ENGINEERING AND TECHNOLOGY MANAGEMENT



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PREFACE

Technological advances in the field of engineering are followed by major and important developments. Güven Plus Grup A.Ş., whose publications are mostly academic books, has gained a lot of prestige with its national and international activities. The "Engineering and Technology Management" book has been published by this publisher that consists of fifteen different chapters which cover various issues and researches of valuable academicians.

Activities that benefit humanity such as development, change, progress, and innovation are a product of labor. Sharing scientific studies that benefit all humanity is of great importance. As scientists, it is our pleasure to touch people's world positively, by publishing works that make their lives easier.

Each chapter in the book consists of original studies which are written by valuable academicians and researchers. We would like to express our gratitude to each of our authors who collected these works in our book and became a part of it.

May everyone who reads and examines this book find it helpful in terms of solving a problem, getting an answer to a question, and getting an opportunity for their further work. Presenting such scientific studies aimed at making a positive contribution to humanity for the benefit of scientists, researchers and industrialists will take our human feelings further and make people look at life more positively.

We believe that this book, which includes chapters on many interesting topics of engineering technologies, will shed light on the academic studies of many researchers and will find a valuable place in the catalogs of the Higher Education Institution, university libraries, and personal archives.

We would like to thank our esteemed authors, referees, technical team, and our dear readers, who have contributed to the realization of this book, which is the result of long efforts and meticulous studies.

Prof. Dr. Ashok JAMMI
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December 2021

HVAC PRACTICES FOR DATA CENTERS

Kaan YILMAZKARASU[1], *Ayhan ONAT*[2]

Abstract: Today, energy consumption accounts for the majority of the import costs of developing countries. This necessitates examining all factors that may affect energy consumption amounts. It is necessary to interpret such factors with an engineering perspective and a mental filter. The electronic conversion of data has been a necessity in any business. Large servers and network equipment are needed to perform the instantaneous transmission request of digital information. These aggregated results and associated equipment are stored in multiple rooms throughout an entire building. Today's data centers are composed of thousands of high-powered and too-small servers running 24/7. Data centers are among the facilities with very high electricity consumption. This kind of consumption reveals too much potential for saving studies. This study is aimed to compare heat loss/gain software for heating, ventilation, and air conditioning engineering designs and to scrutinize the possible differences from an engineering and academic perspective. For a sample data center, a 3D model of the building is created using Trace 700, Carrier Hourly Analysis Program (HAP), Revit and Cypetherm Loads software, and thermal-load calculations are made on this model. The first step of efficiency studies in a mechanical system is the accuracy of calculations. Although the gained loads with the help of environmental conditions for the data centers are too small compared to the device loads, the calculation method or the software used in the thermal calculations in the study shows that the volumes with large outer wall and roof area affect the accuracy of the results.

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Keywords: Data Center Cooling, Cooling Load Calculations, Thermal Load Calculation Softwares

INTRODUCTION

Today, project completion times are getting shorter and shorter in order to meet the sector's needs. For an energy efficient building, it is necessary to quickly calculate heat losses and gains. In a building where an air conditioning project is designed, heating or cooling calculations are a laborious and error-prone process due to the use of many tables and formulas. It has been determined that performing these operations with software will shorten the project period and minimize possible errors (Oranlıer ve Eyriboyun, 2009).

The energy consumed in buildings in European countries is approximately 40% of the total energy consumed (Kürekci ve Kaplan, 2014). It is stated that it causes 30% of the total CO_2 emissions. It is a fact that Turkey is not rich in energy reserve areas. 76% of the total energy in Turkey is purchased from other countries. In addition, this demand increases by approximately 4% in 1 year. Optimization studies and economic savings are important (Alkan ve ark., 2017).

Today, energy efficiency has become a focus for data centers as in all sectors. Energy efficiency in data centers, which are exposed to high-density electrical loads, is much more important than other buildings. Most data centers are designed for the highest load density, cooling loads are not associated with the time parameter. In addition, it is known that mechanical equipment is chosen with more capacity than normal, which will increase both investment and operating costs. Energy efficiency as well as reliability should be considered in data center infrastructure design studies. Since most of the energy consumption for data centers is caused by mechanical cooling systems, strategies should be developed to increase the energy efficiency of cooling systems (Türkmen, 2019).

The software makes calculations with many different engineering assumptions, and the mathematical models used in the background of the assumptions affect the accuracy of the calculation results. In addition, each software uses internationally standards accepted by different count-

ries. In this study, besides the software results, the difference in results that may occur from the calculation methods and standards will be examined and more accurate conclusions will be reached about the results.

There have been previous studies on different or similar software in the literature, and in addition to these, this study includes basic usage information about four different software. This study has been a guide study about software. The analysis of the standards used and the differences in calculation methods constituted the original value of the study. In addition, due to the limited number of studies on data centers in the literature, it is thought that this study will benefit the literature and related sectors. In addition, the number of alternative software to be used is important in terms of more accurate comparison of the results. In order to make the results more meaningful, the software that is known to be used the most in industry and academic studies was preferred.

Due to both commercial concerns and some mathematical processing difficulties, commercial software works with assumptions and estimations. In line with sectoral and academic experiences, these softwares, which have wide use in the field of engineering, as it is necessary for every study, should be verified by independent studies to be done.

In this study, the calculation methods of the software and which standards they use are examined. An existing data center building was selected and cooling loads were calculated with four different software. Simultaneously with the calculations, basic information about the use of the software is given. Finally, possible computational differences based on these results are interpreted.

The results calculated with the software will determine the capacity of the equipment that will consume energy throughout the year. The equipments will cause an energy and cost proportional to its capacity. The accuracy of the calculations means an energy to be saved and the cost of this energy. When these account values, which seem insignificant on a small scale, are considered on a large scale, they mean very large savings values throughout the country and economic gains to be obtained from these savings.

It is predicted that the data obtained from the study will allow the design of more efficient cooling systems for data centers. It is expected to prevent energy consumption and to reduce investment and operating costs on a small scale. When considered on a large scale, it is expected that the amount of imported energy will decrease and space will be opened for new investments.

HVAC Practices for Data Centers

Digital Transformation

Digitalization is a general term for the 'Digital Transformation' of society and the economy. It describes the transition from the industrial age characterized by analog technologies to the information and creativity age characterized by digital technologies and digital business innovations. Digital transformation provides many advantages, from efficiency to security, from spreading a collaborative culture to cost advantages.

It can be said that this transformation is the result of humanity's endless search for improvement. The part of the transformation is the result of productivity works. However, this definition only is insufficient. Similar to many developments in human history, not all of this transformation took place in a controlled manner. With the integration of technology into our lives, most companies and/or people have been forced into this transformation in some way. Figure 1 shows an image of digitalization.



Figure 1. Digitalization

Data Centers

Data Centers are areas where equipment is gathered in a single center for the purpose of obtaining, storing, processing, and transmitting very large data. There is a high density of computer and network equipment in these areas. They can be on a small or large scale, depending on their intended use and capacity. Although data centers are referred to by a single name, they include routers, switches, security devices, storage systems, servers, controllers and more. These are the IT components needs to store and manage the most critical systems that are vital to a company's continued operation. Therefore, the efficiency, security, reliability and continuous improvement of data centers should be a priority for organizations. Figure 2 shows an example of data center interior design.



Figure 2. Data Centers

Why We Need Data Centers?

The growth in the number of users connected to the Internet and the increase in data has led companies to invest in data centers that are growing and have more energy density per m^2.

There are various levels of "Data Center" needs, including government agencies, educational institutions, telecommunications companies, financial institutions, healthcare institutions, retailers of all sizes, and online marketers providing information and social networking services such as Google and Facebook.

While data center designs are unique, they can often be classified as internet-connected or enterprise or internal data centers. Internet-connected data centers support relatively few applications and are generally

browser-based and often have unknown users. In contrast, enterprise data centers serve fewer users but host applications ranging from off-the-shelf to custom applications. Data centers in the world of corporate information technologies; It is designed to support business applications and activities such as e-mail and file sharing, productivity applications, customer relationship management (CRM) and enterprise resource planning (ERP), big data, artificial intelligence and machine learning, communication and collaboration services.

Why are Data Centers so Important?

With digitalization, the developing internet technologies and the increasing number of web pages have become more than the number of people in the world. This means more bandwidth requirement and hence more disk space requirement. Increases in the speed of access had similar results and led to the enrichment of information resources. This situation has revealed the importance of storing and processing big data. An institution must have a data center for all kinds of data it produces or uses. There are various levels of "Data Center" needs, including government agencies, educational institutions, telecommunications companies, financial institutions, healthcare institutions, retailers of all sizes, and online marketers providing services via internet technologies such as Google and Facebook.

