HYCOOL-IT

HYBRID COOLING & MANAGEMENT FOR IT INFRASTRUCTURES

WP1 – Requirements and methodology definition.

Task 1.1 Extraction of processes and requirements and use cases screening.

D1.1 Processes requirements and building typologies screening.

HYCOOL-IT. This project has received funding from the European Union's Horizon Europe programme under grant agreement No 101138623

Disclaimer

Acknowledgement

This project has received funding from the European Union's Horizon Europe programme under grant agreement No 101138623.

Project	
Project Acronym	HYCOOL-IT
Project Title	HYBRID COOLING & MANAGEMENT FOR IT INFRASTRUCTURES
Grant Agreement number	101138623
Call identifier	HORIZON-CL5-2023-D4-01
Topic identifier	HORIZON-CL5-2023-D4-01-04
Funding Scheme	Lump Sum
Project duration	36 months
Coordinator	POLIMI
Website	https://hycoolit-project.eu/

Deliverable			
Deliverable No.	1.1		
Deliverable title	Processes requirements and building typologies screening		
Description	Defining waste heat recovery and BDT based processes requirements, this deliverable will be the basis for developing HYCOOL-IT technologies and solutions across all 3 Tech Pillars and demonstrating them at living lab level through implementation and validation tasks. The screening will be suitable to describe how the project results can be exploited and replicated at higher TRLs beyond the end of this action.		
WP No.	WP1		
Related task	T1.1 – Extraction of Processes and Requirements and Use Cases screening		
Lead Beneficiary	6 - R2M		
Author(s)	Fayaz Ahmed, Sander Smit, Melina Melgarejo, Samuele Spongano, Davide Dainelli (R2M)		
Contributor(s)	POLIMI, IDP, BDTA, IMP		
Type	R		
Dissemination	PU		
Language	English – GB		
Due	31/07/2024	Submission date	31/07/2024

Version	Date	Authors	Description
V.0.1	03/06/2024	R2M	First Draft
V.0.2	10/06/2024	R2M	Section related to mapping requirements and HYCOOL-IT services was added.
V.0.3	04/07/2024	R2M	Results and analysis of additional surveys related to small server rooms were added.
V.0.4	18/07/2024	IMP	Minor grammar corrections.
V.0.5	19/07/2024	IDP	Addition of a use case related to preventive and corrective maintenance.
V.0.6	26/07/2024	POLIMI	Minor corrections related to unit of measurements.
V.1.0	29/07/2024	All Partners	Version for internal review (to be approved by technical coordination)
V.2.0	31/07/2024	WP Leader	Final deliverable

Executive Summary

Following trends in edge computing and artificial intelligence (AI) based applications in IT and server infrastructure developments, many schools and higher educational institutions, hospitals, hotels, small businesses and other services sector buildings typologies need IT server rooms for moving data storage and processing capabilities closer to the source for reduced latency and improved performance. Despite small server rooms found in tertiary sector buildings outnumbering large-scale data centres, energy efficiency and management efforts and public attention have focused on large-scale data centres, while small server rooms (usually housed in services sector buildings) have received little attention. However, examining the increasing trend of the use of server rooms in the services sector, energy efficiency and management of small server rooms are equally important as those of larger data centres. To address this, the HYCOOL-IT project aims to propose a standardised comprehensive set of processes, digital tools and advanced adsorption equipment to achieve a replicable cost-effective thermal management and energy optimisation of IT server rooms located in tertiary buildings. Replication of the proposed solutions will be performed in different types of tertiary buildings, including schools, offices, hospitals, tower buildings, based on technical and economic feasibility studies to assess the economic return of the investment (considering case specific operating conditions, energy savings for IT server cooling and space heating, energy prices, maintenance, discount rates).

This report aims to provide an overview of the main activities that have been performed in the framework of Task 1.1 entitled "*Extraction of Processes and Requirements and Use Cases Screening*". Specifically, the main objective of this task is to systematically extract and define processes and requirements for utilizing waste heat recovery and building digital twin (BDT) approaches as advanced strategies and process improvements to enhance thermal management and energy optimisation in high energy demand IT server rooms within tertiary buildings as proposed by the HYCOOL-IT project.

To achieve this goal, this task conducted an analysis of processes and requirements for integrating waste heat recovery and BDT based processes in IT server rooms, including screening and description of generic use cases, to support the design and development of HYCOOL-IT innovative technologies and solutions to optimise the energy efficiency and thermal management of IT server rooms focusing specifically on integrating and optimizing these server rooms within the building's overall operations.

Table of Contents

List of Figures

List of Tables

Terms and Abbreviations

Acronym	Description
AI	Artificial intelligence
BDT	Building Digital Twin
BDTE	Building Digital Twin Environment
BIM	Building Information Modelling
CAGR	Compound annual growth rate
CPU	Central processing units
CRAC	Computer Room Air Conditioners
CRAH	Computer Room Air Handlers
DCIM	Data Centre Infrastructure Management
EU	European Union
EU DC CoC	European Code of Conduct for Data Centres
EE	Energy Efficiency
HPC	High performance computing
HVAC	Heating, Ventilation, and Air Conditioning
HYCOOL-IT	Hybrid Cooling & Management for IT Infrastructures
IEA	International Energy Agency
ICT	Information and communication technologies
MEP	Mechanical, electrical and plumbing
NRDC	Natural Resources Defense Council
PDU	Power Distribution Units
TWh	Terawatt-hours
TRL	Technology readiness level
TR	Technical requirements
UR	User requirements
UC	Use cases
UPS	Uninterruptible Power System

1. Introduction

A data centre or server room is a physical room, building or facility that houses IT infrastructure (such as computer servers, storages, processing units, and networking equipment) for the purposes of building, testing, and delivering IT applications and services. It also stores and processes the data needed for running and delivering those IT applications and services[1].

Forbes2 asserts that the data centre and server rooms industry and its digital infrastructure serve as the backbone of modern global and integrated economy, powering everything from mobile and web apps, search engines and e-commerce platforms to AI-based applications most notable example being OpenAI´s ChatGPT3 and all other digital innovations and businesses. According to Grand View Research Market Report4, the global data centre and server rooms market size was valued at USD 194.81 billion in 2022 and is projected to grow at a compound annual growth rate (CAGR) of 10.9% from 2023 to 2030. Furthermore, the latest data centre and server rooms market reports from McKinsey & Company5, CBRE6, and Forbes7 also project significant growth in the demand for data centres and server rooms worldwide. In January 2023, McKinsey & Company8 projected the data centre and server rooms industry would grow 10% a year through 2030, with global spending on the development of new facilities hitting $49 billion. According to McKinsey analysis, in the US market alone, demand—measured by power consumption to reflect the number of servers a data centre or server room can house—is expected to reach thirty-five gigawatts (GW) by 2030, up from 17 GW in 2022.

Figure 1 shows McKinsey´s future projections for the US market.

[1] What Is a Data Centre? | IBM
[2] Five Trends Driving the Booming Data Centre Economy In 2024 I Forbes
[3] Introducing ChatGPT | OpenAI
[4] Data Centre Market Size, Share and Growth Report, 2030 Grand View Research
[5] Why invest in the data centre economy | McKinsey & Company
[6] Global Data Centre Trends 2024 | CBRE
[7] Five Trends Driving the Booming Data Centre Economy In 2024 I Forbes
[8] Why invest in the data centre economy | McKinsey & Company

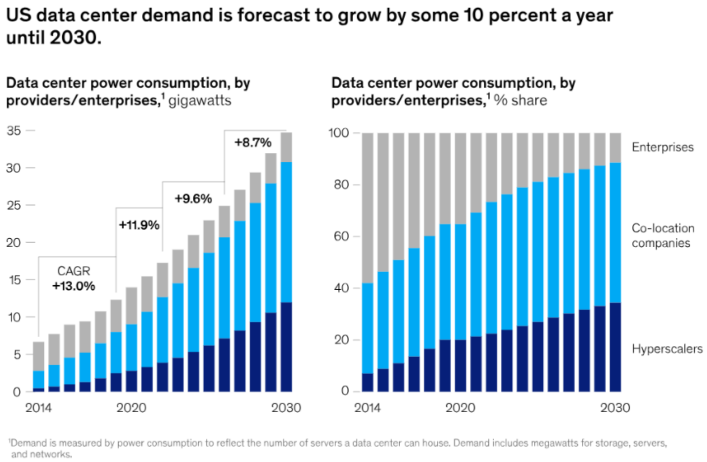


Figure 1 US Data Centres Market Outlook (McKinsey & Company)

Data centres and server rooms are critical for growth of the global economy and keeping pace with digitalization, but also require significant amounts of energy and water to power and cool IT equipment and infrastructure housed in data centres and server rooms [1], [2]. According to the International Energy Agency (IEA)[9], after globally consuming an estimated 460 terawatt-hours (TWh) in 2022, data centres' and server rooms' total electricity consumption could reach more than 1000 TWh in 2026, citing that the projected demand is equivalent to the electricity consumption of Japan[10]. Therefore, it is important to find alternative ways of planning and design, building and running the data centres and server rooms to improve their overall efficiency and sustainability. For instance, Project ASCEND aims to explore the potential and comparative environmental impact of space-based data centres to aid Europe in becoming carbon neutral by 2050[11]. And Microsoft led Project Natick[12] aims to figure out the feasibility of subsea datacentres powered by offshore renewable energy.

Figure 2 shows Microsoft subsea data centres from Project Natick.

[9] IEA – International Energy Agency
[10] AI Boom Will Cause Data Centre Electricity Demand to Double | Data Centre Magazine
[11] Europe wants to deploy data centres into space
[12] Project Natick Phase 2 I Microsoft

Figure 2 Underwater data centre by Microsoft.

Nevertheless, data centres or server rooms are notoriously famous for their excess energy and water consumption [1], [2], which will only keep increasing owing to increased demand for data centres and server rooms in the future [3]. For instance, a hyperscaler's data centre can use as much power as 80,000 households do[13]. To address the increasing energy consumption in data centres or server rooms and mitigate other relevant environmental, economic and energy supply security impact, some regulators and governments are imposing sustainability standards on existing and new data centres and server rooms. For instance, EU led the European Code of Conduct for Energy Efficiency in Data Centres (EU DC CoC)[14] is one such voluntary initiative set up to improve the energy efficiency of data centres or server rooms. Since its launch in 2008, more than five hundred data centres and server rooms have joined the EU DC CoC to improve their energy efficiency. Participants who show a significant reduction in their energy consumption are eligible for the annual EU Data Centres Code of Conduct Awards.

On the topic of efficiency and sustainability, while large-scale data centres owned by large corporations and conglomerates consider energy efficiency to reduce business operating costs, on the contrary small server rooms typically are not particularly motivated in an equivalent manner. They are characterized by decentralized ownership and management and come in many configurations and settings, which creates a unique set of efficiency and sustainability challenges [4]. In the past, energy efficiency and optimisation efforts and public attention have focused on large-scale data centres, while small server rooms (usually housed in commercial buildings) have received little or no attention at all. However, looking at the increasing trend of the uptake of server rooms in the services sector, energy efficiency of small server rooms is equally important as that of larger data centres [4].

While server rooms in tertiary buildings contribute significantly to energy demand, their design and operational management are new areas. Therefore, specific expertise and tools are essential for optimal thermal management and energy efficiency in small server rooms. HYCOOL-IT addresses this need by offering innovative tools and methodologies, using knowledge gained from previous projects

[13] Why invest in the data centre economy | McKinsey & Company
[14] European Code of Conduct for Energy Efficiency in Data Centres

aimed at optimizing energy efficiency in IT server rooms located within tertiary/service sector buildings.

1.1. Purpose and audience of the document

This deliverable discusses processes and requirements for integrating waste heat recovery and BDT-based processes in IT server rooms, focusing specifically on integrating and optimizing these server rooms within the building's overall operations. Additionally, the deliverable describes methodology applied to obtain and translate stakeholders' needs, expressed through user stories from various tertiary building typologies, into requirements for the project. It involves mapping the identified requirements to HYCOOL-IT services to align needs and capabilities of the project. Finally, this process concludes with the description of generic use cases (UCs) providing a solid foundation for the practical execution of the pilots and the implementation of project services.
Finally, the aim of the document is therefore to provide guidelines to execute the further activities of the project.

1.2. Relation to other activities

This is one of the first tasks of the project. The requirements extracted and defined in this task will provide the basis for developing HYCOOL-IT innovative technologies and solutions across all 3 Tech Pillars shown in Figure 3. These innovative technologies and solutions will include: i) innovative ICT approaches and technologies based on Digital Twins, SIMBots and Software in the Loop; and ii) innovative Rack-integrated adsorption chillers. All solutions will be assessed and validated in a living lab.

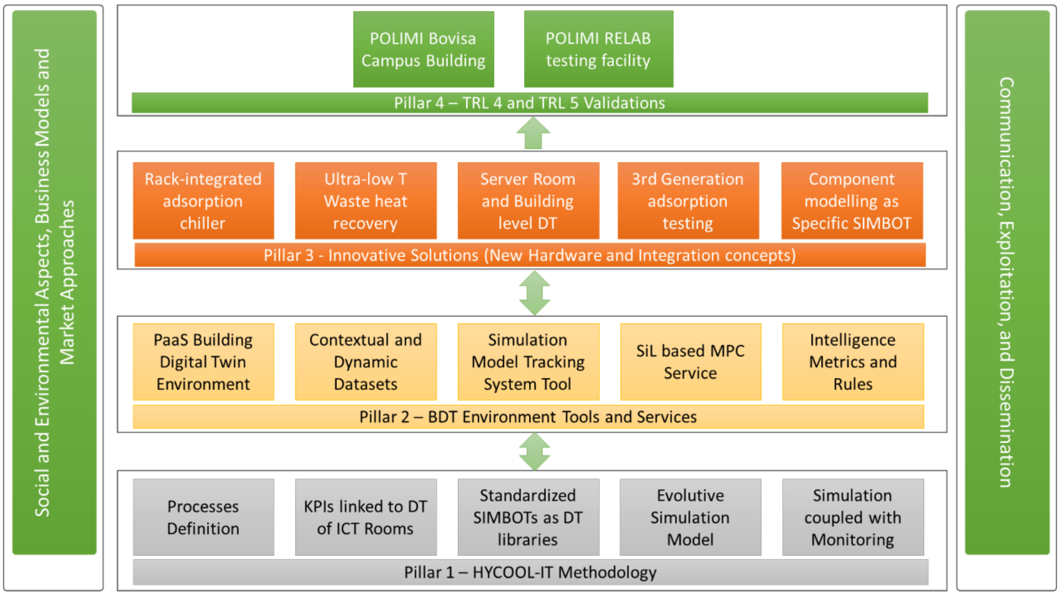


Figure 3 HYCOOL-IT Key Pillars

Specifically, the results of this task can also be highly useful for the other activities of the HYCOOL-IT project to be performed in Task 1.2 (informing potential use cases for the POLIMI pilot site), Task 2.2 (supporting the design of the ICT architecture of the HYCOOL-IT BDT environment), Task 3.1 (supporting the design and implementation strategy), and Task 3.3 (aiding the development of SIMBots for the first set of generic reusable components commonly found in all kinds of tertiary building server rooms). This task and report also achieve "*Milestone No 2: Definition of all Case studies requirements*" of HYCOOL-IT project.

1.3. Structure

The document is structured as follows:

Chapter 2 describes the methodology applied for the extraction of processes and requirements and general use cases screening for server rooms located in tertiary sector and buildings.

Chapter 3 describes the tertiary sector and buildings including the IT server room infrastructures and processes in great details.

Chapter 4 describes and analyse diverse types of building typologies in tertiary/service sector and also responsible for extraction of user stories specific to tertiary building typologies.

Chapter 5 explains the approach employed for turning the user stories into requirements. Including the mapping process applied to link requirements to the related HYCOOL-IT services.

Chapter 6 lists and describes the generic use cases for server rooms located in tertiary sector and buildings.

Chapter 7 draws the conclusions.

2. Methodology

2.1. Requirements extraction and use cases screening approach

This chapter describes the overall methodology applied to obtain and translate stakeholders' needs and expectations, expressed through user stories from various tertiary sector building typologies, into requirements for the project. It involves mapping the identified requirements to HYCOOL-IT services to align the needs and capabilities of the project. Finally, this process concludes with the screening and description of generic use cases providing a solid foundation for the development and testing of HYCOOL-IT tools and services. The information collected from this process allows a better understanding of the specific requirements and challenges associated with managing IT server rooms in each typology of tertiary buildings and supports the development of HYCOOL-IT innovative solutions to optimise the energy efficiency and thermal management of IT server rooms.

Figure 4 shows the HYCOOL-IT approach for requirements extraction and use cases screening.

