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Mechanical Systems for Outpatient and Diagnostic Center with focus on Surgery Block Design

TESI DI LAUREA MAGISTRALE IN
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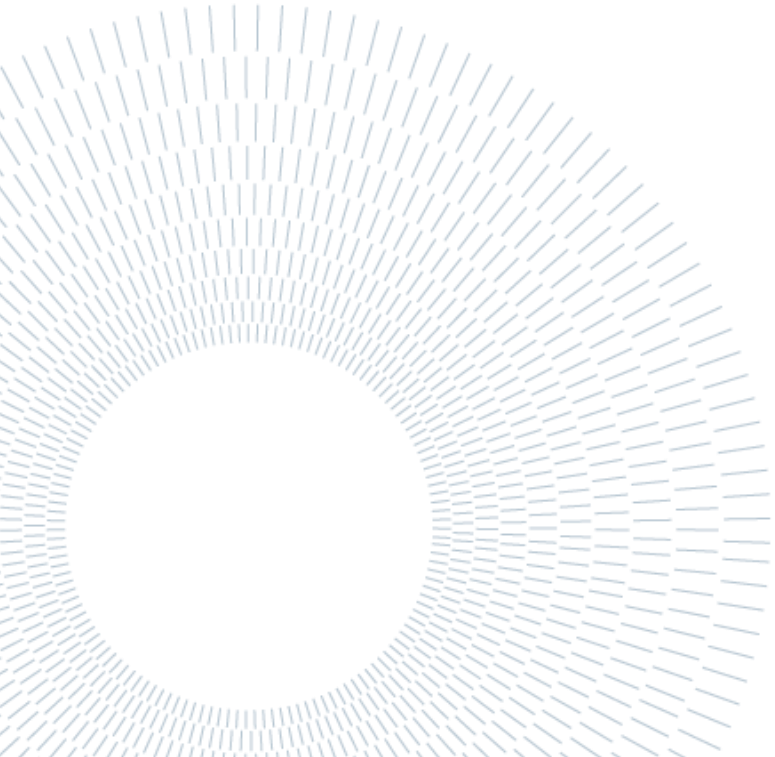


Abstract

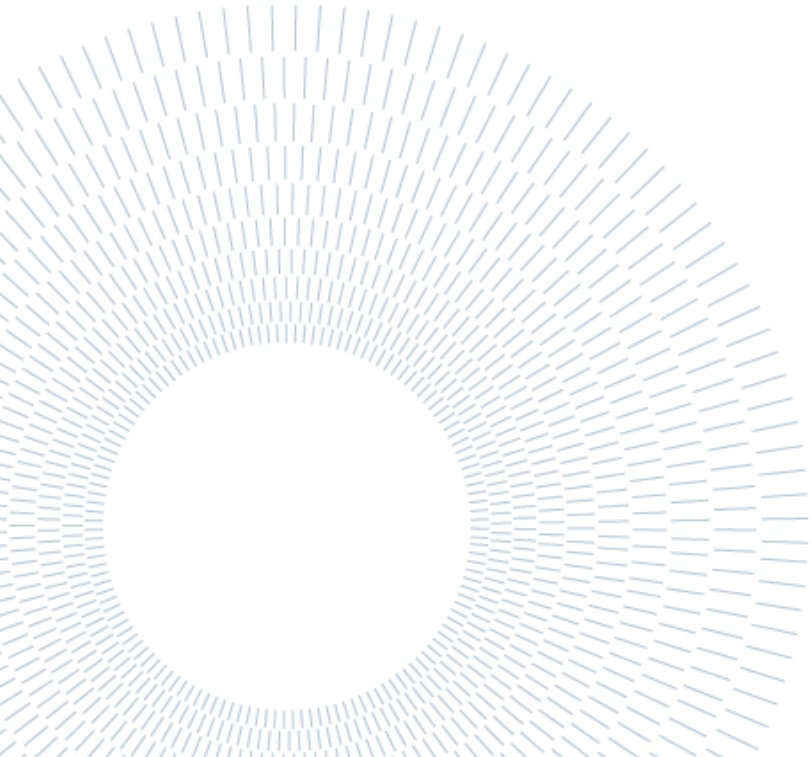
Diagnostic and outpatient centers are healthcare facilities that provide medical services to patients who do not require hospitalization. These centers focus on providing diagnosis, treatment, and preventive care to patients without the need for an overnight stay. The mechanical systems design for these facilities is crucial to ensure their proper functioning and safeguard their medical staff and patients from the spread of bacteria and diseases. The most complex design requirements in these facilities are reserved for surgery rooms and their related surgery block due to their distinctive characteristics of supreme safety and functionality. The design of surgery rooms is rooted in standards and guidelines tailored to a specific project using the practical experience and ingenuity of the design team. The essential characteristics that inform the design of a surgery block are high air exchange rates, elevated air quality standards, comfortable temperature and humidity levels and positive room pressurization among other criteria. This work aims to identify the methodologies used to design the ventilation, cooling and domestic hot water systems for an entire diagnostic and outpatient center and apply them to a case study. Additionally, a specific focus is given to surgery block system design for the fully functioning outpatient and diagnostic center that was established in Milan, Italy. Finally, the real-life results achieved through this methodology will be discussed detailing the calculation outcomes and the actual layout of the developed mechanical systems.

Key-words: design, mechanical ventilation, cooling system, domestic hot water, surgical block, operating room, air quality, pressurization, outpatient center

Abstract in italiano

I centri diagnostici e ambulatoriali sono strutture sanitarie che forniscono servizi medici a pazienti che non necessitano di ricovero. Questi centri si concentrano sulla fornitura di diagnosi, cure e cure preventive ai pazienti senza la necessità di un pernottamento. La progettazione dei sistemi meccanici per queste strutture è fondamentale per garantire il loro corretto funzionamento e salvaguardare il personale medico e i pazienti dalla diffusione di batteri e malattie. Le esigenze progettuali più complesse in queste strutture sono riservate alle sale operatorie e al relativo blocco operatorio per le loro caratteristiche distintive di massima sicurezza e funzionalità. La progettazione delle sale operatorie è basata su standard e linee guida specifici e sull'esperienza pratica e l'ingegnosità del team di progettazione. Le caratteristiche essenziali che informano la progettazione di un blocco operatorio sono principalmente tassi di ricambio d'aria elevati, elevati standard di qualità dell'aria, livelli di temperatura e umidità confortevoli e pressurizzazione positiva della stanza. Questo lavoro si propone di identificare le metodologie utilizzate per progettare i sistemi di ventilazione, raffreddamento e acqua calda sanitaria per un intero centro diagnostico e ambulatoriale e di applicarle ad un caso di studio. Inoltre, viene data particolare attenzione alla progettazione del sistema di blocchi chirurgici per il centro ambulatoriale e diagnostico completamente funzionante che è stato istituito a Milano. Infine, verranno discussi i risultati concreti ottenuti attraverso questa metodologia, dettagliando i risultati del calcolo e il layout effettivo dei sistemi meccanici sviluppati.

Parole chiave: progettazione, ventilazione meccanica, sistema di raffrescamento, acqua calda sanitaria, blocco chirurgico, sala chirurgica, qualità dell'aria, pressurizzazione, centro ambulatoriale



Contents

1 Introduction

Diagnostic and outpatient centers are facilities that provide medical services to patients who do not require hospitalization. These centers focus on providing diagnosis, treatment, and preventive care to patients who do not require an overnight stay. The mechanical systems design for these facilities is crucial to ensure their proper functioning and safeguard their medical staff, patients, and medical equipment. In these healthcare facilities, maintaining a healthy and safe environment necessitates proper heating, ventilation, and air-conditioning (HVAC). HVAC systems contribute to the removal of airborne pathogens and pollutants, facilitate a comfortable environment for patients and staff through the control of temperature and humidity, and maintain medical grade indoor air quality. All occupants in a diagnostic and outpatient center face a significant risk from the spread of airborne infections caused by inadequate HVAC design. In addition, domestic hot water systems are essential for maintaining patient and medical staff safety. They work to lower the likelihood of the growth of bacteria by providing hot water for various purposes. These medical purposes require a dependable and effective supply of hot water to perform sterilization, hygienic hand washing and scrubbing before and after medical diagnostic procedures and operations. Moreover, the mechanical design of a surgery block system in a hospital is critical as its threshold for safety, comfort, and thus optimized working conditions is very high due to the risk of infection and spread of disease.

This work begins in this chapter with a research study on the literature surrounding surgery block design detailing their special requirements, associated problems and peculiarities. The study of the background was instrumental in acquiring the relevant knowledge to define the purposes and the targets of proper surgery block design. The chapter concludes by describing the case study of an outpatient and diagnostic center in Milan, Italy established while working with the energy consultancy company “Rethink Energy” S.r.l and under their experienced guidance.

The work aims in Chapter 2 to illustrate the methodologies utilized for proper design of ventilation, cooling, domestic hot water systems for an outpatient and diagnostic clinic concluding with a focus on the design of its surgery block system. These methodologies are rooted in Italian standards and guidelines then tailored and developed with practical experience and engineering expertise.

The work aims in Chapter 3 to show and discuss the actual results of the application of such methodologies to the case study for each of the designed mechanical systems.

1.1. Air Quality Standards

A surgery room is a type of clean room and must abide by the classifications set. The basis of the clean room standard is the micrometer, or micron for short (μm), which is the size of the particles to be separated. The cleanliness of the air in clean rooms is measured by the number of particles of a given size per volume of air. The maximum concentration limits (particles/m^3 of air) for particles equal to or larger than the sizes considered, and their corresponding clean room classification are shown in Table 1.1. The air quality in the controlled environment determines the classification of clean rooms. Based on the quantity and size of particles per cubic meter of air, the clean room class is the level of cleanliness the room meets. The ISO 14644-1 classification system is the primary authority in the United States and Canada [1]. These classifications are still recognized for clean room specification in European applications specifically for Italy.

The following clean room classes are covered by the ISO standard: ISO 1, ISO 2, ISO 3, ISO 4, ISO 5, ISO 6, ISO 7, ISO 8 and ISO 9. The "cleanest" class is ISO 1, while the "dirtiest" class is ISO 9. The ISO 9 clean room environment is still cleaner than a regular room, despite being in the "dirtiest" class. ISO 6 or more cleanrooms typically use turbulent airflow. ISO 5 and cleaner facilities rely on unidirectional (laminar) airflow [1]. Controlling the air-change per hour (ACH) is a crucial aspect of cleanroom design. It refers to the number of times per hour that filtered outside air replaces the volume of a building or room. In an ordinary home, an air conditioner changes room air 0.5 to 2 times each hour. In a cleanroom, contingent upon classification and its function, air change happens somewhere in the range of 10 to more than 600 times an hour.

ISO Class	Maximum Particles/m^3						Particles/ft^3
	≥0.1µm	≥0.2µm	≥0.3µm	≥0.5µm	≥1µm	≥5µm	≥0.5µm
ISO 1	10						
ISO 2	100	24	10				
ISO 3	1,000	237	102	35			1
ISO 4	10,000	2,370	1,020	352	83		10
ISO 5	100,000	23,700	10,200	3,520	832	29	100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	1,000
ISO 7				352,000	83,200	2,930	10,000
ISO 8				3,520,000	832,000	29,300	100,000
ISO 9				35,200,000	8,320,000	293,000	

Table 1.1: ISO 14644 Clean Room Standards [1]

1.2. Surgical Site Infections (SSI)

The biggest hurdle facing modern-day surgical operations is infections and their spread. Contamination carried by the air can enter a surgery room through the supply air or directly by the patients and their activities or be brought in from adjacent areas. Therefore, to ensure a favorable indoor environment, it is crucial for ventilation systems in operating rooms to effectively minimize the concentration of particles and microorganisms present in the air that are in the vicinity of the surgical area. Moreover, air contaminant reduction during operations, microbial risk mitigation from the surrounding area and air cleanliness reestablishment post operations are the essential aims of operating room ventilation systems. If they are not effective, a common surgical complication ensues referred to as surgical site infection (SSI). As reported by Leaper et al. [2], epidemiological data collected from National Health Service (NHS) hospitals in England indicates roughly 20% of hospital-based infections are SSI. He then estimates that 2-3 % of all patients undergoing surgical operations run a high risk of contracting SSI.

Endogenous or exogenous sources can cause SSIs. Endogenous sources are due to patients themselves. In fact, infection of the patient's wound can be caused by bacteria like Staphylococcus aureus that come from the patient's organs or the flora of their skin. The appropriate clothing that the surgery room occupants must wear and the restricted access to only essential personnel can both mitigate unwanted particles produced by the occupants [3].

On the other hand, direct contact with a contaminated source, implantable material, specialized instrumentation, or airborne microorganisms are considered exogenous sources. Moreover, the propagation of ultra-fine particles (UFP) resulting from the use

of electrosurgical instruments during routine surgery is another significant issue that Meda [4] identified. Both the patient and the medical staff can be harmed by extremely fine particles. In fact, the release of particles can put the patient at risk for SSI, as previously mentioned. According to Ulmer [5], electro cauterization is the cause of the production of the minutest and most harmful particles, which have a mean aerodynamic size of 0.07 μm and are capable of easily passing through standard surgical masks. Additionally, he reported that surgical smoke is made up of 95% steam and the remaining is cellular debris. While water and steam pose no health threats, cellular debris is highly unsafe because of their chemical makeup of acetonitrile and benzene [5].

Even some surgical masks may not be able to filter the ultra-fine particles effectively due to their smaller size compared to mask's textile pores. As a result, serious health risks are posed to both patients and medical staff alike. Therefore, it is imperative to extract surgical smoke, anesthetic gases, and vapors which can be harmful, infectious, and corrosive [3].

1.3. Medical Clothing

The use of High Efficiency Particulate Air (HEPA) filters before introduction of supply air flow into surgery rooms minimizes the risk of microorganism entering the surgery room. HEPA is a type of pleated mechanical air filter used for medical grade applications. Theoretically, this type of air filter can capture at least 99.97% of dust, pollen, mold, bacteria, and any airborne particles with a size of 0.3 microns (μm). The diameter specification of 0.3 microns corresponds to the worst case referred to as the "most penetrating particle size". Therefore, 99.97% efficiency or better is obtained for all particle sizes [6]. In a HEPA filter, diffusion mechanism results in particles smaller than 0.1 μm in size colliding with each other due to their random Brownian motion and are delayed in passing through the filter. The delay facilitates the two other mechanisms to occur to these particles. Interception is when particles passing in the air come in contact with the HEPA filter fibers. Moreover, Impaction is when the larger particles cannot pass through between the fiber and are embedded directly into the fibers themselves. Therefore, particles with greater or lesser size than the "most penetrating particle size" are trapped with even higher efficiency [6]. Due to the use of these filters, one of the primary sources of microorganisms is limited to the endogenous sources from skin particulates of patients and medical staff. Particle dispersion can vary in response to medical staff activity and movement in the surgery room. The first barrier against the release of particles by medical staff during surgery is the surgical clothing which reduces airborne contamination. Simultaneously, surgical clothing can protect surgeons and medical staff members from infections caused by a patient's wound. The amount of skin flakes that are transferred into the air is significantly influenced by the tightness and coverage of the clothing, masks, and caps [7]. Surgeons and medical staff, on the other hand, must be able to move freely

and carry out their duties without any restrictions, so designated clothing must guarantee a comfortable working environment. Mixed materials like cotton and polyester or non-woven materials are the preferred materials for surgical clothing [7]. A study directed by Tammelin et al. [8] suggests that designated medical clothing of non-woven disposable material have higher security against microorganisms than that of blended materials. Additionally, after repeated washing and sterilization, the protective capacity of tightly woven medical clothing can decrease, according to an experimental study [9].

1.4. Humidity and Thermal Comfort

The control of comfort parameters like temperature and humidity in a surgery room necessitates the use of a ventilation system in order to guarantee environmental comfort for both medical staff and patients. It is essential to manage the heat generated by people and equipment within the room in order to maintain a comfortable temperature. According to the Italian standard UNI 11425 [10], the acceptable temperature and humidity ranges are reported in Table 1.2 . Due to demands of summer and winter seasons and the specific requirements of varying surgical procedures, the set temperature in the surgery rooms may vary from the mean of 22°C based on the circumstances. For example, an elevated indoor temperature is a prerequisite for pediatric surgeries due to children's sensitivity to low temperature [11]. Although patient comfort is a priority it must be in balance with the comfort of the medical staff. The medical staff perform diverse activities in different locations within the surgery block while also wearing varying articles of clothing, therefore their comfort levels may not align with their colleagues or patients. Elevated indoor temperature and relative humidity levels may cause discomfort while more critically they promote bacterial growth [11].

prospetto B.2 **Parametri ambientali nei blocchi operatori**

Ambienti	Temperatura [°C]		Umidità relativa [%]		Sovrapressione rispetto all'esterno
	Inverno	Estate	Inverno	Estate	[Pa]
Sale operatorie a elevatissima qualità dell'aria	≥ 20	≤ 24	≥ 40	≤ 60	15[1)]
Sale operatorie a elevata qualità dell'aria					15[1)]
Sale operatorie a qualità dell'aria standard					15[1)]
Depositi sterili	≥ 22	≤ 26	≥ 40	≤ 60	15
Preparazione operandi					10
Preparazione personale					10
Risveglio operati					10
Corridoio pulito/sterile					10
Spazi filtro operandi					5
Spazi filtro personale					5
Substerilizzazione					10
Depositi pulito	≥ 18	≤ 26	≥ 40	≤ 60	10
Depositi sporchi					5

Table 1.2: Temperature,Humidity,Pressurization Parameters for Surgery Block [10]

1.5. Room Pressurization

To prevent air contamination from neighboring rooms to the operating room, which ought to have the cleanest air, room pressurization aims to ensure that the operating room is isolated from neighboring areas in the surgery block. The overpressure in the operating room is determined by establishing an imbalanced airflow that favors the flow of incoming air. Thus, the principle of providing more airflow inside the room than what is extracted from the room achieves the overpressure. The ventilation system must be designed to accommodate not only the needs of the operating room but also facilitate the airflow needs of the neighboring rooms within the surgery block. These rooms are preparation rooms, storage rooms, surgical service rooms, etc. In addition to establishing gradients of pressure between rooms within the surgery block, the entirety of the surgery block should be positively pressurized with respect to the external hospital or clinic rooms surrounding the block. This practice ensures that any air leakage can only travel between more clean to less clean areas. Moreover, it preserves the cleanliness of the surgery block regardless of the air contamination level in the external areas. Door opening frequency is an important parameter to evaluate and minimize as much as possible during surgery. Door opening may be detrimental

to established pressurization if it frequently occurs during a typical surgery operation [3].

Additionally, Smith et al. [12] observed in their research a correlation between the greater frequency of door openings and an increasingly higher level of contamination in the surgery room. In particular, they emphasized that there are two primary contributors to this kind of contamination. These contributors that accelerate the spread of bacteria in the surgical field are an increase in foot traffic and a decrease in the pressure gradient between the protected zone and the surrounding areas [12]. As a result, it is evident that staff members can remain in a more contaminant-free environment by reducing the number of door openings. The Italian standard UNI 11425 recommends the pressurization level by the type of room in the surgery block as reported in Table 1.2.

1.6. Modes of Airflow Introduction

The mode of airflow introduction into a surgery room is a vital design selection and informs airflow patterns. The main modes utilized in surgery rooms are Unidirectional Laminar Airflow (LAF), Fully Turbulent Airflow and Turbulent Mixed Airflow (TMA).

1.6.1. Unidirectional Laminar Airflow

The use of a Unidirectional Laminar Airflow (LAF) system is common in science-based industries like pharmaceuticals, where the requirements for air cleanliness are extremely high. As seen in Figure 1.1, air acts as a piston in a unidirectional airflow arrangement, sweeping all of the air through the room in a process known as piston flow. Air and, as a result, airborne contaminants are directed toward the exhaust grills by this airflow path. Therefore, a tremendous amount of airflow is required which is supplied vertically or horizontally from a large area, such as a ceiling, or wall usually through a supply plenum configuration. The air is then extracted from the furthest points with respect to the supply area to ensure maximum coverage [3]. The performance of the LAF system is significantly impacted by the air velocity (0.2–0.3 m/s) at the ceiling diffusers, which plays a critical role [13].

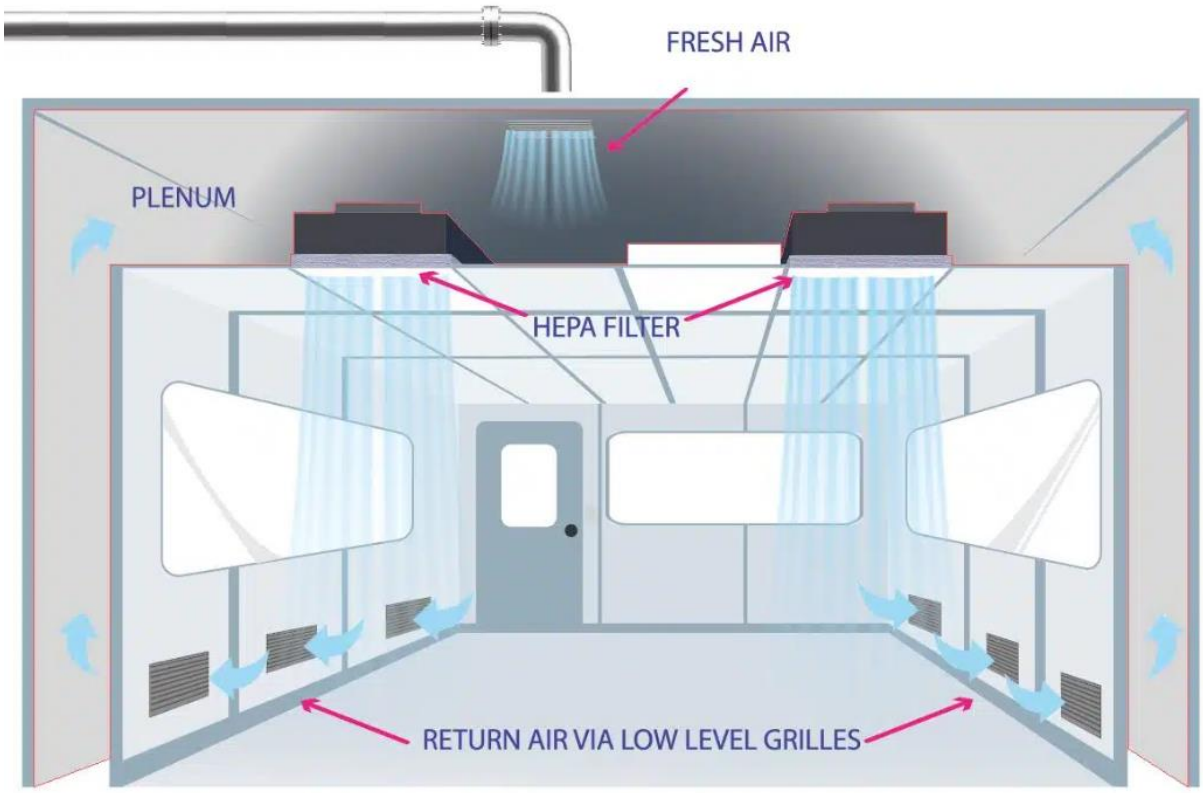


Figure 1.1: Example of Unidirectional Laminar Airflow Configuration [14]

In a Unidirectional Horizontal Airflow configuration, the issue of bacteria produced by medical staff is more pronounced as they perform their activities in the area between the air supply and the operating area. Therefore, the bacteria are more likely to deposit on the surgical equipment and patient's incision site. On the other hand, a minimum velocity of 0.2 m/s at the incision site allows the air to dispel any particles or bacteria in its proximity in the case of Unidirectional Vertical Airflow [15]. This airflow pattern may also be affected by the temperature gradient from instrumentation, occupants and surgical lamps' thermal heat load leading to buoyancy effects. However, Chow et al. [16] concluded that the obstruction effect of the surgical lamp is more significant than any heat dissipation effect that may be present.

1.6.2. Fully Turbulent Airflow

Turbulent Airflow systems which are also referred to as conventional ventilation systems brings in fresh air for the surgery room environment and typically exhaust it at floor level. As seen in Figure 1.2, the inlet airflow achieves the required level of cleanliness through HEPA filters prior to introduction into the room. The air flow will be set to reach high velocity (> 0.3 m/s) thus inducing great convective motions or eddies which facilitate the diffusion of the supplied air with the room air. To remove pollutants from the operating room environment, these systems mostly rely on

dilution. As is typical of such systems, the airflow patterns throughout the entire operating area are entirely mixed and unstable [13]. The dilution process leads to the high concentrations of airborne microbes decaying exponentially over time. The concentration will be fairly uniform throughout the surgery room due to the turbulent mixing [17].