A slow and insecure access to data can cause serious disruption of services. This situation indirectly leads to loss of customers and it is inevitable for companies to experience financial losses. To avoid this loss, many businesses prefer to keep their data in data centers to both reduce costs and benefit from cloud services, rather than the structures created by their own computer networks and servers. The growth in the number of people connected to the Internet and the increase in data sizes have prompted companies to invest in data centers that can store and process more data per m^2. Selection and design of an efficient cooling system is very important as these cost savings will contribute greatly to the expense and income balance of a data center. Data centers are areas where temperature and humidity need to be controlled, the electricity supply is stabilized, continuous electricity supply is provided and spe-

cially air-conditioned. In addition to these, there are cable infrastructure systems, supervised access, security systems and fire detection and extinguishing systems. Thus, this center contains all of an organization's computing (IT) systems and hardware.

Data Center Equipments

In any structure used for data center and similar purposes, it is necessary to make a large number of cable connections. In data centers, certain rack structures are used that enable the equipment to be placed in an organized manner and to protect them against external factors. These structures also significantly reduce the residential area. Data center equipment is usually mounted in racks. But others are configured in prepackaged configurations as large, self-contained cabinets. Rack and cabinet dimensions are determined by the Electronic Industries Association (EIA). The vertical dimension is expressed in "unit" (U) (sometimes rack unit (RU)) and the overall height for a rack is 42U. A U stands for 44.45mm vertical height within the rack. The terms rack and cabinet are used interchangeably, although technically a rack is an open, two- or four-column structure used more for telecom and patch panels than servers; A cabin is a similar four-column frame equipped with side, top, front and rear doors. Examples of two column open rack and four column open rack are shown in Figure 3.

Rack technology should also be in a structure that will allow these equipment, which consumes high electricity, to transfer the heat produced by these equipment to the environment. In this way, the appropriate temperature for the operating conditions of the equipment can be provided by supporting it with cooling systems. Data center components (processors, memory, storage, input/output (I/O), power supplies) are packaged in data center equipment. These equipments mainly consist of servers (capacity, blade etc.), communication equipment (switches, routers etc.) and data storage devices (storage area network (SAN) etc.).

Data center equipment may be of the type that can operate with an air-cooled system or a liquid-cooled system. The critical condition for air-cooled equipment is air intake into the equipment. The important

point for liquid-cooled equipment is the fluid connection to the equipment or rack. Examples of air-cooled racks are shown in Figure 4 and liquid-cooled racks in Figure 5 (TTMD Issue 121).

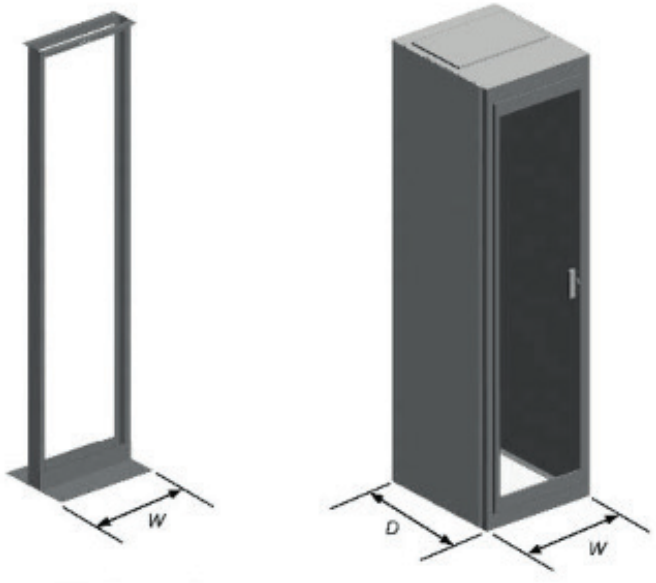

Figure 3. Examples of Two Column Open Rack and Four Column Open Rack

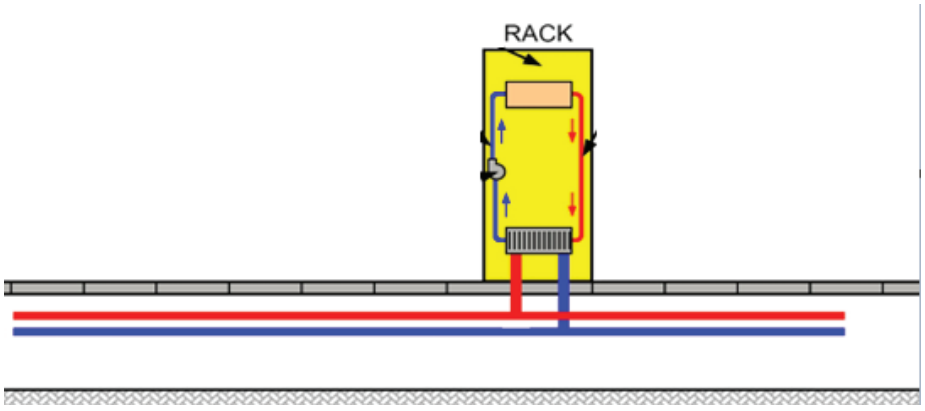

Figure 4. Equipment Air Flow



Figure 5. Equipment Air Flow

Work Load of Data Center Equipments

Data center equipment (hardware) has various workload states ranging from idle (not performing any useful work) to operating at its maximum performance. Hardware workload is managed by software. The number of applications available across all hardware types is certainly in the millions or more. Software can be added or upgraded in a variety of ways, often including remotely. This means that the workload can be very dynamic. Data center equipment lifecycles are much shorter than power and cooling infrastructure lifecycles Application software lifecycles are even shorter. It is critical that power and cooling infrastructure planning considers the lifecycles of hardware and software.

How to Determine Data Center Size Scales

For a data center power and cooling infrastructure planning of U-type cabinets, two common metrics are watts per square meter and kW per rack. The data center industry sometimes uses the average item size (granularity) to define unit sizes. The general consensus in the data center industry is that kilowatts per rack are superior to watts per square metre. However, at the start of a project, there may not be enough information about the amount of racks making the metric multi-particle (granular). Professional calculation is critical for deciding which maximum load characterization to use. It is equally important to characterize the load variation as well as the minimum load. The time step for the load change can be too short (eg seconds, minutes) or too long. It is important to define or develop a detailed load profile, including future possibilities.

Data Center Components

Active Infrastructure Systems and Components

- *Application Software and Geographical Information Systems*
- *Server and Computer Systems*
- *Virtualization and Cloud Systems*
- *Crypto Security*
- *Network and Communication Systems*
- *Data Center Management Systems*
- *Secure Information Sharing and Cyrptographic Communication Solutions*

Passive Infrastructure Systems and Components

- *Air Conditioning Systems*
- *Energy Systems (UPS, Generator)*
- *Fire Alarm and Suppression Systems*
- *Cabling, Floor Covering and Furniture*

Energy Efficiency in Data Centers

The Green Grid (TGG) is a joint institution of government agencies and educational institutes. Data centers support energy efficiency. TGG has developed a new measure in addition to many studies. PUE value; It is the ratio of the total energy consumed in the data center (including the energy used for IT equipment) divided by the energy consumed on the IT equipment. PUE is given in Equation 1.

PUE = Total Facility Power / IT Equipment Power (1)

Data Center Infrastructure Efficiency (DCiE) is defined as the opposite of PUE. This measurement is made annually in order not to be affected by the effects of climate changes in different seasons of the year on energy consumption. For example: In summer, cooling devices for some

regions operate less efficiently and consume more energy to achieve the same cooling load. With the use of advanced air handling units (AHU), PUE values can reach as low as 1.06. In Table 1, the efficiency table determined by The Green Grid is given. In addition, in Table 2, the PUE values estimation table made by EPA for 2011 is given. DCiE is given in Equation 2.

$$\text{DCiE} = \text{IT Equipment Power} / \text{Total Facility Power} \quad (2)$$

Table 1. The Green Grid Efficiency Table

PUE	DCiE(%)	Verimlilik Durumu
3,0	33	Very Inefficient
2,5	40	Inefficient
2,0	50	Average
1,5	67	Efficient
1,2	83	Very Efficient

Table 2. EPA Estimated PUE Values in 2011

Scenarios	PUE
Current Trends	1,9
Improved Operations	1,7
Best Practices	1,3
State-of-the-Art	1,2

Parameters Affecting Thermal Loads in Data Centers

The purpose of the cooling design, as in all cooling designs, is to balance the cooling capacity with the actual thermal load. This requires being able to accurately analyze and understand the thermal release of equipment in the designed data center. Even if all equipment is known, system design is wrong if all parameters affecting the design

are not handled correctly. The cooling design should be able to stabilize the temperatures of all equipment components (processors, memories, storage, I/Q, power supplies) within the data center within their specific operating temperature ranges. This range is generally below the high temperature limit and above the low temperature limit. The designed system should be able to take the necessary measures to balance the conditions. This ensures smooth operation of the system and data integrity. A well-designed system balances component temperatures, data center equipment performance, noise level, and power consumption. Conventional cooling designs are developed over the loads of all factors that can thermally affect the environment. If these factors are considered from the classical point of view, it can be said that the sun (radiation), walls, windows and roofs, air leaks (infiltration), people, lighting and heat emitted by devices. The power distribution ratios for the data center are given in Table 3.