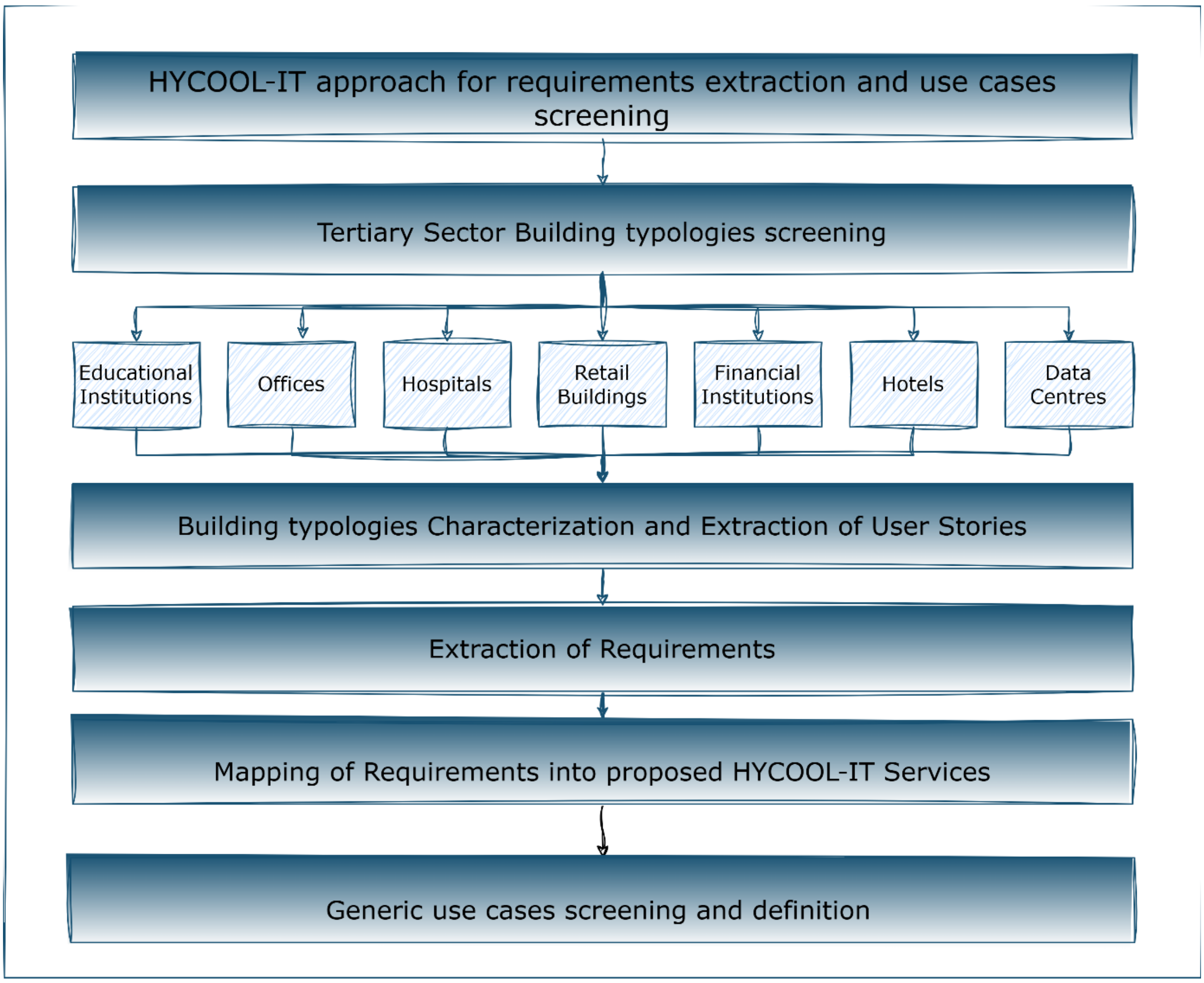


Figure 4 HYCOOL-IT Methodology for user and technical requirements extraction and use cases screening.

2.2. Gathering requirements and defining generic use cases

The first two crucial steps in any software/application development process are gathering requirements and defining use cases[15]. Below information of the steps designed for requirements extraction and use cases screening is provided which will provide basis for the development and testing of HYCOOL-IT tools and solutions in subsequent WPs.

Specifically, HYCOOL-IT translates the needs and expectations of the stakeholders into requirements and defines generic use cases by following steps:

- **Step1: Screening and understanding various building typologies in tertiary sector -** This is the first step of the proposed methodology designed to identify and analyse different typologies of tertiary buildings and their server rooms, key stakeholders and their challenges and needs. For a better understanding of IT server rooms found in different typologies of tertiary buildings, published literature and different surveys related to small server rooms were analysed to help understand the current small scale server room landscape, existing equipment and processes, common efficiency issues, stakeholder involved and their needs and challenges.
- **Step2: Translating stakeholder's challenges and needs into user stories -** This step was designed for extracting user stories from analysis done in the Step1 to identify the needs, expectations, and potential benefits of various users focused on the lifecycle management and optimisation of IT server rooms located in tertiary sector buildings.
- **Step3: Formulation of requirements from user stories –** In this step user stories were converted into requirements providing the basis for the development and testing of HYCOOL-IT tools and solutions in subsequent WPs.
- **Step4: Mapping of requirements to HYCOOL-IT Services:** This step was designed to link the identified requirements representing needs, and expectations of various users focused on the lifecycle management and optimisation of IT server rooms with the capabilities of the HYCOOL-IT project.
- **Step5: Define Generic Use Cases (UCs):** Finally, the last step of the proposed methodology is related to the screening and description of generic use cases that integrate the requirements into a comprehensive package creating detailed descriptions of system-user interactions to satisfy requirements.

[15] Gathering Requirements and Creating Use Cases

3. Understanding Tertiary Sector Buildings and Server Rooms

3.1. Introduction to Tertiary Sector

The tertiary sector also known as the services sector of the economy, encompasses a wide range of activities and businesses, including hospitals, educational institutions, financial institutions, hotels and hospitality, and data centres[16]. Preceded by the primary sector (natural resource extraction) and the secondary sector (manufacturing), the tertiary sector is solely focused on providing services, not goods, to consumers and other organizations. For this simple reason, it is also known as the service sector [17].

3.1.1. Energy Consumption in the Tertiary Sector

After tracking the evolution of the European Union (EU) tertiary sector in the context of the 2030 and 2050 EU energy and climate targets, the study [5] concludes that the tertiary sector (services sector of the economy) is the fastest growing economic sector in terms of energy consumption [5]. According to [5], final energy consumption (FEC) of tertiary sector has increased by 20.7% from 2000 to 2019 in EU27 plus UK, in contrast to the reduction recorded in other sectors, such as industry and households. Electrification, which has surged especially in this sector due to the spread of electric appliances and the development of big data centres and new Information and Communication Technologies (ICT), together with the economic growth and the increase in the area dedicated to services, have been the main determinants triggering the tertiary consumption rise.

Another study confirms the same trend of [3] and states that the energy consumption in the services sector has increased over the years, mainly due to the economic expansion of the sector, and the increased load of ICT. In the services sector, annual electricity consumption in the European Union (EU 28) increased in the period 2003 to 2012 from 698 TWh to 845 TWh, i.e. a growth of 21% while total electricity consumption in the EU 28 in the same period has grown by 4%, and in the residential sector by 5%.

3.1.2. Determinants of increased energy consumption in Tertiary sector

One of the key determinants triggering the tertiary sector energy consumption rise is the growth of data centres and server rooms around the world. Data centres and server rooms consume a significant amount of energy, contributing to the overall electricity consumption in the European Union (EU). Currently, these facilities consume 40-45 TWh, accounting for 1.4-1.6% of total EU electricity consumption[18].

According to [6] electricity consumption of server rooms in tertiary buildings constitutes a significant share of the total energy consumption in finance and public offices, and it was estimated at 4% of the electricity demand in the EU27+2 tertiary sector. Such demand has been growing in recent years and is expected to grow even more, following the increasing trend for the total EU electricity consumption of data centres and server rooms, from 55 TWh/y in 2010 to 160 TWh/y in 2030 [1].

[16] What Are Tertiary Sectors? Industry Defined, With Examples
[17] Tertiary Sector: What Is It & Examples
[18] The EU Code of Conduct for Data Centres

3.2. Understanding Server Rooms in Tertiary Buildings

3.2.1. Server Rooms vs. Data Centres

Since HYCOOL-IT is focused on developing innovative technologies and solutions to optimise the energy efficiency of IT server rooms found in tertiary/service sector buildings. Therefore, it is important to clarify the difference between server rooms vs. data centres to avoid any confusion and to extract specific requirements related to the IT server rooms found in tertiary sector buildings instead of large-scale data centres.

In IT groups and communities, most people consider a server room to be a small area with approximately a few dozen to a few hundred square metres. When a room gets significantly larger than that and begins to house IT equipment related to servers and storage, it can become a data centre. According to Data Centre Knowledge[19], data centres consist of entire facilities/buildings dedicated to housing, storing, and supporting massive arrays of IT servers and processing units, networking infrastructure, and other equipment for building, running and delivering IT applications and services. These facilities often accommodate the needs of multiple organizations and businesses at the same time. On the contrary, a server room is a designated space within a building specifically allocated for housing servers, processing and other equipment on-site. Such rooms are typically integrated into multi-purpose buildings such as educational institutions and hospitals.

International Data Corporation (IDC) proposed data centres and server room classifications [7] are presented in the Table 1.

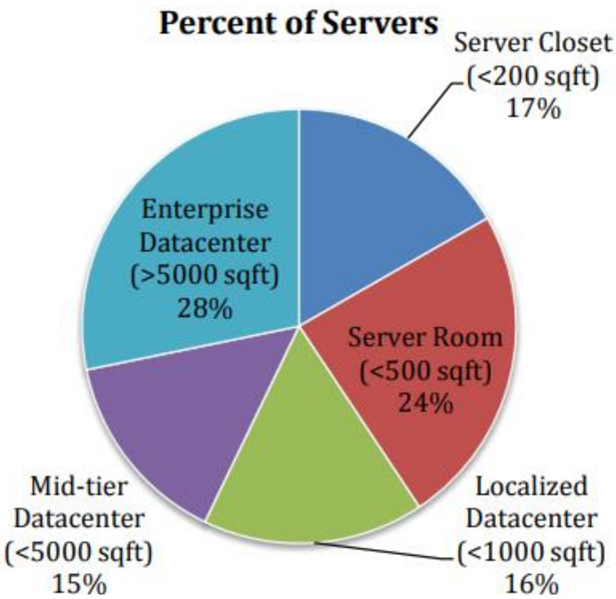
Table 1 Data Centre Classifications (Source: Michelle et al. IDC Special Study. Data Centre of the Future)

<table>
<tr><th>Data Centre Type</th><th>Description</th><th>Square metres</th><th>Facilities (2009 U.S. estimation)</th><th>Total Servers (2009 U.S. estimation)</th><th>Average Servers per Location</th></tr>
<tr><td>Utility Scale</td><td>Generally measured by the size of the facility's total load (in MW), or the quantity of power available to the IT equipment. Typically, larger than 10 MW, and commonly constructed with 40 MW load. This category includes most retail and wholesale co location data centres.</td><td>>9,290.3</td><td rowspan="2">7,006</td><td rowspan="2">3,604,678</td><td rowspan="2">515</td></tr>
<tr><td>Enterprise</td><td>Typically managed and ran by large corporations and institutions. Commonly, occupy spaces in the low tens of thousands of square metres (10,000 square metres can support approximately 1 MW of IT equipment load, with another 1 MW needed for cooling and power delivery systems).</td><td>>464.515</td></tr>
<tr><td>Localized</td><td>These facilities and locations may serve only the local, specific needs of a call centre or office operation (for example), with general, large-scale IT services provided by a data centre in another location.</td><td>46.452 to 464.515</td><td>73,987</td><td>3,977,187</td><td>54</td></tr>
</table>

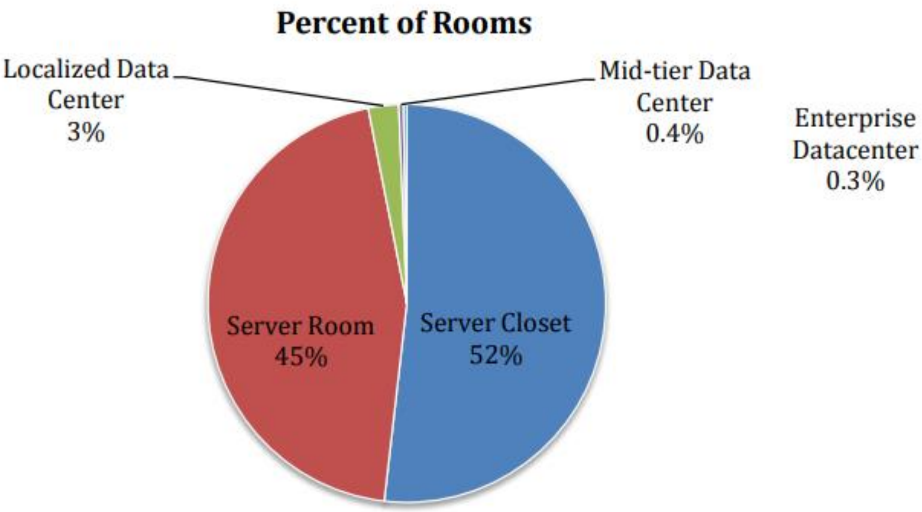
[19] The Pros and Cons of Server Rooms vs. Data Centres (datacentreknowledge.com)

Server Room	These type of facilities and locations often do not have dedicated cooling or power delivery systems or climate conditioning equipment.	18.580 to 46.354	1,170,399	3,057,834	3
Server Closet	Smallest-scale data centre and server rooms.	18.580	1,345,741	2,135,538	2

According to the IDC´s data centres and server rooms industry and market research report [7], half of all computer servers in the U.S. are not in big data centres, but rather located in small scale server rooms and server closets, and other localized data centres (less than a hundred square metres).



Furthermore, according to the IDC report [7], in the U.S., there are approximately two and a half million small and medium-sized server rooms, with approximately more than the 20,000 or so full-fledged data centres.



Some facts and statistics from Europe, according to the data shared by the EURECA project [20] on data centres and IT server rooms serving public authorities in Ireland, the Netherlands and the UK, majority of data centres and server rooms in the public sector in these countries (80%) are up to 25 racks. Considering an average of 2 m2 per rack and 215 W/m2, the 25-rack threshold is more or less comparable with the server room definition. This data is used as an indicator of the presence of large number of server rooms in the EU as well.

This shows that while there might be considerable large data centres, they are vastly outnumbered by these smaller server room. Therefore, the energy efficiency of small server rooms is equally important as that of larger data centres.

3.2.2. Energy Efficiency in Server Rooms

High-energy-demand IT systems, such as those in data centres, universities, hospitals, and financial institutions, contribute significantly to the overall energy consumption and thermal load of tertiary buildings.

Figure 5 presents estimated U.S. data centre electricity consumption by market segment (2011) [8].

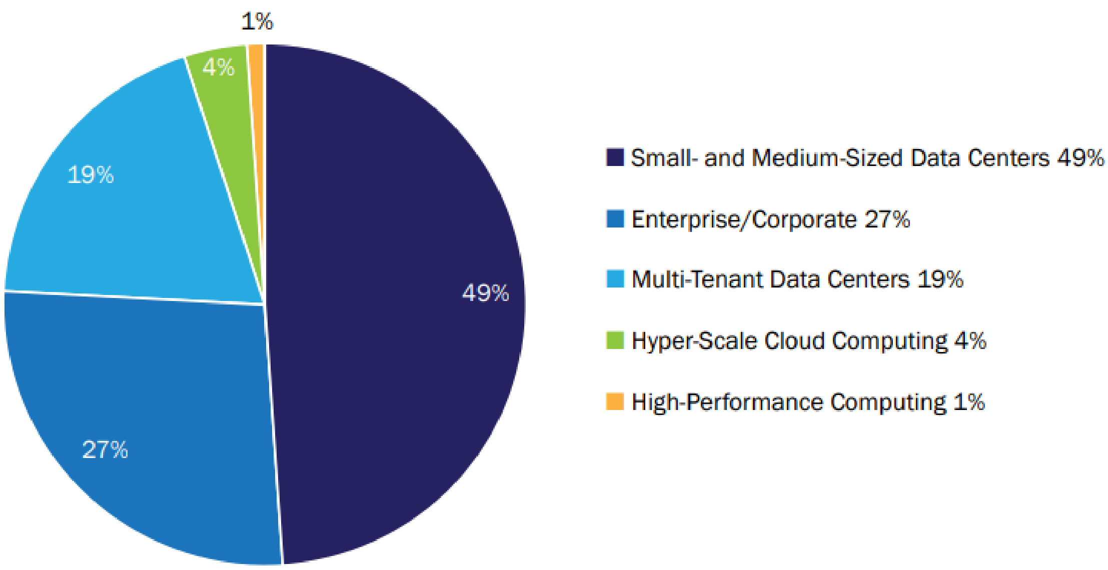


Figure 5 Estimated U.S. data centre electricity consumption by market segment (2011)

On average, within a data centre and server rooms, 52% of the electricity is used by the IT equipment, 38% by the cooling system, and 10% for the remaining equipment (electrical power distribution, UPS…)[21]. Table 2 presents a detailed breakdown of components in each category.

Table 2 Energy Consumption Breakdown

IT Equipment (52% of Electricity Use)	Cooling System (38% of Electricity Use)	Remaining Equipment (10% of Electricity Use)
Servers	CRAC Units (Computer Room Air Conditioning)	UPS (Uninterruptible Power Supplies)

[20] EURECA EU Project
[21] Data Centre Energy Consumption & Power Sources

Storage Systems	Chillers	PDUs (Power Distribution Units)
Network Equipment	Cooling Towers	Switchgears and Transformers
	In-row Cooling Units	Voltage Regulators
	Liquid Cooling Systems	Cabling Infrastructure

According to the NRDC estimates [8] energy waste in U.S. server rooms and closets represents the equivalent output of 7 medium-size coal-fired power plants (500 MW) and costs U.S. businesses over $2 billion per year in electricity costs. Yet most of the attention of the market on energy conservation is focused on large data centres, which are easier and more profitable to address.

Optimizing electricity usage in these areas can lead to significant energy savings and improved sustainability profiles for data centres. Strategies for improvement might include upgrading to more energy-efficient systems, implementing server virtualization to reduce the number of active servers, and enhancing cooling strategies to reduce energy waste.

NRDC concludes in their survey related to server rooms [8] that technologies to significantly reduce energy waste and improve thermal management in server rooms—such as virtualization, power management, and cloud computing—are widely available and can be very cost-effective, in some cases also deployed in other market segments such as large scale data centres. These technologies and approaches provide many business benefits other than energy savings. In small server rooms many of the same benefits can be realized, but the opportunity is often missed because of a lack of information, expertise, time, or incentives.

3.2.3. What is a Server Room?

A server room is a designated space within a building specifically allocated for storing servers and processing equipment on-site to run an organisation's IT workload and applications.

3.2.4. Size of a Server Room

The Server room's size will depend on the organisation's specific needs, and the kW load of the installed equipment but is usually in the 538 to 1076 watt/square meter range[22]. Server room sizing tools similar to this one Server Room Sizing Tool could be helpful in understanding the sizing requirements of the server room. Some organizations have specific requirements, such as the University of Kansas' Lawrence Campus[23], that request hot and cold aisles that are wide enough to provide access to equipment.

