MINISTRY OF FEDERAL AFFAIRS & GENERAL ADMINISTRATION

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BUILDING ENERGY EFFICIENCY IN NEPAL

MANUAL FOR HVAC SYSTEM DESIGN

universität innsbruck
Unit of Energy Efficient Buildings

MinErgy

Greentech Knowledge Solutions Pvt. Ltd.

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Disclaimer

This publication is funded by the European Union under the SWITCH-ASIA Grants Programme. Its contents are the sole responsibility of the BEEN Project and do not necessarily reflect the views of the European Union.

This manual provides practical guidance on energy-efficient HVAC systems for buildings, with a focus on Nepal's climatic and energy context. It supports architects, engineers, and MEP professionals in selecting, designing, and installing HVAC systems that enhance indoor comfort while minimizing energy use. By integrating climate-responsive design and efficient technologies, the manual contributes to low-carbon, resource-efficient building.

Preface

Nepal's construction sector is undergoing rapid transformation, driven by increasing demand for modern, comfortable residential and commercial buildings. However, prevailing construction practices, with limited consideration of local climatic conditions and building envelope performance, often result in high energy consumption and rising operational costs, highlighting the urgent need for energy-efficient solutions in the built environment.

Nepal's building sector already accounts for the majority of the country's total energy consumption. Energy demand in building sector is expected to grow further driven by urban expansion, changing lifestyles, and the increasing use of space-conditioning systems. In recent years, there has been a notable rise in the import and use of air-conditioning equipment. Poor design of HVAC systems not only compromises thermal comfort and indoor air quality but also substantially increases a building's operational energy use.

This Manual on Heating, Ventilation, and Air Conditioning (HVAC) Systems addresses these challenges by providing theoretical and practical guidance for MEP consultants, architects, engineers, and installers through a logical design process. While climate-responsive architecture forms the foundation of energy-efficient building design, high-performance HVAC systems are the essential next step in achieving optimal comfort with minimal energy use. The selection and correct design of these systems, tailored to specific climate zones and building envelope assembly are crucial for securing better thermal comfort, indoor air quality while minimizing system capacity, operational costs and financial investment.

The Manual begins by introducing fundamental comfort criteria and examining the outdoor climate to understand how Nepal's diverse environment influence HVAC system selection and design. Subsequent section present methods for calculating heating & cooling load and energy demand. A comprehensive overview of HVAC systems and technologies is provided, covering heating, cooling, ventilation, and renewable energy-based solutions. The manual also introduces energy simulation and calculation tools to support accurate and modern HVAC system design.

Developed as part of the “BUILDING Energy Efficiency in Nepal” (BEEN) project and funded by the SWITCH-Asia Grants Programme from the European Union, this manual serves as a valuable resource for strengthening HVAC design capacity in Nepal. By integrating technical rigor with practical design strategies, it aims to promote the adoption of energy-efficient HVAC solutions, contributing to a more sustainable and future-ready built environment in Nepal.

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Our Ref. No.:

Message

I, on behalf of the Ministry of Federal Affairs and General Administration (MoFAGA), am pleased to introduce the newly developed **HVAC Manual** as part of the BUILDING Energy Efficiency in Nepal (BEEN) Project, funded by the European Union under the SWITCH-Asia Grants Programme. This manual is a vital resource designed to enhance the energy efficiency of buildings across Nepal.

Nepal has seen rapid urbanization and increased building stocks in recent years. While current building practices prioritize structural safety and aesthetics, energy efficiency to achieve thermal comfort remains under-addressed. As a result, Nepal has witnessed increasing use of active space conditioning systems that are installed without proper calculations and designs. Recognizing this gap, the BEEN Project developed the knowledge product that describes signification and ways to design energy-efficient HVAC (Heating, Ventilation, and Air Conditioning) systems to reduce energy consumption, lower carbon emissions, and improve indoor comfort.