Table 3. Plant Power (The Green Grid)

Electrical Loads	IT Loads	Air Conditioning	Others
Circuit	Telco Equipments	CRAC	Lightings
Distrubution	Network	Chiller	Heating
UPS	Servers	Condensers	BMS
Generator	Storage	Cooling Towers	Security
Battery		DX Systems	Fire F.
Backup Systems		Pumps	
% 10	% 50	% 36	% 4

In data center cooling calculations, most of the factors above have very minor effects besides the thermal loads, which we define as loads from devices. Since these places are designed in isolation for the purpose of use, they are almost not exposed to sun loads. The human and lighting factor in the environment is also effective only in exceptional cases. As can be seen from the table below, IT loads correspond to a 50% part in the evaluation made over the plant power. While classical cooling optimizations are developed based on hourly analysis and calculation of

different cooling needs according to time intervals, such an optimization study is not available for data centers. For example, when calculating the thermal loads for a public building, the time when the density of people in the environment is the highest (peak point) and the moment when the lighting loads are at the highest are not the same. In this case, these two loads are not added linearly when developing the cooling system. Because at the same time, these cooling loads will never overlap.

Considering this, design engineering has become more important than the development of calculations for data centers. It is not possible to predict the minimum demand and maximum demand points, even if the equipment loads vary in direct proportion to the operations performed. For this reason, the missing part in the system is that the cooling process can be carried out in a near-perfect manner rather than the correct calculation of the thermal loads. The fact that IT loads correspond to half of the facility power also supports this situation. The literature has also developed in this direction. Cooling system designs have changed and developed many times until today. The sensitivity of the equipment and the process-specific conditions have been influential in the development.

Environmental Factors

Temperature, Relative Humidity and Dew Point

The temperature parameter has a direct and indirect effect on the ambient internal temperature. In the indoor environment, solar radiation has a direct effect on thermal gains caused by conduction and convection. In addition, it has an indirect effect on the efficiency and cost of indoor cooling, as it will also be effective on the efficiency of systems that use air cooling. Moisture is the least noticeable and overlooked element in a data center that threatens the operation of hardware. Even some of the traditional managers prefer not to consider this element. Humidity, which is a measure of water vapor in the air, can be explained in two ways: absolute or relative humidity. Relative humidity is the actual amount of water vapor in the air. At the same time, it is the percentage ratio between the amount of water vapor that must be present in order for the air to be saturated with moisture at the same reference

temperature. For example, a relative humidity of 40% means that at this temperature, the air contains 40% of the maximum water vapor that it can saturate. Another concept is the dew point or dew point, which is the temperature at which the water vapor in the air transitions from the gaseous state to the liquid state, when the relative humidity is one hundred percent. In this case, the air is considered saturated. In a data center, relative humidity can affect devices in two ways. The first danger is the discharges experienced as a result of the formation of electrostatic differences. The possibility of electrostatic discharge occurs when humidity is at very low levels. In addition, this probability increases with lower temperatures. Electrostatic discharge is difficult for humans to understand and does not have major effects such as injury. But a difference of 10V is enough to damage the hardware. Another dangerous situation is corrosion. This can occur as a result of an electronic device getting wet and some form of condensation of water vapor in the air. For example: In a location with high humidity, the electronic components inside the data center elements may be damaged and data loss may occur. The main thing for data center air conditioning is to ensure that the devices operate at a humidity level where there is no possibility of electrostatic discharge and corrosion. For this, the optimal relative humidity range is between 40% and 55% (This value is also recommended by the TIA/EIA 942 standard.

Design Parameters

Location of Data Center

Although the design parameters appear in different ways, as an example, the world giant Apple has established a data center in the city of Prineville in the state of Oregon. The temperature hovers with an average below 10 degrees in half of the year. In the remaining half, average temperatures not exceeding 20 degrees significantly reduced data center cooling costs. Since the outside air temperatures are quite low in this region, cooling was carried out with free cooling. Apple has realized a solution by planning the plant power and cooling needs based on location. It will not be possible to change the power consumed by the equipment, factors such as human or lighting loads. For the plant, these conditions

will remain constant. However, by developing a design based on external weather conditions, it has achieved a suitable environment and low cost result.

Hardware Layout, Cabinet Number and Density, Hot-Cold Aisle Applications

The temperature of the air entering the IT equipment is an important criterion for the cooling process. From this point of view, various methods have been tried to obtain the desired air temperature.

Hot-Cold Corridor Design Using Raised Flooring

At first the units were designed to face in different directions, and it was soon realized that this was an inefficient design, mixing hot and cold air together. This has resulted in the operating cooling machine setpoint being greatly reduced and cooling costs increasing disproportionately. Subsequently, all units were designed to face the same direction (Figure 6).

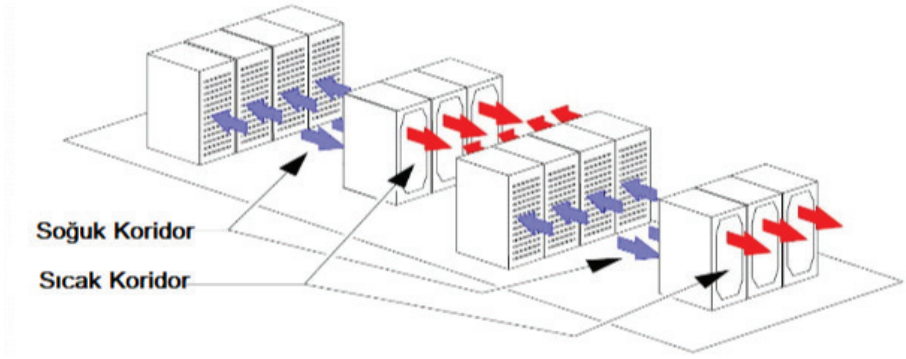

Figure 6. Application of Unit Facing the Same Direction

Although it is efficient compared to the previous settlement, similarly, the cold air supplied to the environment by the grills under the floor is mixed with the hot air to be expelled. In this case, the cold air warmed up before the floor cooling process could be completed. The

desired homogeneous temperature distribution could not be achieved at every point and malfunctions occurred in the servers.

As a solution to this situation, a hot and cold corridor design has been developed (Figure 7). Cold and hot corridors are formed by making the sides of the units to be kept cold facing each other. In this case, the cold air coming out of the grilles performed the necessary cooling process and this heated air was evacuated from where it rose. This situation increased the efficiency considerably, but it was not enough to achieve the desired cooling completely. There is still some mixing of hot and cold weather. A homogeneous separation has been achieved by the method of completely separating the hot and cold corridors by using the physical barrier, which is also frequently used today (Figure 8). Comparisons made in this section are based on cooling with precision control units (CRAC).

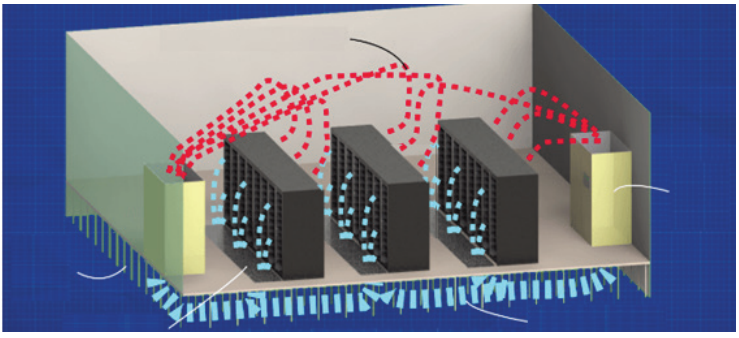

Figure 7. Hot Cold Corridor Application

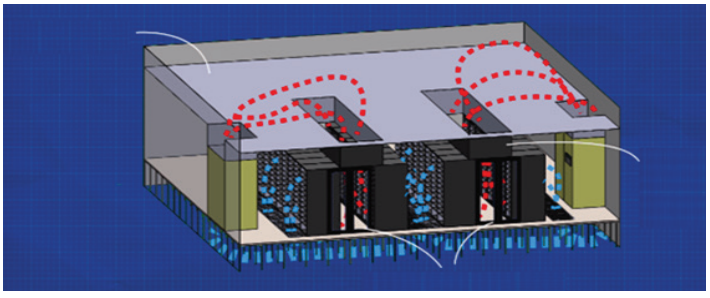

Figure 8. Physical Barrier Application

Cooling Close to the Heat Source

In the classical hot aisle/cold aisle design in the data center, the cooler loses energy until it reaches the source server cabinets. In close-coupled cooling, the chilled water or the refrigerant itself is provided as close as possible to the section where the cooling source is located, without leaving it into the environment until the racks where the servers are located. It is mounted very close to server cabinets. Air is blown directly into the rack without the cooling source air mixing with the air of the data center.