3.2.5. Equipment in IT Server Rooms

There are three categories of equipment that are required to run an organisation's IT network and applications. IT equipment that includes servers, processing and storage systems, and network equipment that provide required computing and connectivity to run IT applications effectively. The

[22] Server Room Designs and Best Practices
[23] Data Centre and Server Room Standards | University of Kansas

other critical category of equipment is the cooling system which is vital to keeping optimal temperatures and humidity levels for IT equipment, preventing overheating and ensuring system reliability. Finally, there is a remaining category of equipment that includes all the infrastructure necessary for power management and distribution within the server rooms. Table 3 describes the equipment available in the IT server rooms.

Table 3 Equipment in IT Server Rooms

Component	Brief Description
Servers	Servers are the computing machines that process and stores data. They run the required applications and services.
Storage	Storage systems consist of devices that store and retrieve data. It can include hard disk drives (HDDs), solid-state drives (SSDs), and network-attached storage devices (NASs). They are essential for data redundancy, backup, and archiving.
Network Equipment	Network equipment is critical for keeping connectivity and managing data traffic efficiently. This includes switches, routers, and other devices that manage the data traffic with the server room, and between the server room and the building.
Security Equipment	These are devices such as firewalls, intrusion detection systems (IDS), access control systems that protect the server rooms and their assets from unauthorized access and attacks.
Power Generators	These are backup power sources that ensure that server rooms stay operational during power outages. They can include diesel generators and battery backups.
Cooling Systems	Cooling systems keep optimal temperature and humidity levels within the server rooms to prevent overheating and damage to the equipment.
Cabling Systems	This refers to the wiring infrastructure that connects devices within the server rooms to the outside world. It includes fibre optics cable, copper cabling, and patch panels.
Fire Suppression	This consists of systems such as sprinklers and fire extinguishers that protect the server rooms from fire damage.
Power Infrastructure	This refers to the electrical components that supply power to the server room. It includes Uninterruptible Power Supply (UPS) and Power distribution unit (PDU).
Raised Floor	These are the elevated floors in the server rooms that allow cabling and other infrastructure to be installed underneath. They also help manage airflow for cooling systems.
Racks and Cabinets	Servers and networking equipment are organized in racks and cabinets, optimizing space and ensuring proper airflow.

3.2.6. Sensor and probes in server rooms

A server room should have sensors throughout the area that measure factors like temperature, power, airflow, and humidity. They must ensure precise environmental control of server room to prevent overheating and condensation. Table 4 shows the type of probes and sensors found in the typical server rooms.

Table 4 Sensors and Probes in the Server rooms

Sensors	Location	Best Practice	Applicable Industry Guidelines
Temperature Sensors	Rack	Install, top, bottom & middle to monitor inlet temperature of devices in rack.	ASHRAE Guidelines

Humidity Sensors	Row	One per cold aisle at the front of rack in middle of row.	ASHRAE Guidelines
Rope leak Sensors Spot leak Sensors	Room	Leak rope placement around each CRAC system, around cooling distribution units, and under raised floors, and any other leak source	No industry Standard

3.2.7. High level architecture of server room monitoring and management solutions.

Typically, server room environmental monitoring and management solutions[24] follow tiered architecture presented in the Figure 6 .

Tier 4 - Application Layer: This layer centralises device monitoring and control and acts as an asset management application.

Tier 3 - IP Network: This offers the information delivery mechanism, which is based on an IP LAN/WAN client intranet.

Tier 2 - Device Management: This layer handles getting readings from air-conditioning systems, UPS equipment and generator sets. In addition, Environmental and Power Management Concentrators gather information from sensors and probes.

Tier 1 - Sensor and probes: At the lowest tier of the management architecture sits the environmental sensors and probes. These gather environmental, physical and power related information, which is relayed to concentrator devices.

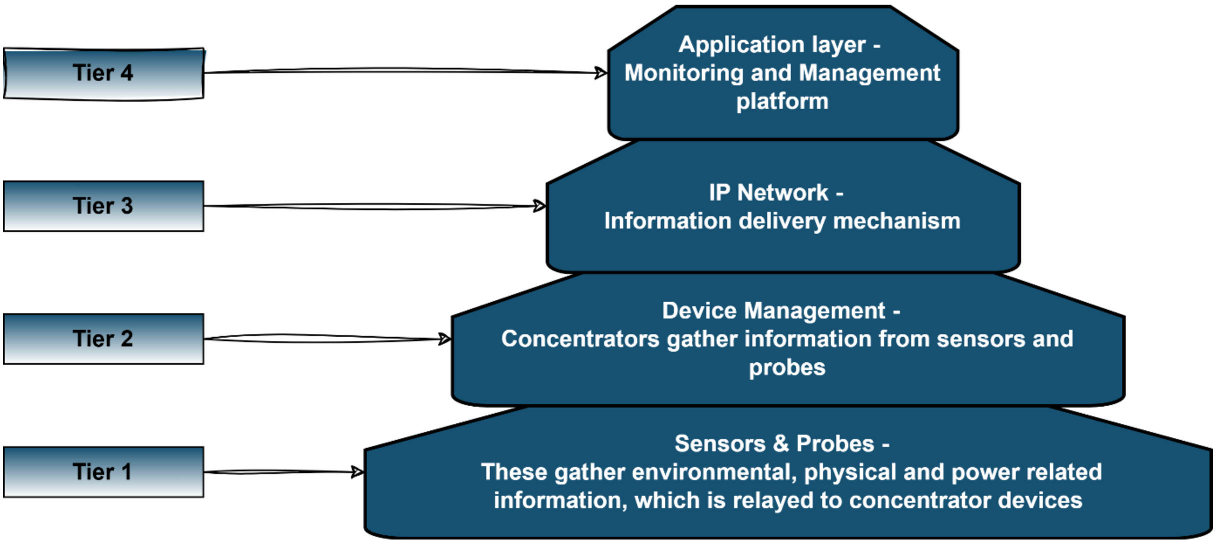


Figure 6 Tiered architecture for Server room monitoring and management solution.

For instance, Schneider offers EcoStruxure Data Centre Solutions[25] for monitoring and management of data centres and server rooms. Their offering cover power, cooling, racks, and management systems to support the deployment of IT equipment in all environments from small edge applications to large scale data centres.

[24] 13 Best Server Room Environmental Monitoring Systems for 2024
[25] EcoStruxure Data Center Solutions | Schneider Electric Global (se.com)

3.2.8. Server room design aspects and considerations

Table 5 Server room design aspects and considerations

Aspect	Brief Description
Server room Layout planning and design	Layout planning and design is paramount. The arrangement of server racks and equipment in a server room can influence airflow and overall cooling efficiency. Conduct a thorough assessment of server room layout to ensure proper airflow and ventilation.
Hot Aisle/Cold Aisle Containment	Implement containment strategies to separate hot and cold air flows, can significantly reduce the overall cooling load and allowing for more efficient emergency cooling.
Server Room Management and Monitoring Solution	Server Room should have a solution like Data Centre Infrastructure Management (DCIM) that collects all the data required to run critical infrastructure efficiently, and delivers a real-time, integrated view of the entire IT facility and its assets. It includes the monitoring, measuring, managing, and controlling of server room utilization and energy consumption of all IT-related equipment and facility infrastructure components.
Precise Environmental Control	A server room should have sensors throughout the area that measure both temperature and humidity. Server rooms ideal temperatures are typically between 18-27°C with humidity levels between 40-60%[26]. Regularly monitor and log temperature and humidity levels using sensors and a centralized monitoring system.
Smart control systems	Usually, HVAC system is needed to maintain optimal temperature control in the server rooms. A server room need to implement smart HVAC control systems to automate the process, ensuring the entire room at the desired temperature and humidity levels.
Cooling and HVAC Design	Design efficient cooling systems to maintain optimal temperature and humidity levels. Consider options like free cooling, hot and cold aisle containment, and liquid cooling.
Redundant cooling system	Implement a redundant cooling system to ensure continuous temperature regulation, even if one unit fails.
Management of Moisture	Dedicated dehumidifier to remove excess moisture from the air during periods of high humidity. Implement a humidifier to add moisture to the air during dry periods to prevent electrostatic discharge.
Fire Suppression System	If a fire occurs, it is usually not recommended to spray a server room with water. The water could damage all the IT and equipment, resulting in a huge disaster. There are quite a few options for this type of system including Inergen systems, Novec systems, and FM-200 systems. These are all designed to extinguish fires while keeping computer equipment safe.
Cable Management Solutions	Server rooms can end up with miles of cables. Designing the room to allow cables to properly run through the ceiling, or under the floor, helps avoid huge messes. Use cable management solutions, such as cable trays, zip ties, or velcro straps, to keep cords organized.
Redundant Power Sources	Having redundant power sources is important not only to ensure the equipment remains up and running at all times, but also to avoid power surges that could damage the servers and other items in the room.

[26] ASHRAE

Physical Security	Server rooms house thousands, or even millions, of dollars' worth of equipment. In addition, the stored data in these rooms can be invaluable. Having the necessary physical security in place to keep it safe is essential.
Dusting and Cleaning solution	Set and maintain a regular cleaning schedule to avoid dust and debris buildup.
Proper insulation and sealing of the server room	Ensure proper insulation and sealing of the server room to minimize the impact of external temperature fluctuations.
Data security	Implement a comprehensive cybersecurity plan to protect your servers from cyber threats.

3.2.9. Understanding heat generation in server rooms

IT equipment and electrical components in server rooms generate a lot of heat. If left unchecked, this heat can have detrimental effects on the performance and stability of the equipment. In past, there have been cases where excess heat generated in the server rooms affected the functioning of the processers, leading to hardware failure, data loss, and reduced equipment lifespan[27]. This was the case for Microsoft when its email services went down for up to 16 hours when a specific section of its data centre was overheated[28].

Before diving into cooling technologies and strategies, it is essential to understand how heat is generated within a server rack. The primary sources of heat in a server rack include the central processing units (CPUs), power supplies, hard drives, and other components that work tirelessly to manage the computational workload. As these components process data, they generate heat as a byproduct, which, if not adequately managed, can lead to heat-related issues and hardware failures. Some key factors contribute to the heat buildup in a server rack:

- **Density:** The higher the density of servers in the rack, the greater the heat generation due to the increased number of components running simultaneously.
- **Workload:** Intensive workloads that require extensive processing power will produce more heat, affecting the overall temperature of the rack.
- **Power consumption:** Servers with higher power consumption will naturally generate more heat. This is an important consideration when selecting and configuring servers for your rack.
- **Location:** The environment where the server rack is housed can also affect heat generation.

3.2.10. Server room cooling systems.

Keeping the server room environment in best condition is essential for the stability and performance of organization's IT infrastructure and workload, ensuring data security, and preventing downtime. Crucial to this maintenance is the cooling system, which ensures precise environmental control within the server room.

More specifically, cooling systems for server rooms have three main tasks:

- **Temperatures control:** Maintenance of stable temperatures in the server room.
- **Humidity control:** servers do not do well in humid environments.
- **Air filtration:** dust and other airborne particles can reduce the lifespan and reliability of computing equipment.

[27] Server Room Cooling: Practical Tips and Tricks for Budget-Friendly Maintenance
[28] Heat Spike in Data Centre Caused Hotmail Outage

According to the study [4] that investigated how IT equipment was deployed, powered, and cooled in small server rooms, cooling systems consume around 25-50% of the energy in server rooms.

Figure 7 shows the consumption of the cooling system in the data centre and server rooms.

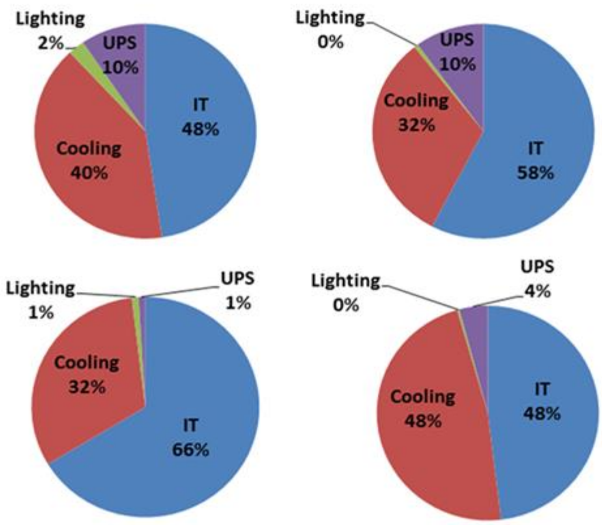


Figure 7 Server Room Energy Consumption Breakdown [4]

According to another study that performed review of air conditioning systems energy performance in data centres and server rooms [9] on average around 40% of energy consumption of the data centres and server rooms can be attributed to the operation of cooling systems with the most efficient cooling systems using 24% of the total energy and the least efficient 61%. Thus, cooling system design plays a pivotal role in the overall efficiency of the data centre and server rooms. Optimizing a cooling system can save power, water, and money for the operator.

Prior to discussing about different cooling technologies and strategies it is important to understand the fundamentals of thermal management process inside data centre and server room and the role played by the cooling systems to maintain the optimal temperature and humidity in the facility.

Figure 8 shows a simplified data centre and server room and its end-to-end thermal management system. The system has been broken down into three components: heat collection (blue), heat transport (grey), and heat rejection (green). In the heat collection phase, the cooling technology captures the heat from the IT equipment. For transport, the heat is carried from the technology cooling system to the heat rejection system. Finally, the heat rejection part generates cool facility water by rejecting the heat to the local environment.

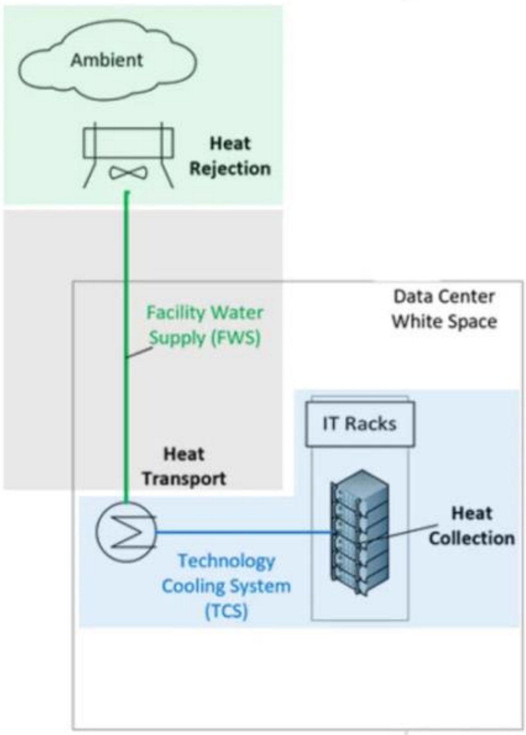


Figure 8 Simplified end-to-end thermal management system in data centres and server rooms (Source: Electronics Cooling)

If an air-cooled system is taken as an example, then the thermal management process inside the server room will follow the following steps:

Table 6 Thermal management process in server rooms

Components	Steps
Heat Collection	Fans blow air over finned heat sinks on IT equipment, capturing heat. The heated air is then directed towards the air handler.
Heat Transport	The air handler transfers the heat from the warm air to the facility water. The facility water, now heated, carries the heat away from the IT equipment area.
Heat Rejection	The heated facility water is directed to a heat exchanger or cooling tower. Here, the heat is transferred from the facility water to the ambient air, cooling the water. The cooled facility water is then recirculated back to the heat collection stage to absorb more heat.

By effectively managing these three components, the thermal management system ensures that the data centre and server room run efficiently, preventing overheating and maintaining the performance and longevity of the IT equipment.

The role of airflow management in cooling system efficiencies

Factors (such as non-optimal air distribution and server hot spots etc.) can drastically reduce the efficiency of the cooling system. If there is more than one server rack, then the racks should be arranged to form a cold aisle and a hot aisle shown in the

Figure 9. Hot and cold air aisles increase the efficiency of air-based cooling systems by enabling more targeted placement of intake and exhaust vents. This prevents hot and cold air mixing so the cooling CRAC or CRAH can work more efficiently.

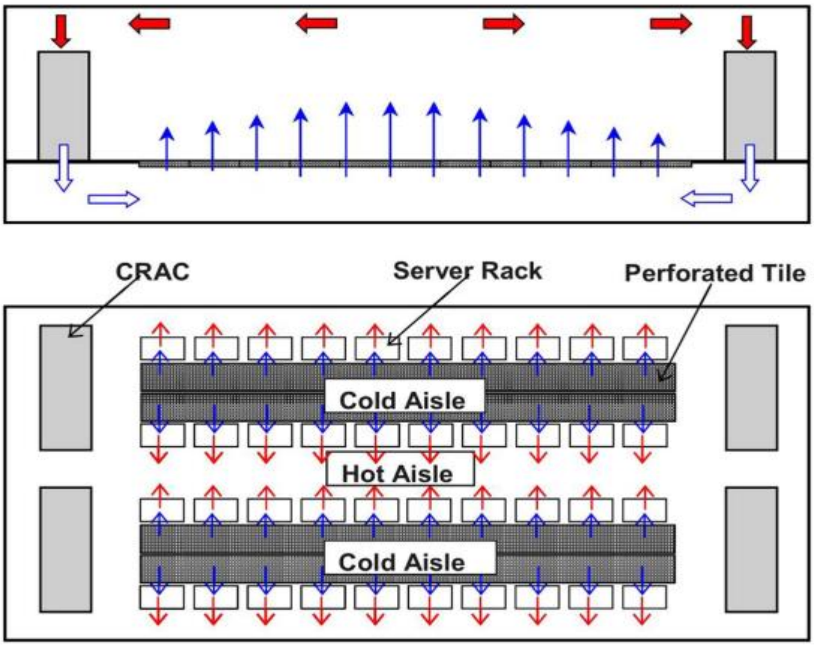


Figure 9 The hot aisle/cold aisle arrangement in a raised-floor data centre.

What is Computer Room Air Conditioner (CRAC)?