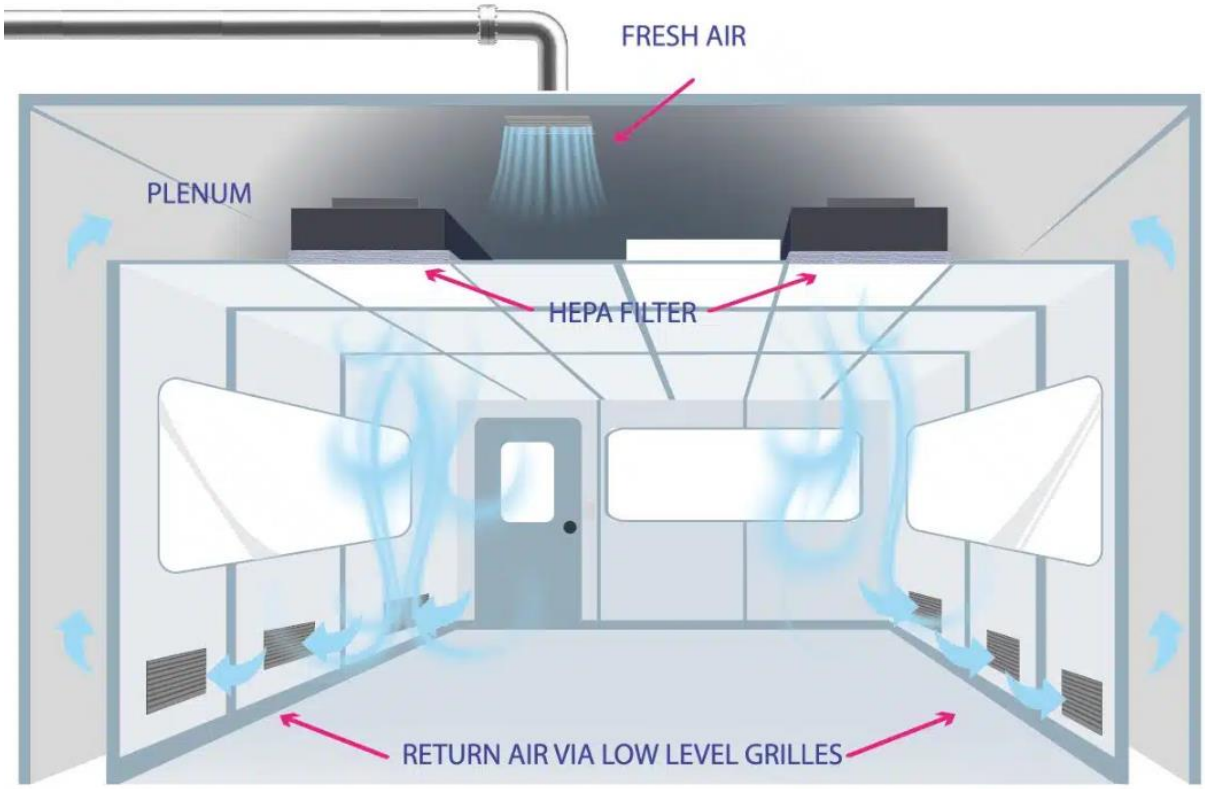


Figure 1.2: Example of Turbulent Airflow Configuration [14]

1.6.3. Turbulent Mixing Airflow

Turbulent Mixing Airflow (TMA) also known as mixed unidirectional airflow since it is considered a compromise between fully laminar and fully turbulent airflows as it combines elements from both. A high-efficiency particulate air (HEPA) filter reduces the contamination in the incoming airflow. TMA is the most prevalent configuration used in surgery rooms due to the need for high level cleanliness in the central operating zone subject to the laminar airflow and a permissible lower level of cleanliness in the surrounding area subject to the turbulent airflow. In TMA, the supply and extraction devices are positioned to ensure a path of clean air supply encompasses the medical staff, equipment, and patients as well as actively ventilation the entirety of the operating area.

As seen in Figure 1.3, the filtered supply air descends from the ceiling and carries away all the particles and microorganisms present in the operating area towards the

surrounding area. In the surrounding area of the surgery rooms, substantial air eddies influence the airflow pattern until they are extracted by the exhaust grills. Usually, the exhaust grills are positioned at different corners of the surgery room and at different elevations within the room. This practice ensures that particles of varying densities like anesthetics gases, microorganisms and surgical smoke are all properly exhausted [3].

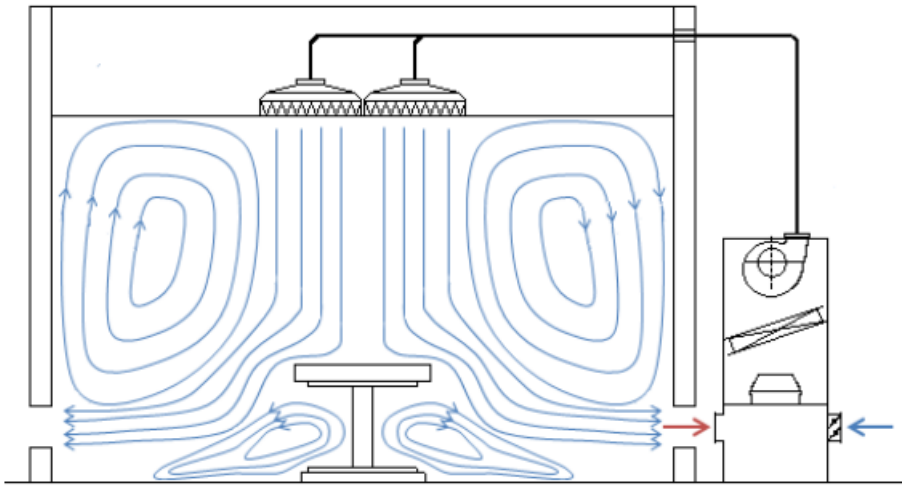


Figure 1.3: Example of Turbulent Mixing Configuration [18]

An operating room's clean air pathway is heavily linked to the arrangement of air supply diffusers and air exhaust grills. As posed by Rim et al. [19], indoor airflow patterns highly influence the effectiveness of ventilation by minimizing stagnant air pockets and ensuring occupied areas of the surgery rooms are effectively supplied with fresh air. Moreover, they aid in contaminant removal and prevent their expansive spread in the surgery rooms.

To that end, experimental measurements were performed by Xue et al. [20] utilizing multiple configurations of turbulent mixed ventilation at two air change rates of 18 and 20 ACH. The operating room indoor air quality was assessed through measurements of various factors of pollutant gas concentration, turbulence intensity, air velocity and temperature. The goal was to understand the effect of mixed ventilation exhaust airflow on the air quality in the surgical space. Their findings affirmed the importance of the airflow path traversing the operating room microenvironment (location of the surgical operation) frequently when traveling from its inlet towards the outlet. Moreover, they emphasized the importance of having unobstructed pathways for the air flow into the microenvironment and the proper positioning of equipment such as surgical lamps. In addition, they discovered that when four supply diffusers were used in ultraclean operating rooms, four exhausts at 20 ACH and six exhausts at 18 ACH produced the highest contaminant removal efficiency (CRE). These experimental finding were compared to the eight exhausts, and

the results were approximately 38% and 35% higher contaminant removal efficiency (CRE) respectively [20]. Their findings are reported Table 1.3.

Case	Inlet			Outlet		CRE
	ACH	number & type	location	number & type	location	
1	20	2 supply grilles	wall	2 exhausts	wall	0.870
2	30	2 diffusers	ceiling	2 exhausts	ceiling	0.550
3		2 diffusers	ceiling	2 exhausts	wall	1.010
4	18	4 diffusers	ceiling	4 exhausts	wall	1.022
5		4 diffusers	ceiling	6 exhausts	wall	1.389
6		4 diffusers	ceiling	8 exhausts	wall	0.873
7	20	4 diffusers	ceiling	4 exhausts	wall	1.412
8		4 diffusers	ceiling	6 exhausts	wall	1.138
9		4 diffusers	ceiling	8 exhausts	wall	0.947

Table 1.3: Layout of Inlet, Outlet and CRE values for different Airflows [20]

1.7. Case Study: Outpatient and Diagnostic Center

In this work, the methodologies and practical implementation of ventilation, cooling, domestic hot water and surgery block design will be investigated for an outpatient and diagnostic center. They were implemented with the guidance and expertise of the energy consultancy company Rethink Energy S.r.l. The project undertaken constituted a newly established outpatient and diagnostic center in Milan, Italy.

The property subject to intervention is part of a larger building complex, consisting of two condominiums. Specifically, the part of the building affected by the intervention consists of commercial premises with offices, bathroom block and storages as seen in Figure 1.4.

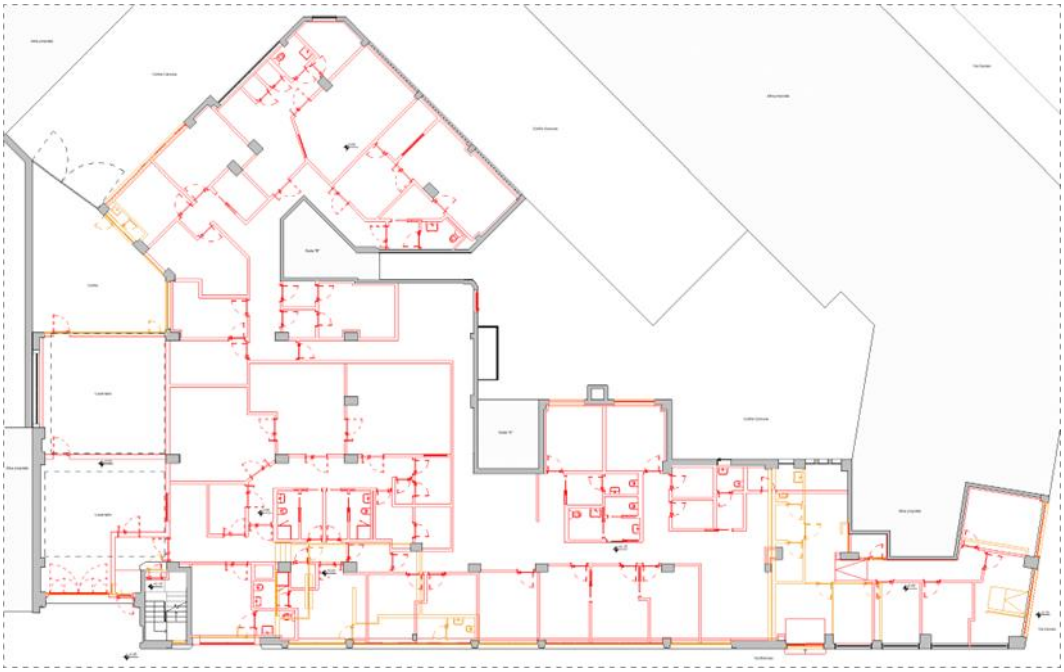


Figure 1.4: Ground Floor Layout of the Center

The project involves the construction of an outpatient center consisting of 16 medical clinics, one for the optician and one for the ophthalmologist, an area dedicated to diagnostics and another area dedicated to day surgery.

In the surgical block there are two surgical rooms with preparation and awakening room, the patient filter, sterilization, dirty/clean filters, two deposits for clean and sterile equipment and finally two changing rooms for doctors with dedicated bathrooms.

The main works to be carried out on mechanical systems can be described as follows:

- New construction of air conditioning system with VRV heat pumps
- New construction of centralized mechanical ventilation system
- New construction of domestic hot water production system with heat pumps
- New construction of Air Handling Unit system dedicated to surgical rooms

2 Methodologies for Mechanical Systems Design

This chapter describes the methodology adopted to design the ventilation system, the cooling system, domestic hot water system and surgery block design for the clinic building described in the Introduction.

2.1. Ventilation System Design

The ventilation system described in this methodology incorporates several components. It comprises a ventilation unit which has inputs of fresh air from the external atmosphere and return air from the ventilated building. The outputs of the unit are expulsion air to the external atmosphere and supply air to the ventilated building. The return and supply air flows are transferred from and to the building through a ducting network. The return and supply ducts are equipped with dampers to regulate the flow to the different areas of the building. The terminal ducts which are the final duct element connect to air flow diffusers in each of the relevant rooms. The diffusers release or retrieve the air in these rooms based on the calculated requirements for ventilation. Service rooms undergo extraction of air with a dedicated system comprised of an extraction fan and its own network of ducts, dampers, and ventilation valves.

2.1.1. Required Flow Rate Calculations

The design methodology is composed of seven main steps. First, evaluation of the architectural area of the building is conducted. The space is divided into several rooms depicted in the architectural reference drawings. The design and calculations are based on verifying the areas of the rooms and inputting that data as a basis for various calculations. The verification process is a combination of practical site inspections to view the layout of the building and architectural reference drawings provided by the responsible subcontractor in progressive degrees of completeness throughout the lifespan of a project. This practice also includes verifying the specified heights from the floor to the above false ceiling throughout the building space.

Second, it is necessary to estimate the room occupancy, which is the average number of people occupying a room based on client's inputs and prior company expertise. The

factors that inform this estimation are the specified function of the room, the number of seats illustrated in reference drawings and special client requirements, etc.

Third, the supply air volumetric flow rate values are calculated based on factors that are related to the functionality of the specific rooms detailed in the Italian standard UNI 10339 [21] as indicated in Table 2.1, where the volumetric air flow required for suitable ventilation in hospitals, clinics, nursing homes and similar buildings are reported.

(seguito del prospetto)

Categorie di edifici	Portata di aria esterna o di estrazione Q_{op} (10^{-3} m^3/s per persona)	Q_{os} (10^{-3} m^3/s m^2)	Note
OSPEDALI, CLINICHE, CASE DI CURA E ASSIMILABILI **			
• degenze (2-3 letti)	11	-	-
• corsie	11	-	-
• camere sterili	11	-	-
• camere per infettivi		-	D
• sale mediche/soggiorni	8,5	-	-
• terapie fisiche	11	-	-
• sale operatorie/sale parto	-		D
• servizi	estrazioni		A

Table 2.1: Air Flowrates based on Room Functionality in Clinic/Hospitals [21]

The required supply volumetric air flow rates in specific rooms ($\dot{V}_{supply}^{required}$) in [m^3/h] is calculated as the multiplication of the recommended supply air flow rate factor (SF) in $\left[\frac{10^{-3}\times m^3}{s\times person}\right]$ by the estimated number of occupants (N_{occ}) in [person] by 3600 [s/h] as seen in equation 2.1:

$$\dot{V}_{supply}^{required} = SF \times N_{occ} \times 3600 \qquad 2.1$$

Forth, as an initial step of the methodology, the return volumetric air flow rates are established based on the principle of creating a balance within each of the rooms that require supply. Therefore, as a starting point, an equality between the required supply and required return air flow values in each of the specified rooms is assumed. In simple terms, what goes in must come out in a relatively balanced way.

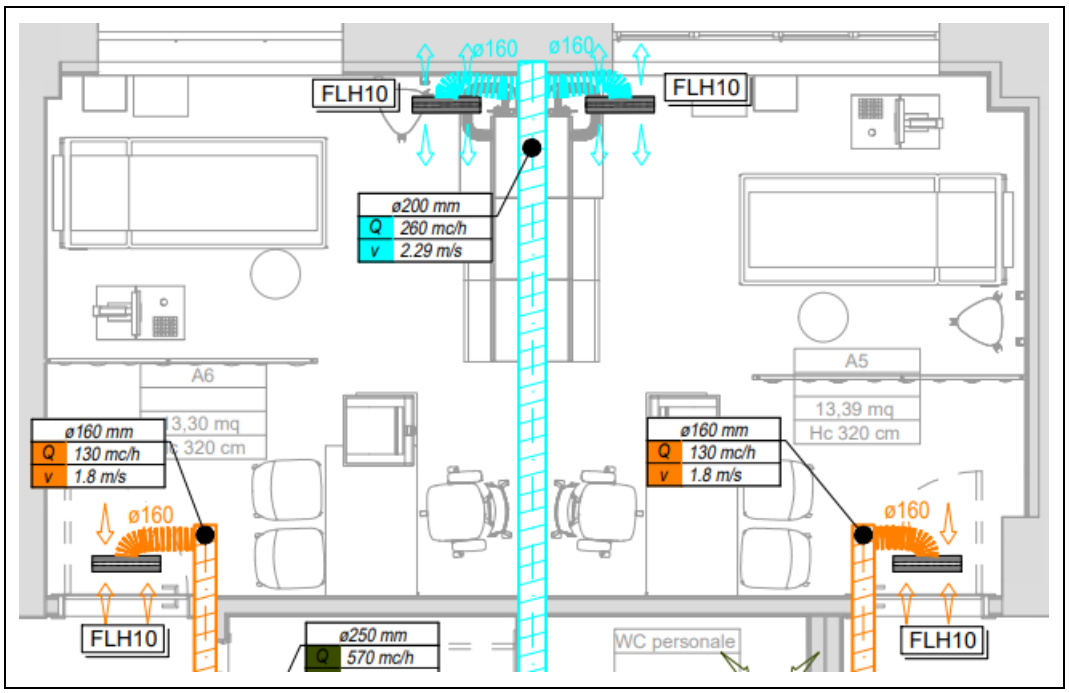


Figure 2.1: Representative Supply/Return Air Flow Balancing

As depicted in the representative Figure 2.1, these two adjacent rooms each have a balanced air flow with 130 m^3/h supply airflow and 130 m^3/h return airflow.

Fifth, the services rooms, as depicted in Note A of Figure 2.2, which include bathrooms, locker rooms, technical rooms and deposit areas must be handled with only extraction of air [21]. This dispels unsanitary air from service rooms out of the building. Moreover, Note D indicates that the ventilation design of the surgery block should be treated separately and under specific rules which will be investigated in an upcoming section [21]. More specifically, it will be designed based on the recommendations of UNI 11425.

* Salvo le indicazioni di cui in 9.1.1.1.

** Per gli ambienti di questa categoria non è ammesso utilizzare aria di ricircolo.

Note : A - *Ricambio richiesto nei servizi igienici:*
- edifici adibiti a residenza e assimilabili 0,0011 vol/s (4 vol/h);
- altre categorie in tabella 0,0022 vol/s (8 vol/h),
il volume è quello relativo ai bagni (antibagni esclusi).

B - *Verificare i regolamenti locali.*

C - *Valori più elevati possono essere richiesti per il controllo dell'umidità.*

D - *Per questi ambienti le portate d'aria devono essere stabilite in relazione alle prescrizioni vigenti ed alle specifiche esigenze delle singole applicazioni.*

Figure 2.2: UNI 10339 Clarifying Notes [21]

The required extraction volumetric air flowrates in the service rooms ($\dot{V}_{extraction}^{required}$) in [m³/h] are calculated as the multiplication of the recommended extraction air flow rate factor (XF) in $\left[\frac{volume}{h}\right]$ by the volume of the service room ($Vol_{service}$) in [m³] as seen in equation 2.2:

$$\dot{V}_{extraction}^{required} = XF \times Vol_{service} \quad 2.2$$

Sixth, given that service rooms require only extraction of air, an overall balancing equation of the air flows in all the rooms in a building can be developed. The total supply volumetric air flow rates in the building ($\dot{V}_{supply}^{total}$) in [m³/h] is calculated as the summation of the total required extraction volumetric air flowrates ($\dot{V}_{extraction}^{total}$) in [m³/h] and the total return volumetric air flowrates ($\dot{V}_{return}^{total}$) in [m³/h] as seen in equation 2.3:

$$\dot{V}_{supply}^{total} = \dot{V}_{extraction}^{total} + \dot{V}_{return}^{total} \quad 2.3$$

The methodology for balancing both sides of equation 2.3 is done generally by either increasing the supply air flow or by reducing return air flows in certain areas to accommodate extraction air flows. This is performed gradually starting from individual rooms and expanding the scope to establish regions of the building that have autonomous balanced air flows.

When feasible, the return and supply flow rates are balanced equally within individual rooms. However, some regions of adjacent multiple rooms include service rooms which dictates the need for regional balancing. This is possible since the rooms are separated by doors and manageable access points of air flow. A room would be calibrated with an excess of supply air relative to its own return air need. Therefore, the supply air would traverse into the other room(s) to satisfy its return/extraction air needs. In practice, corridors and waiting rooms are utilized as points of concentrated supply air flow because they are large areas that extend and border multiple rooms while simultaneously having a relatively low occupancy residence time, since they are by their nature transitional spaces between rooms.

As depicted in Figure 2.3, the square diffuser connected to the blue supply duct supplies 360 m³/h in a corridor and that air traverses the doorway spaces as illustrated by the red arrows and is extracted by the green ventilation valve for extraction. Thus, regions of balanced ventilation can be established. From design point of view, the fact that each individual room does not have to be autonomous with its ventilation

exchange is a benefit because it assists in reducing the number of ventilation diffusers and mechanical installations required when the methodology is utilized efficiently.

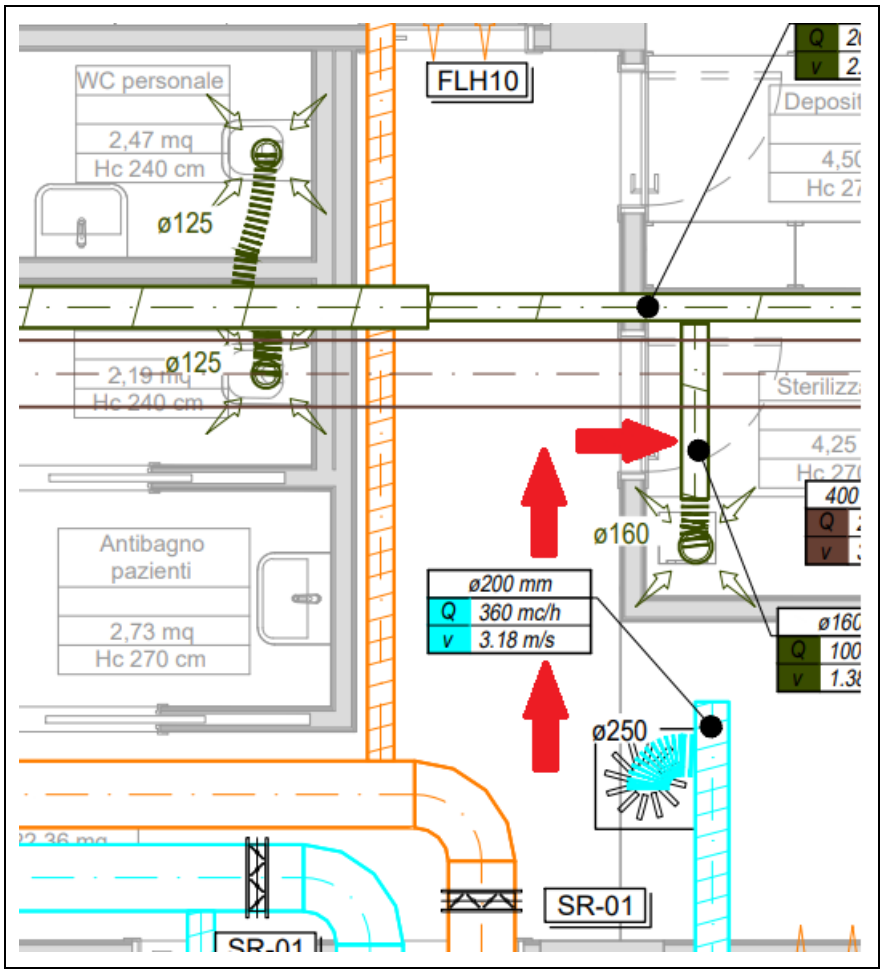


Figure 2.3: Representative Regional Balancing

Seventh, a complete balance of air flow should be designed for the entirety of the rooms in a building. However, in practice on site, the supply and return air diffusers are calibrated to establish a difference in their total flow rates. This is done to create a slightly positive indoor air pressure by having a slightly higher supply of air flow relative to the return of air flow. The benefits of this practice include improving indoor air quality due to the outward expulsion of particulate matter and any other contaminants from the building. In addition, the positive indoor pressure combats any infiltration from the outside air which is especially energetically economical in heating seasons where cold air infiltration would only add to the heating load within a negatively pressurized building. As a company rule of thumb, the difference between the total supply volumetric air flowrates ($\dot{V}_{supply}^{total}$) in [m³/h] and the total return volumetric air flowrates ($\dot{V}_{return}^{total}$) in [m³/h] is estimated the multiplication of 0.3 vol/h

by the total volume (Vol_{total}) in [m³] of all the rooms in the building as seen in equation 2.4:

$$\dot{V}_{supply}^{total} - \dot{V}_{return}^{total} = 0.3 \times Vol_{total} \quad 2.4$$

2.1.2. Air Diffusers Sizing

Air diffusers ventilate air in an enclosed space or room; they are used to manage the air supply and return flowrates in each of the rooms connected through a ducting system to the ventilation unit. The methodology for placing the air diffusers recommends placing the supply and return diffusers at opposite extremes of the room. The diffusers are placed diametrically opposite as in the case of Figure 2.1. This practice ensures that the air flow can cover the entire area and all the air within is replaced routinely. In addition, when possible, the return diffuser is placed near the entrance of a room; this helps facilitate a near autonomous balance of air flow in a room as opposed to having the supply diffuser near the outside areas. Thus, the air within the rooms is sufficiently and efficiently cycled in and out maintaining a stable fresh ventilation stream and avoiding stagnation of unclean air in pockets in the rooms. Different types of air diffusers and valves can be employed. The methods for sizing them are similar and so one example for sizing the linear slot diffuser will be discussed.

2.1.2.1. Linear Slot Diffuser Sizing

Linear slot diffusers produce a specialized air smoothing profile that is perfect for plasterboard false ceiling installation and aesthetically only make the slit visible which meet design needs as seen in Figure 2.4.

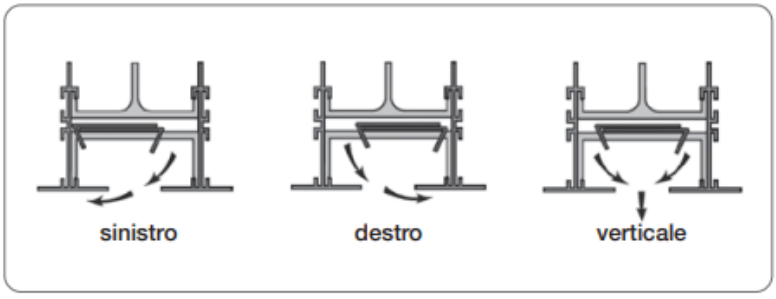


Figure 2.4: Schematic Linear Diffusers [22]

The sizing of the appropriate linear slot diffuser is a combination of three parameter: the required air flow rate in [m³/h], the Noise Criterion (NC) in [dBA] and the adjustable length of the diffuser as seen in the representative Table 2.2.

In practice, an upper limit of the Noise Criterion is set at 30 NC due to the need for minimal noise pollution and disturbance in the building. The air flowrate is established based on calculations. The length of the diffuser is adjustable and is directly proportional to the air flowrate. For example, linear diffuser "10" can supply a maximum 280 m³/h with an NC = 25 at a length = 1000 mm; therefore, the same diffuser can supply a maximum 140 m³/h with an NC = 25 at a length = 500 mm.