Insulation

Insulation is one of the important factors for the environment to be heated or cooled to maintain the current thermal situation for a longer period of time. If the data center is in an area with a very high outdoor temperature, insulating it from the outside environment will positively affect the efficiency. Today, rather than large data centers, small-scale institutions have data centers created to meet their own system requirements. By evaluating the operating temperature conditions of these centers, which are designed as a separate room in the building, it can be determined whether insulation is required between them and other spaces.

For data centers, insulation is made so that the system can work equally and correctly at every point in the section where the cooling process is performed. In addition, this system has a positive effect on efficiency. In order to prevent the possibility of mixing hot and cold air masses, the idea of separating hot and cold corridors from each other has emerged.

Cooling System Selection

The chosen cooling system can directly or indirectly affect the cooling process. Each cabinet can be cooled separately or the data center volume can be cooled completely. In this case, it will be more difficult to provide homogeneous cooling. A possible problem in the system may damage all hardware.

Air Flow Rate

Data centers vary in size and cooling loads. Based on the system cooling density (W/m²), an optimum airflow rate must be determined for an accurate cooling design. The velocity of the cold air directly affects the cooling process. It leaves the environment in a cold way again, before it can leave the air temperature enough to the system faster than necessary. A slow air, on the other hand, may not provide the required cooling load at the appropriate speed and rate, and may cause hot air to accumulate near the equipment. Optimum velocities for the design are determined by examining the effects of air velocities on ambient temperature with computational fluid dynamics analyses. ASHRAE and various institutions have studies and standards on airspeeds. Air speed is determined to provide more comfort in room climates. Some definitions are used to set standards.

- *DR (Draught Rating): Percentage of people who are disturbed by drafts.*
- *PMV (Predicted Mean Vote): The estimated value showing how a defined thermal environment will be perceived by the majority of users according to the specified scale.*
- *PPD (Predicted Percentage of Dissatisfied): Estimated percentage of dissatisfied with indoor air conditioning*

The ASHRAE 55 Standard is based on the -0.5<PMV< +0.5 requirement. According to this standard, it is seen that at least 5% of a group in an environment is not satisfied with the thermal aspect. As can be seen from Figure 9, this limit allows a maximum of 10% dissatisfaction. Therefore, if the PMV value is between the recommended -0.5 and +0.5, the PPD will be less than 10%.

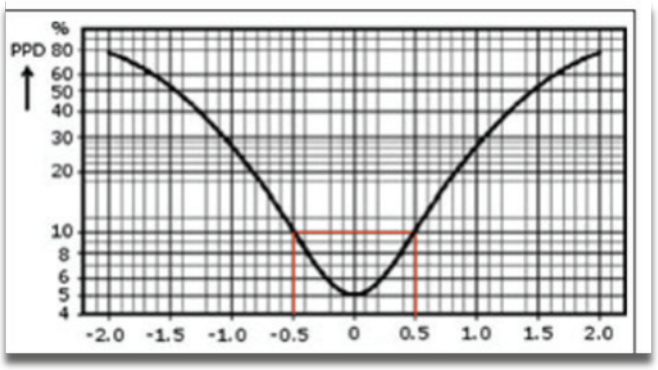

Figure 9. Thermal Sensation and Dissatisfaction Graph

The air velocity that will provide thermal comfort is found according to the NEN-EN-ISO 7730 standard. This standard allows a maximum DR value of 15%. It is essential that the turbulence intensity of the air velocity be measured to calculate the value of DR. Turbulence intensity is the bandwidth of true airspeed relative to the measured average airspeed. The allowable average air velocity is determined by the air temperature and turbulence density in Figure 10. The basic assumption is based on the assumption that 15% of those in the room may be disturbed. For example, in a room with a temperature of 25°C and a turbulence density of 10%, the allowable air velocity according to Figure 10 is 0.28 m/s; 0.23 m/s at 20% turbulence intensity; It is 0.18 m/s at 40% turbulence intensity and 0.16 m/s at 60% turbulence intensity. In the design for data centers, the healthy operation of the devices should be taken into consideration instead of comfort. This means the air velocity required to provide the set humidity value and the set temperature value. In air flow simulations, air velocities that can provide the appropriate temperature and humidity value for the data center area should be determined and the design should be carried out accordingly.

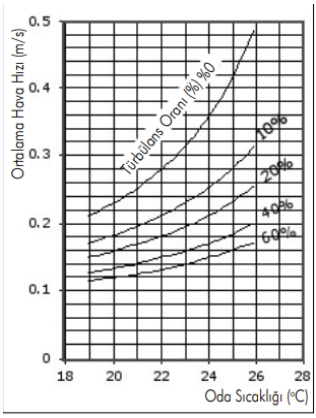

Figure 10. Room Temperature, Turbulence Rate and Average Air Velocity Graph

Pollution

The data center facility is generally well-designed and geographically designed in regions with relatively clean environments. Therefore, there are no concerns about contamination. However, the overall cleanliness of the environment is only one of the criteria for the location of a data center facility. This is usually not considered one of the most important issues. Some data center facilities may have harmful environments from the ingress of outdoor particulate and/or gas contamination. In some rare cases, contamination can also occur within the data center facility itself.

Air Conditioning Systems Used in Data Centers

It is possible to classify the systems used for data centers in various ways. These can be the heat transfer type, system of the indoor unit, the type of fluid used, or the heat transfer type and system of the outdoor unit.

Chilled Water System

Chiller and CRAH units work in this system. Computer Room Air Handling Unit (CRAH) unit works on a different principle with a Com-

puter Room Air Conditioning Unit (CRAC). It uses fans and chilled water coils to reject heat. Figure 11 shows the chiller and CRAH system.

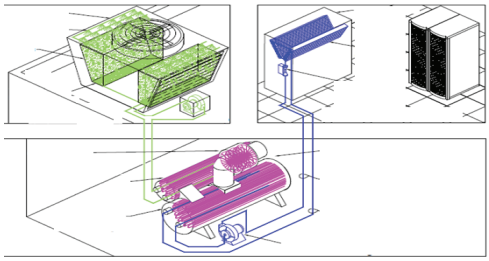

Figure 11. Chiller – CRAH Combined System

Pumped Refrigerant for Chilled Water Systems

There are 2 different liquid cycles in the system. The water cycle works between the chiller and the heat exchanger. The glycol cycle works between the cooler and the heat exchanger. The cooler in the room is glycol cooled. The glycol cycle is separated from the water cycle by a heat exchanger. The cycle runs continuously using pumps. Figure 12 shows how this system works.

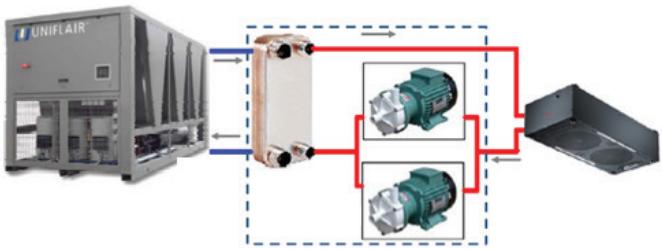

Figure 12. Chiller and Cooling Cycle Combined System Schematic Illustration

Air Cooled System (2-Piece)

The CRAC system works similarly to split air conditioners. Unlike the split system, the compressor is inside the CRAC unit. The CRAC unit transfers the heat from the room air to the refrigerant in the pipes. This

refrigerant discharges the heat to the outside with the condenser. The system show in Figure 13.

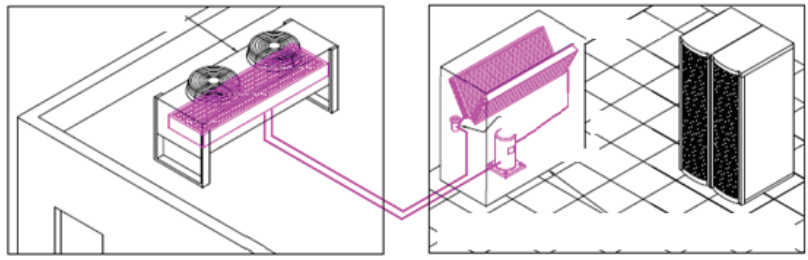

Figure 13. Schematic of Air-Cooled Condenser-CRAC Combined System

Glycol Cooled System

It is very similar to the air-cooled CRAC system. A small heat exchanger is used instead of large condenser coils. The heat exchangers and glycol pipes are quite small compared to the air-cooled system. Because glycol can transfer more heat than air. A pump is used to circulate the glycol. Figure 14 shows the glycol-cooled CRAC and dry cooler combined system.