The Manual provides comprehensive guidance on designing, selecting, and implementing HVAC systems in buildings. It covers key topics such as thermal comfort, indoor air quality, and humidity control along with in-depth analysis of heating and cooling loads, energy demand, and ventilation strategies. Additionally, the Manual explores various technologies and systems, including solar photo voltaic and thermal solutions, to empower the users to make informed decisions to achieve optimal energy performance.

This Manual serves as an essential tool for architects, engineers, builders and all stakeholders involved in the building design and construction sector. By following the best practices outlined in this Manual, we can collectively work towards accelerating energy efficiency, reducing environmental impact, and fostering sustainable development in Nepal. While it is a technical resource, the Manual is also accessible to policymakers and the general public offering insights into the role of HVAC systems in energy-efficient building design and operation.

I extend my heartfelt thanks to all the contributors and partners who have made this manual a great resource and useful tool. Together, let us build a more energy-efficient and sustainable future for our nation.

Nita Pokhrel Aryal
Joint Secretary
Ministry of Federal Affairs and General Administration (MoFAGA)

EUROPEAN UNION

DELEGATION TO NEPAL

Head of Cooperation

Message

This "Manual for Energy-efficient Heating, Ventilation and Air Conditioning (HVAC) Design" is one of the knowledge products that the European Union's SWITCH-Asia funded BUILDING Energy Efficiency in Nepal (BEEN) Project to contribute to reducing energy costs and carbon footprints for consumers, as well as has the potential to be a key milestone in supporting Nepal's transition to a circular economy and meeting both its Sustainable Development Goals and its Nationally Determined Contribution targets.

The European Union (EU) aims to achieve substantial improvements in energy efficiency across all sectors. Energy efficiency is the most immediate and cost-effective approach to reducing energy demand, and crucial for driving sustainable green transitions and enhancing energy security within EU nations. The EU is actively pursuing the decoupling of economic growth from resource use within the EU while simultaneously supporting its partners countries in accelerating their green transitions. Against this backdrop, the EU is committed to supporting Nepal ensuring its infrastructure development with global best practices for energy efficiency, circular economy and climate resilience. This effort aligns with the EU Green Deal and Global Gateway strategies, which serve as the essential delivery mechanism for fulfilling the EU's global climate ambition.

Nepal is as one of the fastest urbanizing developing countries, faces a significant challenge with substantial energy consumption for heating and cooling in its building sector. Therefore, this manual was prepared to improve the design of Heating, Ventilation and Air Conditioning (HVAC) systems that largely contribute to higher energy-consumption for space conditioning in Nepal. The BEEN project has been playing an important role in establishing foundations and subsequently creating knowledge products for upscaling energy-efficiency measures in buildings. This manual is one of the knowledge products generated by the BEEN project, meticulously combining local, national, and international experts and practitioners.

This HVAC manual will be an indispensable tool for engineers, designers, and practitioners to incorporate strategies for efficient HVAC system design. It will significantly help in reducing the energy demand for space conditioning and, crucially, upholding thermal comfort for users in diverse settings across Nepal. It provides crucial instructions for reducing both operating costs and the carbon footprints over the equipment's lifespan.

I wish to extend my sincere gratitude to all partners, especially the government, the private sector, homeowners, and the BEEN project team, for their dedication in developing this valuable resource.

Warm regards,

....

Jose Luis VINUESA-SANTAMARIA,
Head of Cooperation
EU Delegation to Nepal
Kathmandu

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Message

I am incredibly pleased to introduce this comprehensive HVAC manual, a crucial outcome of the BUILDING Energy Efficiency in Nepal (BEEN) Project, funded by the European Union under the SWITCH-Asia Grants Programme. This manual represents a significant step forward in our collective efforts to advance energy efficiency and sustainability within Nepal's built environment.

At BEEN, our core objectives are to enhance capacity, foster markets for energy-efficient solutions, facilitate access to finance, and collaborate with government institutions on supportive policies. This HVAC manual aligns perfectly with these goals and has been developed keeping in mind the HVAC designers. It provides practical guidance and essential resources to empower professionals in the field, directly contributing to the capacity-building efforts vital for a greener future.