Tabella delle portate per L=1000 mm

10	Slot 25 mm Attacco DN 150 mm	1000 mm	Portata m³/h	57		115		170		230		280		340		400	
			Pt (Pa)	2		8		16		29		45		65		87	
			Pst (Pa)	1		5		10		19		29		42		56	
			NC	<15		<15		<15		17		25		32		38	
			Lancio (m) Vt 0,5/0,25 m/s	0,6	1,5	1,8	3,7	2,7	4,6	3,7	5,2	3,7	5,5	4,6	6,1	4,9	6,7
15	Slot 38 mm Attacco DN 200 mm	1000 mm	Portata m³/h	100		170		240		310		360		450		520	
			Pt (Pa)	4		9		19		31		51		67		94	
			Pst (Pa)	3		7		15		25		42		55		77	
			NC	<15		<15		<15		22		30		36		44	
			Lancio (m) Vt 0,5/0,25 m/s	1,5	3,4	2,7	4,6	4	5,5	4,6	6,4	5,2	7	5,8	7,6	6,1	7,9
20	Slot 51 mm Attacco DN 200 mm	1000 mm	Portata m³/h	140		210		280		350		420		500		560	
			Pt (Pa)	4		8		10		23		34		46		60	
			Pst (Pa)	2		5		10		15		22		30		39	
			NC	<15		<15		<15		15		22		30		37	
			Lancio (m) Vt 0,5/0,25 m/s	1,2	3,4	2,7	4,3	3,7	5,2	4	5,8	4,3	7	7,6	8,2	5,2	8,5
30	Slot 76 mm Attacchi 2 x DN 150 mm	1000 mm	Portata m³/h	280		390		500		650		700		800		900	
			Pt (Pa)	7		12		20		30		41		55		70	
			Pst (Pa)	4		8		13		19		26		35		44	
			NC	<15		<15		18		22		28		34		40	
			Lancio (m) Vt 0,5/0,25 m/s	4	6,1	4,6	7,3	5,8	8,2	6,4	9,1	7	9,8	7,3	10,7	7,9	11,3

Table 2.2: Linear Diffuser Sizing [22]

2.1.3. Ducting System

Ventilation ducting systems are designed to distribute air from the ventilation unit throughout the building and provide fresh air for the occupants. The basic components of a ventilation ducting system include supply ducts, return ducts, extraction ducts, flexible connections, and dampers. Supply ducts distribute the air to the different areas of the building. They are typically made of sheet metal and can be either circular or rectangular in shape. Return ducts are responsible for collecting air from different areas of the building and returning it to the ventilation unit. Extraction ducts are used to remove stale air, moisture, and other pollutants from the building and are typically

installed in areas like bathrooms, locker rooms, and kitchens. Air flow dampers are placed on the ducts to regulate the flow of air through the ducting system and control the air flowrates reaching each area. Finally, flexible connections connect the terminal duct to the corresponding diffuser and should not exceed 1 meter in length.

2.1.3.1. Duct Sizing and Distribution

The ducting systems in all their types must traverse the false ceiling space located above the rooms of the building. The distribution of these networks aims to extend to all the rooms that require supply, return, extraction in an efficient and thus economical way. Some of the main constraints that inform the sizing and distribution of ducting system are the face velocity, structural constraints, and topography of the building.

The first constraint is the face velocity of the air flow in the duct. High face velocity within a duct leads to a high noise level to the adjacent rooms which is discomforting issue for occupant of a building.

The face velocity (v_{face}) in [m/s] is calculated by the multiplication of the volumetric air flow rate ($\dot{V}$) in [m^3/h] by 3600 [s/h] divided by the sectional area of the duct (A_{duct}) in [m^2] as seen in equation 2.5:

$$\frac{\dot{V} \times 3600}{A_{duct}} = v_{face} \qquad 2.5$$

The face velocity dictates the limits of the duct sizing be it rectangular or circular based on rule of thumb parameters derived by practical experience related to the function of the duct.

Parameters are defined such that the face velocity values are:

- not larger than 2 m/s for terminal ducts and flexible connections
- not larger than 4 m/s for secondary ducts
- not larger than 6 m/s for main ducts

The second constraint is a structural one where the structural integrity of a rectangular ducts may be compromised when its width exceeds its height by three times. Therefore, a rectangular duct should not exceed a dimensional ratio of width: height of 3:1

The third constraint is the spatial and topographic constraint of the false ceiling. Obstructions like beams, fixtures, machinery may create difficulties in navigating efficient pathways. In addition, the supply, return, and extraction ducting systems must coexist in an optimum configuration and not hinder one another's pathway. Therefore, the dedicated design of the ducting systems is limited by the constraints

mentioned and must be optimized to yield a high standard of functionality while minimizing costs.

2.1.4. Ventilation and Extraction Unit Sizing

The ventilation and extraction units are sized respectively based on the supply air flow rate and extraction air flow rate requirements previously calculated. Their static pressure head values are selected based on rule of thumb estimation and prior project expertise. A safety factor for the respective flow requirements is incorporated to assure that the selected units are safely sized. The static pressure head and the volumetric flow rate requirements are the two main criteria that guide the choice of the adequate units based on performance graphs supplied by the manufacturer as seen in Figure 2.5:

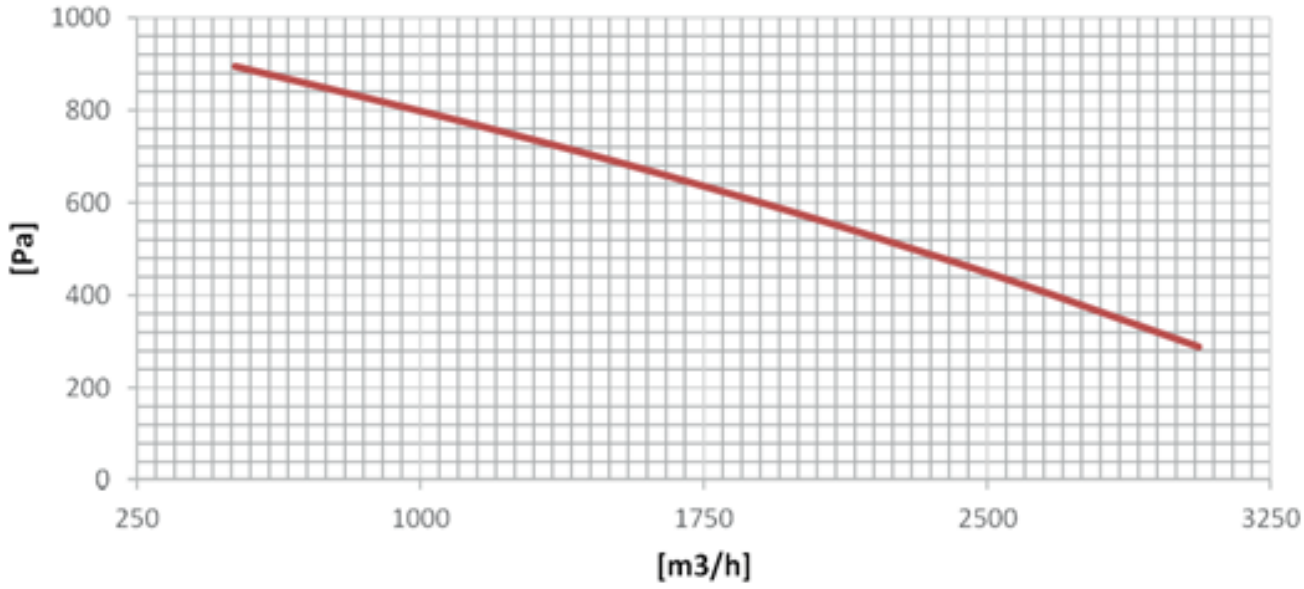


Figure 2.5: Ventilation Unit Performance Graph [23]

2.2. Cooling System Design

The methodology for the design of the cooling and heating system entails a Variable Refrigerant Volume (VRV) system. It is a type of air conditioning system that uses refrigerant to directly heat or cool the air. This multi-split system uses a single outdoor unit to supply refrigerant to multiple indoor units referred to as fan coil units. Each fan coil unit can be controlled individually, allowing for precise temperature control in different areas of the building. The refrigerant flows through a two-pipe system in a closed loop, absorbing heat from the indoor air and releasing it to the outdoor air in cooling mode and vice versa in heating mode.

One of the key features of a VRV cooling system is its flexibility. The system can be customized to fit the specific needs of the building, with a wide range of fan coil unit types and sizes. In addition, the system is highly efficient with advanced controls that can modulate the refrigerant flow to match the cooling demand of the building. This can result in significant energy savings compared to other types of air conditioning systems. One of the main benefits of using this type of system is high energy efficiency which is translated into lower operating costs.

2.2.1. Cooling Load Estimation

The design methodology adhered to is based on practical evaluation of different sensible cooling loads based on estimated factors. These estimated factors are rooted in prior company expertise and rules of thumb. Multiple components are considered when assessing the sensible cooling load requirements in the building. These components that inform the sensible cooling loads are lighting loads, average occupant load, large machinery load and other miscellaneous loads. Lighting cooling load refers to the amount of heat generated by lighting fixtures in a building that need to be removed by the air conditioning system to maintain a comfortable indoor temperature. When lights are turned on, they produce both light and heat. The heat generated by lighting fixtures adds to the overall heat load of the building which increases the demand on the air conditioning system. Average occupant cooling load refers to the amount of heat generated by the occupants of a building that needs to be removed by the air conditioning system. The load caused by occupants can be affected by several factors, including the number of people in the space, their activity level, and their clothing choices. The human body produces heat through metabolic processes and this heat is released into the surrounding environment contributing to the overall heat load of the building. Other miscellaneous loads refer to the amount of heat generated by any other sources in the building for example computers, printers, kitchen appliances, etc. Large machine loads refer to the amount of heat generated by mechanical or electrical equipment in a building as a byproduct of their operation.

After the steps of area validation and occupancy estimation previously conducted, the load requirements for cooling are calculated using estimated factors regarding lighting loads (LF), average occupant load (PF) and other miscellaneous loads (OF).

The sensible cooling load for lighting ($L_{lighting}$) in [W] is equal to the multiplication of the room area (A_{room}) in [m^2] by the lighting load factor (LF) in $\left[\frac{W}{m^2}\right]$ as seen in equation 2.6:

$$L_{lighting} = A_{room} \times LF \tag{2.6}$$

The lighting load factor (LF) is assumed to be 15 $\left[\frac{W}{m^2}\right]$.

The sensible cooling load for average occupant cooling load $(L_{occupants})$ in [W] is equal to the multiplication of estimated number of occupants $(N_{occupants})$ in [person] by the average occupant load factor (PF) in $\left[\frac{W}{pers}\right]$ as seen in equation 2.7:

$$L_{occupants} = N_{occupants} \times PF \quad 2.7$$

The average occupant load factor (PF) is assumed to be 60 $\left[\frac{W}{pers}\right]$.

The sensible cooling load for other miscellaneous loads (L_{other}) in [W] is equal to the multiplication of the room area (A_{room}) in [m²] by the other miscellaneous loads factor (OF) in $\left[\frac{W}{m^2}\right]$ as seen in equation 2.8:

$$L_{other} = A_{room} \times OF \quad 2.8$$

The other miscellaneous load factor (OF) is assumed to be 20 $\left[\frac{W}{m^2}\right]$.

Large machine sensible loads are specified by their respective manufacturer and are added to the considerations. Additional sensible loads related to the function of large machines extend to the adjacent control rooms and technical rooms of each.

For each room, the total sensible cooling load $(L\,^{total}_{sensible})$ in [W] is equal to the sum of all previous load components in [W] as in equation 2.9:

$$L\,^{total}_{sensible} = L_{lighting} + L_{occupants} + L_{other} + L_{machines} \quad 2.9$$

For each room, the total cooling load in [W] is calculated by the multiplication of a 130% factor (to account for the latent cooling load) by the total sensible cooling load in [W] as seen in equation 2.10

$$L\,^{total}_{cooling} = 1.3 \times L\,^{total}_{sensible} \quad 2.10$$

The total sensible cooling load estimations act as the starting point for sizing the fan coil units and ultimately the VRV external unit.

2.2.2. Fan Coil Unit Sizing

A fan coil unit (FCU) is a device used to control the temperature and humidity of a room in a building. It is typically installed in a ceiling, wall, or floor and is connected in this case to a VRV system.

The basic components of an FCU include a heat exchanger (coil), a fan, and a control system. The heat exchanger can function as either a heating coil (for heating) or a cooling coil (for cooling) and it works by exchanging heat with the air that flows over it. The fan draws air through the heat exchanger and blows it into the room thus distributing the conditioned air throughout the space.

The methodology dictates that the total cooling load for each individual areas or rooms defined in the building acts as a lower bound for the fan coil unit capacity. For each room, a FCU is selected with a cooling capacity that is greater than the calculated total cooling load requirement. The capacity selected is sufficiently oversized based on the manufacturer ranges of capacities to ensure maximum flexibility in operation. The units work in both cooling/heating modes; therefore, it is assumed as a company rule of thumb, that when the cooling load requirements are satisfied, the heating load requirements are implicitly satisfied.

2.2.3. VRV External Unit Selection

After assessing the fan coil unit selection for the entire building, the total of all the fan coil unit capacities in the building and a scheme of the layout of the fan coil unit positioning is relayed to the relevant manufacturer. The manufacturer provides a scheme for the selection of the appropriate VRV external unit, multitube distributors and tube sizing for both tubes transferring refrigerant as seen in Figure 2.6:

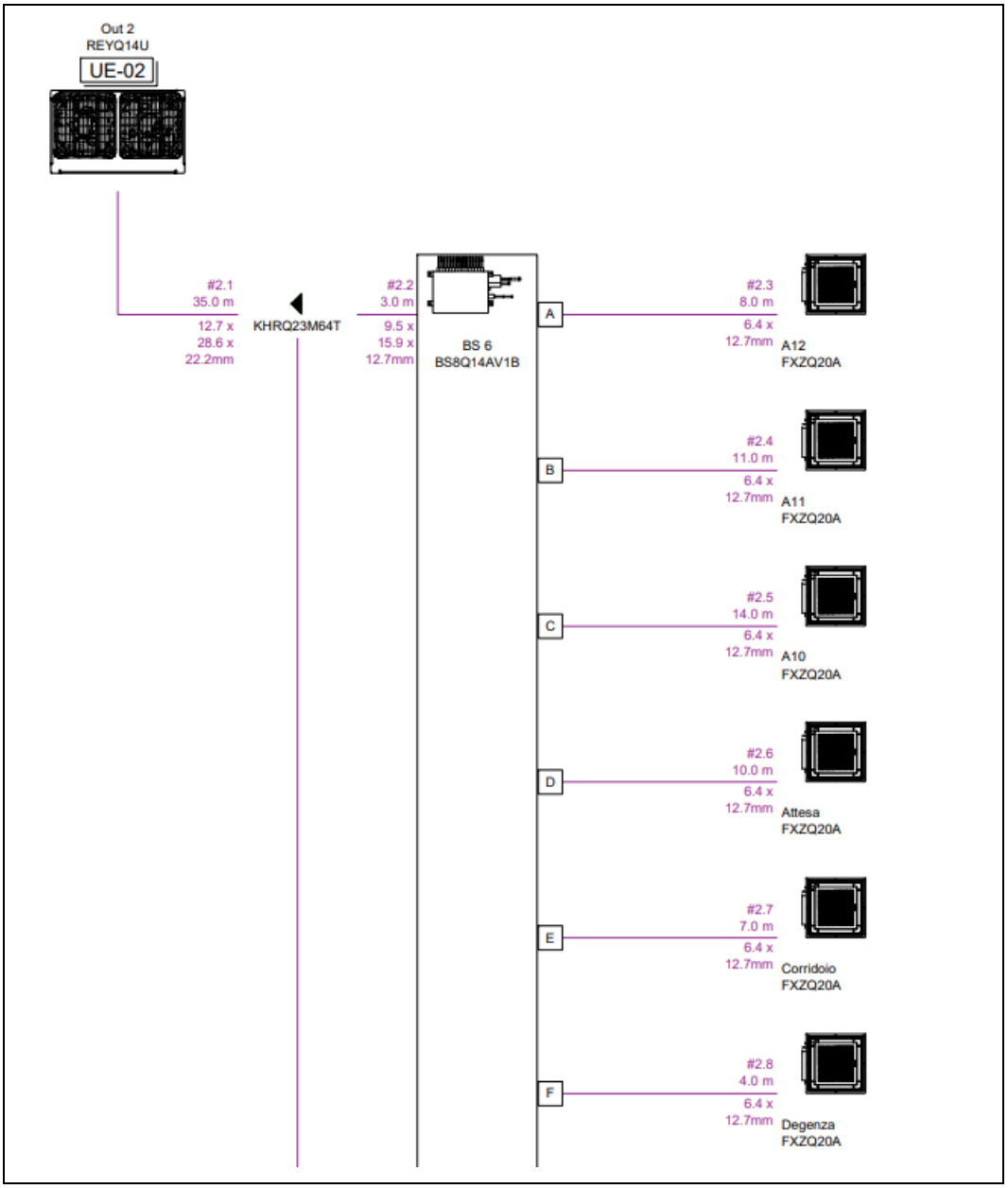


Figure 2.6: Scheme of VRV System

2.3. Domestic Hot Water System Design

The methodology will describe the main aspects of design of a domestic hot water system comprised of a heat pump double system consisting of an outdoor unit, an indoor unit, and two redundant domestic hot water tanks for an instantaneous DHW production system. This configuration as seen in Figure 2.7 and is connected to the network of hot water pipes that is spread throughout the building.

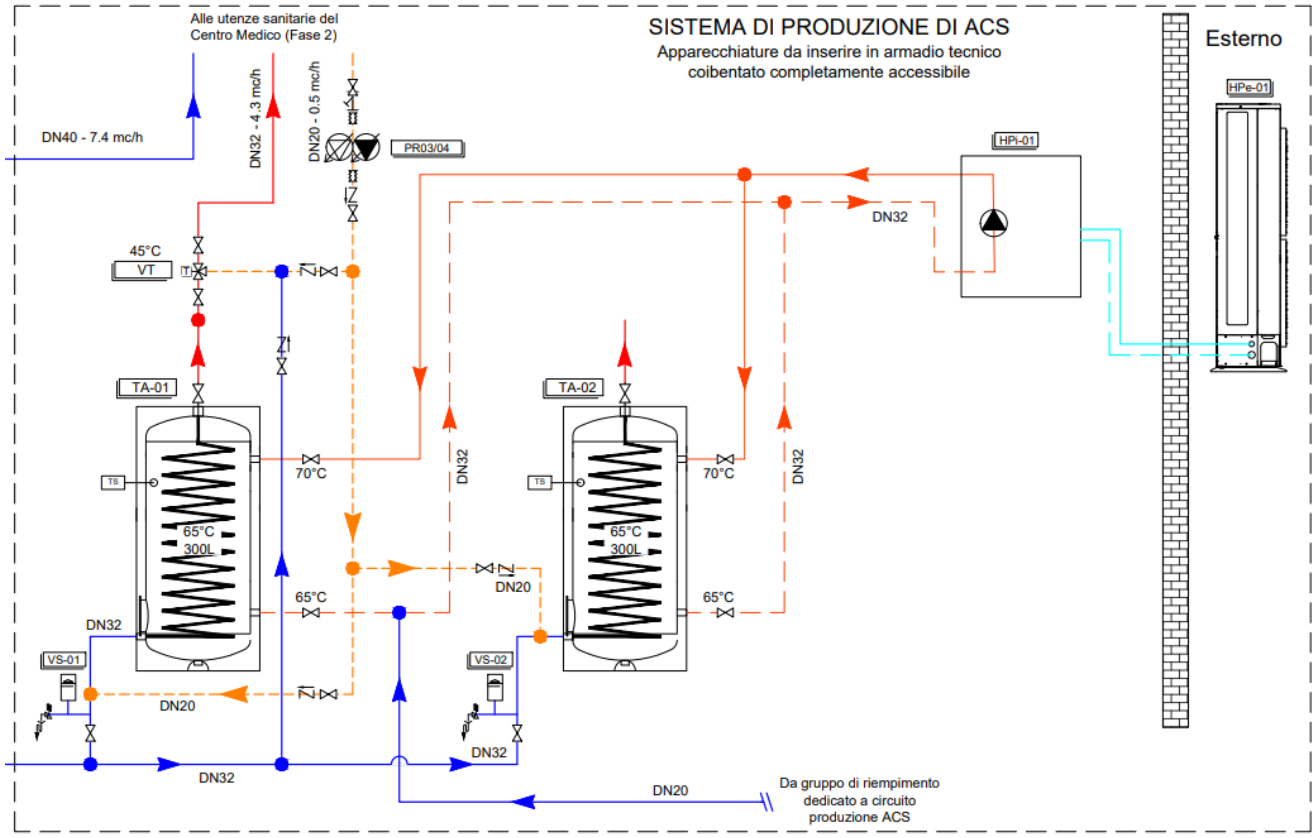


Figure 2.7: Scheme of Heat Pump/Hot Water Tank System

2.3.1. Hot Water Tank and Heat Pump Sizing

The hot water tank sizing considers many inputs pursuant to the Italian standard UNI 9182:2014 [24]. The first input is the total peak consumption of hot water. The only utility that requires hot water in the clinic are washbasins. For each washbasin, their peak consumption is evaluated based on their function/location in the building; either to be used in the WC, in clinic rooms or surgery block. The peak consumption was estimated based on prior projects' values to avoid overestimations. The total peak consumption ($C_{\substack{total \\ peak}}$) in [liters] is calculated as the summation of the products of each

washbasin's peak consumption in [liters] by their number in the building as seen in equation 2.11:

$$C_{\underset{peak}{total}} = C_{\underset{peak}{WC}} \times N_{WC} + C_{\underset{peak}{Clinic}} \times N_{Clinic} + C_{\underset{peak}{surgery}} \times N_{surgery} \quad 2.11$$

The second input is the usage temperature (T_{usage}) in [°C] which is the temperature at the outlet of the faucet and has a value of 40 °C [24].

The third input is the cold water temperature (T_{cold}) in [°C]. Its value depends on many factors like the ground temperature, the outside temperature, and the area of origin. In practice, however, it can be assumed:

- 10-12 °C in Northern Italy
- 12-15 °C in central Italy
- 15-18 °C in southern Italy [24]

The fourth input is the average storage temperature ($T_{storage}$) in [°C]. This temperature should be higher than 60 °C to overcome legionella disease and maintain the cleanliness of the potable water. The fifth and sixth inputs are the duration of the peak load (d_{peak}) in [h] and duration of preheating ($d_{preheat}$) in [h] which are assessed based on Table 2.3:

TAB. 2 - DATI PER IL CALCOLO DEI BOLLITORI

TIPO UTENZA	Consumi nei periodi di punta		temperatura utilizzo	periodo punta	periodo prerisc.
Edifici Residenziali	260 l 340 l	per ogni alloggio con 1 locale servizi (1) per ogni alloggio con 2 locali servizi (1)	40°C	1,5 h	2,0 h
Uffici e Simili	40 l	per servizi (WC+lavabo)	40°C	1,5 h	2,0 h
Alberghi, Pensioni e Simili (4)	180 l 130 l	per camere con servizi dotati di vasca per camere con servizi dotati di doccia	40°C	(2)	2,0 h
Ospedali (4)	120 l	per ogni posto letto	40°C	2,0 h	2,0 h
Cliniche (4)	150 l	per ogni posto letto	40°C	4,0 h	2,0 h
Caserme, Collegi e Simili (4)	80 l	per ogni posto letto	40°C	2,0 h	2,0 h
Palestre e Centri Sportivi	150 l 60 l	per ogni doccia per ogni rubinetto	40°C	0,3 h	1,5 h
Spogliatoi di Stabilimenti	150 l 60 l	per ogni doccia per ogni rubinetto	40°C	0,3 h	(3)

Table 2.3: UNI 9182 Data for Calculating Hot Water Tank [24]

The total heat needed to heat the water required in peak period (Q_{peak}^{total}) in [kcal] is calculated as the multiplication of the total peak consumption ($C_{\substack{total \\ peak}}$) in [liters] by the difference between the usage temperature (T_{usage}) in [°C] and the cold water temperature (T_{cold}) in [°C] by the heat capacity of water in [kcal/(kg.°C)] by the density of water in [kg/m³] divided by 1000 [l/m³] as seen in equation 2.12:

$$Q_{peak}^{total} = \frac{C_{\substack{total \\ peak}} \times cp_{water} \times \rho_{water} \times (T_{usage} - T_{cold})}{1000} \quad 2.12$$

The hourly heat required (Q_{hourly}) in [kcal/h] is calculated as the total heat needed to heat the water required in peak period ($Q_{\substack{total \\ peak}}$) in [kcal] divided by the summation of the duration of the peak load (d_{peak}) in [h] and duration of preheating ($d_{preheat}$) in [h] as seen in equation 2.13:

$$Q_{hourly} = \frac{Q_{\substack{total \\ peak}}}{(d_{peak} + d_{preheat})} \quad 2.13$$

Therefore, the heat pump minimum power required ($P_{\substack{heat \\ pump}}$) to supply the usage temperature in [W] is equal to the hourly heat required (Q_{hourly}) in [kcal/h] multiplied by the conversion factor 1.163 [W.h/kcal] as seen in equation 2.14:

$$P_{\substack{heat \\ pump}} = 1.163 \times Q_{hourly} \quad 2.14$$

The heat to be accumulated in the tank ($Q_{\substack{tank \\ Acc.}}$) in [kcal] is calculated by the multiplication of the hourly heat required (Q_{hourly}) in [kcal/h] by the duration of preheating ($d_{preheat}$) in [h] as seen in equation 2.15:

$$Q_{\substack{tank \\ Acc.}} = Q_{hourly} \times d_{preheat} \quad 2.15$$

Therefore, the minimum volume of the hot tank (V_{tank}) in [liters] can be calculated by the multiplication of the heat to be accumulated in the tank ($Q_{\substack{tank \\ Acc.}}$) in [kcal] by 1000 [l/m³] divided by the heat capacity of water in [kcal/(kg.°C)] by the density of water in

[kg/m³] by the difference between the average storage temperature ($T_{storage}$) in [°C] and the cold water temperature (T_{cold}) in [°C] as seen in equation 2.16.

$$V_{tank} = \frac{\underset{Acc.}{Q_{tank}} \times 1000}{cp_{water} \times \rho_{water} \times (T_{storage} - T_{cold})} \quad 2.16$$

After determining the minimum required volume of the hot water tank, that value is a baseline to select the actual tank volume which is significantly increased incorporating a safety factor. Afterwards, equation 2.16,2.15 and 2.14 are utilized to determine the actual size of the heat pump system corresponding to the selected hot water tank.