CRAC is an umbrella term that represents any type of cooling system designed to cool IT servers and other equipment, and they can vary greatly in design and the technologies they use. Since every server room and data centre will have a unique design and layout, as a result, every cooling system is also different. One feature which varies is the substance with which air conditioning systems carry heat away, (such as water, air, or chemical refrigerant) which is often referred to as 'the medium'. The basics of an air conditioning system is that a medium goes through two heat exchanges, one to remove heat from the servers, and then another to remove heat from the medium [9]. According to [10] air as the fundamental cooling medium is still the most common means to take heat out of a data centre or server room. However, at some point soon, heat flux (a measure of heat flow rate intensity) from the next generation of processors/ GPUs will be too high to manage with direct air cooling.

One of the most impactful requirement trends over the last decades has been the power consumption of IT equipment, as a direct function of chip performance. ASHRAE[29] describes three eras over the last decades: the single-core era (2000-2010), the multi-core era (2011-2017), and the power wars era (2018-present) [10]. As just one example, the maximum power consumption of NVIDIA's latest GPU is 160% higher than that of the company's earlier generation chips[30]. Gone are the days when increased performance came without increasing power demand. Now, more computation requires more watts.
Directly proportionate to power consumption is what ASHRAE refers to as the "degree of cooling difficulty" (the inverse of thermal resistance) [11]. The degree of cooling difficulty rose modestly during the single-core era and was flat during the multi-core era. But since 2018, cooling difficulty intensified dramatically. With multicore parts reaching performance limits, the only choice for increased performance is increased power. Table 7 shows that the improvements in the performance of processors/ GPUs have increased drastically the difficulty of cooling data centres and server rooms.

Table 7 Degree of Cooling Difficulty Trends

	Degree of Cooling Difficulty (Inverse Thermal Resistance) Trend
2000-2010 (Single-core Era)	Rising modestly
2011-2017 (Multi-core Era	Flat
2018-2025 (Power Wars Era)	Rising very dramatically

This magnitude of heat flux generated by the next generation of processors/ GPUs "puts a strain on traditional data centre and server room cooling systems—pushing the limits of air-based cooling.

Air vs. liquid medium for cooling

In simple words, air is not as effective a heat transfer medium as liquid, and at some point, is unable to remove all the heat generated by high-power chips, resulting in sub-optimal performance or equipment damage. When it comes to heat transfer, liquids are fundamentally more efficient than air—because they are denser, have higher specific heat capacities, and lower thermal resistance [10]. According to [10] the shift to liquid cooling has multiple benefits such as:

- **High Heat Flux:** Modern processors and high-performance computing (HPC) systems generate significant heat. Liquid cooling is more efficient at removing heat compared to traditional air cooling, which helps in maintaining optimal operating temperatures.
- **Precision Cooling:** Liquid cooling can be targeted precisely to the heat sources, leading to more effective cooling with lower energy consumption.

3.2.11. Lifecycle management and optimisation of IT Server rooms

As good genes do not guarantee the health and well-being of a person, a good plan and design alone do not guarantee that an IT server room is well-designed and will remain efficient and accessible over the course of its lifespan. For each phase of the IT server room life cycle, proper care and action must be taken to continuously meet the business needs of the facility.

[29] The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
[30] World Leader in Artificial Intelligence Computing | NVIDIA

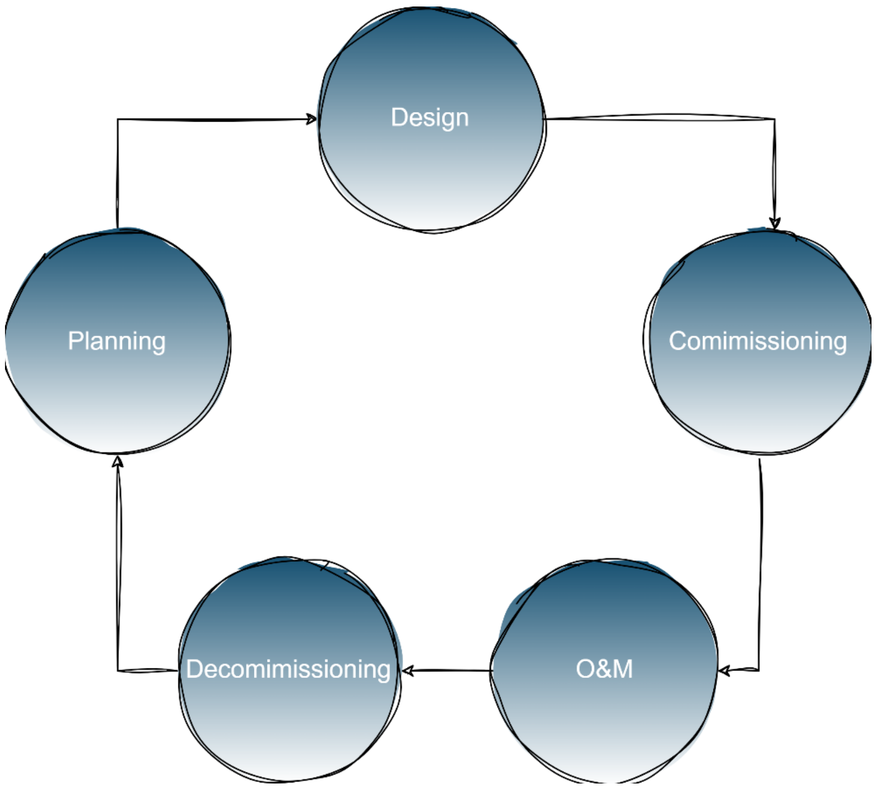


Figure 10 Phases of the IT server room.

Below information about specific actions and considerations for each of the five phases of the IT server room life cycle is provided [12].

Plan

Table 8 Plan Phase - Key Actions and Considerations

Key Actions and Considerations	
Capacity planning and assessment	Evaluate the current and future IT requirements of the organization and businesses, including capacity, performance, and scalability.
Cost estimations and Budgeting	Develop a detailed budget covering all aspects of the server room, including infrastructure, equipment, and operational costs.
Location Selection	Choose a suitable location within the building, considering factors like accessibility, security, and environmental risks.
Regulatory Compliance	Identify and plan for compliance with relevant regulations and standards.

Design

Table 9 Design Phase - Key Actions and Considerations

Key Actions and Considerations	
Architectural Design	Create detailed architectural plans, including layout, space utilization, and structural considerations.
Cooling and HVAC Design	Design efficient cooling systems to maintain optimal temperature and humidity levels. Consider options like free cooling, hot and cold aisle containment, and liquid cooling.

Power Infrastructure	Plan for robust power infrastructure, including UPS systems, PDUs, and backup generators to ensure continuous operation.
Cabling and Network Design	Develop a structured cabling plan to support current and future networking needs, ensuring minimal clutter and easy maintenance.
Security Measures	Design security systems, including physical security (access control, surveillance) and cybersecurity measures to protect sensitive data.

Commissioning

Table 10 Commissioning Phase - Key Actions and Considerations

Key Actions and Considerations	
Procurement and Installation	Procure and install all infrastructure components, including servers, racks, cooling systems, power systems, and cabling and network equipment.
Testing and Validation	Conduct thorough testing and validation of all systems (IT equipment, power, cooling, cabling and network equipment) to ensure they meet design specifications, performance criteria, and regulatory and industry standards.
Training and Documentation	Provide training for IT staff on the operation and maintenance of the new systems and equipment. Prepare comprehensive documentation, including as-built drawings, system configurations, and operational procedures.

O&M

Table 11 O&M Phase - Key Actions and Considerations

Key Actions and Considerations	
Monitoring	Implement continuous monitoring of environmental conditions (temperature, humidity), power usage, and system performance using remote monitoring tools and dashboards.
Preventive Maintenance	Establish a preventive maintenance schedule for all critical systems, including HVAC, power, and networking equipment to prevent failures and extend lifespan.
Optimisation and control (Energy Efficiency)	Implement energy efficiency measures, such as optimizing cooling systems, using energy-efficient hardware, and managing power usage to reduce operational costs and environmental impact.
Capacity Management	Regularly assess and manage capacity to ensure that the server room can manage current and future workloads without issues
Security Management	Continuously update and maintain security measures to protect against evolving threats, including regular security audits and updates

Decommissioning

Table 12 Decommissioning Phase - Key Actions and Considerations

Key Actions and Considerations	
End-of-Life Assessment	Determine when equipment or the entire server room has reached the end of its useful life and plan for decommissioning.
Data Migration	Ensure that all critical data is securely migrated to new infrastructure or archived before decommissioning old systems.
Disposal of Equipment	Follow proper protocols for the disposal of electronic equipment, ensuring compliance with environmental regulations and data security standards.

Site Restoration	Restore the site to its original condition or repurpose it for other uses, ensuring that all decommissioned infrastructure is safely removed.
Documentation and Reporting	Document the decommissioning process and provide reports on the disposition of assets, data migration, and compliance with regulatory requirements.

Each phase of the IT server room lifecycle requires careful planning, execution, and management to ensure the IT server rooms remain efficient, accessible, and capable of meeting business needs. By addressing the specific actions and considerations in each phase, organizations and businesses can optimize the performance and longevity of their server rooms while minimizing costs and risks.

Given that IT server rooms are still relatively new when it comes to design and O&M, thus specific knowledge and tools for lifecycle management and optimisation of IT server rooms need to be developed. HYCOOL-IT fills this gap by promoting openBIM, digitalization and SIMBotS simulation practices to optimally manage the design, commissioning, O&M and decommissioning of IT systems.

4. Building typologies screening, process improvements and user story collection

This section describes diverse types of building typologies in the tertiary sector. These typologies include educational institutions, hospitals, office buildings, financial institutions, retail buildings, hotels and hospitality, and data centres. Each typology is characterized by the size of their server rooms, usage and services buildings offer, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders.

Furthermore, this section presents analysis of some survey results to understand the current small scale server room Landscape, equipment, common efficiency issues, stakeholder involved and their needs and challenges. Building on the surveys´ results and analysis, this section discusses the idea of utilizing waste heat recovery and BDTs approaches as advanced strategies and process improvements to enhance thermal management and energy optimization in high energy demand IT server rooms within tertiary buildings as proposed by the HYCOOL-IT project.

Finally, this section extracts the user stories to identify the needs, expectations, and potential benefits for various users focused on the lifecycle management and optimisation of IT server rooms. User stories will be the key starting points for the formulation of user requirements. By developing these user stories and extracting requirements from them, the HYCOOL-IT project Building Digital Twin based Methodology can be extended to comprehensively cover the entire lifecycle of IT server rooms, enhancing efficiency, sustainability, and performance across all phases.

4.1. Building Typologies and Characterization

Data centres and server rooms store, process and redirect the information that is critical to the operation of modern-day hospitals, public offices, schools and universities, IT services, financial institutions and virtually every aspect of an organisation doing business in Industry 4.0[31]. Following future trends such as edge computing in server infrastructure developments and advancements in artificial intelligence (AI) and machine learning (ML) based applications, many companies, schools and higher educational institutions, hospitals, and hotels and other services sector buildings require server rooms for moving data processing closer to the source for reduced latency and improved performance, crucial for real-time applications like IoT, autonomous vehicles, and VR. These organizations have requirements to house applications and servers in a secure and resilient manner on premise locations. Unlike large data centres that serve multiple clients, server rooms typically support IT workload and application of a single organization or building. Technically speaking, server rooms in tertiary sector buildings as targeted by the HYCOOL-IT project are typically housed and integrated into multi-purpose buildings such as educational institutions and hospitals. Therefore, they can be of any size and shape depending on the needs and IT workload of organisations. Because of this, the server room may be laid out in a non-standard way. The reason this is important is that it can affect the planning for managing the environment, including airflow and cooling.

[31] The keys to successful data centre facilities management | Data Centre Magazine

The specific size of a server room in tertiary building typologies varies widely. It usually depends on the organization's current and predicted future needs and IT workload, the amount of IT equipment, and the environmental controls needed. For rough estimations, the size of the room depends on the kW load of the installed IT equipment but is usually in the 538 to 1076 watt/m2 range. Proper planning and scalability are key to ensuring that the server room can accommodate growth and changes in technology.

Nevertheless, the section Understanding Tertiary Sector Buildings and Server Rooms describes in detail the small-scale server room landscape. Below high-level description of the landscape of the server rooms found in different typology of tertiary sector buildings is provided.

4.1.1. Educational Institutions

A new paradigm for enabling high performance computing (HPC) systems in higher education institutions is underway[32]. HPC is used by higher education institutions, industry, and research labs around the world for modelling, simulation, and data analysis to enable scientific discovery [13]. Researchers who work for universities and higher education institutions, particularly in engineering and scientific fields, are generating massive amounts of data and petabytes of information and require powerful computing resources. For example, institutions like NASA Centre for Climate Simulation, MIT Lincoln Laboratory Supercomputing Centre, and University of Texas at Austin are some of the research institutions that are eager to pursue research science initiatives using HPC, providing scientists with the ability to access large data sets and powerful computer resources.

The new HPC based computing paradigm for higher educational institutions means abandoning ageing IT infrastructure and server rooms and embracing new server rooms housing servers with advanced and powerful processors/ GPUs. This type of servers that support HPC based applications generate a lot of heat and, therefore, require more efficient cooling technologies such as liquid based cooling methods such as direct-to-chip cooling, immersion cooling, or using cooling plates. HYCOOL-IT proposed Rack-integrated adsorption chiller could also be a practical option for cooling this type of server rooms of higher education institutions that support HPC based workload and applications. Nevertheless, HPC based applications require highly specialized IT infrastructure and server room designs because the performance demands are staggeringly high.

Typology Characterization

Furthermore, this typology is broadly characterized by the building usage, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders and their needs.

Table 13 Educational Institutions typology

Characteristics	
Buildings Usage	School and university buildings with laboratories, offices for staff, lecture rooms, student group rooms.
IT Applications and Computing Load	
Supported applications	Use IT server rooms for administrative and academic and research applications. Including the learning management systems (LMS), research data management and databases, administrative software, research science initiatives using HPC.
Computing Load	Moderate to high, especially in research-intensive institutions.

[32] High performance computing (HPC) systems in higher education

Equipment in Server Rooms	
Type	Servers for LMS, HPC, research databases, web hosting, networking equipment.
Electricity Usage	Moderate to high, depending on the institution's size and research intensity.
Waste Heat Recovery Potential	
Potential	Moderate to high, especially in large universities involved in research science initiatives using HPC.
Relevant Stakeholders	
Stakeholders	IT departments, administrative staff, researchers, students.

4.1.2. Hospitals

Newer technologies are allowing for remote access, x-rays are accessible from the doctor's office, and worldwide video teleconference is becoming more commonplace. As a result, the server rooms for hospitals are demanding more respect and attention[33].

Today, hospital networks provide all kinds of functions and services that may vary from traditional accounting and administrative to highly advanced remote surgery. Increased lives depend on the information provided by the network. The increased use of digital medical imagery continues to increase the need for information storage that must be accessible in real time. These requirements force most hospitals to continually upgrade their server rooms. Unfortunately, most hospital and institutional data centres and server rooms are not able to expand because of poor planning.

Traditionally, server rooms in the hospitals were designed around low-density computer servers and processing and storage equipment that needed a lot of space. But the current growth profile of hospitals projecting the hospital's needs of advanced servers, networking, and storage. Advancements in the powerful processors/ GPUs' technology can put more computer power in a smaller hardware. While that sounds exciting and could be necessary for meeting the growth profile of hospitals, but there is a price that must be paid through the generation of more heat, which requires more advanced cooling solutions—and the use of more power[34].

Typology Characterization

Furthermore, this typology is broadly characterized by the building usage, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders and their needs.

Table 14 Hospitals typology

Characteristics	
Buildings Usage	Patient care, administration, research.
IT Applications and Computing Load	
Supported applications	Require secure and reliable IT server rooms for patient data management. Electronic health records (EHR), medical imaging, telemedicine.
Computing Load	High due to real-time data processing and storage.
Equipment in Server Rooms	
Type	Servers for EHR, imaging storage, networked medical devices. The increased use of digital medical imagery continues to increase the need for information storage that must be accessible in real time.

[33] The Data Centre Now the heart of the hospital?
[34] The Data Centre Now the heart of the hospital?

Electricity Usage	High.
Waste Heat Recovery Potential	
Potential	High, particularly in large hospitals with extensive IT infrastructure.
Relevant Stakeholders	
Stakeholders	IT departments, healthcare professionals, patients, regulatory agencies.

4.1.3. Office Buildings

In the realm of office and commercial buildings, advanced AI technologies are paving the way for a smarter, more responsive work environment. Employees and tenants now interact with building systems through mobile apps and intuitive voice commands, managing tasks like booking conference rooms, adjusting lighting, and controlling HVAC systems. This leap forward needs robust on-site server rooms that manage data processing close to the source, drastically cutting down on latency and boosting performance. This setup is vital for real-time operations, such as adaptive energy management systems that respond instantly to occupancy changes, security systems that can dynamically adjust based on real-time threat assessments, and personalized services that enhance tenant comfort and productivity. By embedding these advanced technological capabilities directly within the infrastructure, office and commercial buildings are becoming hubs of efficiency and innovation, significantly elevating the user experience.

Typology Characterization

Furthermore, this typology is broadly characterized by the building usage, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders and their needs.

Table 15 Office Buildings typology

Characteristics	
Buildings Usage	Workspaces, meeting rooms, communal areas.
IT Applications and Computing Load	
Applications	Enterprise resource planning (ERP), customer relationship management (CRM), office productivity tools.
Computing Load	Moderate
Equipment in Server Rooms	
Type	Servers for ERP, CRM, email servers, network infrastructure.
Electricity Usage	Moderate.
Waste Heat Recovery Potential	
Potential	Moderate, depending on server room size and load.
Relevant Stakeholders	
Stakeholders	IT departments, employees, management, clients.

4.1.4. Financial Institutions

Financial institutions are using modern technologies to offer enhanced customer experiences through mobile apps and other engagement tools, allowing clients to perform real time financial transactions, check account balances, invest in stocks, and receive financial advice with voice commands. This shift is driving financial institutions to set up their own server rooms to move data processing closer to the source, reducing latency and improving performance. This infrastructure is crucial for real-time applications, such as fraud detection and instant transaction processing, which are essential for keeping security and enhancing the customer experience.

Typology Characterization

Furthermore, this typology is broadly characterized by the building usage, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders and their needs.