The impact of this manual is multifaceted. Firstly, it serves as a comprehensive reference, offering invaluable insights into efficient HVAC system design, optimization techniques, and the integration of renewable energy sources. Secondly, it acts as a tool for empowerment, equipping HVAC professionals to design and implement systems that create healthier, more comfortable, and significantly more energy-efficient indoor environments. Finally, it serves as a catalyst for positive change, driving progress towards a more sustainable future for Nepal.

As you explore the pages of this manual, I encourage you to view it not merely as a reference but as a source of inspiration and innovation. Let the principles outlined here spark your creativity and enable you to redefine what is possible in sustainable HVAC design.

I extend my deepest gratitude to everyone who contributed to the development of this manual and to you, the reader, for your unwavering commitment to advancing energy efficiency within Nepal's built environment. Together, we can build a brighter, more sustainable future for all.

Warm regards,

DI Dr. techn. Daniel Neyer
Project Leader (BEEN)

Acknowledgement

This *"Manual for HVAC System Design"* has been prepared with the invaluable support, guidance, and encouragement of our esteemed partners and collaborators. We gratefully acknowledge the valuable contributions and support of individuals and institutions who have contributed in development of this manual.

The publication of this manual, led by the BUILDING Energy Efficiency in Nepal (BEEN) Project, has been possible because of the financial support by the European Union under the SWITCH-Asia Grants Programme. We would like to express our gratitude to Dr Ranjan Prakash Shrestha, Senior Programme Manager, Delegation of the European Union to Nepal, for his continuous guidance and support. His strategic insights were invaluable in aligning the manual to needs and commitments of European Union and Government of Nepal.

We extend our heartfelt gratitude to Ms Subha Laxmi Shrestha for her technical expertise, constructive feedback, and coordination support in bringing together local experts for consultation and validation of the manual's content. We would also like to thank all HVAC engineers and technicians engaged during the development phases of this manual. Their practical insights helped ensure the technical soundness and relevance of the document to the local context.

Our sincere appreciation goes to Dr Wolfgang Streicher and Mr Michael Strobel, the principal authors of this manual, for their leading role and substantial contributions to its development and adaptation to the Nepali context. Their expertise, leadership, and commitment were fundamental to the successful preparation of this manual.

Finally, we acknowledge the collective efforts of all project partners, technical experts, and stakeholders whose dedication and contributions have made this publication possible.

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01 Introduction

Buildings account for 30% of the global final energy consumption and 26% of the global energy-related CO_2 emissions (IEA, 2025).It is estimated that by 2030, the global building stock will increase by 15% (IEA, 2025). The rise in construction, along with increased urbanization and living standards, especially in developing countries, will continue to drive energy consumption in buildings. The primary sources of energy consumption in buildings encompass the energy used for construction, space heating/cooling, lighting, and the appliances and equipment installed in them.

Nepal is one of the top ten fastest-urbanizing countries (Bakrania, 2015).The current urban percentage of the country is at about 22.4% with an annual urban population growth of 3.1% (UN DESA, 2018). Many policies on access to clean, reliable, and appropriate energy in rural areas and the development of the renewable energy sector have been implemented in the country. It has resulted in 94% of the total population having access to electricity today, whereas only 19% in the year 2000 (IEA, 2025). In Nepal, 61% of the total energy consumption is in the residential and commercial building sectors (WECS Nepal, 2025, p. 67).

Most buildings in Nepal are designed without consideration for local and changing climatic conditions, leading to low thermal comfort and an increased demand for energy to achieve it. The rising heating and cooling needs, driven by an improved living standard and the growing affordability of space conditioning, result in increased energy use, when building designs are not appropriate. Passive design strategies during the early phases of the design can enhance thermal comfort and significantly reduce energy consumption.