2.3.2. Flowrate and Piping Evaluation

The methodology used to evaluate the required flowrates and corresponding size of the domestic hot water and cold water galvanized steel pipes is based on the recommendations of Italian standard UNI 9182:2014 [24].

First, assessment of the so called "load unit" for each sanitary appliance including washbasins, sinks, kitchen sinks is conducted.

This assessment is done using Table 2.4. It details the load unit values for each different utility for both cold water and hot water.

Unità di carico (UC) per le utenze degli edifici ad uso pubblico e collettivo (alberghi, uffici, ospedali, ecc.)

Apparecchi singoli

Apparecchio	Alimentazione	Unità di carico		
		Acqua fredda	Acqua calda	Totale acqua calda + acqua fredda
Lavabo	Gruppo miscelatore	1,50	1,50	2,00
Bidet	Gruppo miscelatore	1,50	1,50	2,00
Vasca	Gruppo miscelatore	3,00	3,00	4,00
Doccia	Gruppo miscelatore	3,00	3,00	4,00
Vaso	Cassetta	5,00	-	5,00
Vaso	Passo rapido o flussometro	10,00	-	10,00
Orinatoio	Rubinetto a vela	0,75	-	0,75
Orinatoio	Passo rapido o flussometro	10,00	-	10,00
Lavello	Gruppo miscelatore	2,00	2,00	3,00
Lavatoio di cucina	Gruppo miscelatore	3,00	3,00	4,00
Pilozzo	Gruppo miscelatore	2,00	2,00	3,00
Vuotatoio	Cassetta	5,00	-	5,00
Vuotatoio	Passo rapido o flussometro	10,00	-	10,00
Lavabo a canale (per ogni posto)	Gruppo miscelatore	1,50	1,50	2,00
Lavapiedi	Gruppo miscelatore	1,50	1,50	2,00
Lavapadelle	Gruppo miscelatore	2,00	2,00	3,00
Lavabo clinico	Gruppo miscelatore	1,50	1,50	2,00
Beverino	Rubinetto a molla	0,75	-	0,75
Doccia di emergenza	Comando a pressione	3,00	-	3,00
Idrantino ∅ 3/8"	Solo acqua fredda	2,00	-	2,00
Idrantino ∅ 1/2"	Solo acqua fredda	4,00	-	4,00
Idrantino ∅ 3/4"	Solo acqua fredda	6,00	-	6,00
Idrantino ∅ 1"	Solo acqua fredda	10,00	-	10,00

Table 2.4: UNI 9182 Load Unit per Utility [24]

Second, after calculating the load unit for each of the utilities that requires potable water like washbasins, sinks and kitchen sinks, the summation of load units at various intervals of the piping layout is performed. This is done by selecting section points in the piping network and evaluating the number and type of utilities connected to this section point.

Third, Table 2.5 is used to convert the summation of load units into water flow rates in [l/s].

Utenze delle abitazioni private e degli edifici collettivi (alberghi, ospedali, scuole, caserme, centri sportivi e simili)

Vasi con cassette

Unità di carico UC	Portata l/s	Unità di carico UC	Portata l/s	Unità di carico UC	Portata l/s
6	0,30	120	3,65	1 250	15,50
8	0,40	140	3,90	1 500	17,50
10	0,50	160	4,25	1 750	18,80
12	0,60	180	4,60	2 000	20,50
14	0,68	200	4,95	2 250	22,00
16	0,78	225	5,35	2 500	23,50
18	0,85	250	5,75	2 750	24,50
20	0,93	275	6,10	3 000	26,00
25	1,13	300	6,45	3 500	28,00
30	1,30	400	7,80	4 000	30,50
35	1,46	500	9,00	4 500	32,50
40	1,62	600	10,00	5 000	34,50
50	1,90	700	11,00	6 000	38,00
60	2,20	800	11,90	7 000	41,00
70	2,40	900	12,90	8 000	44,00
80	2,65	1 000	13,80	9 000	47,00
90	2,90			10 000	50,00
100	3,15				

Table 2.5: UNI 9182 Load Unit to Flowrate Conversion [24]

Forth, the total flow rate value acquired after assessing the entire building and all the utilities $\dot{V}_{water}$ informs the total flow rate requirement for hot water which is connected to the heat pump and hot water tank system. The total flow rate requirement for cold water is also assessed and informs the value needed to be extracted from the existing cold water network.

Fifth, using the continuity equation, the minimum diameter of the tube (d_{min}) in [mm] is calculated as 2 multiplied by the square root of the product of the water flowrate ($\dot{V}_{water}$) in [l/s] by 10^3 divided by the product of the maximum acceptable velocity (c_{max}) in [m/s] by π as seen in equation 2.17. The maximum acceptable velocity c_{max} is set at 2 m/s based on practical experience.

$$d_{min} = 2\sqrt{\frac{\dot{V}_{water} \times 10^3}{\pi \times c_{max}}} \quad 2.17$$

Sixth, the minimum internal diameter (d_{min}) is then converted to nominal diameter (DN) values. This is assessed at various section points in the network to size the different sections of the piping.

2.4. Surgical Block System Design

2.4.1. Surgical Block Design Parameters

The aim of the methodology is to investigate the main mechanical aspects of a ventilation and air conditioning system capable of meeting the requirements of a fully functioning surgery block. The surgery block should achieve ISO 7 air quality level for "operating rooms with high air quality". The air quality standards are defined in line with the ISO 14644-1 standards [1] as seen in Table 1.1. The achievement of the ISO 7 air quality standard is elaborated on in the upcoming section 2.4.5.

Additionally, the surgery block system design must adhere to all other recommendations in line with the guidelines of Italian standard UNI 11425:2011 [10]. Therefore, the main parameters that should be achieved are specified in Table 2.6.

The most critical rooms to any surgery block design are the surgery or operating rooms. In the case study, two surgery rooms correspond to the room type "Sale opertorie a elevata qualita dell'aria" from Table 2.6. The criteria that they must adhere to are:

1- Indoor temperature and relative humidity conditions for summer ($T_{db\ summer} \leq 24°C$, $RH_{summer} \leq 60\%$) and winter ($T_{db\ winter} \geq 20°C$, $RH_{winter} \geq 40\%$)
2- Overpressure with respect to the outside with a positive pressurization of +15 Pa compared to the areas outside of the surgery block
3- Air replacement rate of 15 vol/h in the surgery room
4- Requirement of recirculation of air in the system
5- Final level of filtration achieved through the utilization of HEPA H14 filters.
6- Sound pressure level of 45 dBA

The special requirements for surgery rooms are highlighted when compared to the standard ventilation requirements for "regular" rooms that were addressed in section 2.1.1. The requirements for indoor temperature and relative humidity are similar in both as they are general guidelines for summer and winter thermal comfort; however, the need for a specific value of overpressure is solely indicated for surgery room design due to the need for contamination control from the external areas. Moreover, the 15 vol/h air replacement rate for surgery rooms is not contingent on the occupancy as is the case for "regular" rooms ($\leq 0.011\ m^3/s$/person) and aims to ensure high turnover of air to maintain the air cleanliness levels and contaminant removal. In a similar sense, air introduced into surgery rooms must be properly filtered to a high level before it is supplied which is not a necessity in "regular" rooms. Acceptable sound pressure levels for all types of rooms are achieved through ventilation units with properly insulated components like fans, motors, ducts, and accessories to prevent mechanical noise propagation in the false ceiling of any building. Moreover, the proper positioning of

these components in strategic areas mitigates noise pollution alongside the work of duct silencers and attenuated dampers and grills.

prospetto B.2 **Parametri ambientali nei blocchi operatori**

Ambienti	Temperatura [°C]		Umidità relativa [%]		Sovrapressione rispetto all'esterno	Aria esterna	Aria di ricircolo	Classi di pulizia secondo UNI EN ISO 14644-1	Livello di filtrazione finale	Livello di pressione sonora
	Inverno	Estate	Inverno	Estate	[Pa]	[vol/h]	[-]			[dBA]
Sale operatorie a elevatissima qualità dell'aria	≥ 20	≤ 24	≥ 40	≤ 60	15[1)]	15	SI[2)]	ISO 5	H 14	45[3)]
Sale operatorie a elevata qualità dell'aria					15[1)]	15	SI[2)]	ISO 7	H 14	45[3)]
Sale operatorie a qualità dell'aria standard					15[1)]	15	- [4)]	ISO 8	H 14	45[3)]
Depositi sterili	≥ 22	≤ 26	≥ 40	≤ 60	15	≥ 2 [5)]	- [4)]	-	H 14	45
Preparazione operandi					10	≥ 2 [5)]	- [4)]	-	≥ H12	-
Preparazione personale					10	≥ 2 [5)]	- [4)]	-	≥ H12	-
Risveglio operati					10	≥ 2 [5)]	- [4)]	-	≥ H12	-
Corridoio pulito/sterile					10	≥ 2 [5)]	- [4)]	-	≥ H12	-
Spazi filtro operandi					5	≥ 2 [5)]	- [4)]	-	≥ F9	-
Spazi filtro personale					5	≥ 2 [5)]	- [4)]	-	≥ F9	-
Substerilizzazione					10	≥ 2 [5)]	- [4)]	-	≥ H12	-
Depositi pulito	≥ 18	≤ 26	≥ 40	≤ 60	10	≥ 2 [5)]	- [4)]	-	≥ H12	-
Depositi sporchi					5	≥ 2 [5)]	NO	-	≥ F9	-

Note:
1) Le sale operatorie ad uso di pazienti infetti, sono in depressione rispetto ai locali limitrofi.
2) Si faccia riferimento agli esempi proposti in appendice D.
3) Nel caso di ristrutturazioni in cui sia necessario realizzare sale operatorie in classe ISO 5 utilizzando sistemi di ricircolo in ambiente, si può al massimo raggiungere i 48 db(A); tale scelta deve essere motivata nel documento di progetto
4) Secondo la necessità di pulizia dell'aria nonché dal controllo.
5) Valore minimo da assumere in assenza di altri valori che stabiliti in funzione delle esigenze specifiche di affollamento, delle sorgenti di contaminanti e basata sull'analisi del rischio.

Valori imposti dalla legislazione vigente (Decreto del Presidente della Repubblica del 14/1/1997)

Table 2.6: UNI 11425 Parameters for Operating Block [10]

Additionally, a specification for recirculation of air is only ascribed to surgery rooms in Appendix D of the Italian standard UNI 11425. The Appendix provides some examples of design solutions to be adopted for correct design and installation of the system. In example type 1, the Italian standard specifies that the system should consist of an external air and recirculated air treatment unit dedicated to each operating room (and possibly to its support rooms), flanked by further treatment units for the remaining rooms of the operating block [10]. The schemes are depicted in Figure 2.8 where scheme (1) and scheme (2) are interchangeable.

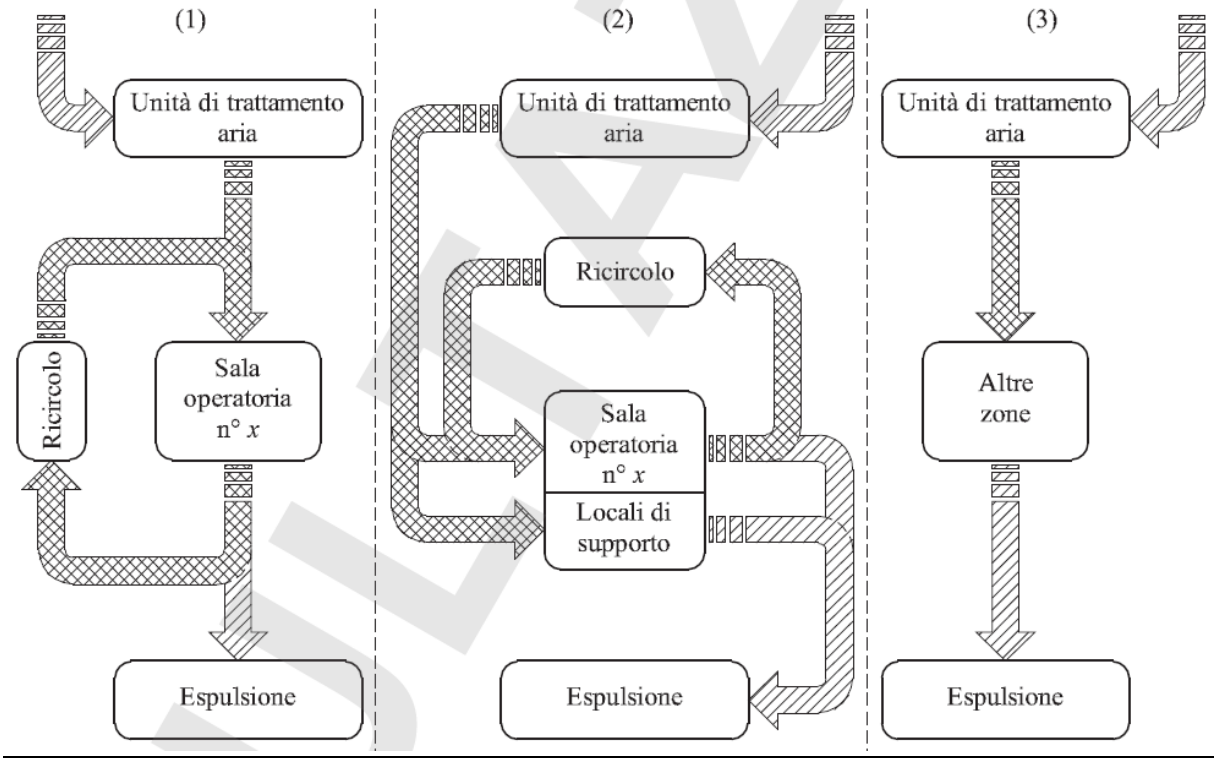


Figure 2.8: UNI 11425 Recirculation Schemes [10]

However, in the case study configuration, no recirculation of air is utilized since it would require an air handling unit for each individual room in a surgery block as stated above. The fresh air intake of the AHU is equal to the total supply to the rooms and the return air is fully extracted back to the unit for expulsion with no recirculation throughout the network. Economic considerations by the client to a large extent and spatial constraints to a lesser extent informed this design choice to use one air handling unit for the entire block while eliminating the idea of air recirculation.

2.4.2. Mechanical System Configuration

The selected configuration for the mechanical system is comprised of an air handling unit with heat recovery applied to recover and reuse the thermal energy from the exhaust airflow and acts as an initial step of preheating the incoming fresh air. However, there is no temperature control on the heat recovery. Therefore, a build-in preheating coil is present in the AHU to guarantee the correct temperature is achieved inside the AHU and as a safety measure in case of any failure in the heat recovery. The heat recovery section is indicated by the red rectangle in Figure 2.9. The locations of the preheating coil and the cooling coil are indicated by the yellow and blue rectangles respectively.

Therefore, after the heat recovery section, the AHU facilitates both winter and summer operation through the functioning of preheating coil sized for operating in winter conditions, cooling coil sized for operating in summer conditions and finally a humidification section. The AHU is capable of supplying and returning the adequate airflow for the treated surgery block as seen in Figure 2.9.

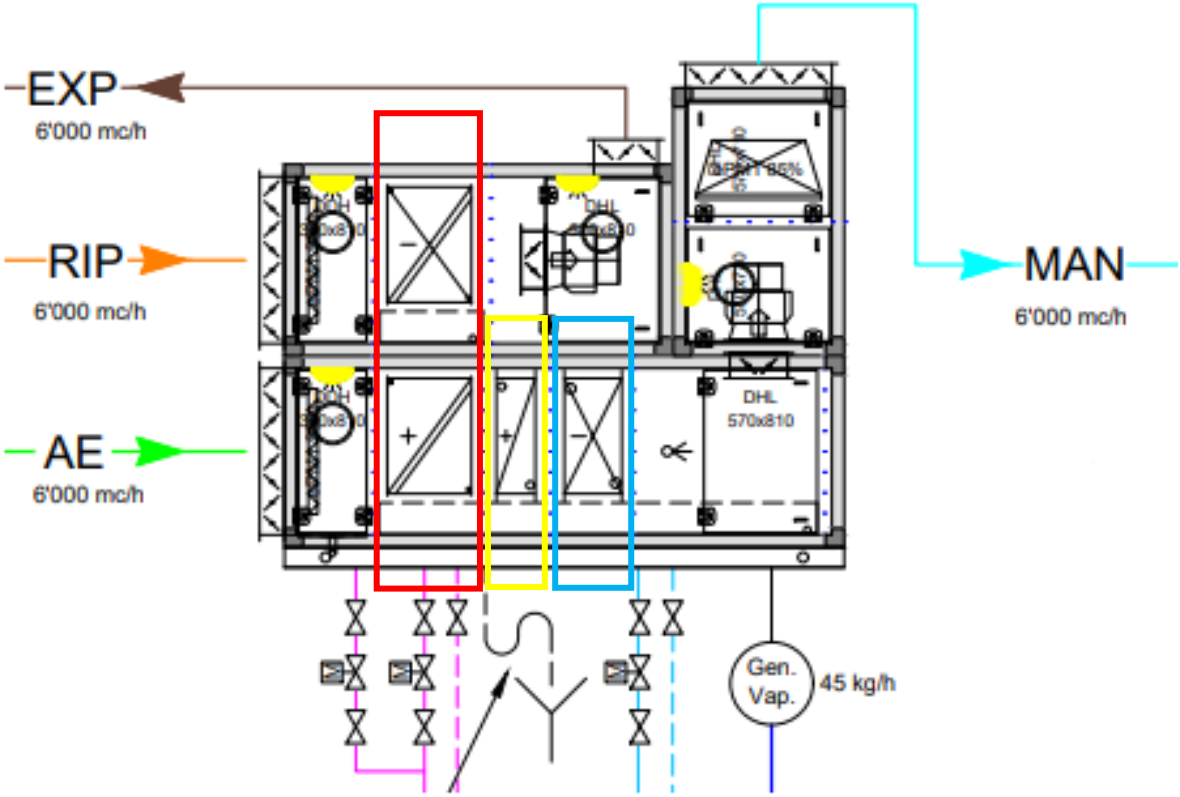


Figure 2.9: Surgery Block Air Handling Unit Scheme

The steam generator connected to the humidification section is supplied by the pre-existing cold water network, whereas the preheating and cooling coil are fed with hot water and chilled water respectively by a 4-pipe multifunction heat pump as seen in Figure 2.10. The multifunction heat pump provides independent simultaneous production of hot and chilled water of calculated flowrates and at appropriately selected water temperatures to facilitate the proper functioning of the coils. The selected temperatures are 45°C and 40°C for hot water supply and return respectively. The selected temperatures are 7°C and 12°C for chilled water supply and return respectively. Additionally, the multifunction heat pump also feeds post-heating coils with the hot water. The post-heating coils (PH-0X) in this configuration are not built-

in components of the air handling unit but rather are situated on the four supply air flow ducts that treat different areas of the surgery block as schematized in Figure 2.11. The sizing of all these coils with required power and flowrates in addition to the air flow handled by the AHU represent the main criteria to be assessed in this mechanical configuration. Moreover, the essential aspects that underpin the AHU system and design of a surgery block are cooling load evaluation, air exchange rate, air quality, temperature, humidity, and room pressurization.

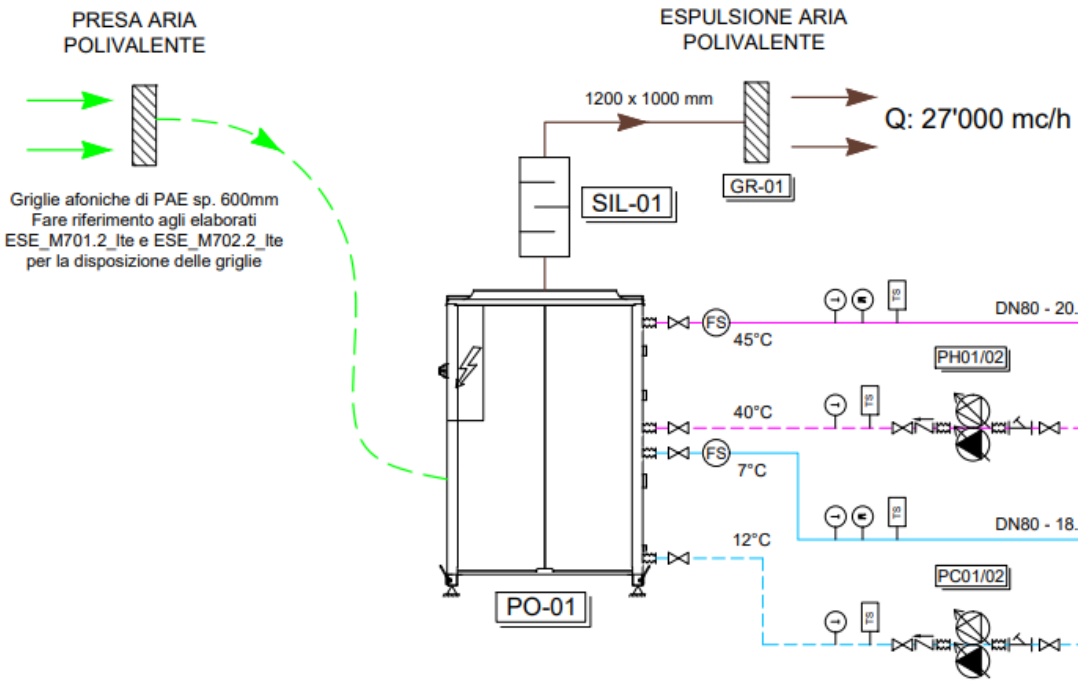


Figure 2.10: 4-pipe Multifunction Heat Pump Scheme

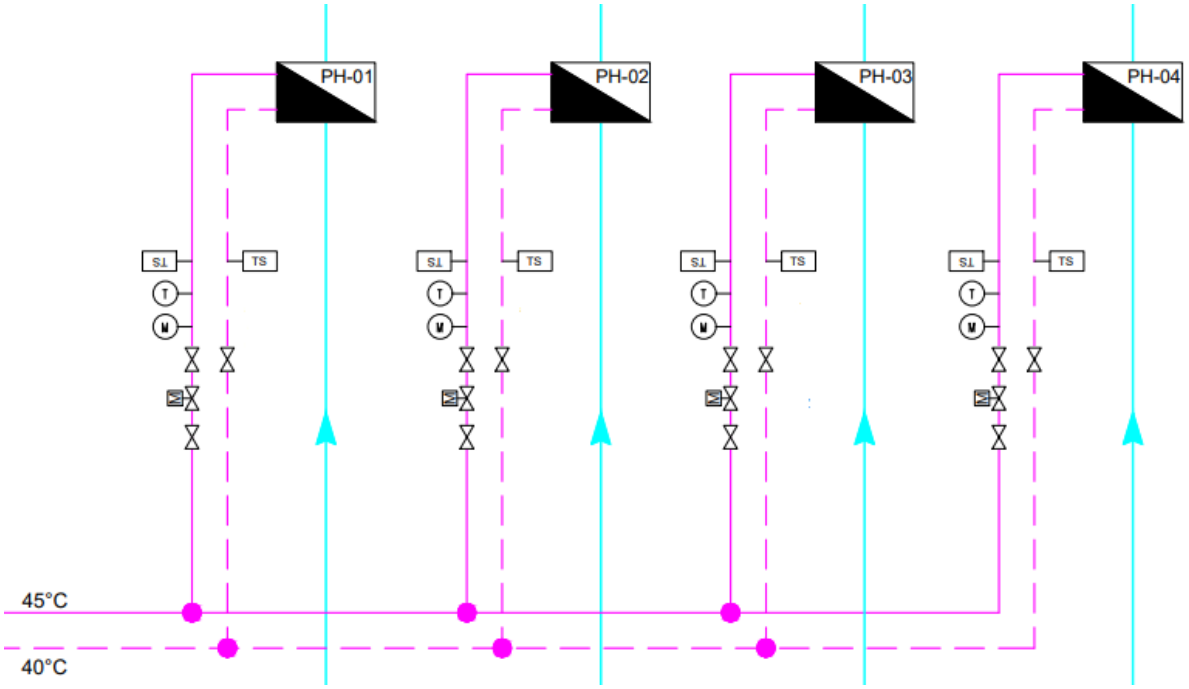


Figure 2.11: Post-Heating Coils Scheme

2.4.3. Cooling Load Evaluation

The methodology utilized for cooling load evaluation of the surgery block was conducted in a similar fashion to the one elaborated in section 2.2.1. However, the designated internal loads refer to some different aspects specific to the surgery room. Mainly, the operating room equipment internal loads must be incorporated.