Table 16 Financial Institutions typology

Characteristics	
Buildings Usage	Transaction processing, customer service, data management.
IT Applications and Computing Load	
Applications	Transaction processing systems, databases, financial analytics.
Computing Load	High due to real-time processing and large data volumes.
Equipment in Server Rooms	
Type	High-performance servers, secure storage solutions, robust networking.
Electricity Usage	High.
Waste Heat Recovery Potential	
Potential	High, given the intense computing needs.
Relevant Stakeholders	
Stakeholders	IT departments, financial analysts, customers, regulatory bodies.

4.1.5. Retail Buildings

Advanced AI based technologies are allowing shoppers to use their mobile devices or smart speakers to search for products and place orders with voice commands, enhancing the customer experience. This is driving the retail buildings and facilities to have their own server rooms for moving data processing closer to the source for reduced latency and improved performance, crucial for real-time applications for enhancing the customer experience.

Typology Characterization

Furthermore, this typology is broadly characterized by the building usage, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders and their needs.

Table 17 Retail Buildings typology

Characteristics	
Buildings Usage	Sales, inventory management, customer service.
IT Applications and Computing Load	
Applications	POS systems, e-commerce platforms, inventory management systems.
Computing Load	Moderate to high.
Equipment in Server Rooms	
Type	POS servers, web servers, network infrastructure.
Electricity Usage	Moderate.
Waste Heat Recovery Potential	
Potential	Moderate, depending on store size and IT load.
Relevant Stakeholders	
Stakeholders	IT departments, sales staff, customers, suppliers.

4.1.6. Hotels and Hospitality

Hospitality industry is adopting newer technologies to enable their guests to use their mobile devices to book rooms, request services, and access personalized recommendations. This innovation is prompting hotels to set up dedicated server rooms to bring data processing closer to the source, minimizing latency and enhancing performance. This infrastructure is crucial for delivering real-time services, such as instant room upgrades, dynamic pricing adjustments, and personalized guest experiences, ensuring that visitors enjoy a seamless and enriched stay.

Typology Characterization

Furthermore, this typology is broadly characterized by the building usage, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders and their needs.

Table 18 Hotels and Hospitality typology

Characteristics	
Buildings Usage	Guest services, reservations, administrative functions.
IT Applications and Computing Load	
Applications	Reservation systems, guest management software, Wi-Fi services.
Computing Load	Moderate.
Equipment in Server Rooms	
Type	Reservation servers, management software servers, networking equipment.
Electricity Usage	Moderate.
Waste Heat Recovery Potential	
Potential	Moderate, especially in large hotels with extensive IT services.
Relevant Stakeholders	
Stakeholders	IT departments, hotel management, guests, booking agents.

4.1.7. Data centres

Data centres consist of entire facilities/buildings dedicated to housing, storing, and supporting massive arrays of IT servers and processing units, networking infrastructure, and other equipment for building, running and delivering IT applications and services.

The increasing energy consumption in data centres and the need to reduce the related environmental, economic, and energy supply impacts demand that data centres become more energy-efficient, reuse waste energy such as heat, and use more renewable energy sources, in order to achieve EU climate and energy goals set for 2030 and 2050 [1], [2].

Table 19 presents four levels of data centre classification according to the Uptime Institute, which measures availability and security[35].

Table 19 Data centre classification

Data centre classification	Description	Availability	Security
Tier I	Basic capacity	99.61%	Basic
Tier II	Redundant capacity components	99.741%	Redundant components

[35] Digital Infrastructure Authority | Tier Certification & Training - Uptime Institute

Tier III	Concurrently maintainable	99.982%	N+1 fault tolerant
Tier IV	Fault-tolerant	99.995%	2N+1 fully fault tolerant

Typology Characterization

Furthermore, this typology is broadly characterized by the building usage, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders and their needs.

Table 20 Data centre typology

Characteristics	
Buildings Usage	Hosting, data storage, cloud services.
IT Applications and Computing Load	
Applications	Cloud services, data processing, web hosting
Computing Load	Extremely high, due to large-scale data processing and storage.
Equipment in Server Rooms	
Type	High-density servers, large-scale storage systems, advanced cooling solutions.
Electricity Usage	Extremely high.
Waste Heat Recovery Potential	
Potential	Extremely high, with potential for significant energy recovery.
Relevant Stakeholders	
Stakeholders	Data centre operators, cloud service providers, customers, regulatory bodies.

4.1.8. Considerations Across Different Typologies

This section discusses some aspects and considerations that are relevant for various typologies of buildings in the tertiary sector.

Building Integration: How server rooms integrate with the building's overall HVAC and power systems can affect efficiency. Dedicated systems usually offer better optimization but require more upfront investment.

Local Climate: Geographic location and local climate conditions significantly influence cooling system design and energy use. Buildings in hotter regions or with variable weather patterns may see higher cooling energy usage.

Energy Efficiency Initiatives: The presence of green building certifications or adherence to energy efficiency standards (like LEED or ENERGY STAR) can also affect how electricity is distributed among systems in server rooms across different buildings.

In summary, while the basic components of server rooms—IT equipment, cooling, and power infrastructure—are consistent, the scale and specific energy use distribution can vary widely based on the building type and its requirements. Understanding these nuances is crucial for designing and managing energy-efficient IT environments tailored to the specific needs of the building typology.

4.2. Current Server Room Landscape: Survey Results and Analysis

This section analyses published literature and data centres and server rooms surveys to obtain the overview of the current small scale server room landscape, existing equipment and processes, common efficiency issues related to power and cooling of server rooms and operation of IT equipment, stakeholder involved and their needs and challenges.

4.2.1. Lawrence Berkeley National Laboratory Survey -2014 [4]

The survey conducted by LBNL [4] analysed thirty (30) small server spaces across a range of institutions including educational institutions, hospitals, public offices and small businesses. The main goal of the study and survey was to investigate the type of IT and other equipment (such as power and cooling systems) involved and how it was deployed, powered, and cooled in small server rooms. Table 21 summarizes the final list of organizations and the corresponding number of server rooms included in the survey.

Table 21 Server Room Survey List [4]

Organization Type	Rooms/Closets Surveyed
Academic & Research	6
Academic & Research	10
Healthcare	1
High-Tech	6
High-Tech	1
Local Government	3
Local Government	2
Small Companies	1

Figure 11 shows the distribution of the floor area of the thirty server rooms surveyed and analysed in the LBNL study. Among the thirty surveyed IT server rooms in the study [4], most measured 500 square feet or less (or 46.45 square meters), with several over 1,000 square feet (or 92.90 square meters).

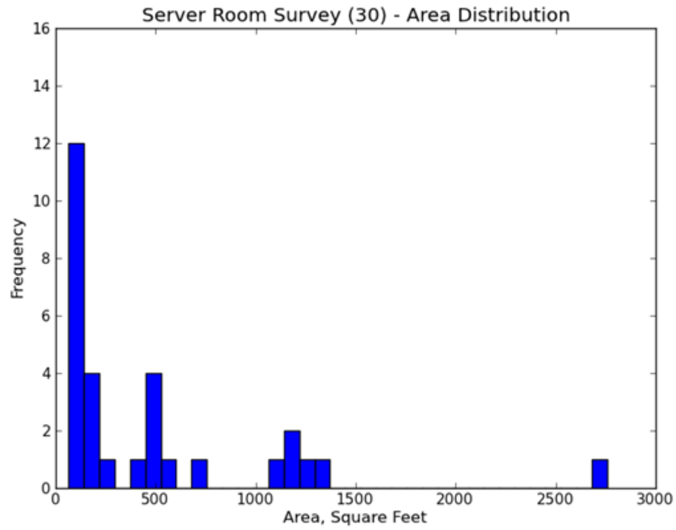


Figure 11 Server Room Survey - Area Distribution Histogram

The surveyed IT server rooms demonstrated a significant variation in the number and type of servers and other IT equipment, unique layout and rack arrangements, and power and cooling systems. Most server rooms and spaces and closets had either dedicated cooling or a mix of dedicated cooling and building specific cooling, although a few spaces depended solely on building specific cooling systems for cooling the server rooms. Dedicated cooling systems and technologies found in the server rooms varied from wall mounted AC units and fan/cooling coils in smaller server rooms and spaces, to computer room air conditioners/ computer room air handlers (CRACs or CRAHs) and roof mounted AC units in larger server rooms and spaces. Some CRAC/CRAH units found in the server rooms and spaces used chilled water loops if the facility had a central chilled water plant. The surveyed IT server rooms and spaces also relied on various backup power systems and configurations - some servers rooms and spaces were connected to a centralized UPS backed by battery storage systems, while others connected their servers to rack-level UPS units. Many server rooms were connected to the building backup generators. Other servers had no backup power at all. Most of the server rooms and spaces surveyed in the study were powered from traditional power grid.

Common efficiency Issues

Earlier section discussed the existing equipment and processes found in the server rooms and spaces, this section presents the most common efficiency issues (related to both IT equipment, and power and cooling systems) identified across the rooms and institutions surveyed in the LBNL study [4]:

First and foremost, most of the small server rooms and spaces surveyed in the LBNL study were not initially designed to be served as server room spaces. Therefore, server rooms and equipment layout and configurations and cooling systems and schemes were suboptimal and not fit for energy efficiency and future upgrades.

Secondly, most of the small server rooms and spaces surveyed in the LBNL study confirms that often server operators/owners did not pay utility bills so were not motivated to implement energy efficiency upgrades and improvements. This is because small server rooms are often not sub metered, and utility bills are often paid for by the larger organization or the primary buildings operator, or by the landlord in the case of full-service leases, and server owners are provided little to no feedback on energy consumptions and costs, which provides no incentive and motivation to implement energy efficiency upgrades and improvements in the server rooms and spaces.

Thirdly, most of the small server rooms and spaces surveyed in the LBNL study shows that often business operations took priority over energy efficiency. It is because servers in small server rooms often provide internal business or operational functions such as administration and research services in educational institutions, while high-tech web-based companies such as Amazon EC2[36] and Rackspace[37] operate data centres whose profits depend on operating servers efficiently.

IT specific issues

This section discusses the IT related issues and observations found in the server rooms and spaces surveyed in the LBNL study.

- Due to limited budgets and resources, and lack of effective policy for regular IT equipment monitoring, equipment in small server rooms and spaces was frequently older and outdated, occupied a larger space and footprint, and consumed more energy.
- Additionally, the IT equipment found in the server rooms and spaces surveyed in the LBNL study often had low utilization rate; server consolidation and virtualization could be used for improving energy efficiency and overall sustainability.
- It is also widely reported that larger and centralized data centres often achieve much higher energy efficiency than small server rooms, and small server room owners may save on labour and energy costs by deciding to move servers from local to centralized data centres. However, a major barrier that the study identified that made server owners to keep their servers physically close to them, and not move servers from local to centralized data centres because they had little incentive to move servers because owner and operator were not responsible for paying the energy costs (principal-agent problem).

Cooling specific issues

This section discusses the cooling systems related issues and observations found in the server rooms and spaces surveyed in the LBNL study.

- The LBNL study found that most of the small server rooms often run at low room temperature setpoints, resulting in overcooling with unnecessarily high energy consumption and costs. The LBNL study discussed several underlying reasons for running server rooms at low room temperature setpoints:
    - The study found that there was a common misconception that server spaces should be kept at temperatures of around 22°C - and that keeping server spaces colder is better and efficient;
    - Another reason study found that server spaces operators were concerned that higher temperatures may not provide adequate buffer in the event cooling equipment fails in these relatively small server rooms and spaces;

[36] Amazon EC2 - Cloud Compute Capacity - AWS
[37] Cloud Solutions from Rackspace Technology, the Industry Leader

- The study found that another reason was that the owner and operator were not responsible for paying the energy costs, and over-cooling was therefore not a primary concern (principal-agent problem), and
- Finally, in some cases the cooled air was sometimes poorly directed in small server spaces and resulted in local hot spots; to compensate, operators relied on extra cooling.

One efficiency feature found in large data centres is the separation of hot and cold air to minimize cooling requirements. This was often not the case in the observed small server rooms, in which the room size and configurations were not set up for hot/cold air separation, creating suboptimal cooling.

4.2.2. Natural Resources Defence Council Survey - 2012 [8]

Another interesting study and survey related to server rooms and spaces was conducted by the Natural Resources Defence Council (NRDC)[38]. NRDC is a national nonprofit environmental organization from the U.S. working to ensure the rights of all people to clean air, clean water, and healthy communities. Due to rapid growth of data centres and server rooms operations and their associated energy and water consumption, the NRDC conducted a study and survey [8] comprising a set of questions for IT managers managing small IT server rooms to understand opportunities and barriers to energy efficiency within the small server room market. These questions addressed various issues related to their current fleet of server rooms and landscape, existing equipment and processes, server consolidation and virtualization practices, cloud computing, obstacles to implementing efficiency improvements and upgrades, energy consumption and costs, and billing. The organizations that were part of the study and interviewed for the survey ranged from 3 to 750 employees in the local office where the server room and space was found, along with some big organizations with thousands of employees worldwide. The range in number of computer servers also varied, from one in a small church organization to fifty-five in a department of a state university.

Some organizations housed all their servers off-site, and thirteen percent of all respondents owned zero servers, running their whole operation and IT workload in the cloud by leasing server compute capabilities from vendors like Amazon EC2[39] and Rackspace[40].

NRDC Survey Results

One of the main insights from the NRDC study and survey is that small and medium-sized businesses run servers in a variety of ownership configurations that may make efficiency and sustainability upgrades difficult. For example,

- Thirteen percent of respondents do not own servers and operate exclusively using cloud computing services such as Amazon EC2[41] and Rackspace[42].
- Twenty percent of respondents use at least one server in the cloud.
- Twenty-three percent of respondents either rent servers at an off-site location or host their own servers at a co-location.

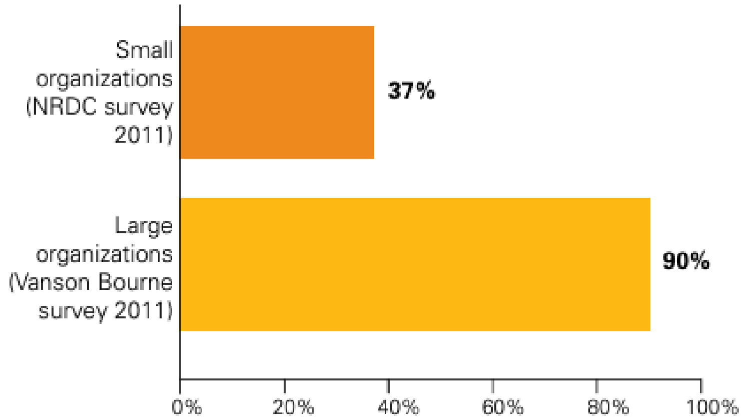
---

[38] Natural Resources Defense Council | NRDC
[39] Amazon EC2 - Cloud Compute Capacity - AWS
[40] Cloud Solutions from Rackspace Technology, the Industry Leader
[41] Amazon EC2 - Cloud Compute Capacity - AWS
[42] Cloud Solutions from Rackspace Technology, the Industry Leader

While companies using cloud computing services are likely to be using very efficient servers and other equipment—because providers such as Amazon EC2[43] and Rackspace[44] have strong motivation and financial incentives to make their large server fleets and other equipment as efficient as possible—on the contrary, hosting a server at an off-site location may not be as efficient due to a classic misalignment of incentives (principal-agent problem). If the company decides which hardware to lease or buy, but the host pays the electricity bills at the off-site location, the server operator does not have a financial incentive to optimize the energy efficiency of its servers. This split-incentive situation is like the owner-tenant problem so common in commercial buildings.

Another interesting feedback and insights are related to the indicators of virtualization adoption by smaller businesses lag larger ones. A 2011 VansonBourne[45] study and survey of large companies' server consolidation and virtualization practices shows that most companies have tried or implemented server consolidation and virtualization practices and plan to adopt more in the future, but still have a long way to go before achieving deep and sustainable transitions to a mostly virtual server fleet (

). On the contrary to VansonBourne[46] survey, NRDC survey's results demonstrated starkly different results, especially in the percentage of companies and organisations that have implemented virtualization and the percentage that plan to adopt or promote virtualization in the future. Whereas ninety percent of large companies have virtualized at least one server in their fleet, only thirty seven percent of small companies have done so. This illustrates that there is still a lot of education and marketing to be done in this sector.



[43] Amazon EC2 - Cloud Compute Capacity - AWS
[44] Cloud Solutions from Rackspace Technology, the Industry Leader
[45] Vanson Bourne
[46] Vanson Bourne

Figure 12 Use of virtualization - small vs Large Organizations

It was also found in the NRDC study and survey that small companies have not adopted server consolidation and virtualization practices because of misaligned incentives and lack of information and awareness.

Table 22 Server room survey insights

Percent of companies that do not pay their utility bill based on kWh (e.g. full-service leases which include a fixed fee for utilities).	**54%**
Percent of companies whose IT managers do not have regular access to the utility bill or building-wide energy consumption data.	**58%**
Percent of companies that do not have ready access to server electrical consumption data.	**93%**

Earlier responses from the survey show that barely half of small server room respondents pay for their energy consumption. It is simple that if an organization or company is on an all-you can eat energy plan, it loses the motivation and incentives to adopt more efficient technologies and practices that reduce energy consumption. According to the survey, sixty percent of the people that make server buying decisions do not have access to their company's energy bill. This is important, as server rooms can account for anywhere from thirty to seventy percent of an organization's electricity consumption (particularly in office-based organizations). Because over ninety percent of organizations and companies do not have a way of monitoring server room electrical use, this opportunity is being overlooked as a strategic way to seriously reduce overhead costs and environmental impact.

The responses also suggest that companies are more aware of software costs than energy costs. None of the organizations and companies surveyed in the NRDC study listed energy savings as a main driver for moving to the cloud instead listed performance and cost of software as their main drivers for server consolidation and virtualization or using cloud computing services such as Amazon EC2[47] and Rackspace[48].

NRDC study responses also demonstrates that some companies are concerned about data privacy and security particularly healthcare and educational organizations.

NRDC study finds corporate inertia as one of the reasons for holding back energy efficiency upgrades. According to the study responses, a common obstacle to adopting new energy-efficiency technologies and practices was simply corporate inertia and devoting attention to other business priorities over energy savings.