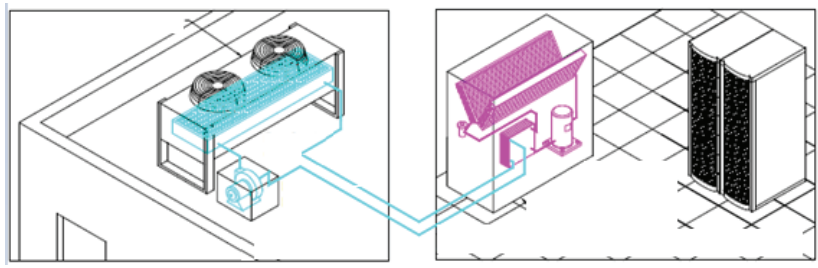

Figure 14. Demonstration of Glycol Cooled CRAC-Dry Cooler Combined System

Water Cooled System

If the CRAC unit is water-cooled and a cooling tower is added to the system, this system is called a water-cooled system. It is very similar to glycol cooled systems as all cooling components are contained within the CRAC unit.

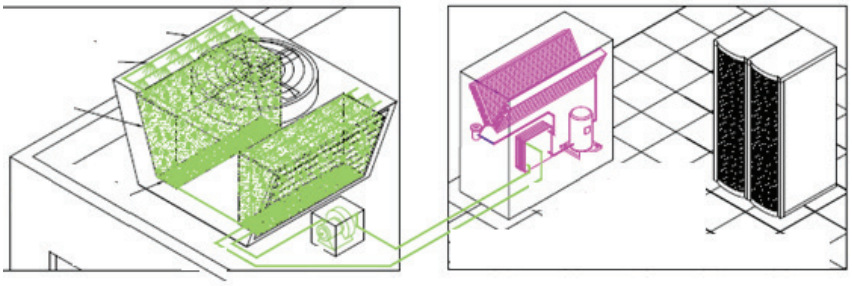

Figure 15. Demonstration Of Water-Cooled CRAC-Dry Cooler Combined System

Air Cooled Self Contained System (1-Piece)

The heat is transferred to the air and is removed directly from the IT room with ductwork. In case the system does not work, the backup system should be designed to cool this removed additional heat. Exhaust air should also be supplied from outside the computer room. This will prevent vacuum in the room. These systems are generally limited to 15 kW capacity. Air cooled self contained system is shown in Figure 16. Figure 17 shows an example of an air-cooled stand-alone system.

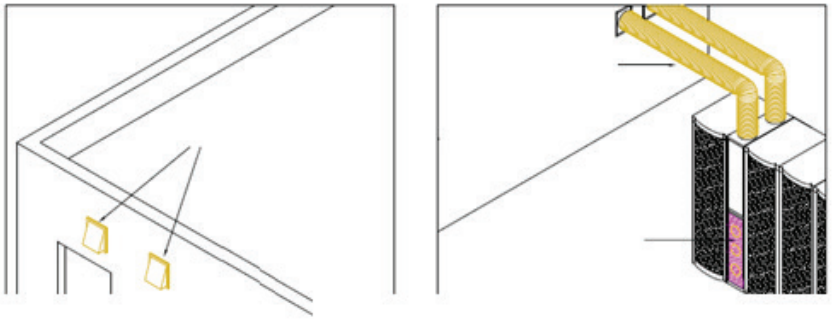

Figure 16. Schematic İllustration of Self-Running System with Air-Cooled Ducts



Figure 17. Air Cooled Self Contained & Portable Self Contained Cooling Unit

Direct Fresh Air Evaporative Cooling System

Direct fresh air evaporative cooling system is a system created with an evaporative cooler and duct system. The cooling system can be operated in two different ways as economizer and free cooling mode. In general, the DX air-cooled system is preferred for backup cooling systems in data centers. Evaporative system is most beneficial in dry climates. Figure 18 shows an example of a direct fresh air evaporative cooling system.

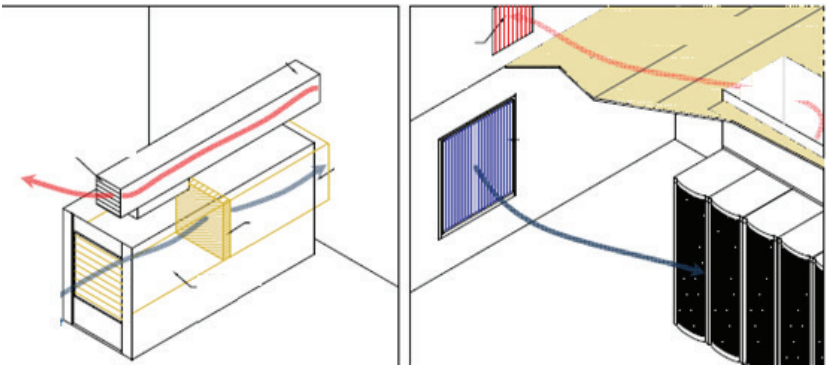

Figure 18. Types of Direct Fresh Air Evaporative Cooling System Equipment

Indirect Air Evaporative Cooling System

Indirect fresh air evaporative cooling system is a system created with an evaporative cooler and duct system. In this system, outside air is used for cooling. By using a heat exchanger, heat is transferred out

between the outdoor air and the air to be cooled in the data center. The heat exchanger separates the IT room. Evaporation support is also used in the system. Water is sprayed into the heat exchanger. An exemplary representation of an indirect air evaporator is shown in Figure 19. An example of a complete cooling system with this type of heat removal method is shown in Figure 20.

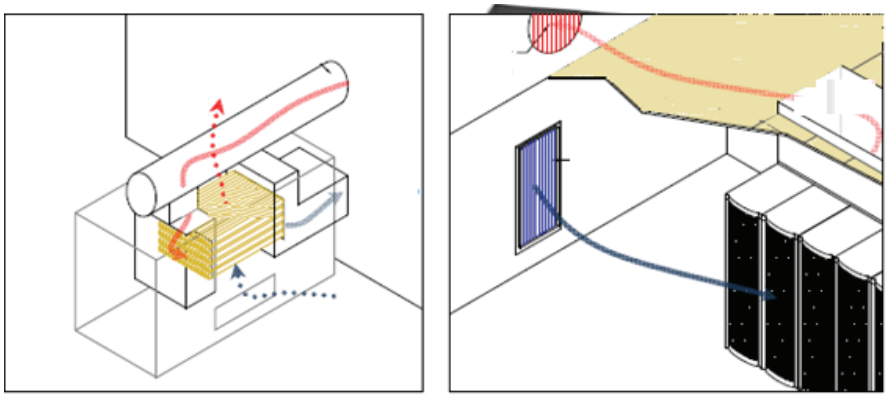

Figure 19. An Indirect Air Evaporator

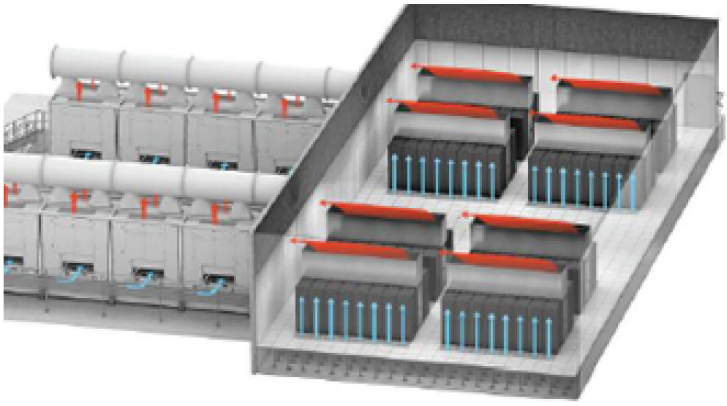

Figure 20. A Data Center Cooled by An İndirect Air Evaporator

Self Contained Rooftop System

It is a system installed with a package type rooftop unit and ductwork. Rooftop system is not traditional cooling system for new data centers. Figure 21 shows an example of a rooftop unit.