For each designated area in a surgery block, the total sensible cooling load ($L_{sensible}^{total}$) in [kW] to be treated is roughly estimated as the sum of the internal loads, as in equation 2.9 and 2.10. Therefore, the summation of the light load (L_{lights}) in [kW], equipment load $(L_{equipment})$ in [kW] and occupant load ($L_{occupants}$) in [kW] are considered in equation 2.18:

$$L_{sensible}^{total} = L_{lights} + L_{equipment} + L_{occupants} \quad 2.18$$

Afterwards, for each area, the supply air flowrate needed for cooling $(\dot{V}_{cooling})$ in [m³/h] is calculated as the multiplication of the total sensible cooling load ($L_{sensible}^{total}$) in [kW] by 3600 in [s/h] divided by the density of air (ρ_{air}) in [kg/m³] by heat capacity of air (cp_{air}) in [kJ/(kg.°C)] by the temperature difference between the supply air to the room and the ambient air in the room (ΔT_{air}) in [°C] as seen in equation 2.19:

$$\dot{V}_{cooling} = \frac{L^{\,total}_{\,sensible} \times 3600}{\rho_{air} \times cp_{air} \times \Delta T_{air}} \quad 2.19$$

The evaluation of the temperature difference between the supply air sent to the room and the ambient air in the room depends on the type of flow introduction into the designated room. The selection of the type of flow is a design choice.

The Italian standard UNI 11425 specifies conditions for utilizing mixed unidirectional airflow as follows: "In the case of mixed unidirectional flow, the air introduced during the cooling phase, must be at a temperature between 0.5°C and 2°C below the ambient temperature"[10]. The critical area is defined as the central area encompassing the surgical table (location of the surgical operation) and all its ancillary equipment.

The Italian standard does not explicitly discuss the case of turbulent airflow introduction; however, it can be inferred from the above specification for mixed unidirectional airflow, that the Italian standard UNI 11425 does not set a limit on the temperature difference for turbulent airflow; therefore, it can exceed 2 °C. Thus, this flexibility in (ΔT_{air}) allows a degree of freedom when evaluating the supply air flowrate needed for cooling. Increasing this value leads to a reduction in the airflow to be handled; thus, a more compact and less expensive AHU can be selected. Therefore, the airflow pattern in the case study was selected as turbulent airflow to minimize costs per the clients wishes.

2.4.4. Air Replacement Rate

For each of the designated areas, the recommended total supply air flowrate ($\dot{V}_{rec}$) in [m^3/h] based on the air replacement factor as is calculated as the multiplication of the area of the room (A) in [m^2] by the height of the room (H) in [m] by the air replacement factor (R) in [vol/h] as seen in equation 2.20:

$$\dot{V}_{rec} = A \times H \times R \quad 2.20$$

The air replacement factor for the surgery room as an example is 15 vol/h as specified in section 2.4.1. After evaluation of equations 2.17, 2.19 and 2.20 for each designated room, the maximum value between the ($\dot{V}_{cooling}$) and ($\dot{V}_{rec}$) is selected. This ensures that the selection of supply air flowrate satisfies both the ventilation recommendation and cooling load requirements for the designated areas. Therefore, the selected supply

air flowrate ($\dot{V}_{selected}$) in [m³/h] of the AHU is the summation of the maximum values between ($\dot{V}_{cooling}$) and ($\dot{V}_{rec}$) of all the designated areas. Moreover, it is the first calculated input for the sizing of the air handling unit.

2.4.5. Air Quality and Filtration

Air quality in a surgery block and more specifically in a surgery room is of the utmost importance to avoid bacterial and viral contamination during procedures. Properly established particulate concentration levels safeguard patients and doctors from disease and infection. Class ISO 7 air quality dictates that the maximum allowable concentration for particles of diameter 0.5 μm or greater is 352,000 particles/m³ and of diameter 1 μm or greater is 83,200 particles/m³ and of diameter 5 μm or greater is 2,930 particles/m³.The achievement of this criterion is aided by the Italian standard's recommendation of utilizing High Efficiency Particulate Air (HEPA) filters at the terminal section of the supply duct directly before introduction into the designated rooms [10]. The HEPA H14 absolute filter is considered medical grade and boasts a capture efficiency of 99.995% for all particles of diameter greater than or equal to 0.2 μm. In practice, H14 filters are placed at the terminal position of the supply air flow ducts in addition a redundancy of H14 filters is placed strategically up the line of the supply ducts as a safety precaution to ensure the desired air quality.

Moreover, it is recommended to use two levels of filtration to prevent the dirtying of the components of the AHU and of the ducts. Pre-filtration carried out with a filter of minimum efficiency equal to F6 built-in at entrance of the air handling unit. F6 is a synthetic bag filter defined with an Average Efficiency (Em) of 0.4 μm particles where 60% ≤ Em < 80% according to EN 779:2012 [25]. This keeps the AHU clean. In addition, filtration is carried out with an F9 efficiency synthetic bag filter incorporated into the outlets of the AHU to keep the delivery ducts towards the surgical block clean [10]. F9 is a synthetic bag filter defined with an Average Efficiency (Em) of 0.4 μm particles where 95% ≤ Em according to EN 779:2012 [25]. These methods of filtration and other redundancies ensure the air quality within the controlled rooms and preserve the health of the AHU and its network of components and ducts.

2.4.6. Temperature and Humidity

The temperature and humidity control of the surgery block is ensured through control system set points with adequate temperature and humidity sensors throughout the design. These set points are informed by the Italian standard UNI 11425 for summer and winter seasons as seen in Table 2.6. The control system manages the proper functioning of the pre-heating, post-heating, cooling coils and steam generator corresponding to the air handling unit. These components must be properly sized to ensure flexibility of ranges when dealing with any disruption or change in the external environment conditions.

2.4.6.1. Cooling Coil Sizing

The cooling coil is sized to operate in summer conditions. The enthalpy of the external summer conditions ($h_{external}$) is evaluated at the selected values of high temperature summer conditions. Whereas the enthalpy at the cooling coil ($h_{\substack{cooling\\coil}}$) is evaluated at the selected values of cooling coil functioning based on practical experience. For the surgery block, the required cooling power of the cooling coil to achieve the full range of possible enthalpy jump ($P_{cooling}^{total}$) in [kW] is calculated as the multiplication of selected supply air flowrate ($\dot{V}_{selected}$) in [m³/h] by the density of air (ρ_{air}) in [kg/m³] by the difference between the enthalpy at external summer conditions and the enthalpy at the coiling coil for the selected conditions ($h_{external} - h_{\substack{cooling\\coil}}$) in [kJ/kg] divided by the 3600 [s/h] as seen in equation 2.21:

$$P_{cooling}^{total} = \frac{\dot{V}_{selected} \times \rho_{air} \times (h_{external} - h_{\substack{cooling\\coil}})}{3600} \quad 2.21$$

The total cooling power ($P_{cooling}^{total}$) in the surgery block gives the required power for the cooling coil which is another input for selection of the AHU. In addition, that value informs the capacity sizing of the 4 - pipe multifunction pump.

The cooling coil water flowrate required ($\dot{V}_{water,C}$) in [l/h] is calculated as the multiplication of the total cooling power ($P_{cooling}^{total}$) in [kW] by 3600 [s/h] by 1000 [l/m³] divided by the density of water (ρ_{water}) in [kg/m³] by the heat capacity of water (cp_{water}) in [kJ/(kg.°C)] by the temperature difference of water exiting and entering the cooling coil (ΔT_{water}) in [°C] as seen in equation 2.22:

$$\dot{V}_{water,C} = \frac{P_{cooling}^{total} \times 3600 \times 1000}{\rho_{water} \times cp_{water} \times \Delta T_{water}} \quad 2.22$$

2.4.6.2. Heating Coils Sizing

The required heating power of the preheating coil and post-heating coils ($P_{heating}$) in [kW] is calculated as the multiplication of the selected supply air flowrate based on the coil placement ($\dot{V}_{selected}$) in [m³/h] by the heat capacity of air (cp_{air}) in [kJ/(kg.°C)] by the density of air (ρ_{air}) in [kg/m³] by difference in temperature between the outlet air (T_{air}^{out}) and the inlet air (T_{air}^{in}) in [°C] divided by 3600 [s/h] as seen in equation 2.23. The preheating coil is sized to operate in winter conditions which informs the air

temperature selection. The post heating coil is sized to operate in summer conditions which informs the air temperature selection.

$$P_{heating} = \frac{\dot{V}_{selected} \times cp_{air} \times \rho_{air} \times (T_{air}^{out} - T_{air}^{in})}{3600} \quad 2.23$$

The heating coil water flowrate required ($\dot{V}_{water,H}$) in [l/h] is calculated as in equation 2.22, by replacing $P_{cooling}^{total}$ with $P_{heating}$ and by considering the proper ΔT_{water}.

2.4.6.3. Humidifier

An AHU will have a humidification section located after the preheating and cooling coils. Its role is to ensure suitable vaporized water when needed to humidify the air exiting the AHU and satisfying the desired indoor conditions as prescribed by the Italian standard UNI 11425. The control system with the aid of humidity and temperature sensors will evaluate the external air conditions and then act on an external electric steam generator connected to the AHU humidification section to provide the needed water quantity. As a company practice and to guarantee flexibility of design, the maximum difference between the humidity ratio at recommended indoor conditions (e.g. design winter condition as in Table 2.6, $T_{drybulb}$ = 20°C, RH = 40%) and the humidity ratio at extreme outdoor conditions with low temperature and low relative humidity ($T_{drybulb}$ = -5 °C, RH = 5%) in [kg_{water}/kg_{dryair}] is assessed. This full range value is a design input relayed to the manufacturer for the AHU design. Thus, ensuring that the control system has the necessary operating range when dealing with any humidity condition variations.

2.4.7. Room Pressurization

Pressurization aims at guaranteeing the cleanliness of the surgery room. This avoids the entrance of contaminants carried by the air from the less controlled neighbouring spaces. Air flows travels from an adjacent room through crevasses in the doors and access points into the sterile controlled environment. The pressure gradient between these rooms is the primary component that dictates the direction of the airflow. Positive pressurization of the controlled rooms expels the flow outwards and with it any air suspended contaminants. Therefore, the pressurization of surgery rooms must be kept positive with respect to its exterior surroundings to ensure its pristine cleanliness [26].

The pressurization is maintained by utilizing differential pressure probes. These probes send feedback to the controlling system which in turn acts on the flow

controlling equipment. Flow controlling equipment include motorized flow regulators and constant flow regulators which can implement flow variations depending on the desired set points in the controlling system. This is because pressurization is achieved by creating a difference between the volumetric air flow supply and the volumetric air flow return in a designated room. Usually, the amount of returned or extracted air is reduced to facilitate the required pressure difference. The Italian standard UNI 11425 recommends the pressure difference in Pascals. For example, as seen in Table 2.6 the recommended pressure difference for an operating room with high air quality is a positive +15 Pa gradient with respect to the surrounding rooms.

3 Outpatient Center Results

This chapter describes the results of the design of the ventilation system, the cooling system, domestic hot water system and surgery block design for the outpatient and diagnostic center described in the Introduction.

3.1. Ventilation System Results

3.1.1. Flowrate Outcomes

The relevant rooms in the outpatient center include hospital bedrooms, corridors, clean rooms, physical therapies which, based on the Italian standard UNI 10339, require a minimum recommended supply air flowrate factor of 0.011 m^3/s/person. The medical rooms/living areas require a minimum recommended supply air flowrate factor 0.0085 m^3/s/person. Moreover, the services rooms which include bathrooms, locker rooms, technical rooms and deposit areas must be handled with extraction of air for sanitary reasons. Thus, service room ventilation requires a minimum recommended extraction air flowrate factor of 8 volumes/h [21]. This is especially important in an outpatient center where improper ventilation can be detrimental to occupants' and patients' short and long-term health. The recommendations of the Italian standard UNI 10339 and the verified dimensions of the outpatient center are established. They facilitate the evaluation of required supply volumetric air flowrates using equations 2.1. Additionally, the required extraction volumetric air flowrates in the service rooms are calculated using equation 2.2. Afterwards, the overall balancing process of the air flows in all the rooms of the clinic is evaluated adhering to equation 2.3. The required values for all the air flowrates are obtained and rounded up to the nearest tenth as an incremental design safety factor. The results are recorded in Table 3.1 and Table 3.2.

Center Rooms	Area	Height	Volume	Occupancy	Supply Flowrate	Return Flowrate
	[m²]	[m]	[m³]	[person]	[m³/h]	[m³/h]
Desk Radiologia/Corridoio	53.6	3.2	171.52	6	**240**	**240**
Attesa	15.4	3.2	49.28	3	**120**	**120**
A10	14.2	3.2	45.44	3	**100**	**100**
A11	12.9	3.2	41.28	3	**100**	**100**
Filtro a prova di fumo 1	4.2	2.7	11.34	-	**-**	**-**
A12	11.8	3.2	37.76	3	**100**	**100**
Degenza	16	3.2	51.2	2	**80**	**-**
Deposito sporco	2.1	2.7	5.67	-	**-**	**50**
WC pazienti	3.6	2.4	8.64	-	**-**	**80**
WC pazienti	3.8	2.4	9.12	-	**-**	**80**
Degenza	17	3.2	54.4	2	**80**	**-**
Vano Scala	10	-	0	-	**-**	**-**
Filtro a prova di fumo 2	8.8	2.7	23.76	-	**-**	**-**
Attesa/Corridoio	22.2	2.7	59.94	5	**250**	**200**
Refertazione	11.9	3.2	38.08	3	**150**	**150**
Mammografo	11.8	3.2	37.76	3	**150**	**150**
Corridoio	36.4	2.7	98.28	-	**180**	**-**
Control room RX	3.4	2.7	9.18	1	**50**	**-**
Spogliatoio RX	3	2.7	8.1	2	**-**	**70**
Rx	14.4	3.2	46.08	2	**150**	**200**
A13	16.5	3.2	52.8	3	**100**	**100**
A14	13	3.2	41.6	3	**100**	**100**
A15	16.2	3.2	51.84	3	**100**	**100**
Deposito Pulito	5.3	2.7	14.31	-	**-**	**120**
TAC	23.2	3.2	74.24	2	**250**	**250**
WC TAC	3.4	2.4	8.16	1	**-**	**70**
Control room TAC	6	2.7	16.2	1	**50**	**50**
Spogliatoio/emergenza	11.1	2.7	29.97	2	**200**	**240**
Disimpegno	2.8	2.7	7.56	1	**-**	**-**
Spogliatoio TAC	4.9	2.7	13.23	1	**100**	**100**

Table 3.1: Balanced Air Flowrate Results (1/2)

Center Rooms	Area	Height	Volume	Occupancy	Supply Flowrate	Return Flowrate
	[m²]	[m]	[m³]	[person]	[m³/h]	[m³/h]
Ufficio	15.6	2.6	40.56	4	**130**	**130**
Area Break/Cucinotto	38	2.6	98.8	8	**520**	**320**
Vano Scala	10	-	-	-	**-**	**-**
Spogliatoio M	5.8	2.6	15.08	2	**130**	**130**
Antibagno M	1.9	2.4	4.56	1	**-**	**-**
WC M	2	2.4	4.8	1	**-**	**40**
Spogliatoio F	5.9	2.6	15.34	2	**130**	**130**
Antibagno F	2	2.4	4.8	1	**-**	**-**
WC F	1.9	2.4	4.56	1	**-**	**40**
WC H	3.6	2.4	8.64	1	**-**	**70**
Spogliatoio	1.4	2.7	3.78	2	**-**	**40**
Spogliatoio	1.4	2.7	3.78	2	**-**	**40**
LT TRM	8.6	2.7	23.22	1	**200**	**250**
Control Room TRM	22	3.2	70.4	3	**200**	**-**
Total	499		1,415	85	**3,960**	**3,960**

Table 3.2: Balanced Air Flowrate Results (2/2)

Table 3.1 and Table 3.2 account for all the rooms of the outpatient center excluding the surgery block rooms which, as it was already mentioned, are treated for ventilation and air conditioning by a dedicated air handling system to be investigated independently. In addition, the Magnetic Resonance Imaging (MRI) diagnostic room is excluded from the calculations and is investigated by the relevant supplier due to its proprietary nature.

As seen in the two tables, the total supply air flowrate required is equal to the total return air flowrate for the entirety of the center. This is achieved by segmenting the space into regions of balanced ventilation composed of neighboring rooms. The rooms in the first column are color coded to indicate the theoretical regions established where the mass balance is imposed. Taking the green-coded region as an example, initially the technical room and the control room for the MRI named "LT TRM" and "Control Room TRM" respectively each have a calculated supply air flowrate by evaluating equation 2.1. The two locker rooms "Spogliatoio" and the bathroom "WC H" are service rooms subject to only extraction of air by evaluating equation 2.2. The values within this region should be balanced. The "Control Room TRM" has 200 m^3/h supply flow and its return flow is set to zero within the room; this allows the return of air to be performed by the extraction of the service rooms. Moreover, the "LT TRM" has an increased return air flow of 250 m^3/h with respect to its supply of 200 m^3/h. The flow difference of 50 m^3/h is also subject to the extraction of the service rooms.

The selected ventilation unit must be capable of handling the total return and supply flowrates of 3,960 m^3/h. It is a controlled mechanical ventilation unit for the introduction of fresh air and exhaust air expulsion installed in the technical room. Its main technical characteristics are:

- low power consumption
- supply and return flowrate = 4100 m^3/h
- up to three filtration stages on the delivery side
- high efficiency counter-current plate heat exchanger (thermal energy recovery up to 93%)
- 50 mm double coating panel, insulation with mineral wool for better acoustic attenuation and thermal insulation
- electronically commutated motor fan class IE5
- BMS integration via dedicated interfaces (Modbus, BACnet)

The extraction fan is selected as a sealed ventilation box with directly coupled centrifuge dynamically balanced high performance brushless EC motor and impeller sized to handle extraction airflow of 1400 m^3/h.

Positive indoor pressurization is achieved after the installation of the system. It is primarily done by reduction of the return flow through calibration of the control system in line with equation 2.4.

3.1.2. Ventilation Graphical Layouts

The design of the ventilation network was illustrated using AutoCAD software and the overall layout of the return and supply network is displayed in Figure 3.1, while the layout of the extraction network is displayed in Figure 3.3. The ventilation unit is connected to the return and supply network and the extraction fan is controlling the extraction network. Although these two systems are separate, the exchange of air flow between them is synergetic; both systems coexist and contribute to the comprehensive ventilation system underpinned by the values in Table 3.1 and Table 3.2.

The ducting network is sized respecting the constraints detailed in the methodology and by evaluating equation 2.5. The return and supply ducts enter the false ceiling of the building from the technical area and extend primarily above the corridor spaces branching out from the main ducts into secondary ducts, into terminal ducts, into flexible connections and finally to the diffusers and valves as seen in Figure 3.1. All the ducts are properly insulated; however, navigation of the ducting network above corridors is a design practice to reduce the risk of noise disturbance in patient and diagnostic rooms. Terminal branches are fitted with dampers compatible with the dimensions of the ducts to regulate the flow inputs and outputs.

Fire dampers (TF-02) are sized to the dimensions of the duct and integrated in strategic locations throughout the ducting networks as prescribed by the relevant subcontractor as seen in Figure 3.2. The main purpose of a fire damper is to prevent flame from crossing a fire barrier. They are installed near walls and are a protection measure; they react to heat so that when the temperature threshold is surpassed, the damper promptly shuts. The flexible connections reach the suitably positioned diffusers at multiple intervals to supply and return the airflows. The diffusers are usually incorporated into the false ceiling and are the pivotal points of air exchange.

The supply and return network of the green-coded region (Table 3.2) is depicted in Figure 3.2. The supply duct into this region branches out of the main supply duct sized to carry 400 m^3/h of supply air. A circular terminal branch equipped with a circular damper (SR-02) connects to the appropriately sized linear diffuser (DF-02) through a flexible connection. The linear diffuser supplies the "Control Room TRM" with the 200 m^3/h flowrate required. Similarly, another terminal branch is sized to supply the "LT TRM" with the remaining 200 m^3/h flowrate. The return duct into this region branches out of the main return duct sized to return 250 m^3/h. The return duct equipped with a circular damper (SR-02) connects directly to the appropriately sized linear diffuser (DF-02) through a flexible connection.

The extraction network of the green-coded region is depicted in Figure 3.4. The extraction duct into this region branches out of the main extraction duct sized to extract 150 m^3/h of extracted air. Three terminal branches equipped with circular dampers (SR-02) connect to the appropriately sized ventilation valves through a flexible

connection. The ventilation values extract 40, 40 and 70 m^3/h from the two locker rooms “Spogliatoio” and the bathroom “WC H” respectively.