Finally, unaligned incentives and lack of information and expertise were also found common issues by the NRDC study preventing companies from taking advantage of server room energy efficiency technologies and best practices.

[47] Amazon EC2 - Cloud Compute Capacity - AWS
[48] Cloud Solutions from Rackspace Technology, the Industry Leader

4.2.3. Survey results and insights for HYCOOL-IT

This section summarizes the main results and insights from the LBNL, NRDC, and IDC studies and surveys that could be used by the HYCOOL-IT project.

First of all, according to the IDC study [7], although there may be considerable number of large data centres, they are vastly outnumbered by the smaller server rooms and spaces. Therefore, the energy efficiency of small server rooms and spaces is equally important as that of larger data centres.

Secondly, authors in the LBNL study concluded that [4] many of common inefficiencies noted in the current small scale server rooms mainly resulted from organizational rather than technical issues. Because of the inherent space and resource limitations, server rooms and equipment layout and configurations and cooling systems and schemes were often suboptimal and not fit for energy efficiency and future upgrades.

Thirdly, the NRDC concludes in their study and survey [8] that the technologies and practices to significantly improve energy efficiency in small server rooms and spaces—such as virtualization, power management, and cloud computing—are very cost-effective, and are already broadly deployed in large scale data centres. These technologies provide many business benefits other than energy savings. In small server rooms many of the same benefits are available, but the opportunity is often missed because of a lack of information, expertise, time, or incentives.

To address common inefficiencies found in earlier surveys and support the design, installation, and maintenance of server rooms, HYCOOL-IT aims to leverage openBIM, digitalization and ICT approaches and technologies based on Digital Twins, SIMBotS and advanced simulation practices, and innovative Rack-integrated adsorption chillers.

Finally, it is evident from the earlier sections that this report has used some market data and surveys of server rooms from the U.S. The primary reason for using data from the U.S. market is the lack of comprehensive and easily available data on conditions of small scale server rooms available from the European market. Despite geographical differences, the U.S. and European markets share significant similarities in terms of technology, infrastructure, operational practices, and industry standards, making U.S. data relevant and applicable to the European context.

4.3. Processes Improvements and requirements

Building on the surveys´ results and analysis, this section discusses the idea of utilizing waste heat recovery and BDTs approaches as advanced strategies and process improvements to enhance thermal management and energy optimization in high energy demand IT server rooms within tertiary buildings as proposed by the HYCOOL-IT project.

In this regard, this section describes waste heat recovery and BDT based processes, understanding the current state, and setting up the necessary technological and operational requirements for integrating waste heat recovery and digital twin technologies in the IT server rooms to improve their thermal management and energy optimisation.

4.3.1. BIM based Digital Twins for tertiary buildings server rooms.

A BIM-based building digital twin is a highly detailed digital representation of an asset that integrates BIM technology. It represents the 3D geometry of the building plus metadata. The metadata could include real time data from sensors and IoT devices installed in the building that watch various

parameters (humidity, temperature, occupancy, etc.). Hence the digital twins can simulate the behaviour and performance of the building. Moreover, utilising data analytics and machine learning helps professionals in predicting outcomes and in optimising building operations.
The goal of the HYCOOL-IT project is to develop BIM-based building digital twins of server rooms that encompass the whole server room's infrastructure to support the lifecycle management and optimisation of IT server rooms. The figure below shows the HYCOOL-IT digital twin-based approach.

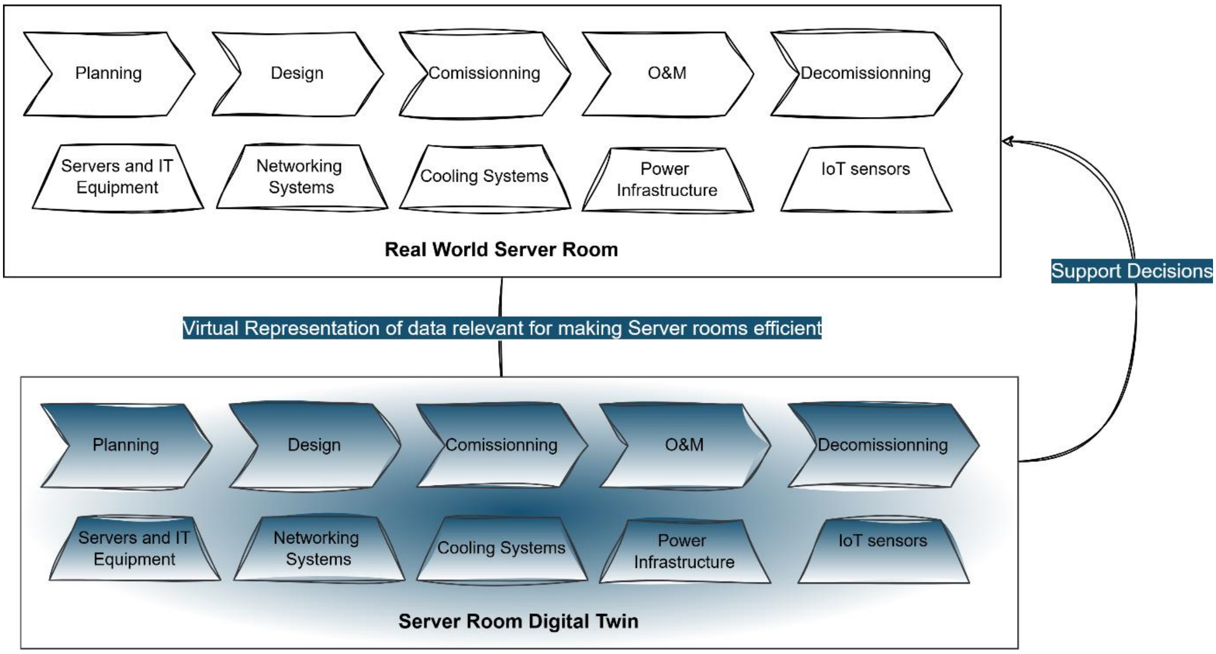


Figure 13 HYCOOL-IT Digital Twin based approach

SIMBots representing various components of server rooms (such as IT equipment, cooling units, and other equipment) will be developed and utilized as "SIMBots as Building Digital Twin Libraries," to model different aspects and scenarios, which are pivotal for ensuring the optimal planning, design and operation of internal facilities and limiting energy consumption in the server rooms. In this way a single overarching Digital Twin for the IT server room will be developed, which includes detailed simulations and models of various subsystems and components provided by SIMBots.
Below BIM and BIM-based building digital twin concepts are introduced, and general overview of their development process and requirements is provided.

Building information modelling (BIM)

BIM definition

BIM or Building Information Modelling is an intelligent 3D model-based tool that provides a digital representation of the physical and functional characteristics of a facility. It enables the AEC professionals to efficiently plan, design, construct and manage construction projects throughout their life cycle. BIM is a shared knowledge resource for information among professionals because not only includes detailed geometry and data about building elements but it integrates many various types of data including spatial data (location, coordinates), material properties (types of materials and physical properties like thermal resistance and conductivity), performance data (energy performance metrics, life cycle assessment data and carbon footprint), cost data (material take offs, cost estimation), construction data (timelines and project schedule), MEP data (maintenance schedules, warranty and service life information), operational data (BMS integration, occupancy data, FM information) and many more. Incorporating these data types, a BIM model could provide a comprehensive and integrated decision support tools which enhance decision making and could improve the overall project efficiency and effectiveness.

BIM development process (commonly used approaches and tools)

The development of a BIM follows a structured process and uses various tools at different stages.

First the main goals of the project must be established. Hence, a list of project goals, scope and feasibility must be conducted. This planning phase uses basic 3D modelling for initial design concepts. So, tools like Sketch Up or Autodesk Revit could be used.

To develop the design tools like Autodesk Revit, ArchiCAD or Vectorworks could be used to model the detailed 3D design and to perform the preliminary analysis of systems.

To develop construction documentation and create detailed construction documents and specifications tools like Autodesk revit and Tekla Structures are needed.

To coordinate the various disciplines info (structural plus architectural plus MEP) and to plan and coordinate the construction activities. Hence, to perform clash detection and 4D simulation time tools like Naviswork, Synchro and Vico office are needed.

To implement the construction plan on-site and perform quality control there are tools like Trimble Connect and BIM 360.

Finally, to manage and maintain the assets, to conduct maintenance and facility operations and assets management, common data environment (CDE) platforms like Archibis, BIMCollab and Maximo could be utilised. CDE platform is a centralised repository for all project information that enhances the collaboration and data sharing among professionals.

Table 23 Tools and Approaches for BIM

Tools and Approaches	
Autodesk Revit:	Comprehensive BIM software for architectural design, MEP, and structural engineering. Supports detailed 3D modelling, construction documentation, and collaboration.
ArchiCAD:	BIM software focused on architectural design.
Vectorworks:	Suitable for architectural and landscape design.
Navisworks	Tool for project review, clash detection, and construction simulation. Supports integration of models from different disciplines.
Tekla Structures	BIM software for structural engineering and construction. Focuses on detailed modelling of steel and concrete structures.
SketchUp	3D modelling software popular for conceptual design and early-stage modelling.
BIM 360	Cloud-based platform for construction management. Facilitates collaboration, document management, and real-time project updates.
Synchro	Software for 4D BIM, linking 3D models with project schedules. Helps in construction planning and simulation.
Procore	Construction management platform. Integrates with BIM models for project management, document control, and collaboration.

BIM development requirements

After the definition of the overall project goals and outcome, a comprehensive document outlining how BIM will be implemented in the project has to be conducted.

This document will outline the information exchange protocols, the list of all professionals involved (roles and responsibilities), workflows, specific modelling standards (e.g. Level of Development LOD or Level of Information LOI, standard content libraries), the technology infrastructure (hardware and software), the communication procedure (frequency of meetings and attendees required), the preferred format for the information exchange and the collaboration procedure (file permissions, folder structure, naming conventions etc.).

BIM-based Building digital twin

BIM-based building digital twin definition

A BIM based digital twin plays a crucial role in the entire lifecycle of a building, from design and construction to operation and maintenance, offering significant benefits in terms of efficiency, performance, and sustainability. A digital twin indeed can be integrated with various technologies such as IoT (Internet of Things) able to connect the building with various building systems and devices enabling real time data collection. AI and Machine learning analyse data to predict trends and detect operational anomalies. The Cloud Computing facilitates the building data storage, processing and sharing across different devices. Augmented reality (AR) provides immersive experiences for maintenance training and facility management.

BIM-based building digital twin development process (commonly used approaches and tools)

The development of a BIM-based building digital twin development process involves several steps, integrating different technologies to create the dynamic, real time digital representation of the building from the static (geometrical) model. First, the objectives of the digital twin must be decided. Hence, all relevant stakeholders must develop their project requirements and expectations that could be for instance improving the operational efficiency of the building or perform the predictive maintenance and corrective maintenance in case of detecting any anomaly. Then, a BIM model must be created using the authoring software like Autodesk Revit, ArchiCAD or Bentley System. This includes creating a detailed 3d geometry of all the needed components and embedding the metadata. In the meantime, sensors and IoT devices must be installed in the building to collect real time data. At this point the real time data must be embedded in the BIM model. This involves linking the sensors to specific BIM components (assets) and setting up a database to store and manage all the data generated by the BIM digital twin. Next, simulation models to predict the performance of building systems must be developed. This includes energy modelling, HVAC performance simulations etc. And the machine learning methodology must be implemented to analyse the data, detect system anomalies and provide predictive insight. Finally, tests of the BIM digital twin are needed to ensure the accuracy and reliability.

Table 24 Tools and Approaches for BIM based digital twin.

Tools and Approaches	
Azure Digital Twins	Enables the creation of comprehensive digital models of physical environments. It integrates IoT data to build dynamic digital twins.
AWS IoT Core	Web Services' platform for connecting IoT devices and integrating their data into applications, including digital twins.

Siemens MindSphere	IoT platform that can connect and integrate data from various sensors and devices to create a digital twin.
EnergyPlus	An open-source energy simulation engine that can be used to model building energy consumption and performance.
Ansys	Provides simulation software for structural, thermal, and fluid dynamics analysis, which can be integrated into the digital twin for advanced simulations.
Dynamo	A visual programming tool to perform complex design automation and parametric modelling.
Unity Reflect	Integrates BIM tools to create immersive VR and AR experiences, enhancing the visualization of the digital twin.
Autodesk Forge	A platform for building cloud-based applications that visualize and analyse 3D models.
Enscape	A real-time rendering and VR plugin for BIM software, useful for creating realistic visualizations of the digital twin.
Tableau	A data visualization tool that can be used to analyse and present data from the digital twin.
Power BI	A business analytics service that can visualize and share insights from the digital twin data.
Python/R	Programming languages that are widely used for data analysis and machine learning. Libraries like Pandas, Scikit-learn, and TensorFlow can process and analyse data from the digital twin.
BIMcollab	A platform for issue management and model validation that integrates with various BIM tools via APIs.
Node-RED	A flow-based development tool for visual programming, suitable for integrating IoT devices and creating workflows for the digital twin.

BIM-based building digital twin development requirements

It is important to ensure that the digital twin can integrate with existing building management systems (BMS), enterprise resource planning (ERP) systems, and other relevant platforms and develop user interfaces that allow stakeholders to interact with the digital twin. This could be through dashboards, mobile apps, or web portals.

Hence, high performance computers are needed for running BIM software, simulations, and real-time data processing. A reliable and fast internet connection to ensure seamless data transfer between devices and platforms is needed, together with cloud-based storage solutions for hosting BIM models and data from sensors/IoT devices.

Policies and procedures for data collection, storage and security must be outlined as well as the preferred format for the data exchange and the collaboration procedure.

4.3.2. Waste Heat process and requirements.

According to [14], [15] data centres and IT server rooms consume significant amounts of energy and responsible for emitting carbon emissions in building or even global energy sectors (around 3% of global energy consumption), which are also significant waste heat producers (e.g., waste heat from year-round uninterrupted operation of IT equipment and cooling system). The heat generated in server rooms usually occurs from the operations of electronic equipment, such as servers, storage devices, and networking equipment. This heat is typically expelled into the room air, raising the ambient temperature. The typical temperature of waste heat from server rooms is generally around 20°C to 40°C, which is considered low-grade because it is not high enough for direct use in traditional heating systems that often require higher temperatures[14].

Waste heat from data centres and server rooms can provide low temperature heat to buildings for heating purposes, a practice investigated for large data centres but not yet mature [15]. The challenge is to combine the waste heat characteristics (temperature, availability) from IT server rooms, which depend on the specific server cooling technology (e.g., air cooling, liquid cooling) with the characteristics of the heating demand in buildings (e.g., space heating, domestic hot water), which depend on a variety of building related factors (e.g., climate, type of building, insulation, heating system).

When the heat output in a server room or datacentre is sufficient enough, it can be captured and repurposed. Several countries in Europe notably Scandinavian countries with hyperscale-type datacentre facilities have already adopted this practice and plan to utilise it further in the future as datacentre facilities operations scale. The heat can be captured in hot-aisles and via the cooling system and technologies deployed and transferred by heat pumps into a higher temperature system. Typical uses include district heating schemes.

Figure 14 presents the waste heat recovery process in data centres with CRACs/CRAHs.

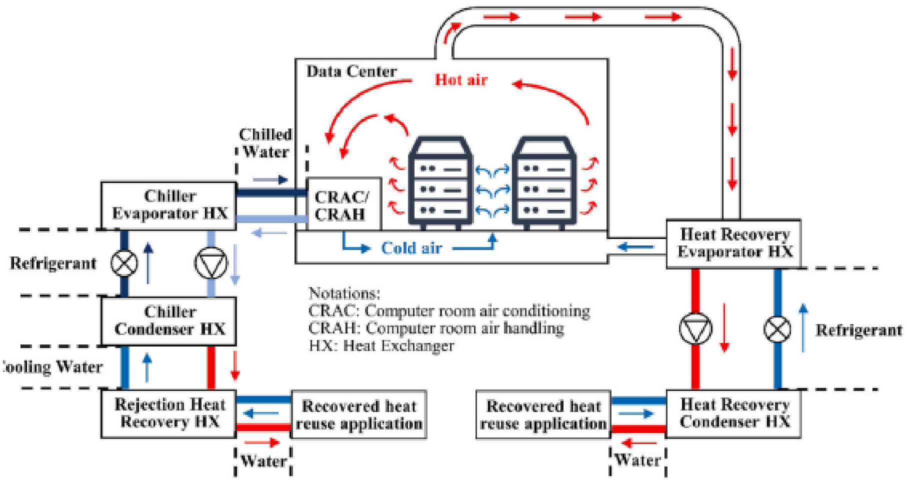


Figure 14 Waste heat recovery in DCs with CRACs/CRAHs [14]

To exploit this low-grade heat effectively, technologies such as heat pumps or heat exchangers can be used to raise the temperature of captured heat to a more useful level of temperature, or it can be used directly in applications that require lower level temperatures, such as pre-heating of domestic hot water or for use in underfloor heating systems. The integration of such heat recovery solutions can significantly enhance the overall energy efficiency of buildings, contributing positively to environmental sustainability efforts by reducing the heating load on other systems and lowering the overall energy consumption.

Figure 15 and Figure 16 illustrates the integration of such heat recovery solutions into the district heating systems.

