX BATARYASI EXPANSION KIT		18	3.830,00	68.940,00

## 7.6 Price offer for the devices of System C

ROBUR ISI POMPASI TEKLİFİ						
	Yapılacak İşin Cinsi	Marka	Birim	Miktar	Malzeme B.fiyat	Tutar
1	<b>ROBUR CİHAZLARI</b> <b>GAHP-AR</b> Isıtma veya soğutma cihazı 18 kw soğutma, Min.3 C soğuk su 38 kw ısıtma, Max.65 C sıcak su	ROBUR	Ad	35	9.900,00	346.500,00
	<b>GA-ACF 60-HR</b> Soğutma ve Soğuturken Bedava Sıcak Su 18 kw soğutma, Min.3 C soğuk su 25 kw sıcak su, Max.80 C sıcak su	ROBUR	Ad	16	6.600,00	105.600,00
	<b>GA-ACF 60</b> Soğutma ve Soğuturken Bedava Sıcak Su 18 kw soğutma, Min.3 C soğuk su	ROBUR	Ad	45	6.100,00	274.500,00
	<b>CALDERIA 100</b> Duvar tipi dış ortam yoğuşmalı kazan cihazı 100 kw ısıtma, Max.90 C sıcak su	ROBUR	Ad	2	3.500,00	7.000,00
	<b>DDC KONTROL PANELİ</b>	ROBUR	Ad	6	750,00	4.500,00
<b>TOPLAM TUTAR(€)</b>						<b>738.100,00</b>

1 KDV dahil edilmemiştir.

Teklif no:34-200033

Tarih: 11/01/2020

## **8 PERSONAL BACKGROUND**

Name Surname: Halmyrat Tokgayev

Birth date/place: 1991/Turkmenistan

### **Education**

High school: Turkmengala etrap no:14 (1997-2008), Mary/Turkmenistan.

Turkish Language Program: Turkish Language Learning, Research and Application Center (2010-2011), Ankara/Turkey.

School of foreign language: Yildiz Technical University (2011-2012), Istanbul/Turkey.

Exchange program: Universitat Politècnica de València, Mechanical Engineering Department (2015), Valencia/Spain.

Bachelor's degree: Yildiz Technical University, Mechanical Engineering Department (2011-2017), Istanbul/Turkey.

Master Degree: Marmara University, Mechanical Engineering Department (2017-2020), Istanbul/Turkey.

### **Experience**

Mechanical Engineer, Beta Teknik San. Ve Tic. Ltd. Şti. (2015- ...), Istanbul/Turkey.

Internship Engineer, Galaksi Yapı Mimarlık Mühendislik San. Ve Tic. Şti. (2015), Ashgabat/Turkmenistan.

Internship Engineer, Öztürk Makine Doğalgaz Tesisat Taahhüt San. Ve Tic. Şti. (2014), Istanbul Turkey.

Service Personnel, Motel 6 Merrillville (2013), Indiana State/USA.