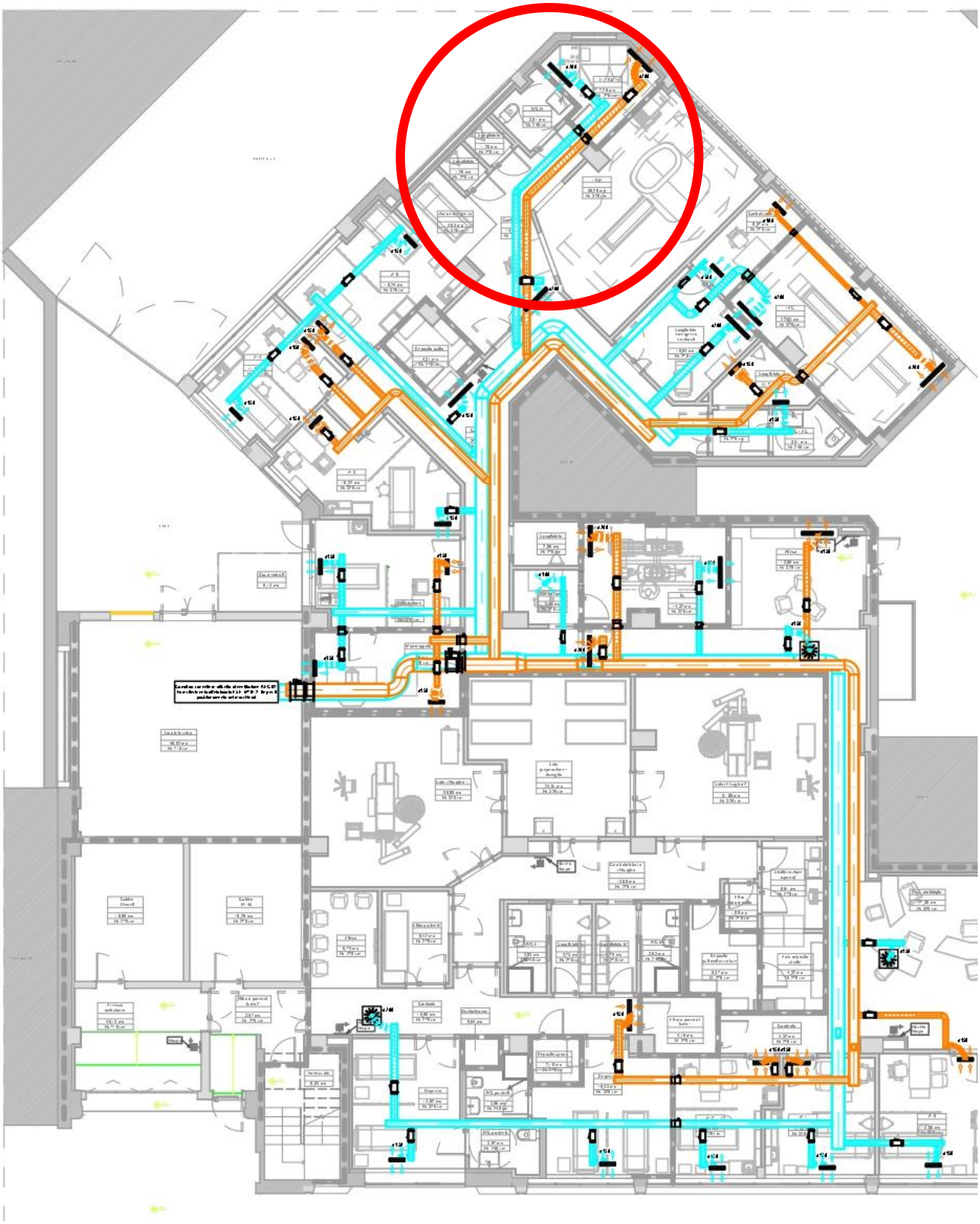


Figure 3.1 Supply and Return Network

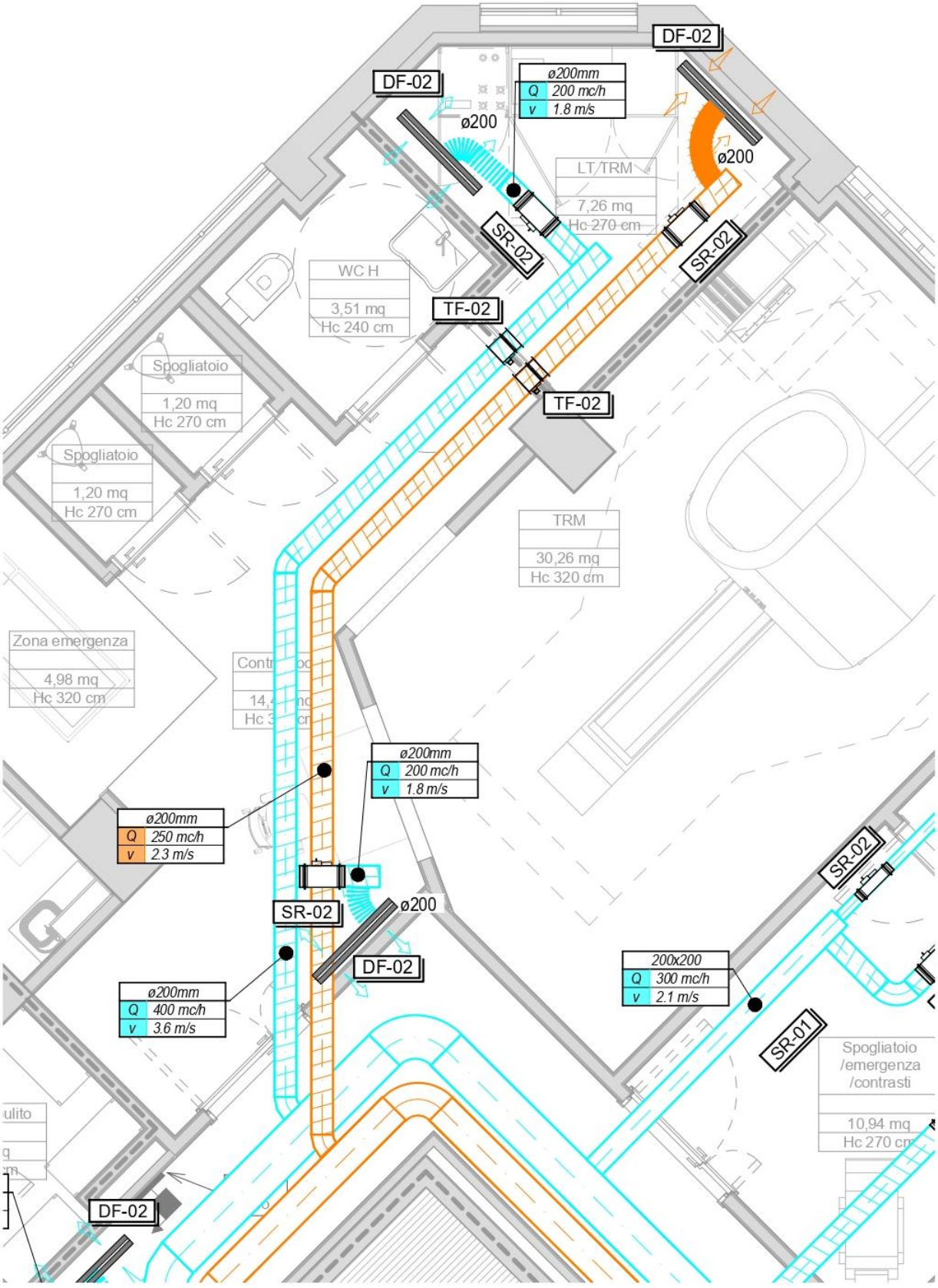


Figure 3.2: Highlighted Zone of Return and Supply Network

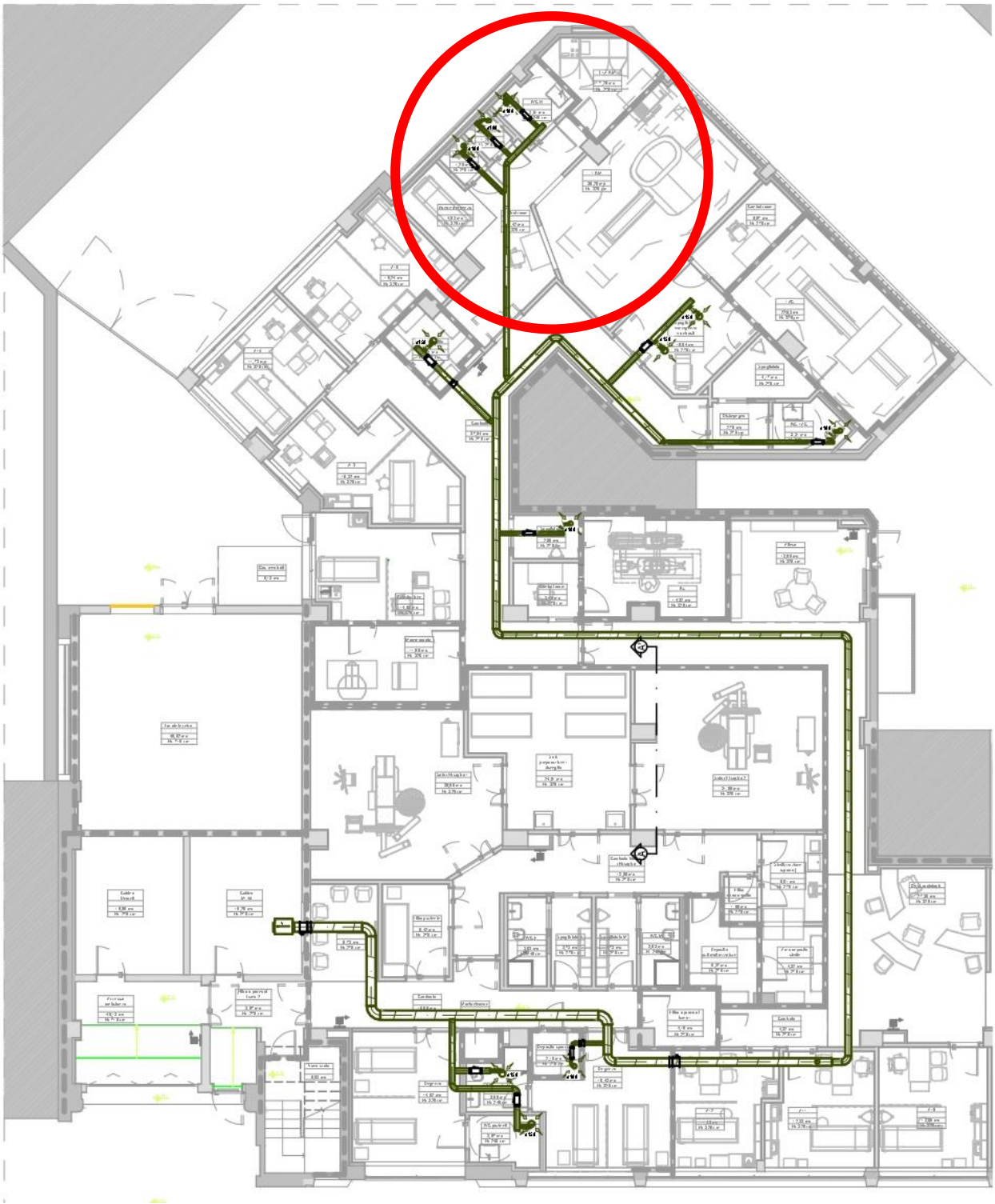


Figure 3.3: Extraction Network

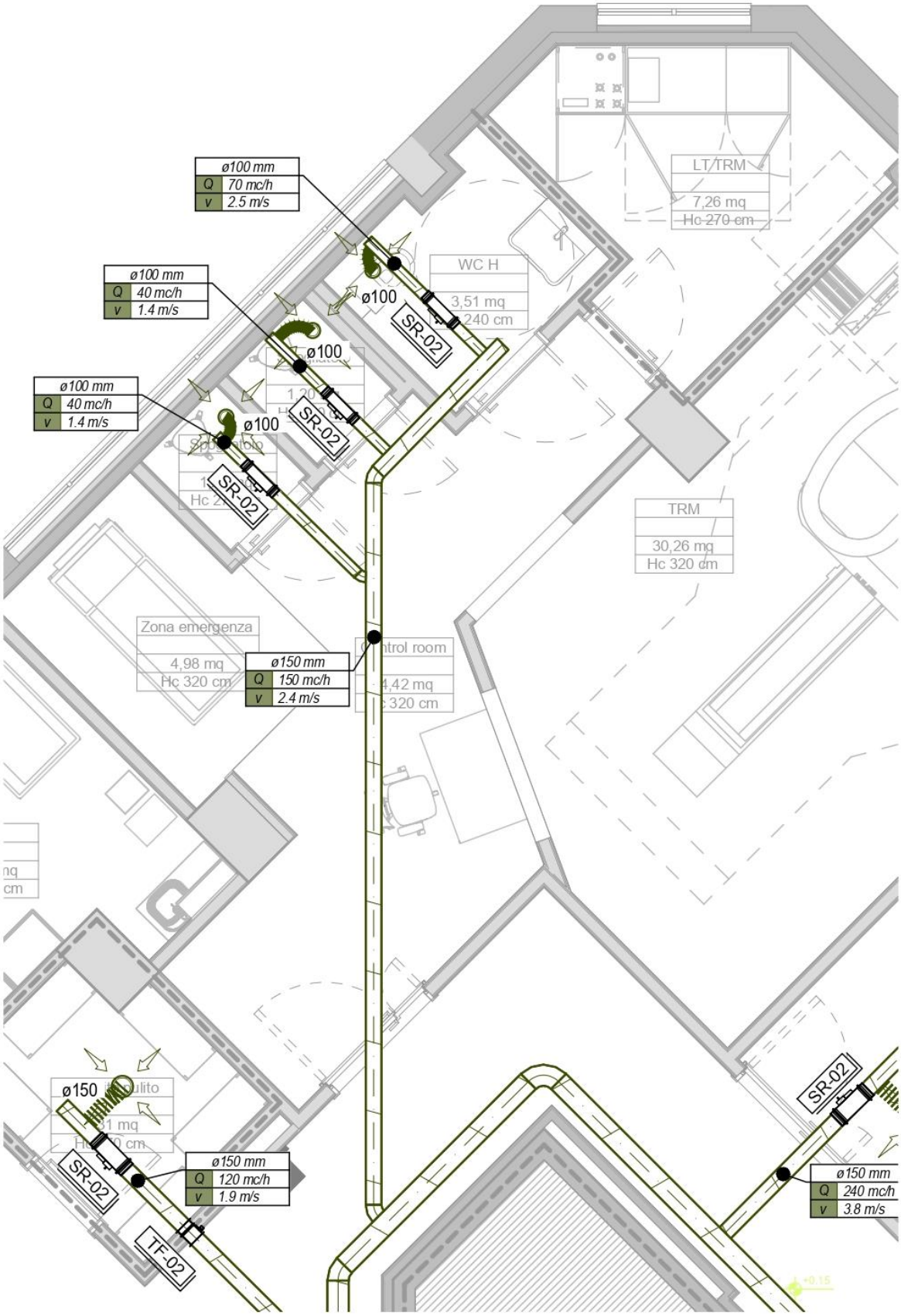


Figure 3.4: Highlighted Zone of Extraction Network

3.2. Cooling System Results

3.2.1. Cooling Load Outcomes

The Magnetic Resonance Imaging is excluded from the calculations since its air conditioning design was conducted in full by its manufacturer due to its proprietary nature. Similarly, as it was previously illustrated, the surgery block rooms are excluded since their ventilation and air conditioning is controlled by a dedicated air handling system to be investigated independently.

The necessary values for all the needed inputs including areas, heights, and occupancy relevant to the outpatient center were gathered and validated. The cooling load estimations in the outpatient center for light loads, occupancy load and other loads were calculated utilizing equations 2.6, 2.7 and 2.8 respectively. To properly evaluate these equations, the estimated factors for the outpatient center were selected based on prior project expertise. The lighting load factor (LF) is assumed to be 15 $\frac{W}{m^2}$. The average occupant load factor (PF) is assumed to be 60 $\frac{W}{pers}$. Moreover, the other miscellaneous load factor (OF) is assumed to be 20 $\frac{W}{m^2}$. Meanwhile, the values for the large machine loads where exclusively relevant to the diagnostic rooms, mainly the X-Ray (RX), Mammography (Mammografo), Computed Axial Tomography (TAC) and Magnetic Resonance (TRM). These diagnostic rooms contain specialized equipment for testing and examining their patients which necessitated large load requirements. Therefore, their respective machine suppliers provided values for load assessment encompassing the diagnostic rooms and extending to their corresponding technical rooms and control rooms. Afterwards, the total sensible cooling loads were evaluated using equation 2.9. Finally, the total cooling load was estimated by the practical equation 2.10. All the inputs and results are obtained and recorded in Table 3.3 and Table 3.4.

After calculating all the needed values, the fan coil unit selection is done by considering the supplier's range of FCU cooling capacities which are incremental. The utilized FCU cooling capacities from the company's designated supplier are progressively 1.7 kW, 2.2 kW, 3.6 kW, 4.5 kW. The selection is conducted based on the value of the total cooling load and by incorporating a safety margin up to the utilized FCU capacity to ensure maximum flexibility in operation. These results are also indicated in Table 3.3 and Table 3.4.

Center Rooms	Light Load	Occupancy Load	Machine Load	Other Load	Sensible Cooling Load	Total Cooling Load	FCU Capacity
	[W]	[W]	[W]	[W]	[W]	[W]	[kW]
Desk Radiologia/Corridoio	804	360	-	1,072	2,236	2,907	**3.6**
Attesa	231	180	-	-	411	534	**2.2**
A10	213	180	-	284	677	880	**2.2**
A11	194	180	-	258	632	821	**2.2**
Filtro a prova di fumo 1	63	-	-	-	63	82	**-**
A12	177	180	-	236	593	771	**2.2**
Degenza	240	120	-	320	680	884	**2.2**
Deposito sporco	32	-	-	42	74	96	**-**
WC pazienti	54	-	-	-	54	70	**-**
WC pazienti	57	-	-	-	57	74	**-**
Degenza	255	120	-	340	715	930	**2.2**
Vano Scala	-	-	-	-	-	-	**-**
Filtro a prova di fumo 2	132	-	-	-	132	172	**-**
Attesa/Corridoio	333	300	-	-	633	823	**2 x 2.2**
Refertazione	179	180	450	238	1,047	1,360	**2.2**
Mammografo	177	180	840	236	1,433	1,863	**2.2**
Corridoio	546	-	-	-	546	710	**2.2**
Control room RX	51	60	120	68	299	389	**2.2**
Spogliatoio RX	45	120	-	-	165	215	**-**
Rx	216	120	800	288	1,424	1,851	**2 x 2.2**
A13	248	180	-	330	758	985	**2.2**
A14	195	180	-	260	635	826	**2.2**
A15	243	180	-	324	747	971	**2.2**
Deposito Pulito	80	-	-	-	80	103	**-**
TAC	348	120	5,300	464	6,232	8,102	**2 x 4.5**
WC TAC	51	60	-	-	111	144	**-**
Control room TAC	90	60	150	120	420	546	**2.2**
Spogliatoio/emergenza	167	120	-	-	287	372	**-**
Disimpegno	42	60	-	-	102	133	**-**
Spogliatoio TAC	74	88	-	-	162	210	**2.2**

Table 3.3: Cooling Load and FCU Capacity Results (1/2)

Center Rooms	Light Load	Occupancy Load	Machine Load	Other Load	Sensible Cooling Load	Total Cooling Load	FCU Capacity
	[W]	[W]	[W]	[W]	[W]	[W]	[kW]
Ufficio	234	240	-	312	786	1,022	**2.2**
Area Break/Cucinotto	570	480	-	760	1,810	2,353	**2.8**
Vano Scala	-	-	-	-	-	-	**-**
Spogliatoio M	87	120	-	116	323	420	**1.7**
Antibagno M	29	60	-	38	127	164	**-**
WC M	30	60	-	40	130	169	**-**
Spogliatoio F	89	120	-	118	327	424	**1.7**
Antibagno F	30	60	-	40	130	169	**-**
WC F	29	60	-	38	127	164	**-**
WC H	54	60	-	-	114	148	**-**
Spogliatoio	21	120	-	-	141	183	**-**
Spogliatoio	21	120	-	-	141	183	**-**
LT TRM	129	60	3,000	172	3,361	4,369	**4.5**
Control Room TRM	330	180	2,000	440	2,950	3,835	**4.5**
Total	7,185	5,068	12,660	6,954	31,867	41,427	**71.80**

Table 3.4: Cooling Load and FCU Capacity Results (2/2)

When selecting the size and placement of the fan coil units, practical and design liberties were taken. As a company practice, when possible FCUs should be placed in all the medical rooms, corridors, waiting rooms and similar rooms that have consistent occupancy. Moreover, in these rooms the lowest FCU capacity was set at 2.2 kW regardless of the room's total cooling load requirement as an oversizing measure to ensure flexibility if future developments (additional equipment, increased occupancy, architectural modifications, etc.) to the diagnostic center would require it. When possible, service rooms like WC rooms, locker rooms, storage rooms and other transition rooms like anterooms "Antibagno" are not equipped with their own FCU.

The "RX" room was equipped with two fan coil units as a precaution and redundancy to never interrupt its functioning per the client's request. Similarly, "Attesa/Corridoio" was equipped with two fan coil units at a distance from one another due to the large area of this space and to ensure air conditioning coverage over the full area.

The sizing and selection of the external VRV unit and its distribution network is the sole responsibility of the manufacturer who studies the calculations of FCU capacities, and their locations as presented by the company. After the study is completed, the network is established as seen in Figure 2.6.

3.2.2. Cooling System Graphical Layouts

Figure 3.5 depicts the overall layout of the VRV network in the outpatient center. The VRV external units are placed in the exterior of the outpatient center adjacent to technical area due to spatial constraints. Two lines of copper piping, one for supply and the other for return, extend from each of the external units carrying refrigerant R-410A. The pipes are illustrated as a single line in Figure 3.5 for graphical simplicity. These pipes carrying refrigerant traverse the false ceiling space available above the rooms in the outpatient center and connect to refrigerant distributors.

The distributors receive the refrigerant and, depending on their configuration, have numerous outlets for the pipes to connect to as many or as few fan coil units as needed. The role of multitube distributors (DS-01) is to create distribution hubs at strategic points in the layout with multiple outlets to connect to fan coil units as seen in Figure 3.6. The distributors are placed above service rooms and transitional areas to minimize any noise disturbance from their functioning by avoiding the false ceiling above medical and diagnostic rooms. In this outpatient center, monotube distributors (DS-02) are also utilized exclusively for diagnostic rooms like the “RX”, “Mammografo” and “TAC” to give specialized care to these critical areas with individual supply. These diagnostic areas comprised of the diagnostic rooms are highly critical since their proper functioning cannot be disturbed. Therefore, monotube distributors facilitate quick response to indoor requirements in case the fan coil units need to switch between heating and cooling modes.

After passing through the distributors, the two piping lines connect to the fan coil units. The fan coil units are usually installed in the false ceiling in the available tiles avoiding light fixtures and all other obstructions present in the false ceiling. Each fan coil unit can be controlled individually and works independently from the other through the thermostat present in the room. The fan coil units supply the conditioned air to the relevant rooms thus ensuring comfortable climatization within the outpatient center.

Figure 3.5: VRV Network

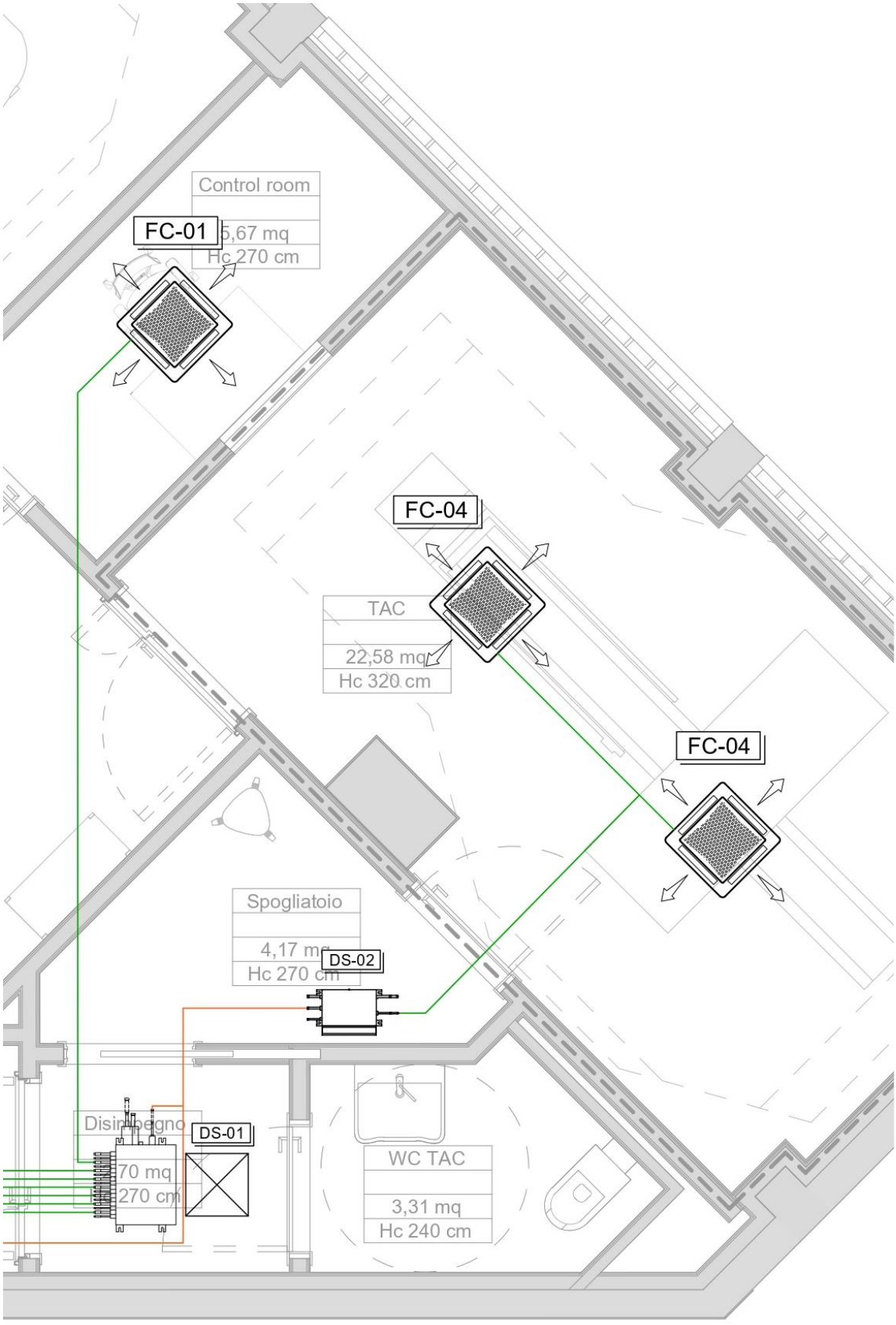


Figure 3.6: Highlighted Zone in VRV Network

3.3. Domestic Hot Water System Results

3.3.1. Hot Water Tank and Heat Pump

The system configuration as seen in Figure 2.7 is achieved by evaluating the relevant parameters and equations detailed in the methodology. The configuration is then connected to the network of hot water pipes spread throughout the building.

In the outpatient clinic, the only utility that requires hot water are washbasins. Their peak consumption was estimated based on prior projects' values and depending on their location/function in the outpatient center. Afterwards, the total peak consumption ($C_{\underset{peak}{total}}$) highlighted in green is calculated using equation 2.11. The values selected and the results are reported in Table 3.5.

Location	Utility	Peak Consumption	Number	Total Peak Consumption
		[liters]	[units]	[liters]
WC	Washbasin	40	6	**240**
Clinic Room	Washbasin	30	16	**480**
Surgery Block	Washbasin	60	2	**120**
Total	-	-	24	**840**

Table 3.5: DHW Total Peak Consumption

The selected parameter values needed to evaluate the minimum volume of the hot tank (V_{tank}) and minimum power required of the heat pump ($P_{\underset{pump}{heat}}$) are highlighted in green and reported in Table 3.6.

Parameter	Unit	Recommended Values	Selected Values
$\boldsymbol{T_{usage}}$	°C	40	**45**
$\boldsymbol{T_{cold}}$	°C	10-12	**10**
$\boldsymbol{T_{storage}}$	°C	60	**65**
$\boldsymbol{d_{peak}}$	h	4	**4**
$\boldsymbol{d_{preheat}}$	h	2	**2**

Table 3.6: DHW Parameter Evaluation

The usage temperature (T_{usage}) is the temperature at the outlet of the faucet and has a recommended value of 40 °C. For the purposes of the clinic, a slightly higher usage temperature of 45 °C was selected based on practical experience.

The clinic located in Milan is situated in northern Italy where the cold water temperature is 10-12 °C. Therefore, the cold water temperature (T_{cold}) was selected as 10 °C due to it being the lower limit based on the location of the clinic.

The average storage temperature ($T_{storage}$) should exceed a recommended value of 60 °C. Therefore, the average storage temperature was selected as 65 °C as a safety precaution to avoid legionella disease and ensure the cleanliness of the potable water.

The duration of the peak load (d_{peak}) and duration of preheating ($d_{preheat}$) were selected for clinics as 4 hours and 2 hours respectively derived from Table 2.3.

The minimum volume of the hot tank (V_{tank}) and minimum power required of the heat pump ($P_{\substack{heat\\pump}}$) are calculated through the numerous steps detailed in the methodology (section 2.3.1). The selected parameters displayed in Table 3.6 are combined with the approximated values of heat capacity of water (cp_{water} = 1 kcal/(kg.°C)) and density of water (ρ_{water} = 1000 kg/m^3). These parameters and approximations underpin the evaluation of the relevant equations. The total heat needed to heat the water required in peak period (Q_{peak}^{total}) is evaluated using equation 2.12. The hourly heat required (Q_{hourly}) is evaluated using equation 2.13. The heat pump minimum thermal power required ($P_{\substack{heat\\pump}}$) to supply the usage temperature is evaluated using equation 2.14. The heat to be accumulated in the tank ($Q_{\substack{tank\\Acc.}}$) is evaluated using equation 2.15. Finally, the minimum volume of the hot tank (V_{tank}) is evaluated using equation 2.16. The results are reported in Table 3.7.

Outputs	Unit	Values
$\boldsymbol{Q_{peak}^{total}}$	kcal	**29,400**
$\boldsymbol{Q_{hourly}}$	kcal/h	**4,900**
$\boldsymbol{P_{\substack{heat\\pump}}}$	W	**5,699**
$\boldsymbol{Q_{\substack{tank\\Acc.}}}$	kcal	**9,800**
$\boldsymbol{V_{tank}}$	liter	**178**

Table 3.7: DHW Outputs

The values of (V_{tank}) and ($P_{\substack{heat\\pump}}$) highlighted in green are the minimum requirements to achieve the desired conditions. In practice, based on these calculations the actual tank volume is selected to be oversized significantly at 300 liters. Two tanks are

incorporated where the second tank is identical and used as redundancy in case of any malfunction in the first tank.

After inputting the actual tank volume, the actual heat pump power is evaluated by progressively re-evaluating equations 2.16,2.15,2.14. The resulting actual heat pump power is 9,595 Watts. These two values are relayed to the relevant supplier for selection of the system components.

3.3.2. Flowrates and Graphical Layouts

Figure 3.7 depicts the layout of the hot, cold and recirculation galvanized steel piping network. The hot water lines in red are connected to the heat pump and hot water tank system previously evaluated. Additionally, the recirculation pipes in orange contain the recirculated hot water that is reintroduced into the DHW system. On the other hand, the cold water piping in dark blue is connected to the preexisting cold water system. The three piping lines spread out in the clinic area and connect to the appropriate utilities to supply their requirement of water.