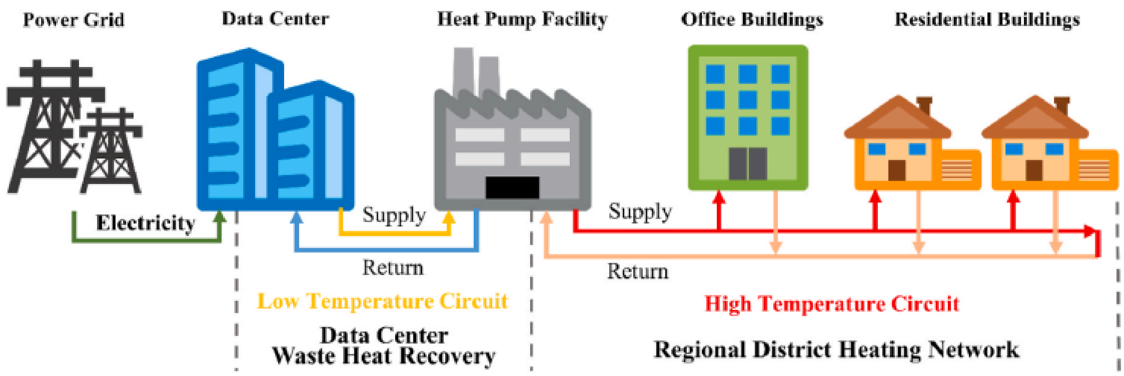


Figure 15 Waste heat recovery (low-temperature) in DCs to DH systems (high-temperature) [14]

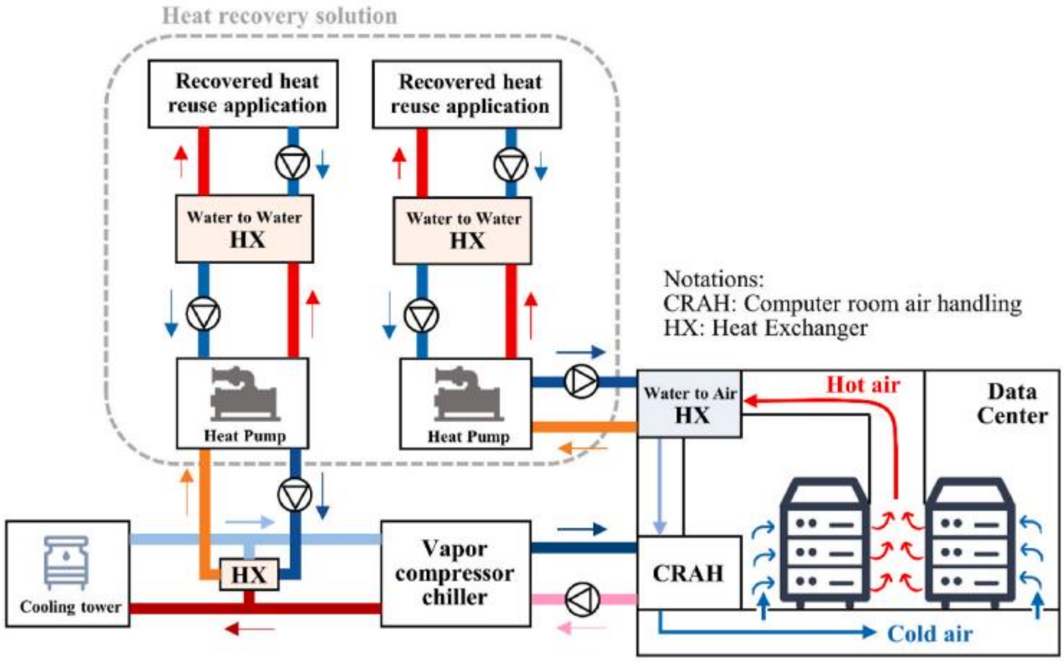


Figure 16 Schematic of combined DC with CRAHs and DH networks system with HPs [14]

4.4. Collection of user stories - approach

This section extracts the user stories to find the needs and challenges, expectations, and potential benefits for various users and stakeholders focused on the lifecycle management and optimisation of IT server rooms located in tertiary sector buildings. User stories will be the key starting points for the formulation of user requirements.

By developing these user stories and extracting requirements from them, the HYCOOL-IT Building Digital Twin based Methodology can be extended to comprehensively cover the entire lifecycle of IT server rooms, enhancing efficiency, sustainability, and performance across all phases. Extending the Building Digital Twin Methodology through user stories involves creating detailed scenarios that outline how different stakeholders interact with the digital twin to achieve specific goals. Table 25 outlines the four-step process for collecting, describing and prioritising user stories aligned with the project goals.

Table 25 User stories collection approach

Steps	Approaches
Step 1: Better understanding of IT server rooms found in different typologies of tertiary buildings.	Literature Review and Analysis.
Step 2: Identification of User Groups and Stakeholders.	Analysis based on Step 1.
Step 3: Identification and listing of user stories.	Literature Review.
Step 4: Preparing and Prioritising user stories.	Literature Review and Analysis.

Step1: For better understanding of IT server rooms located in different typologies of tertiary buildings, published literature and different surveys related to small server rooms were analysed which helped understand the current small scale server room Landscape, equipment and processes, common efficiency issues, stakeholder involved and their needs and challenges.

Step2: Identification of Stakeholders - Using the analysis conducted in the step 1, relevant stakeholders involved in the lifecycle of an IT server room, especially focusing on areas like design, construction, and operations and maintenance of IT server rooms were identified.

Table 26 Key Stakeholders involved in the lifecycle of an IT server room.

Stakeholder	Roles and responsibilities
Architect	Responsible for planning and designing the physical structure and layout of the server room.
MEP Engineers	Responsible for designing and implementing mechanical, electrical, and plumbing systems of the server rooms.
Commissioning Agent	Responsible for ensuring that all systems are installed and function as intended.
IT Manager	Manages the IT-related equipment and resources (such as servers, storage and network switches) within the server room.
Facility Manager	Responsible for managing the infrastructure components (such as power distribution units and computer room air conditioners) and environmental controls in the server rooms.
Energy Managers	Focus specifically on optimizing energy usage and implementing energy-efficient practices within the building, including server rooms.
Maintenance Engineer	Responsible for performing regular maintenance on HVAC systems and IT equipment, ensuring operational continuity.
Network Administrator	Responsible for managing network resources, ensuring efficient data flow and connectivity within server room and outside world, and minimizing downtime.
Building Owner	Own and manage the building where the server room is located.
Security Officer	Ensuring the security of data and infrastructure.

Step3: Results of step 1 and step 2 were used to identify and list user stories that address the common efficiency issues and needs of key stakeholders identified in the section related to Current Server Room Landscape: Survey Results and Analysis. The first list of user stories include:

1) Large data integration from sensors and systems with the platform.
2) BIM-based building digital twins of server rooms.
3) Plan with growth profile and requirements in mind.
4) Analyse unique design options for energy efficiency in thermal management.
5) Optimize server rack layout for proper airflow and ventilation.

6) Model and simulate server room components (IT equipment, cooling units, etc.).
7) Optimize design and size of cooling systems and other equipment.
8) Design redundant power and cooling equipment.
9) Develop adaptive thermal profiles for different server room areas for targeted cooling.
10) Real-time monitoring, visualization, and continuous system analysis.
11) Develop and validate HVAC control algorithms for energy efficiency.
12) Utilize AI-powered energy management systems for dynamic optimization of cooling and energy usage.
13) Predictive maintenance.
14) Implement hybrid cooling solutions, including waste heat reuse strategies.
15) Utilize BMS data for identifying waste heat utilization potentials.
16) Implement server virtualization and consolidation.

Step4: This step focuses on preparing and prioritising user stories. Given that IT server rooms are still relatively new when it comes to design and O&M, therefore, we have selected eight user stories and prioritised the user stories from the design and O&M phases for more detailed descriptions and requirement extraction.

Table 27 User stories descriptions

User Story 1: Large data integration from sensors and systems with the HYCOOL-IT platform.
Server rooms and buildings where they are located have number of sensors and monitoring and control systems. Such as BMS systems controlling and logging heating, ventilation, domestic hot water, lighting and cooling of buildings and server rooms. Also, in cases of the large server rooms they can have dedicated server rooms infrastructure management tools to monitor, measure, manage and/or control server room resources and energy consumption of both IT-related equipment (such as servers, storage and network switches) and facilities infrastructure components (such as power distribution units and computer room air conditioners). They are server room-specific (they are designed for server rooms use), rather than general building management system tools, and are used to optimize server rooms power, cooling and physical space. Therefore, to do anything meaningful with the server rooms, integration of these systems and sensors into the HYCOOL-IT platform is required.
User Story 2: BIM-based building digital twins of server rooms.
The use of digital twin concept not so commonly reported in the published literature and surveys analysed. Therefore, for this user story, the end-users would like to: Develop a BIM-based Digital Twin of server rooms as simulation tool for different what-if scenarios, and optimization strategies. Develop a 3D model of the server rooms. Implement end-to-end management from planning the design and selecting the equipment to testing and commissioning, including operation and maintenance of managed assets.
User Story 3: Analyse unique design options for energy efficiency in thermal management.
As discussed in one of the surveys we analysed that most of the small server rooms were not initially designed to run as server spaces. As a result, room and equipment configurations and cooling schemes were suboptimal regarding energy efficiency and future upgrades. This is also because IT server rooms are still relatively new when it comes to design skills and approaches. Therefore, they could benefit from improved design tools and approaches. Different design options can be analysed to improve energy efficiency in the thermal management of sever rooms (hot/cold aisle containment, server virtualization, efficient cooling equipment, variable speed fans, temperature monitoring) including exhaust heat reutilization for building

space heating and/or domestic hot water preparation, either directly in the building distribution network or through micro (block -level), new generation thermal grids.
User Story 4: Model and simulate server room components (IT equipment, cooling units, etc.).
For this user story, the end-users would like to: Use SIMBots like solution to model and virtually represent various components of server rooms (such as IT equipment, cooling units, other equipment) to model and simulate various aspects and scenarios, which are pivotal for ensuring the optimal planning, design and operation of server room resources. Continuous simulation of building and server room components and resources including energy consumption to find optimization opportunities.
User Story 5: Real-time monitoring, visualization, and continuous system analysis.
For this user story, the end-users would like to: Real-time monitor temperature, humidity and other environmental control variables, and power usage in a server room. Install temperature and humidity sensors and use smart meters for energy monitoring. Intuitive dashboard and visualization tool to display real-time data, simulation results, including historical data analysis (users: facility manager and occupants). Alarm notifications (email and SMS) if there are temperature or other environmental factors that could lead to system downtime and loss of service.
User Story 6: Develop and validate HVAC control algorithms for energy efficiency.
For this user story, the end-users would like to: Develop advanced algorithm to control HVAC and other equipment by following the input coming from measurements in server rooms and BDT as well as simulation. Algorithms should dynamically adjust cooling mechanisms based on real-time data, such as workload and external temperature, ensuring optimal cooling at all times. Evaluate and validate control systems and algorithms in a simulated environment before deploying them in the real world.
User Story 7: Predictive maintenance.
For this user story, the end-users would like to: Evaluate predictive analytics tools to anticipate system failures or inefficiencies, allowing pre-emptive adjustments to maintenance schedules and operations.
User Story 8: Waste heat reuse strategies
For this user story, the end-users would like to: Analyse copious amounts of highly detailed BMS data available to identify potentials for utilizing waste heat generated in data centres. Implement waste heat reuse strategies.
User Story 9: Preventive and corrective maintenance
For this user story, the end-users would like to: Preventive maintenance – includes regular and periodic (time-based) schedules. Corrective maintenance – occurs when an issue is noticed.

5. Requirements

This section extracts and defines the requirements from the user stories described in the earlier section. In the following table (Table 28), all the preliminary requirements are reported for each user story.

Table 28 User requirements extracted from user stories.

User Story	User Requirements
User Story 1: Large data integration from sensors and systems with the HYCOOL-IT platform.	Integration of probes and sensors in the HYCOOL-IT platform for server room environmental control. Integration of server rooms infrastructure management tools in the HYCOOL-IT platform. Integration of BMS in the HYCOOL-IT platform.
User Story 2: BIM-based building digital twins of server rooms.	They want to: Develop Digital twin of the server rooms. Create “what…if” interactions. Use Digital Twin as simulation tool. Use Digital Twin as visualisation and monitoring tool. 3D model of the server room can be useful.

User Story 3: Analyse unique design options for energy efficiency in thermal management.	They want to: Analyse unique design options to improve energy efficiency in the thermal management of sever rooms (hot/cold aisle containment, server virtualization, efficient cooling equipment, variable speed fans, temperature monitoring) including exhaust heat reutilization for building space heating and/or domestic hot water preparation.
User Story 4: Model and simulate server room components (IT equipment, cooling units, etc.).	They want to: Virtual representation of server room components (such as IT equipment, cooling units, other equipment) to model and simulate various aspects and scenarios. Continuous simulation of building and server room components and resources including energy consumption to identify optimization opportunities.
User Story 5: Real-time monitoring, visualization, and continuous system analysis.	They want to check: Real-time data (energy consumption, temperatures and humidity). Dashboard to display real-time data, simulation results, including historical data analysis (users: facility manager and occupants). Alarm notifications (email and SMS) if there are temperature or other environmental factors that could lead to system downtime and loss of service.
User Story 6: Develop and validate HVAC control algorithms for energy efficiency.	They want to: Dynamically adjust cooling mechanisms based on real-time data, such as workload and external temperature, ensuring optimal cooling at all times.
User Story 7: Predictive maintenance.	They want to: Anticipate system failures or inefficiencies, allowing pre-emptive adjustments to maintenance schedules and operations.
User Story 8: Waste heat reuse strategies	They want to: Understand potentials for using waste heat generated in server rooms. Implement waste heat reuse strategies.
User Story 9: preventive and corrective maintenance	They want to: Schedule periodic maintenance Data analysis providing alerts about any malfunctioning

5.1. Mapping of user requirements into HYCOOL-IT services

This section is dedicated to mapping user stories and requirements with HYCOOL-IT tools and services. It is a critical step in this methodology to ensure that the identified needs of stakeholders in terms of user stories and user requirements are matched with the specific capabilities and services that HYCOOL-IT can provide.

Table 29 Mapping of user requirements into HYCOOL-IT services

User Story	User Requirements	HYCOOL-IT tools and services	Partner Involved	WP (Task)
User Story 1: Large data integration from sensors and systems with the HYCOOL-IT platform.	Integration of probes and sensors in the HYCOOL-IT platform for server room environmental control. Integration of server rooms infrastructure management tools in the HYCOOL-IT platform. Integration of BMS in the HYCOOL-IT platform.	Building Digital Twin Environment (BDTE)	BDTA, IDP	WP2, WP3
User Story 2: BIM-based building digital twins of server rooms.	They want to: Develop Digital twin of the server rooms. Create “what…if” interactions. Use Digital Twin as simulation tool. Use Digital Twin as visualisation and monitoring tool. 3D model of the server room can be useful.	SimBOTs BIM-based Digital Twin	BDTA, IDP	WP2, WP3
User Story 3: Analyse unique design options for energy efficiency in thermal management.	Analyse unique design options to improve energy efficiency in the thermal management of sever rooms (hot/cold aisle containment, server virtualization, efficient cooling equipment, variable speed fans, temperature monitoring) including exhaust heat reutilization for building space heating and/or domestic hot water preparation.	SimBOTs BIM-based Digital Twin BIM-based Digital Twin as simulation tool	BDTA, IDP	WP2, WP3

User Story 4: Model and simulate server room components (IT equipment, cooling units, etc.).	Virtual representation of server room components (such as IT equipment, cooling units, other equipment) to model and simulate various aspects and scenarios. Continuous simulation of building and server room components and resources including energy consumption to identify optimization opportunities.	SimBOTs Generic SIMBot libraries for IT rooms Specific SIMBot of Rack-integrated adsorption chiller system libraries	BDTA	WP3
User Story 5: Real-time monitoring, visualization, and continuous system analysis.	They want to check: Real-time data (energy consumption, temperatures and humidity). Dashboard to display real-time data, simulation results, including historical data analysis (users: facility manager and occupants). Alarm notifications (email and SMS) if there are temperature or other environmental factors that could lead to system downtime and loss of service.	Simulation Model Tracking System (SMTS)	BDTA, IDP	WP2
User Story 6: Develop and validate HVAC control algorithms for energy efficiency.	They want to: Dynamically adjust cooling mechanisms based on real-time data, such as workload and external temperature, ensuring optimal cooling at all times.	SiL Predictive Control Module	IMP	WP2
User Story 7: Predictive maintenance.	They want to: Anticipate system failures or inefficiencies, allowing pre-emptive adjustments to maintenance schedules and operations.	Simulation Model Tracking System (SMTS)	BDTA, IDP	WP2
User Story 8: Waste heat reuse strategies	They want to: Understand potentials for using waste heat generated in server rooms. Implement waste heat reuse strategies.	Rack-integrated adsorption chiller	SORGE	WP4
User Story 9: preventive and corrective maintenance	They want to: Schedule periodic maintenance Data analysis providing alerts about any malfunctioning	Assets data with the characteristics and information for their	IDP, BDTA	WP2

		maintenance (stored in specific data base)		

5.2. Relevant norms, standards, frameworks and best practices

Table 30 presents a list of relevant norms and organisations for data centres and IT server rooms.

Table 30 Data centres Norms and relevant organisations

Institution Name	Specialization
Uptime Institute	Data centre standards, certification and training.
International Electrotechnical Commission (IEC)	Electrical and electronics standards for data centres.
American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)	Data centre thermal guidelines and best practices.
Telecommunications Industry Association (TIA)	Data centre Infrastructure standards and guidelines.
The Green Grid	Energy efficiency and sustainability in data centres.
Data Centre Dynamics (DCD)	Global data centres conferences and media
The Open Compute Project (OCP)	Open-source hardware for data centres
National Institute of Standards and Technology (NIST)	Cybersecurity guidelines and best practices for data centres.
Building Industry Consulting Service International (BICSI)	Information and communication technology (ICT) Infrastructure design and installation.
Information Technology Infrastructure Library (ITIL)	Best services for IT management in data centres.

Table 31 presents a list of relevant standards and frameworks for data centres and IT server rooms. Identifying and applying relevant frameworks and standards to the identified requirements will allow to form a comprehensive foundation for guiding the design, implementation, and operation of the of HYCOOL-IT Solution to best support thermally efficient ICT server rooms of tertiary buildings across their lifecycle.