Figure 21. Rooftop Unit

Immersion Cooling

Servers or other IT components are immersed in a special liquid with a low boiling point, thermal conductivity but not electrical conductivity. Figure 22 shows the working principle of the 2-phase system. The boiling point of the Novec 7100 liquid used here is 61°C. The main reason for choosing a fluid with a low boiling point is to be able to boil at operating temperatures of the equipment without any problems. When the liquid surface layer reaches the boiling temperature, the vapor bubbles rise. With the help of the condenser placed at the top of the system, the excess heat in the rising steam bubbles is transferred to the fluid in the condenser. As a result, the vapor bubbles become liquid again and drip down with the help of gravity. The cycle continues like this. The immersed liquid can transfer its heat to another cycle with the help of a pump without any evaporation process. These types of systems are called single-phase systems (Liu and Yu, 2021).

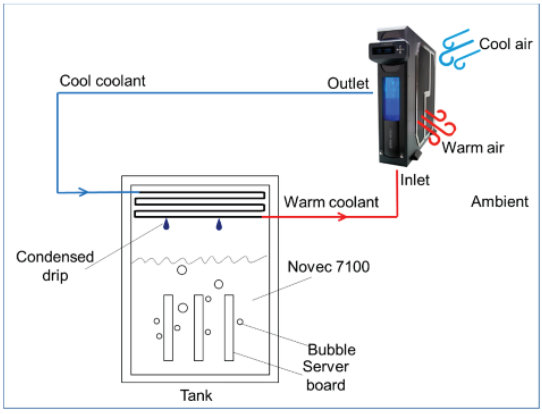

Figure 22. The Schematic of Immersion Cooling System

Carbon Emissions in Data Centers

In 2012, the electricity consumption of all data centers around the world was calculated as approximately 270 TWh. This rate corresponds to 1.4% of the total world electricity consumption. Considering the increasing need for data centers day by day; It is predicted that the energy consumption of data centers in 2030 will be 13% of the world's total energy consumption. Considering these analyzes and forecasts, it is an inevitable fact that energy consumption in data centers will create a big problem for the next 20 years (Sen, 2019). This consumption also reveals the importance of carbon emission rates for data centers. Figure 23 shows the carbon emission percentages by industry.

Figure 24 shows the comparison of carbon emission rates in data centers with the carbon emissions of some countries. Worldwide, the annual carbon emission value is approximately 30 billion tons, based on 2015 data.

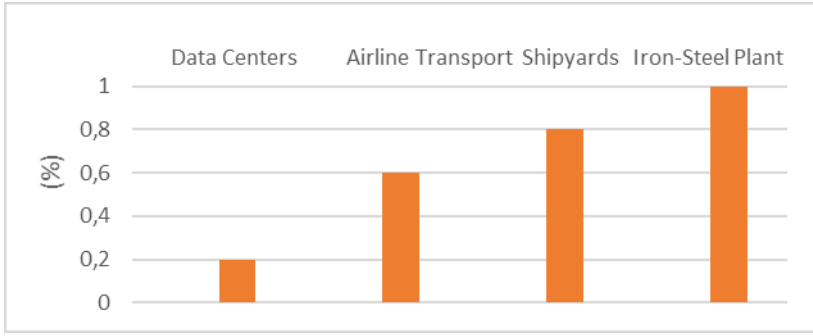

Figure 23. Sector-Based Carbon Emission Percentages

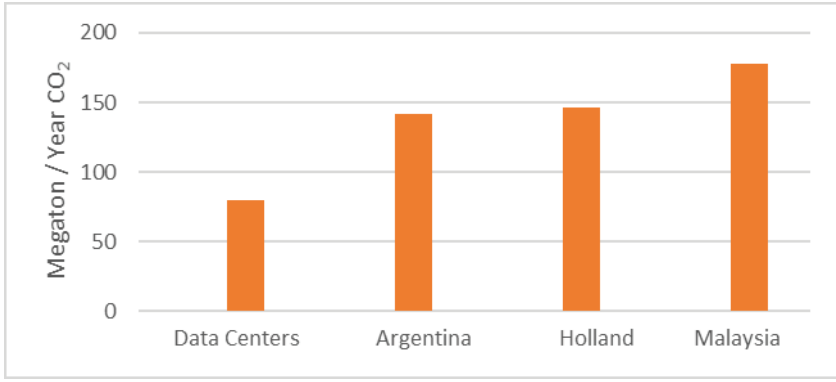

Figure 24. Country-Based Carbon Emission Percentages

In addition, according to the study conducted in 2007, the annual carbon emission amount, which was 80 million tons for the same year, is predicted to be 340 million tons for 2020 with a growth rate of 11% (Forrest et al., 2008).

EXAMPLE APPLICATION

Example Data Center Features

Figure 25 shows sample data center floor plan.

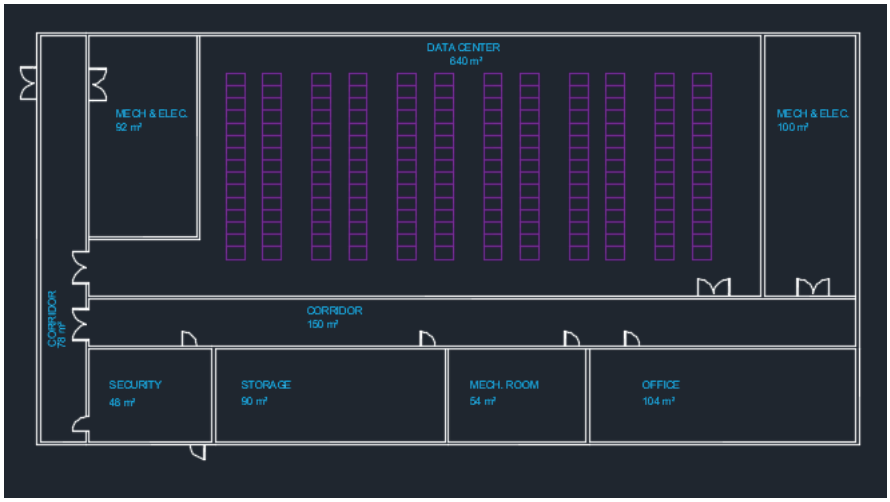

Figure 25. Sample Data Center Floor Plan

Table 4. Design Conditions for Data Center

Province	**Adana**
Summer Design KT Temperature	35,9°
Summer Design YT Temperature	23,8°
Winter Design KT Temperature	1°
Elevation	39m
Latitude, Longitude	37,00, 35,42
Floor Height	4,6m
Number of Cabins	180 units of 20 kW 42U Cabinet
Hourly Air Exchange Rate	0,1
Surface Absorption Ratio	0,45

Table 5. Cooling Setpoint Temperatures on Design

Location Name	Temperature [°C]	Moisture
Data Center	18-27	5.5°C DP with %60 RH and 15°C ÇN
Office Space	Summer Set Temperature:20°C Winter Set Temperature:24°C	%60
Security Room	Summer Set Temperature:20°C Winter Set Temperature:24°C	%60

Table 6. Total Heat Transfer Coefficients

Structural Element	U (W/m²K)	SHGC
Earth Contact Flooring	0,6278	-
Roof	0,45	-
Interior Wall	0,37	-
Outer wall	0,38	-
Window	1,8927	0,65

Cooling Load Analysis

Loads from the External Walls

External wall cooling loads of the data center volume were calculated using 4 different software. The heat gain values provided from the south facade are given in Figure 26. It has been observed that the calculation values vary for the outer walls. In addition, additional loads from thermal bridges can be calculated with the Cypetherm Loads software. For this study, this value was calculated as 327 W. The external wall cooling loads comparison chart is given in Figure 26.

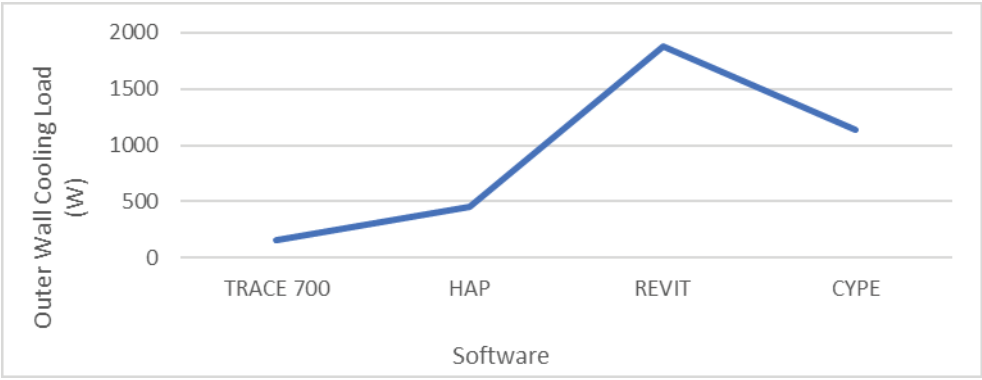

Figure 26. Comparison of Cooling Loads

Loads From the Interior Walls

The thermal loads gained from the interior are calculated and shown in Figure 27. It has been observed that the inner wall calculation values are more stable for all four software compared to the outer wall values. The internal wall cooling loads comparison chart is given in Figure 27.