As seen in Figure 3.8, when dealing with WC rooms the piping lines connect to water collectors (CI-01) installed on the wall which have five outputs for cold water and four outlets for hot water. These collectors serve to distribute the supply based on the needs of the WC utilities through pre-insulated multilayer plastic tubes of DN16 based on company practices. To supply all other rooms, the piping network terminal branches that connect to their utilities is galvanized steel of DN15. However, all other piping prior to the water collectors and terminal branches are evaluated based on their calculated flowrates adherent to the detailed methodology.

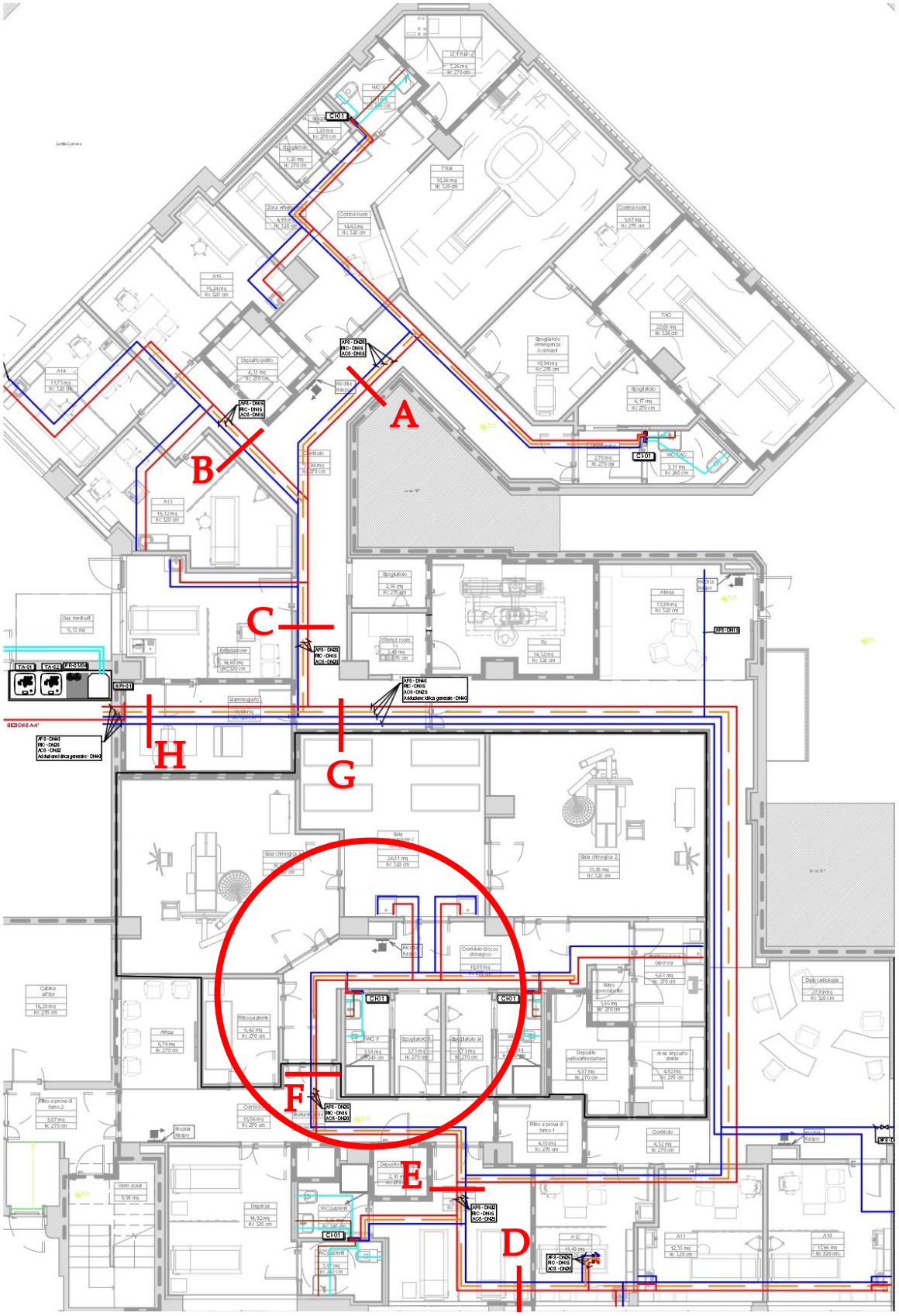


Figure 3.7: Hot and Cold Water Network

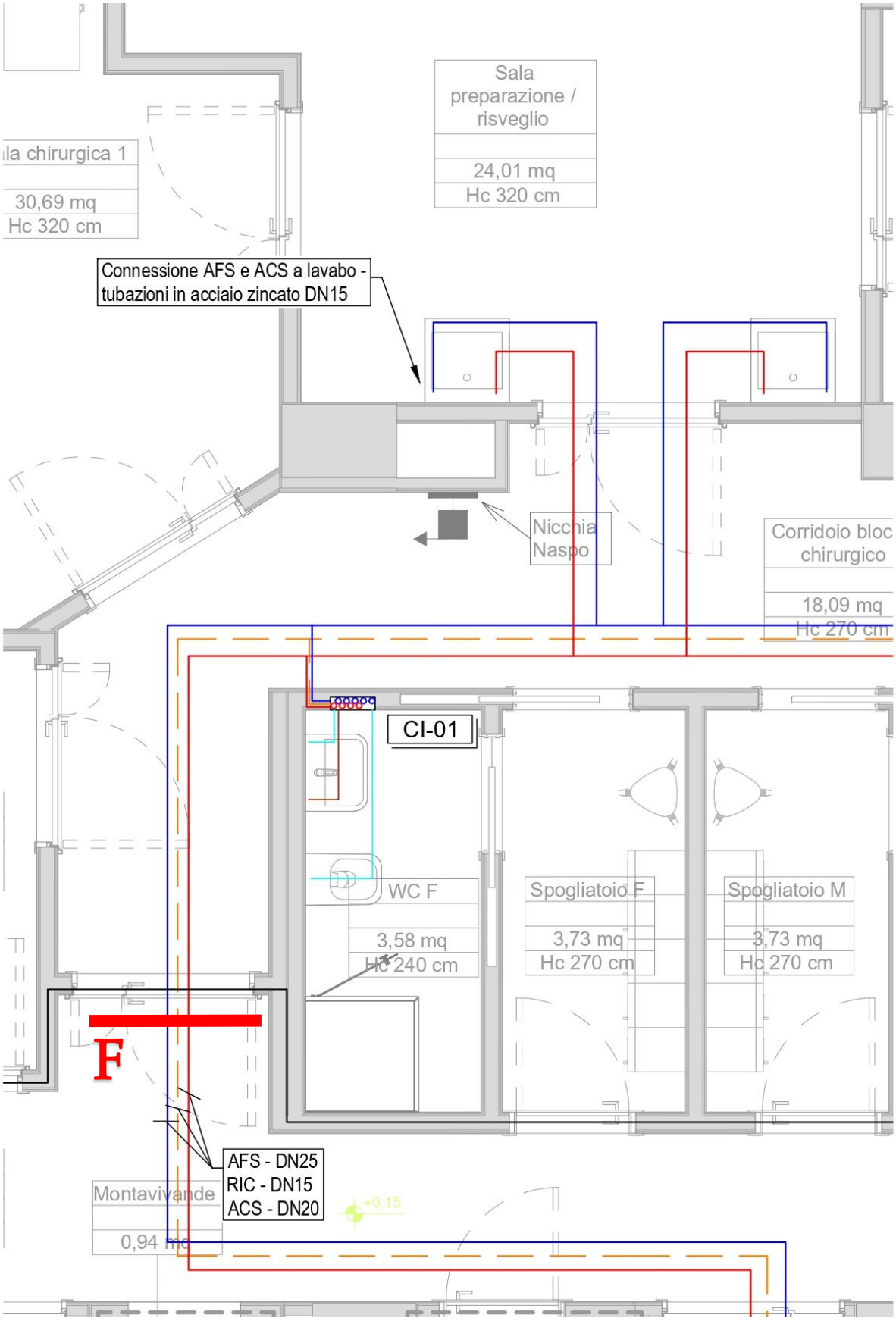


Figure 3.8: Highlighted Zone of Hot and Cold Water Network

The "Load Unit" for the relevant utilities present in the clinic extracted from Table 2.4 are reported in Table 3.8.

Clinic Utility	Cold Water Load Unit	Hot Water Load Unit
	[-]	[-]
Clinic Washbasin	1.5	1.5
Kitchen Washbasin	3	3
Toilet	5	-

Table 3.8: Load Unit for Clinic Utilities

As seen in Figure 3.7, section points indicated by letter values are selected at various intervals of the tubing layout. Starting progressively from the terminal piping to the main piping lines and for each of the hot water and cold water, "load units" are evaluated and summed up to the section point. Gradually, this is done until all utilities are accounted for, and the starting point of piping network is reached. The conversion of "load units" to water flowrates in [l/s] is evaluated using Table 2.5. The minimum diameter of the tube (d_{min}) is calculated using equation 2.17. The results of this practice are reported in Table 3.9.

Section Point	Cold Water			Hot Water		
	Load Unit Sum	Flowrate	d_{min}	Load Unit Sum	Flowrate	d_{min}
	[-]	[l/s]	[mm]	[-]	[l/s]	[mm]
A	14.5	0.7	21.2	4.5	0.2	12.1
B	3.0	0.2	9.8	3.0	0.2	9.8
C	19.0	0.9	23.8	9.0	0.5	16.9
D	20.5	1.0	24.6	10.5	0.5	18.3
E	33.5	1.4	29.4	13.5	0.7	20.5
F	17.5	0.8	23.0	7.5	0.4	15.5
G	52.5	2.0	35.5	21.0	1.0	24.9
H	71.5	2.4	39.4	30.0	1.3	28.8

Table 3.9: Cold and Hot Water Flowrate and Sizing

The nominal diameter of the lines at the section points is assessed based on the calculated minimum diameter while setting as a company rule of thumb the lower limit of the nominal diameter at DN15. The flowrates highlighted in green in the table are the maximum required supply flowrates for each of cold water and hot water networks within the outpatient center.

3.4. Surgery Block Results

The surgery block in the outpatient center is subject to an independent ventilation and air-conditioning system. Therefore, it was excluded from the main ventilation system and VRV system of the diagnostic center discussed in previous sections and is subject to a specific air handling unit configuration detailed in this section. The surgery block as seen in Figure 3.9 is comprised of two surgical rooms with preparation and awakening room. The adjacent rooms are the patient filter, sterilization, dirty/clean filters, two deposits for clean and sterile equipment, two changing rooms for doctors with dedicated bathrooms and a surgery corridor. For the purposes of this investigation, the adjacent rooms are referred to as a group by “Related Areas”.

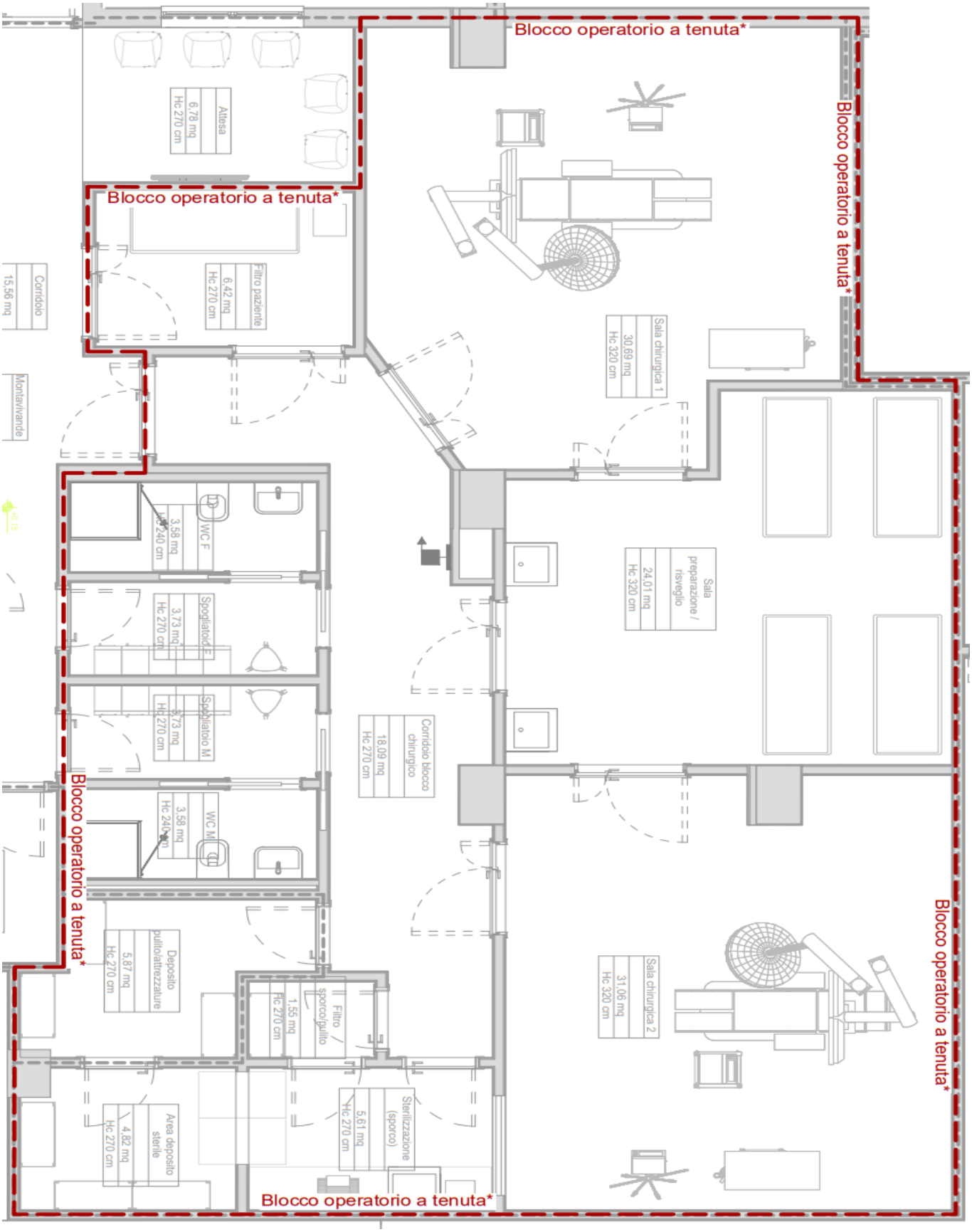


Figure 3.9: Surgery Block Layout

3.4.1. Cooling Load and Air Replacement Outcomes

For the surgery block, the light loads (L_{lights}), equipment loads $(L_{equipment})$ and occupant load $(L_{occupants})$ were prescribed by the client's consultant based on their own evaluations. Moreover, the equipment loads for both surgery rooms correspond to a specialized surgical operating lamp in each of the rooms. For each designated area in a surgery block, the total sensible cooling load $(L_{sensible}^{total})$ to be treated is calculated using equation 2.18. Afterwards, the supply air flowrate needed for cooling $(\dot{V}_{cooling})$ is calculated using equation 2.19. The values of $(\dot{V}_{cooling})$ were rounded up to the nearest hundredth.

The equation is evaluated with the approximated values of heat capacity of air (cp_{air} = 1 kJ/(kg.°C)) and density of air (ρ_{air} = 1.2 kg/m^3). Moreover, a design input for the temperature difference between the supply air to the room and the ambient air in the room (ΔT_{air}) was selected at 4 °C as elaborated on in the methodology. The results are reported in Table 3.10.

Location	L_{lights}	$L_{equipment}$	$L_{occupants}$	$L_{sensible}^{total}$	$\dot{V}_{cooling}$
	[W]	[W]	[W]	[kW]	[m^3/h]
Surgery Room 1	600	1,600	420	2.62	**2,000**
Surgery Room 2	600	1,600	420	2.62	**2,000**
Preparation Room	950	0	280	1.23	**1,000**
Related Areas	800	0	140	0.94	**800**

Table 3.10: Supply Flowrate based on Cooling Load

Afterwards and for each designated area in a surgery block, the recommended supply air flowrate $(\dot{V}_{rec})$ based on the air replacement factor specified by the Italian standard UNI 11425 is calculated using equation 2.20. The values of $(\dot{V}_{rec})$ were rounded up to the nearest hundredth. The air replacement factors (R) were selected by practical experience while also adhering to the recommended values detailed Table 2.6. The results are reported in Table 3.11.

Location	A	H	R	$\dot{V}_{rec}$
	[m^2]	[m]	[vol/h]	[m^3/h]
Surgery Room 1	31	3.2	15	**1,500**
Surgery Room 2	34	3.2	15	**1,700**
Preparation Room	27	3.2	8	**700**
Related Areas	56	2.7	6	**1,000**

Table 3.11: Supply Flowrates based on Replacement Factor

Finally, the maximum value between the ($\dot{V}_{cooling}$) and ($\dot{V}_{rec}$) is chosen for each designated area in a surgery block. Their total represents the selected supply air flowrate ($\dot{V}_{selected}$) highlighted in green which informs the total flowrate of supply and return to be managed by the air handling unit. The results are reported in Table 3.12.

Location	$\dot{V}_{cooling}$	$\dot{V}_{rec}$	$\dot{V}_{selected}$
	[m³/h]	[m³/h]	[m³/h]
Surgery Room 1	2,000	1,500	**2,000**
Surgery Room 2	2,000	1,700	**2,000**
Preparation Room	1,000	700	**1,000**
Related Areas	800	1,000	**1,000**
Total			**6,000**

Table 3.12: Selected Supply Flowrates

3.4.2. Coil Sizing Outcomes

3.4.2.1. Cooling Coil

For the surgery block, the required cooling power of the cooling coil to achieve the full range of possible enthalpy jump ($P_{cooling}^{total}$) is calculated using equation 2.21. The enthalpy jump of the selected range ($h_{external} - h_{\substack{cooling \\ coil}}$) is evaluated to cover the full range of possible conditions for the cooling coil. The enthalpy of the external summer conditions ($h_{external}$) is evaluated at the selected values of Dry Bulb Temperature = 35°C and Relative Humidity = 40%. The enthalpy at the cooling coil ($h_{\substack{cooling \\ coil}}$) is evaluated at the selected values of Dry Bulb Temperature = 13°C and Relative Humidity = 95%. Moreover, the cooling coil water flowrate required ($\dot{V}_{water,C}$) is calculated using equation 2.22.

The equations are evaluated with the approximated values of density of air (ρ_{air} = 1.2 kg/m³), the heat capacity of water (cp_{water} = 4.186 kJ/(kg.°C)) and the density of water (ρ_{water} = 1000 kg/m³). Moreover, a design input for the temperature difference of water existing and entering the cooling coil (ΔT_{water}) was selected at 5 °C. The results are reported in Table 3.13.

$\dot{V}_{selected}$	$h_{external}$	$h_{\substack{cooling \\ coil}}$	$P_{cooling}^{total}$	$\dot{V}_{water,C}$
[m³/h]	[kJ/kg]	[kJ/kg]	[kW]	[liter/h]
6,000	72	35	**74**	**12,728**

Table 3.13: Cooling Coil Sizing

3.4.2.2. Preheating and Post-heating Coils

The required heating power of the preheating coil and post-heating coils $(P_{heating})$ is calculated using equation 2.23. The heating coil water flowrate required $(\dot{V}_{water,H})$ is calculated using equation 2.22, by replacing $P_{cooling}^{total}$ with $P_{heating}$ and by considering the proper ΔT_{water}. Moreover, design inputs of the outlet air (T_{air}^{out}) and the inlet air (T_{air}^{in}) were selected based on practical experience. The results are reported in Table 3.14.

Heating Coil	$\dot{V}_{selected}$	T_{air}^{in}	T_{air}^{out}	$P_{heating}$	$\dot{V}_{water,H}$
	[m³/h]	[°C]	[°C]	[kW]	[liter/h]
Preheating	6,000	-5	20	**50**	**8,600**
Post-heating 1	2000	13	24	**7.3**	**1261**
Post-heating 2	2000	13	24	**7.3**	**1261**
Post-heating 3	1000	13	24	**3.6**	**631**
Post-heating 4	1000	13	24	**3.6**	**631**

Table 3.14: Heating Coil Sizing

3.4.3. Air Quality and Pressurization Outcomes

The air handling unit is incorporated with an F7 efficiency fine dust filter at its inlet and an F9 efficiency synthetic bag filter at its outlet for protection of the unit and increased redundancies in air filtration. Additionally, the return ducts from the surgery block are equipped with G4 efficiency coarse particle filter directly on the return grills. Figure 3.10 represents the network of components in the technical area between the air handling unit and the clinic's outer wall. The supply duct represented by a blue line carries the selected supply air flow from the air handling unit. It branches out into four supply ducts; each carries the required air flow for the four designated areas as calculated in Table 3.12. Then the supply air undergoes filtration in each of the branches through the recommended HEPA H14 filters labelled as (FAH-0X). The air passes across the post heating coils for air conditioning. The post heating coils (PH-0X) have a water circuit fitted with temperature sensors and motorized valves to calibrate their proper functioning. The air flow is then calibrated utilizing the motorized flow regulators (VAV) fitted on each branch. Silencers (SIL-0X) work to minimize the noise level before the ducts traverse the clinic's outer wall. Similarly, four return branches represented by orange lines carry returning air flow from the designated areas. The return air undergoes silencing and is controlled by their motorized flow regulators (VAV). The return branches converge to facilitate the total return of the air back to the air handling unit.

In this configuration, the total supply is equal to the total return of air thus no part of the air is recirculated. Air recirculation is usually utilized by mixing 70%-80% of the exhaust air into the fresh outside air entering the AHU. This process leads to a reduction in energy consumption when heating the fresh outside air especially in the winter season. The exhaust air carries thermal energy and mixes it with the fresh outside flow thus increasing its temperature and reducing the required power for heating it. This has a positive impact on the energy efficiency. Despite its benefits, no recirculation of air is utilized since it would require an air handling unit for each individual room in a surgery block. This is because it is not permissible to recirculate one room's return air into another room by utilizing the same AHU. Therefore, economic considerations to a large extent and spatial constraints to a lesser extent informed the use of one air handling unit for the entire block while eliminating the idea of air recirculation.

The H14 filters provide the pivotal step in ensuring the air quality level is met pursuant to the standard. The motorized flow regulators (VAV) are controlled on each of the eight supply and return branches by the Building Management System (BMS) to achieve the pressurization required based on the inputs of differential pressure probes. This is done by adjusting the supply and return air flows in each of designated areas. The return flow regulators reduce the amount of returned air through the BMS internal logic to ensure a positive pressurization of +15 Pa for both surgery rooms and sterile

storage. Moreover, a pressure difference of +10 Pa for the preparation room and all other related areas is established per the recommendations of the Italian standard.