Table 31 Relevant standards and frameworks

Relevant standards and frameworks	Application
ISO/IEC/IEEE 42010:2011	Framework for architecture descriptions that supports the needs of different stakeholders in the development, analysis, and sustainment of HYCOOL-IT solution.
ISO 19650 Series	Guidance for managing information throughout the lifecycle of buildings, with a strong emphasis on BIM.
ISO 29481-1:2010	For the development of Information Delivery Manuals as part of the BIM process.
ASHRAE 90.4 and Standard 90.1-2022	Both standards aim to improve energy efficiency and reduce the environmental impact of buildings and built environments.
ANSI/ASHRAE Standard 55 and ASHRAE TC 9.9	Both serve complementary but distinct roles in the building industry, with the former focusing on the operational aspects of data centres and the latter on human thermal comfort across a wide range of indoor environments.

Power Usage Effectiveness (PUE)	Industry-standard metric for measuring the energy efficiency of data centres, including specific ICT rooms within those facilities.

6. Use Cases

The requirements provided just us an outline of what HYCOOL-IT is trying to build. Use Cases are the next step in the design process. In this section we describe generic use cases that integrate the requirements into a comprehensive package that describes the interaction of the user with the system.

6.1. Description of Use Cases

Table 32 presents use case related to technical and semantic interoperability for data collection, storage and processing.

Table 32 UC_1 Technical and semantic interoperability for data collection, storage and processing

Technical and semantic interoperability for data collection, storage and processing	
ID	UC_1
Name	Technical and semantic interoperability for data collection, storage and processing.
Goals	The stakeholders want to collect historical, real time and contextual data from the probes and sensors in server rooms, including from server rooms specific infrastructure management tools and BMS and store it in a uniform and standard manner.
Actors	All the stakeholders.
Trigger events	The user wants to automatically monitor data from the telemetry, IoT/IT systems and other data sources of the IT server room and the building to understand the server rooms and building´s behaviour and help him/her in decision-making.
Preconditions	• Historical data is available and accessible in repositories or other media. Real-time data is exposed using open communication protocols. Other data of the server room and building is also available and accessible. Contextual data can be obtained for public services (e.g. weather data). The specifications of the communication mechanism in the server room and building are known and shared with technical developers.
Basic Flow (Description)	The proper adapters/drivers/connectors/gateways access to the historical and real-time data offered by the server room and building. The real-time monitored data is stored in the Timeseries data base of the data lake. Contextual information of the server room and building is stored in the data lake. Data quality mechanism is applied to the acquired data. This high-quality data is transformed into the common HYCOOL-IT data model. This data is enriched and linked with meta-data information using the knowledge graph data base. The data is pre-processed and aggregated to create data marts. The information of the data marts is exposed using BI mechanism. The user, HYCOOL-IT services and HYCOOL-IT BDTs consume data from the data lake.

Basic Flow (Postconditions)	High-quality federated and enriched data is exposed to the user and upper-level services.

Table 33 presents use case related to data cleaning and preprocessing service.

Table 33 UC_2 Data cleaning and preprocessing service

Data cleaning and preprocessing service	
ID	UC_2
Name	Data cleaning and preprocessing service.
Goals	The stakeholders need high-quality data to ensure: the development of high-quality services. decisions are made using the correct and right information.
Actors	All the stakeholders.
Trigger events	The user wants to automatically analyse the quality of the data being collected according to seven strict data quality criteria and principles, and when possible, to obtain an automatic cleansing and preprocessing of the missing and/or inaccurate data.
Preconditions	Historical data is available in the data lake. Real-time data is being automatically collected from the server rooms and buildings and stored in the data lake.
Basic Flow (Description)	Data quality mechanism is applied in the historical real-time data available in the Timeseries DB for providing indicators on data accuracy, completeness, reliability, consistency, relevance, accessibility, timeless. When possible, data cleansing and preprocessing mechanism, based on ML techniques, are applied to the dataset to complete the data gaps. Data quality mechanism is applied to the data being collected in real-time from the server room and the building, before storing it in the Timeseries DB, cleaning the data when needed for completeness. Model checking technologies and methods are applied to the equipment, server room and buildings' models. Schema checking technologies and methods are applied to the HYCOOL-IT data model knowledge graph for consistency. Any error when applying dynamic and static data quality mechanisms are notified to the user through a GUI/dashboard.
Basic Flow (Postconditions)	The user is informed about the quality of the data being managed in his/her server rooms.

Table 34 presents the use case related to BIM-based Building digital twin for monitoring and visualization.

Table 34 UC_5 Digital Twin for monitoring server room

BIM-based Building digital twin for monitoring and visualization	
ID	UC_3
Name	BIM-based Building digital twin for monitoring and visualization.
Goals	The stakeholders want to develop BIM-based Building digital twin: To represent both the 3D geometry of the server room and building plus metadata. The metadata could include real time data from sensors and IoT

	devices installed in the server room that monitor various parameters (humidity, temperature, occupancy, etc.). Leverage the BIM-based Building digital twin to simulate the behaviour and performance of the server room and building.
Actors	All the stakeholders.
Trigger events	The user wants to have an integrated view of the server room through user interfaces that allow them to interact with the BIM-based Building digital twin. This could be through dashboards, mobile apps, or web portals for real-time monitoring, visualization, and continuous system analysis.
Preconditions	3D model of the server room and building providing a digital representation of the physical and functional characteristics of a facility is available. Collecting real time data from sensors and IoT devices installed in the server room that monitor various parameters (humidity, temperature, occupancy, etc.). Integration with server room specific monitoring and management systems including existing building management systems (BMS), and other relevant platforms enabling real time data collection is completed. The data storage, processing and sharing across different devices is facilitated through cloud computing. Data analytics and machine learning is being used to help professionals in predicting outcomes and in optimising server room and building's operations. User interfaces that allow stakeholders to interact with the digital twin are developed. This could be through dashboards, mobile apps, or web portals.
Basic Flow (Description)	User login to the user interface that allow them to interact with the BIM-based Building digital twin (through dashboards, mobile apps, or web portals). User selects the Digital Twin of the desired server room. User can monitor real-time monitoring, visualization, and continuous system analysis.
Basic Flow (Postconditions)	The stakeholder is having access to user interfaces that allow them to interact with the BIM-based Building digital twin. This could be through dashboards, mobile apps, or web portals.

Table 35 presents the use case related to BIM-based Building digital twin for simulation tool – design aspects.

Table 35 UC_4 BIM-based Building digital twin for simulation tool – design aspects

BIM-based Building digital twin for simulation tool – design aspects	
ID	UC_4
Name	BIM-based Building digital twin for simulation tool – design aspects.
Goals	Simulation environment ("what…if " interaction) to evaluate the impact of unique design options to improve energy efficiency in the thermal management of sever rooms (hot/cold aisle containment, server virtualization, efficient cooling equipment, variable speed fans, temperature monitoring) including exhaust heat reutilization for building space heating and/or domestic hot water preparation.
Actors	Facility Manager.

Trigger events	The arrangement of server racks and other equipment in a server room can influence airflow quality, cooling efficiency, and overall energy requirements. The user wants to understand the impact of design changes, prior to implementing these in the server rooms at hand, invoking the building digital twin.
Preconditions	3D model of the server room and building providing a digital representation of the physical and functional characteristics of a facility is available. Collecting real time data from sensors and IoT devices installed in the server room that monitor various parameters (humidity, temperature, occupancy, etc.). Integration with server room specific monitoring and management systems including existing building management systems (BMS), and other relevant platforms enabling real time data collection is completed. The data storage, processing and sharing across different devices is facilitated through cloud computing. Data analytics and machine learning is being used to help professionals in predicting outcomes and in optimising server room and building's operations. User interfaces that allow stakeholders to interact with the digital twin are developed. This could be through dashboards, mobile apps, or web portals.
Basic Flow (Description)	User selects the Digital Twin of the server room. User sees 3D model of server room and building representing different physical and functional characteristics of a facility. User can set some design inputs (for example including hot/cold aisle and other infrastructure related configurations, such as waste heat recovery to supply space heating) and clicks the "Simulation" button. User sees the effects of the performed simulation: KPI related to sustainability like CO2 emissions, energy consumption, energy cost.
Basic Flow (Postconditions)	The user can have a clear understanding on how to fine-tune server room layout and infrastructure design to reduce energy costs without effecting environmental control of server room (or what the trade-off would be).

Table 36 presents the use case related to BIM-based Building digital twin for simulation tool – operational aspects.

Table 36 UC_5 BIM-based Building digital twin for simulation tool – operational aspects

BIM-based Building digital twin for simulation tool – operational aspects	
ID	UC_5
Name	BIM-based Building digital twin for simulation tool – operational aspects.
Goals	Simulation environment ("what…if " interaction) to evaluate the impact of operational parameter changes (e.g. setpoints of HVAC system).
Actors	Facility Manager.
Trigger events	The user wants to understand the impact of operational changes, prior to enforcing these in the server rooms at hand, invoking the building digital twin.
Preconditions	3D model of the server room and building providing a digital representation of the physical and functional characteristics of a facility is available.

	Collecting real time data from sensors and IoT devices installed in the server room that monitor various parameters (humidity, temperature, occupancy, etc.). Integration with server room specific monitoring and management systems including existing building management systems (BMS), and other relevant platforms enabling real time data collection is completed. The data storage, processing and sharing across different devices is facilitated through cloud computing. Data analytics and machine learning is being used to help professionals in predicting outcomes and in optimising server room and building's operations. User interfaces that allow stakeholders to interact with the digital twin are developed. This could be through dashboards, mobile apps, or web portals.
Basic Flow (Description)	User selects the Digital Twin of the server room. User sees real-time and historical information about the server room and building energy consumption (thermal and electric). User can set some simulation inputs (for example including scheduling of HVAC systems, set points occupancy distribution in spaces) and clicks the "Simulation" button. User sees the effects of the performed simulation: KPI related to sustainability like CO2 emissions, energy consumption, energy cost.
Basic Flow (Postconditions)	The user can have a clear understanding on how to fine-tune HVAC system operation to reduce energy costs without effecting environmental control of server room (or what the trade-off would be).

Table 37 presents the use case related to Digital Twin for monitoring and control of server room environment.

Table 37 UC_6 Digital Twin for monitoring and control of server room environment

Digital Twin for monitoring and control of server room environment	
ID	UC_6
Name	Digital Twin for monitoring and control of server room environment.
Goals	The stakeholders want to develop BIM-based Building digital twin: To maintain temperature and humidity levels in the server room.
Actors	Facility Manager and IT Manager.
Trigger events	A server room should maintain the temperature and humidity levels for optimal operations within the server room. Server rooms ideal temperatures are typically between 18-27°C with humidity levels between 40-60%[49]. The user wants to automatically maintain the optimal temperature and humidity levels in the server room.
Preconditions	3D model of the server room and building providing a digital representation of the physical and functional characteristics of a facility is available. Collecting real time data from sensors and IoT devices installed in the server room that monitor various parameters (humidity, temperature, occupancy, etc.).

[49] ASHRAE

	Integration with server room specific monitoring and management systems including existing building management systems (BMS), and other relevant platforms enabling real time data collection is completed. The data storage, processing and sharing across different devices is facilitated through cloud computing. Data analytics and machine learning is being used to help professionals in predicting outcomes and in optimising server room and building's operations. User interfaces that allow stakeholders to interact with the digital twin are developed. This could be through dashboards, mobile apps, or web portals.
Basic Flow (Description)	User can check the current temperature and humidity levels in the server room utilising data analytics and machine learning methods. Suggest and implement actions such as adjusting cooling systems to keep the desired temperature and humidity levels in case of deviations.
Basic Flow (Postconditions)	The Facility and IT Manager is aware of server rooms environmental conditions (e.g., temperature and humidity levels).

Table 38 presents the use case related to Digital Twin for optimal energy management as control system for cooling and energy systems.

Table 38 UC_7 Digital Twin for optimal energy management as control system for cooling systems

Digital Twin for optimal energy management as control system for cooling and energy systems	
ID	UC_7
Name	Digital Twin for optimal energy management as control system for cooling and energy systems.
Goals	Control system to monitor cooling and energy systems within the server room.
Actors	Facility Manager.
Trigger events	The user wants to see cooling and energy systems real time.
Preconditions	3D model of the server room and building providing a digital representation of the physical and functional characteristics of a facility is available. Collecting real time data from sensors and IoT devices installed in the server room that monitor various parameters (humidity, temperature, occupancy, etc.). Integration with server room specific monitoring and management systems including existing building management systems (BMS), and other relevant platforms enabling real time data collection is completed. The data storage, processing and sharing across different devices is facilitated through cloud computing. Data analytics and machine learning is being used to help professionals in predicting outcomes and in optimising server room and building's operations. User interfaces that allow stakeholders to interact with the digital twin are developed. This could be through dashboards, mobile apps, or web portals.
Basic Flow (Description)	User access to Digital Twin. User clicks to "cooling and energy systems" button. User sees cooling and energy systems real time data.
Basic Flow (Postconditions)	The user can see cooling and energy systems data real time to make analysis.

Table 39 presents the use case related to Digital Twin for predictive maintenance.

Table 39 UC_8 Digital Twin for predictive maintenance

Digital Twin for predictive maintenance	
ID	UC_8
Name	Digital Twin for predictive maintenance.
Goals	The stakeholders want to develop BIM-based Building digital twin: To predict system failures or inefficiencies, allowing pre-emptive adjustments to maintenance schedules and operations.
Actors	Facility Manager.
Trigger events	A server room should run 24/7/365. The user wants to automatically predict and know server room and building's anomalous situations before they occur.
Preconditions	3D model of the server room and building providing a digital representation of the physical and functional characteristics of a facility is available. Collecting real time data from sensors and IoT devices installed in the server room that monitor various parameters (humidity, temperature, occupancy, etc.). Integration with server room specific monitoring and management systems including existing building management systems (BMS), and other relevant platforms enabling real time data collection is completed. The data storage, processing and sharing across different devices is facilitated through cloud computing. Data analytics and machine learning is being used to help professionals in predicting outcomes and in optimising server room and building's operations. User interfaces that allow stakeholders to interact with the digital twin are developed. This could be through dashboards, mobile apps, or web portals.
Basic Flow (Description)	User accesses the dashboard, and an alert and notifications are shown. User clicks on the alert and notifications and details about the outcome of detection system is shown. User can add & change the status of the alert to resolved / pending / ignore.
Basic Flow (Postconditions)	The Facility Manager is aware of server room and building's anomalous situations (e.g., detection of abnormal electricity consumption behaviour of some equipment in the server room or in the building, or smart meter problem).

7. Conclusions

In this deliverable, an analysis of processes and requirements for integrating waste heat recovery and BDT-based processes in IT server rooms was performed, focusing specifically on integrating and optimizing these server rooms within the building's overall operations.

Since HYCOOL-IT aims to replicate the proposed tools and solutions in diverse types of tertiary buildings, therefore, a description of diverse types of building typologies in the tertiary sector has been provided in this report. These typologies include educational institutions, hospitals, office buildings, financial institutions, retail buildings, hotels and hospitality, and data centres. Each typology is characterized by the size of their server rooms, usage and services buildings offer, IT applications and computing load, type of equipment in their server rooms, electricity usage of their server rooms, waste heat recovery potential, relevant stakeholders.

This report also presents results and analysis of some studies and surveys highlighting the current small scale server room Landscape, existing equipment and processes, common efficiency issues, stakeholder involved and their needs and challenges.

Finally, this approach allowed us to systematically extract and define processes and requirements, including screening and description of generic use cases, to support the design and development of HYCOOL-IT innovative technologies and solutions to optimise the energy efficiency and thermal management of IT server rooms focusing specifically on integrating and optimizing these server rooms within the building's overall operations.

References

[1] European Commission. Joint Research Centre., *Trends in data centre energy consumption under the European code of conduct for data centre energy efficiency.* LU: Publications Office, 2017. Accessed: Jun. 10, 2024. [Online]. Available: https://data.europa.eu/doi/10.2760/358256

[2] H. Rong, H. Zhang, S. Xiao, C. Li, and C. Hu, 'Optimizing energy consumption for data centers', *Renew. Sustain. Energy Rev.*, vol. 58, pp. 674–691, May 2016, doi: 10.1016/j.rser.2015.12.283.

[3] EC JRC, 'A Market Transformation Programme for Improving Energy Efficiency in Data Centres', EC JRC, 2014.

[4] H. Y. Cheung, 'Energy Efficiency in Small Server Rooms: Field Surveys and Findings, LBNL Report', Lawrence Berkeley National Laboratory, 2014.

[5] S. Tsemekidi Tzeiranaki, P. Bertoldi, M. Economidou, E. L. Clementi, and M. Gonzalez-Torres, 'Determinants of energy consumption in the tertiary sector: Evidence at European level', *Energy Rep.*, vol. 9, pp. 5125–5143, Dec. 2023, doi: 10.1016/j.egyr.2023.03.122.

[6] IEECB, 'Improving Energy Efficiency in Commercial Buildings: IEECB Focus 2010', Proceedings of the 6th International Conference, 2010.

[7] Michelle et al, 'Data Centre of the Future, IDC Special Study', International Data Corporation, 2007.

[8] D. Bennett, 'Opportunities and Barriers to energy efficiency on the small server room Market, NRDC Report', Natural Resources Defense Council, 2012.

[9] J. Ni and X. Bai, 'A review of air conditioning energy performance in data centers', *Renew. Sustain. Energy Rev.*, vol. 67, pp. 625–640, Jan. 2017, doi: 10.1016/j.rser.2016.09.050.

[10] Stream Data Centers, 'Liquid Cooling is More Sustainable, White Paper', 2024.

[11] ASHRAE Technical Committee 9.9, 'Emergence and Expansion of Liquid Cooling in Mainstream Data Centers, White Paper', 2021.

[12] Patrick Donovan, 'Fundamentals of Managing the Data Center Life Cycle for Owners'.

[13] P. Smith, 'The Value Proposition of Campus High Performance Computing Facilities to Institutional Productivity: A Production Function Model', *SN Comput. Sci.*, vol. 5, no. 5, p. 551, May 2024, doi: 10.1007/s42979-024-02888-0.

[14] X. Yuan, Y. Liang, X. Hu, Y. Xu, Y. Chen, and R. Kosonen, 'Waste heat recoveries in data centers: A review', *Renew. Sustain. Energy Rev.*, vol. 188, p. 113777, Dec. 2023, doi: 10.1016/j.rser.2023.113777.

[15] NeRZ, 'Utilization of Waste Heat in the Data Center', White paper.