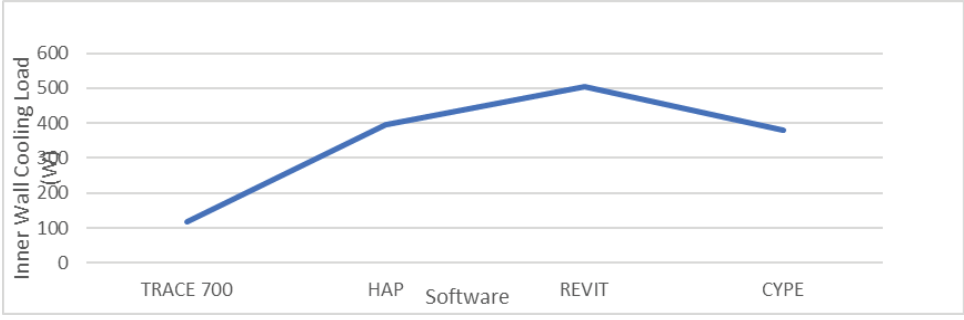

Figure 27. Loads from the Interior Walls

Loads From the Roofs

The thermal loads gained from the roofs are calculated and shown in Figure 28. It has been observed that the cooling value calculated as 670 W in the Trace 700 software is lower than the other 3 software. In addition, it has been observed that the loads for the other 3 software are calculated close to each other.

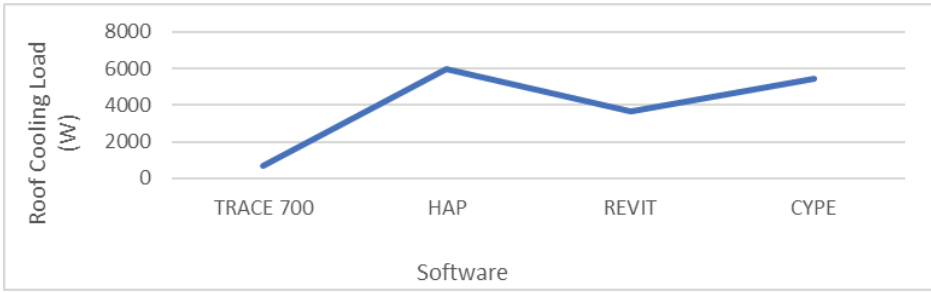

Figure 28. Loads From the Roofs

Standard Analysis

Revit and Cyptherm Loads software use RTS method, HAP, Transfer Function method, Trace 700 software uses TETD-TA1 method. In line with the results obtained, it has been observed that the values are closer to each other among the software using the same calculation methods, and the values diverge as different standards and methods are used. Data center total cooling load calculations according to calculation methods are shown in Figure 29.

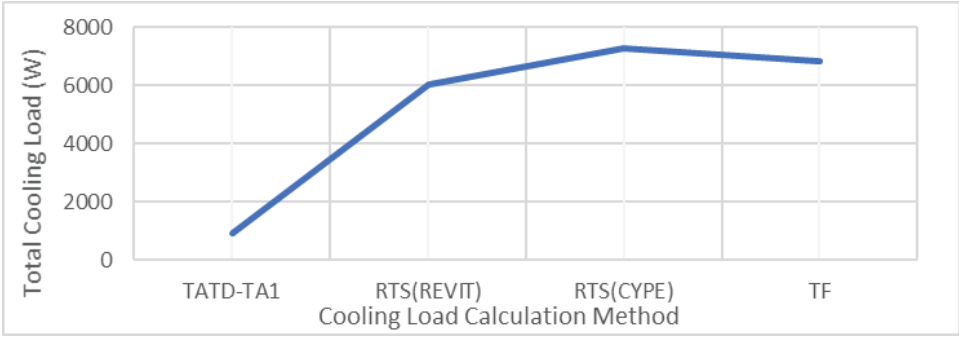

Figure 29. Average Cooling Loads According to Mathematical Methods

Comparison of Device Loads and Other Thermal Loads

The cooling of data centers is the volume where the cooling need is too high considering the cooling per square meter compared to the comfort cooling process. 180 units of 20kW 42U cabinets created a total cooling load of 3.6 MW. The unit cooling load per square meter for the data center, which is considered to be 640 m² for the project, is 5625 W. When

the other thermal loads are averaged across all software, it has been observed that only 10.3 W per square meter of cooling load is created.

BIM Based Softwares

It has been observed that when BIM-based software is used, it is not necessary to define the relations of the spaces with each other separately. In addition to the physical model, the software was able to calculate these relationships with the help of the information built on the physical model and used them in cooling load calculations. For example, in an account to be made with HAP, the user must enter the outer wall area of a place. However, when BIM-based software such as Cypetherm Loads or Revit is used, the necessary information is processed on this wall while creating the architectural model. If the concept of information modeling is considered for any wall object, it means creating a meaningful physical model by processing some information into it. The software will obtain the outer wall area from the created physical model and continue the calculations. It will also be able to do this for all other objects that will affect the calculation. Since the physical state of the architectural model can be followed instantly by the user, a possible error can be easily noticed. In this case, the number of data to be entered will be much less. However, this situation reveals the necessity of making the right definitions while creating the model. A wall that is not defined as an external wall will cause the heat loss calculation to be less than the actual calculation value. All the observations here support the previous studies in the literature on the concept of BIM. The observed data are presented in Figure 8 and Figure 9.

BIM provides very serious reductions in construction costs and durations, although it causes small increases in project costs and durations. The graphical representation between the effort spent and the accuracy of the process for BIM-based software is given in Figure 30. The graphical representation between the effort spent and the accuracy of the process for non-BIM-based software is given in Figure 31.

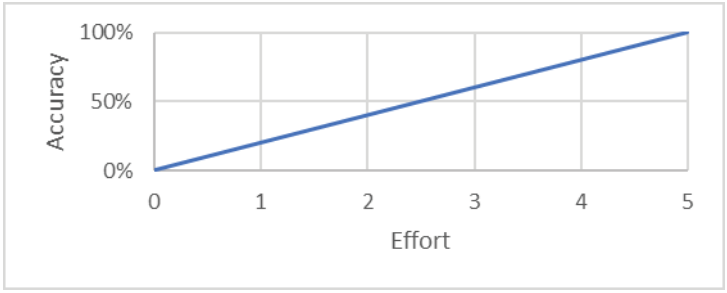

Figure 30. Accuracy in BIM-Based Software



Figure 31. Accuracy in Non-BIM Software

Carbon Footprint

For the data center we have designed, it is calculated that 4093 tons of carbon dioxide gas will be released annually by accepting the PUE efficiency value of 2, and an IT hardware power of approximately 400 kW. By accepting the same efficiency rates, it has been calculated that approximately 716,219 tons of carbon dioxide emissions are made annually for the data centers in Turkey, taking into account the critical IT power of the data centers established in 2015. Comparing the carbon emission values of the existing installed data center in Turkey with the carbon emission values throughout the country will not yield any significant results due to the low installed capacity in our country. For this reason, the comparison was made over the CO2 emission values of Turkey and the emission values of all data centers in the world. The emission values of data centers in the world and Turkey's total emission values are compared in Figure 32.

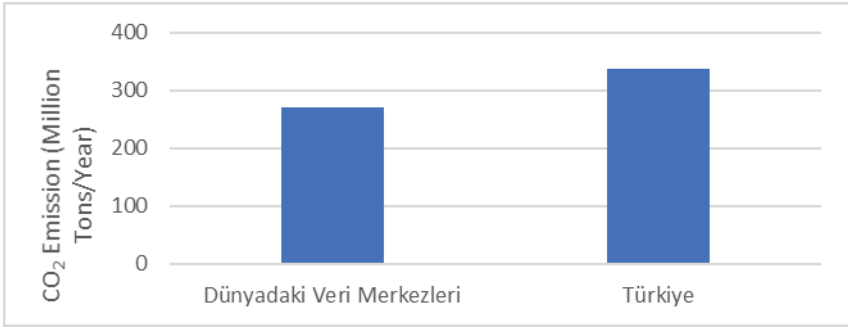

Figure 32. Turkey's Carbon Emission Values and Data Centers in the World

While the electricity consumption of data centers all over the world was 203 TWh in 2007, the carbon emission value produced was 80 million tons. Annual electricity consumption values calculated with the assumption of 10.4% compound annual growth rate are given in Figure 33. The annual carbon emission values calculated by assuming a compound annual growth rate of 11% are given in Figure 34.