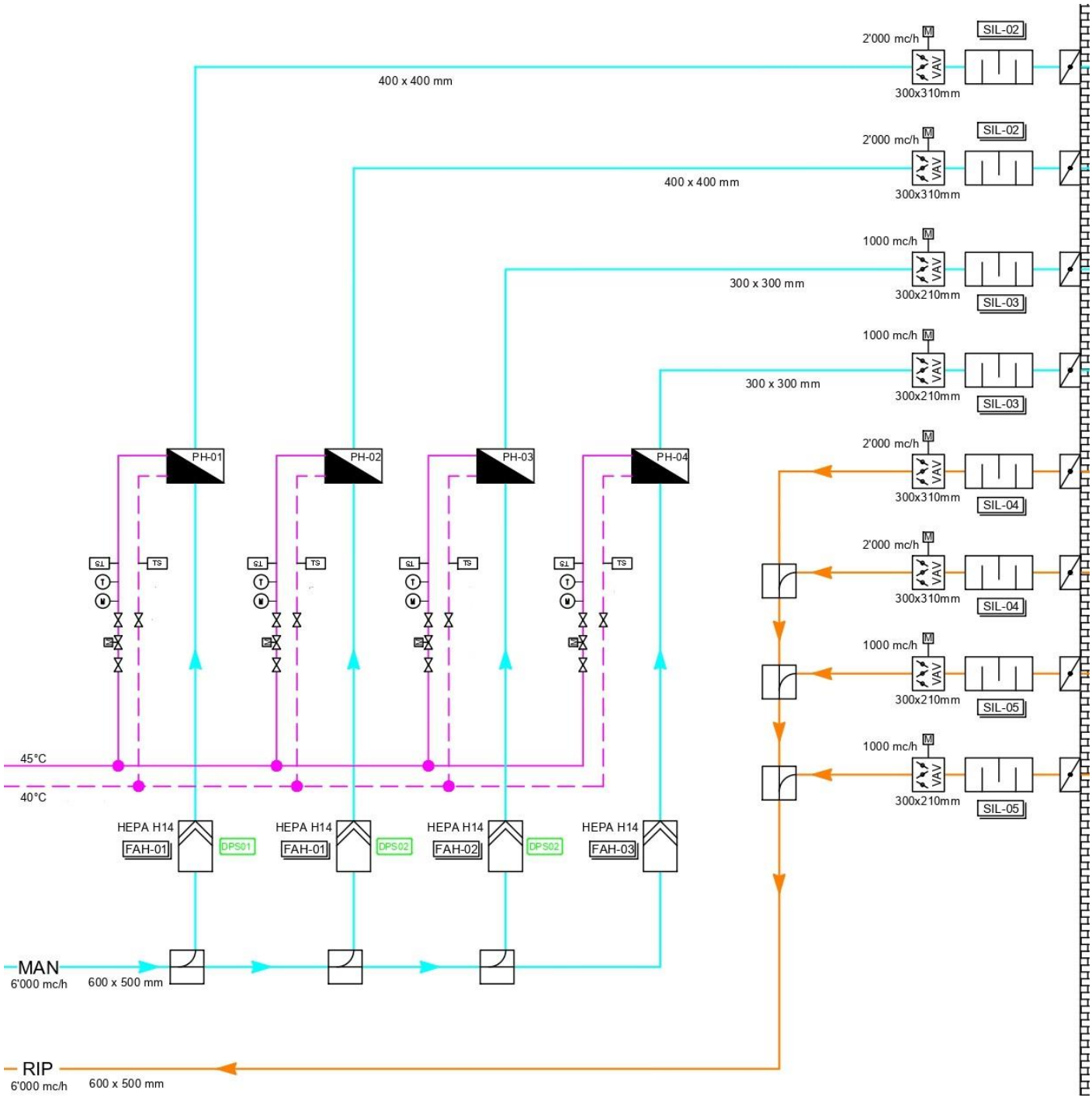


Figure 3.10: Ducting Scheme in Technical Area

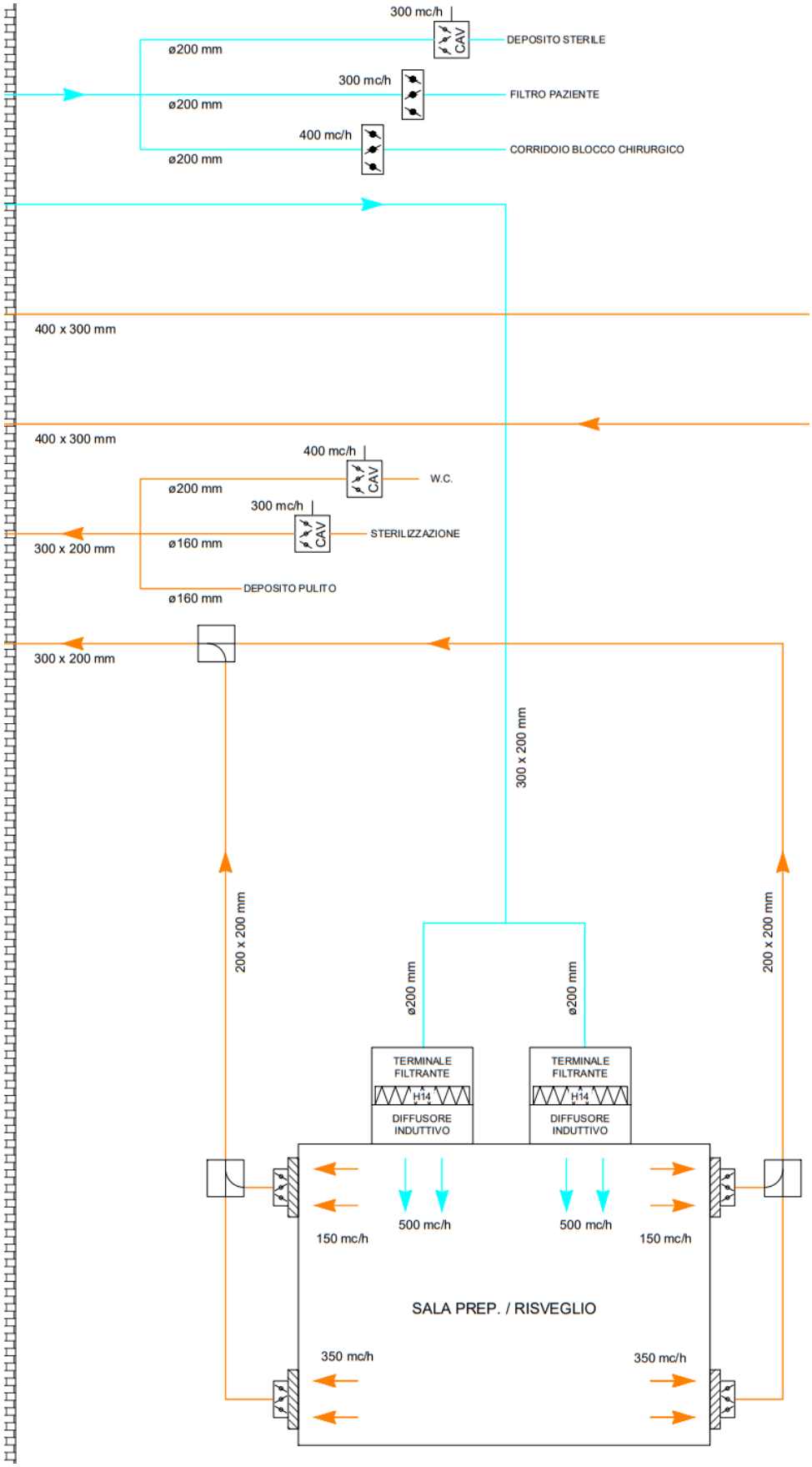


Figure 3.11: Preparation Room and Related Rooms Scheme

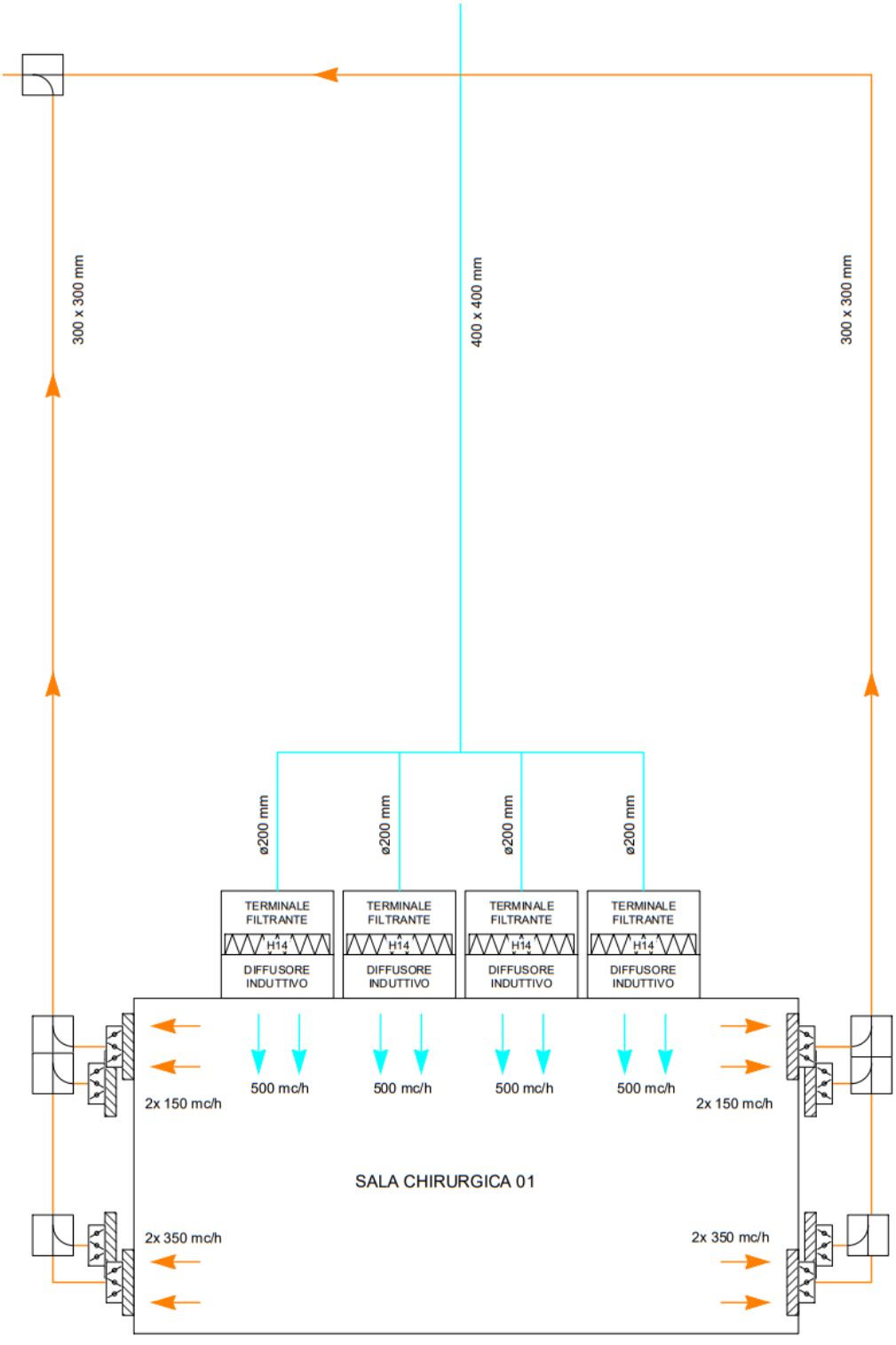


Figure 3.12: Surgery Room Scheme

Figure 3.11 represents the network of components inside the outpatient center from the technical area and reaching the Preparation Room and "Related Areas". For the Preparation Room, the supply duct traverses the false ceiling and then evenly splits its 1000 m^3/h air flow to deliver to two square diffusers situated in the ceiling of the room. Before introduction into the room, the air is once again treated through H14 filters assuring the air quality level. The detailed distribution of the air flow in the Preparation Room is depicted for supply and return air in Figure 3.13 and Figure 3.14 respectively.

The "Related Areas" are treated as an autonomously balanced region. The 1000 m^3/h supply air flow for this area is directed through supply branches to the three indicated rooms in Figure 3.11 while the return air flow is removed from the service rooms indicated. A combination of manual dampers and constant flow regulators are equipped on all these branches to ensure the appropriate distribution of the air flow and provide another controllable element for the BMS system respectively. The detailed distribution of the air flow in the "Related Areas" is depicted for supply and return air in Figure 3.13 and Figure 3.14 respectively.

Figure 3.12 represents the network of components inside the outpatient center between the technical area and reaching the "Surgery Room 1". Both surgery rooms are designed with identical configurations so only "Surgery Room 1" is depicted in this scheme. The supply duct traverses the false ceiling and then evenly splits its 2000 m^3/h air flow to deliver to four square diffusers situated in the ceiling of the room. Before introduction into the room, the air is once again treated through H14 filters assuring the air quality level. The detailed distribution of the air flow in both surgery rooms is depicted for supply and return air in Figure 3.13 and Figure 3.14 respectively.

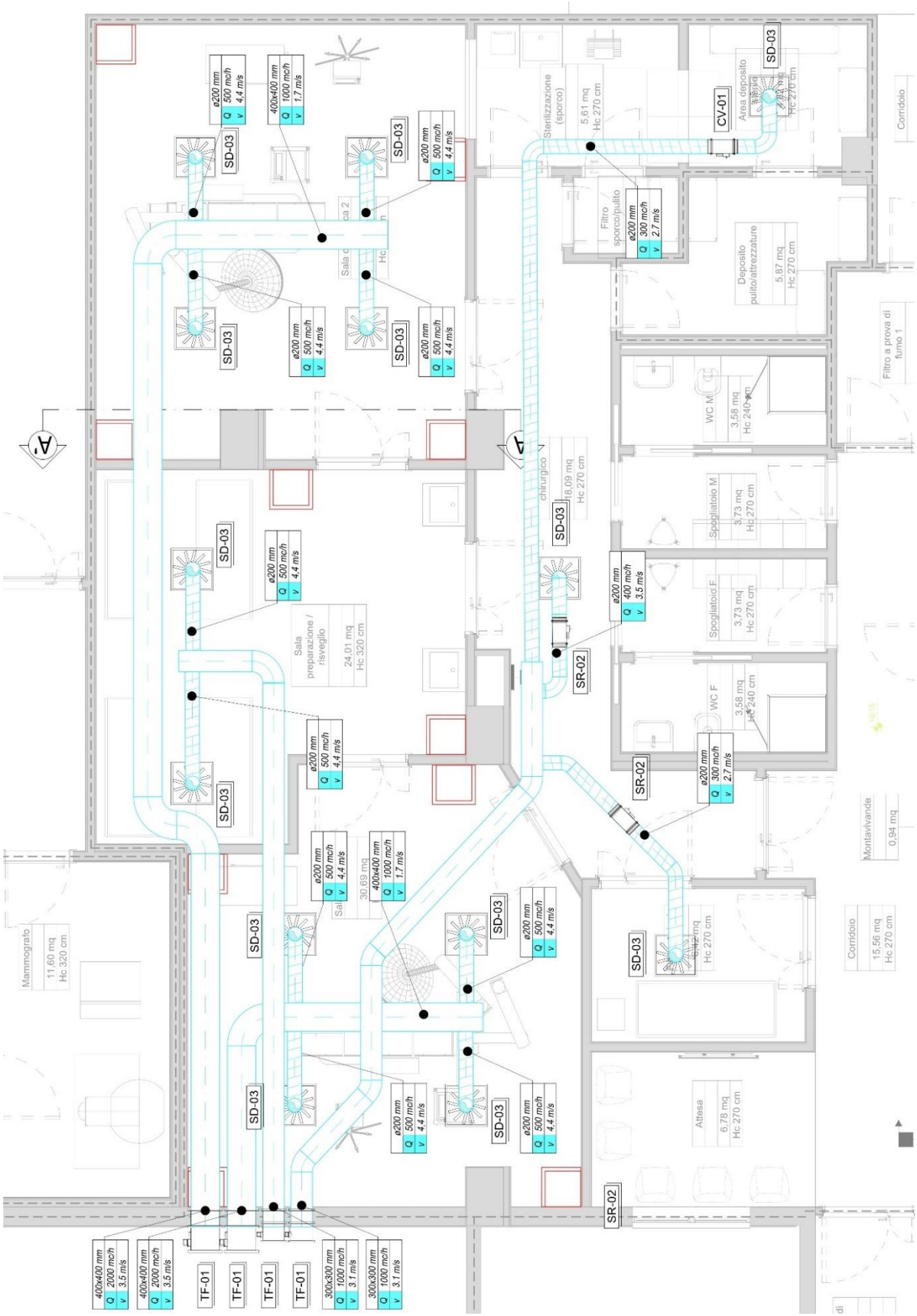


Figure 3.13: Surgery Block Supply Network

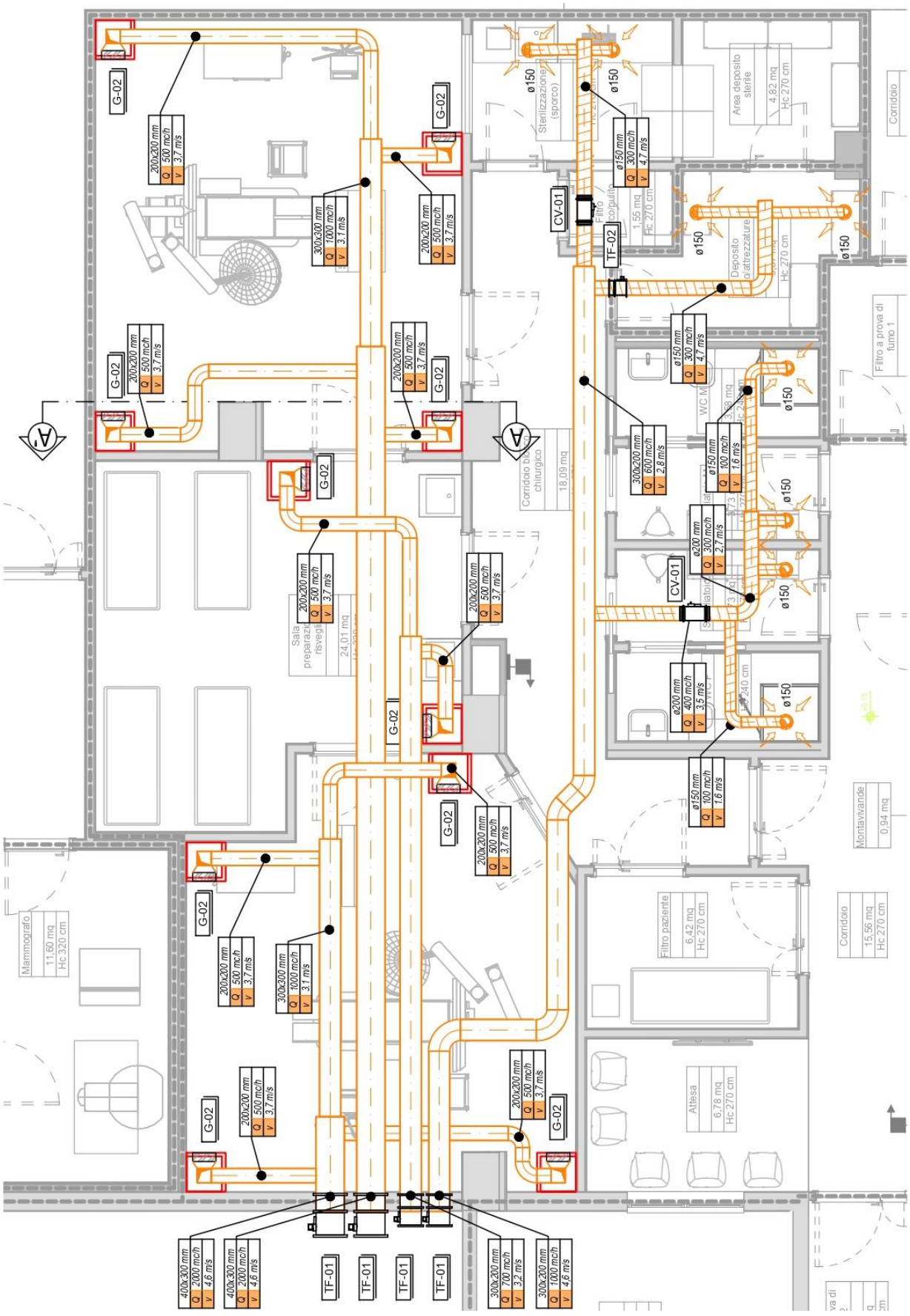


Figure 3.14: Surgery Block Return Network

As seen in Figure 3.13, the selected configuration for supply air introduction in each of the surgery rooms and the preparation room have similar characteristics. The supply air is introduced vertically into the room through the ceiling. They utilize square diffusers with equal values of flow. The diffusers are spaced apart from each other and in the case of surgery rooms equidistant from each other. Their aim is to ensure the entirety of the room is lapped with supply air throughout its volume.

As seen in Figure 3.14, the selected configuration for return air removal in each of the surgery rooms and the preparation room have identical characteristics. Return columns are constructed adjacent to the walls of the rooms and in corners when feasible. These return columns retrieve equal values of return air. Each return column is equipped with a return grill (G-02) at the top and bottom of the structure as seen in Figure 3.15. The return grills retrieve the air with similar ratios. Approximately two-thirds of the return air is removed from the bottom return grills while the other third is returned from the top near the ceiling as displayed in Figure 3.11 and Figure 3.12.

These characteristics are prevalent in surgery room design and are informed by previous projects. The combination of the supply and return configurations guarantees that the entire volume is swept with supply air and then retrieved in a fashion that encompasses all the air in the room.

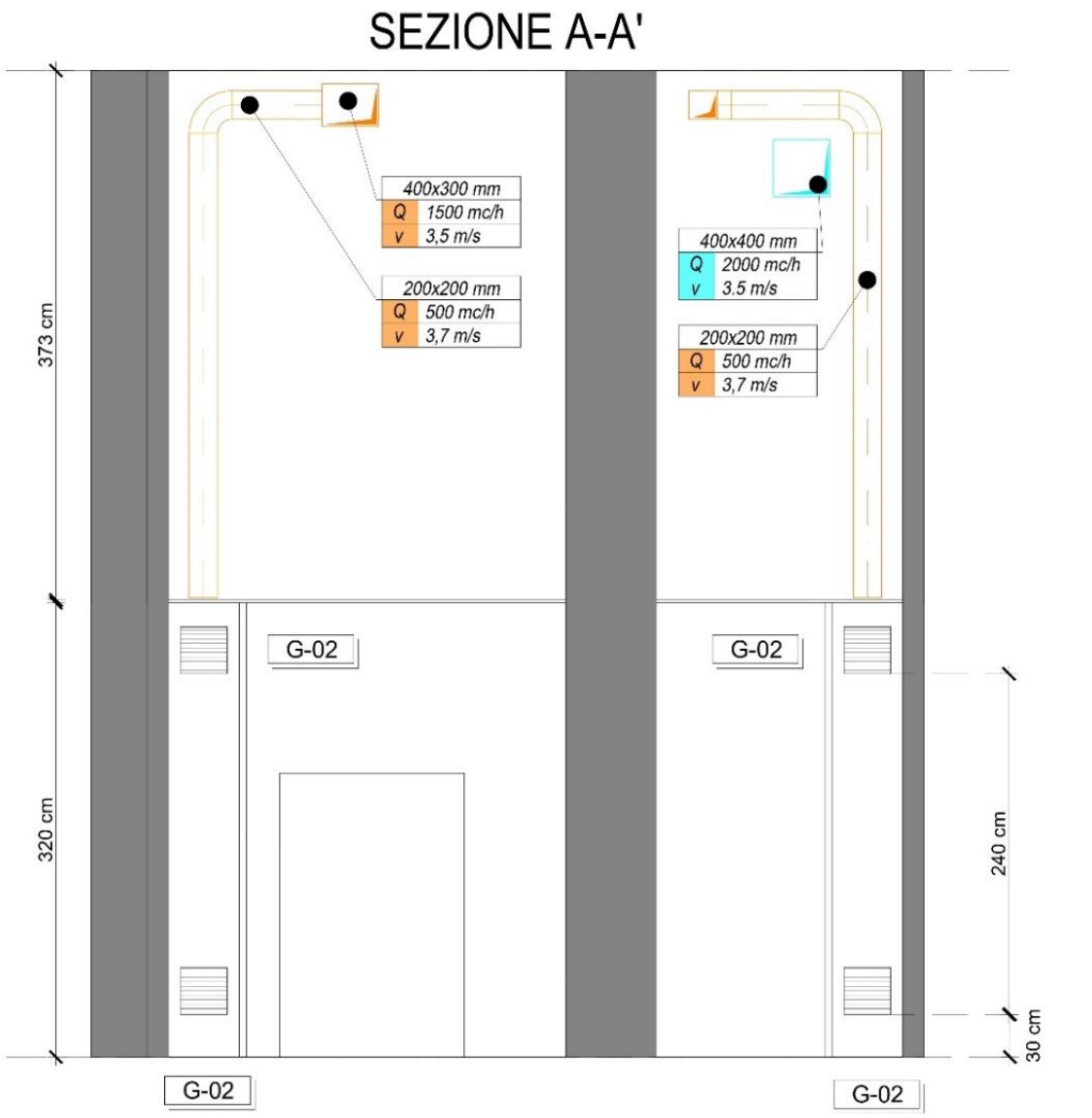


Figure 3.15: Section A-A' of Figure 2.14

4 Conclusions

The objective of this work was to explore and apply the methodologies employed in designing the ventilation, cooling, domestic hot water and surgery block systems for a fully operational outpatient and diagnostic center. These methodologies were constructed based on the Italian standards (UNI 10339, UNI 11425, UNI 9182); however, standards only provided the framework for the project. The process of establishing a design project was navigated using engineering skills and experience to tailor to the specific needs of the case study. The development of a practical project is a balance of the theoretical engineering design approach with the real-world requirements of cost and client demands. For example, equations based on standards were utilized to size the hot water tank for the domestic hot water production; however, the resulting tank was intentionally oversized, and a second identical tank was also incorporated. This served to ensure a safety factor in design, allow the client the flexibility to connect future utilities to the pre-existing tanks if future developments of the project required it, and meet the client's requirements of continuous production of hot water in case of malfunction in one tank. Additionally, this work aimed to provide an in-depth depiction of the practical outcomes achieved using the methodologies including a comprehensive breakdown of the calculation results and the actual configuration of the mechanical systems that were developed.

The outcomes of the ventilation system design for the main area of the project excluding the surgery block are comprised of two synergetic systems. A supply and return air ventilation network of ducts, dampers and diffusers equipped with an appropriately sized ventilation unit. Additionally, an extraction air network of ducts, dampers and ventilation valves equipped with an appropriately sized extraction fan. Both systems are tailored to the outpatient and diagnostics center's ventilation requirements and achieve the desired air quality needs based on the recommendation of the Italian standard UNI 10339. The challenges faced in designing these systems were rooted in spatial and cost constraints due to the architecture of the false ceiling and client's budget respectively. These challenges were overcome by constructing the ducting networks using design ingenuity to avoid obstacles and eliminate excessive ducting to achieve the targets.

The outcome of the cooling system design is comprised of a Variable Refrigerant Volume (VRV) system. A network of refrigerant piping, refrigerant distributors and fan coil units equipped with an appropriately sized external VRV unit. The system is tailored to the outpatient and diagnostics center's cooling requirements and achieves

the desired air conditioning needs based in justified company practices. The challenge was to position the fan coil units throughout the outpatient and diagnostic center to ensure effective air conditioning while keeping their quantity at an acceptable minimum.

The outcome of the Domestic Hot Water design is comprised of a heat pump and hot water tank system. A network of hot water piping extends to all the designated utilities equipped to the heat pump and hot water tank system. The system is tailored to the outpatient and diagnostics center's hot water requirements and achieves the desired hot water supply needs based on the Italian standard UNI 9182.

The outcome of the Surgery Block design is comprised of an air handling unit system acting upon its network of ducts, diffusers, flow regulators to achieve the required positive indoor pressurization and ventilation needs of the surgery block. Simultaneously, appropriately sized cooling coil, heating coils and humidification section corresponding to the AHU achieve the air conditioning needs. A collection of various grade filters throughout the network ensures the air quality of the surgery block. The parameters to be achieved were informed by the Italian standard UNI 11425. The challenges in the surgery block design were spatial and cost constraints. These constraints informed the choice of turbulent airflow introduction into the surgery rooms which facilitated the design of a more compact AHU with respect to laminar flow requirements. Moreover, guidelines for recirculation dictated that a designated AHU for each surgery block room be established. This course of action was not feasible from an economical and spatial perspective which led the design to be a singular AHU capable of handling the entire airflow requirements for the surgery block. The choice of airflow introduction paired with the decision to eliminate recirculation facilitated a suitably sized AHU system for the particular needs of the case study.

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