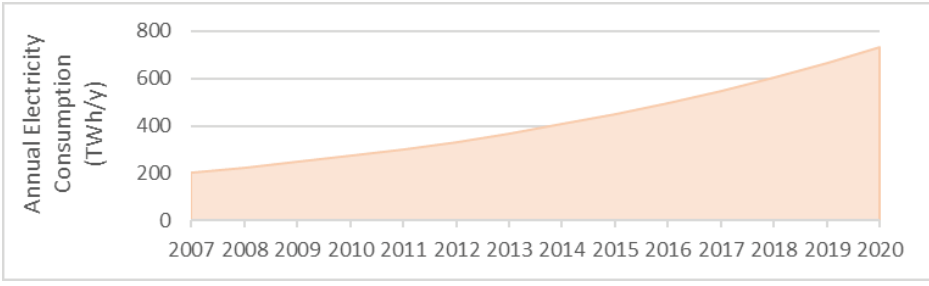

Figure 33. Electricity Consumption of Data Centers by Years

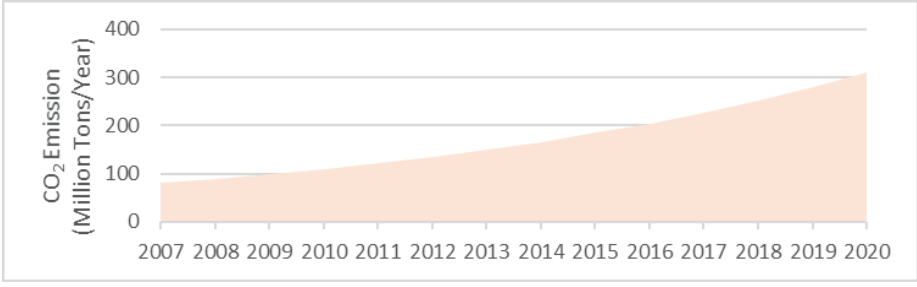

Figure 34. Carbon Emission Values of Data Centers by Years

The annual electricity consumption values and carbon emission values calculated for the next 5 years, assuming the same compound annual growth rates, are given in Figure 35 and Figure 36.

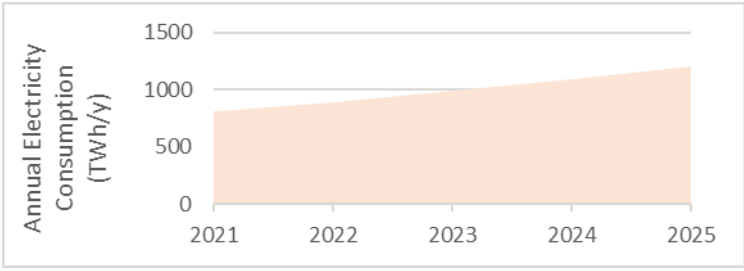

Figure 35. Estimated Electricity Consumption of Data Centers for the Next 5 Years

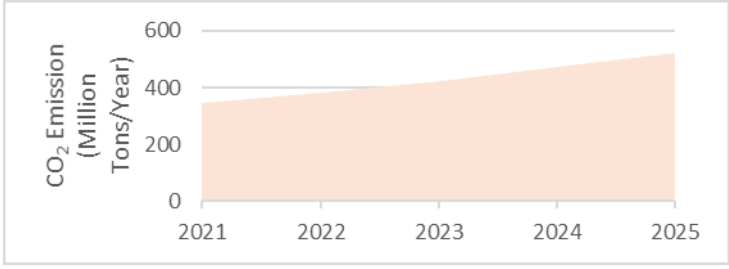

Figure 36. Estimated Carbon Emission Values of Data Centers for the Next 5 Years

RESULTS

In the study, it was predicted that a possible data center planned to be established for Turkey could be established in Ankara and Eskişehir provinces. Considering the electricity infrastructure, internet infrastructure and external weather conditions, installations can be made in cities similar to the ones foreseen.

It has been concluded that the necessity of making all data entries manually in non-BIM-based software for cooling calculations increases the margin of error. Working on the process data entry for a longer time may increase the accuracy of the calculations to some extent. In BIM-based software, the margin of error will be reduced to zero in direct pro-

portion to this effort. However, it has been concluded that this calculation process will take longer as the information modeling will be done in the building together with the physical model.

In the studies conducted for the data of 2015, it was concluded that the carbon emission rates of the data centers have a very serious effect on the total carbon emission rates in the world, and this effect will be much greater in the coming years with the ever-increasing demands.

It has been calculated that the total amount of carbon emissions from the data centers in Turkey is 0.22% of the total amount of carbon emissions in the country. Although this value may seem low, the main reason is that the total installed data center capacity in our country is much less than the total data center capacity worldwide. When this comparison is made for the 2015 data worldwide, it has been determined that this rate is around 1%. Compared to the world average, our country has 1/5 less data center installed capacity.

Calculations on data center electricity consumption values and carbon emission values, based on annual growth rates for the past ten years, have revealed the importance of efficiency studies to be carried out.

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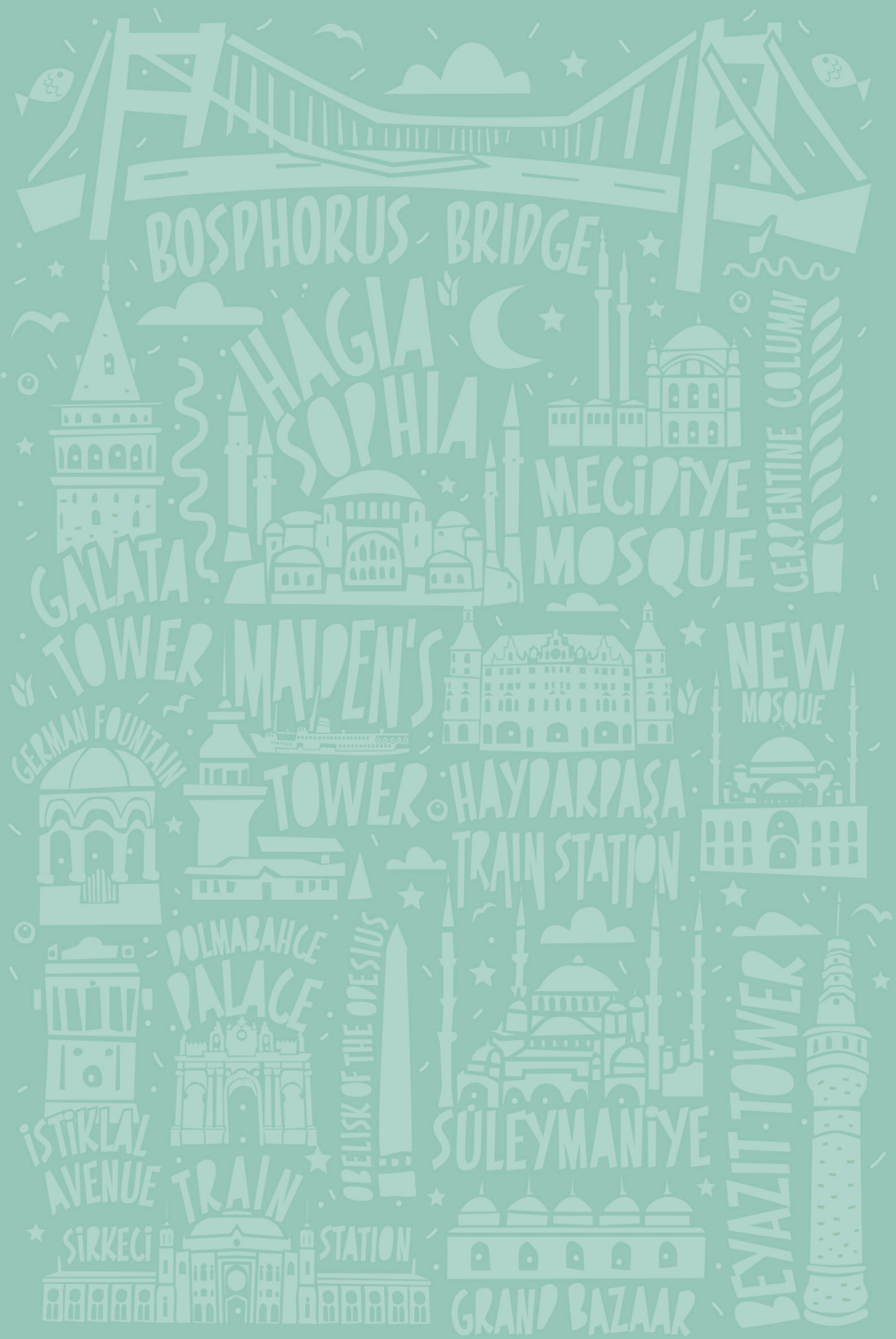

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