1.1 Energy use in Buildings

Globally, around 40% of the energy consumed in buildings is attributed to Heating, Cooling, Ventilation, and Air-Conditioning (HVAC) systems. In India, HVAC systems contribute to 40% - 60% of the electricity consumption in commercial buildings, while in urban residential buildings, cooling consumes 30% - 40% of the electricity used.

Nepal generates electricity mostly from hydropower, with surpluses exported to India in wet seasons and minor deficits imported from India during the dry seasons. Nepal's total energy consumption accounts for 640 PJ in 2022, of which 58.5% are covered by traditional energy resources, namely fuelwood, agricultural residue and animal waste. 90% of biomass is used for heating and cooking (WECS Nepal, 2025). Around 21 million people still rely on traditional biomass for cooking (IEA, 2025).

The residential energy consumption in Nepal has been increasing at the rate of 2.2% per annum in the last two years, which is higher than the population growth rate of Nepal (WECS Nepal, 2022, p. 56). Around 14% of the building energy is used for space cooling and space heating in residential sectors (WECS Nepal, 2025), and the same amount of energy is consumed for water heating and lighting purposes (WECS Nepal, 2025).

The selection, correct design, and layout of HVAC systems is crucial to secure comfortable indoor air quality, indoor climate control and energy efficient operation of the systems at minimized financial effort in initial investment and operation costs.

However, an efficient and proper design of a building HVAC system is not the sole solution to tackle the current and future demands on buildings. The fundamental approach is to design and build energy efficient buildings in the first place. Climate-responsive building design has a huge potential in energy savings. Clients, architects and engineers can reduce the building energy demand already in early phases.

Complementary BEEN Manuals

The BEEN projects provides useful support and assistance in the following manuals:

- BEEN – Manual for Energy-efficient Building Design
- BEEN – Manual on Application of Building Insulation Materials
- BEEN – Manual for Hollow fired Brick Production
- BEEN – Manual for Door and Window Installation

The BEEN Baseline Report on Operational Energy Consumption in Buildings identified that most buildings in Nepal already have a kind of HVAC system installed, whether it is just a ceiling fan or a firewood oven (BEEN Project, 2024). Figure 1 shows the share installation of systems for cooling, heating, or both for the three types of residential buildings, hotels, and day-use office buildings.

Figure 1: Installation of HVAC systems in different building types in Nepal. Source: BEEN Project, 2024

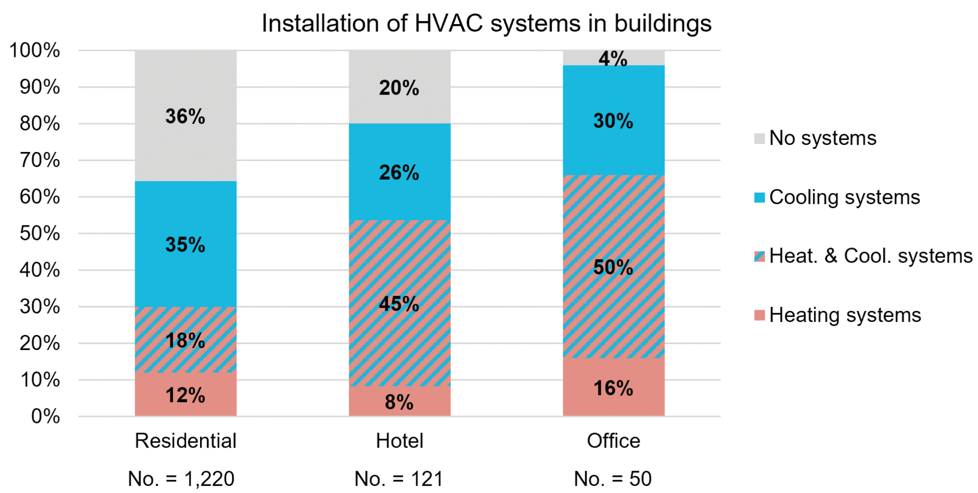
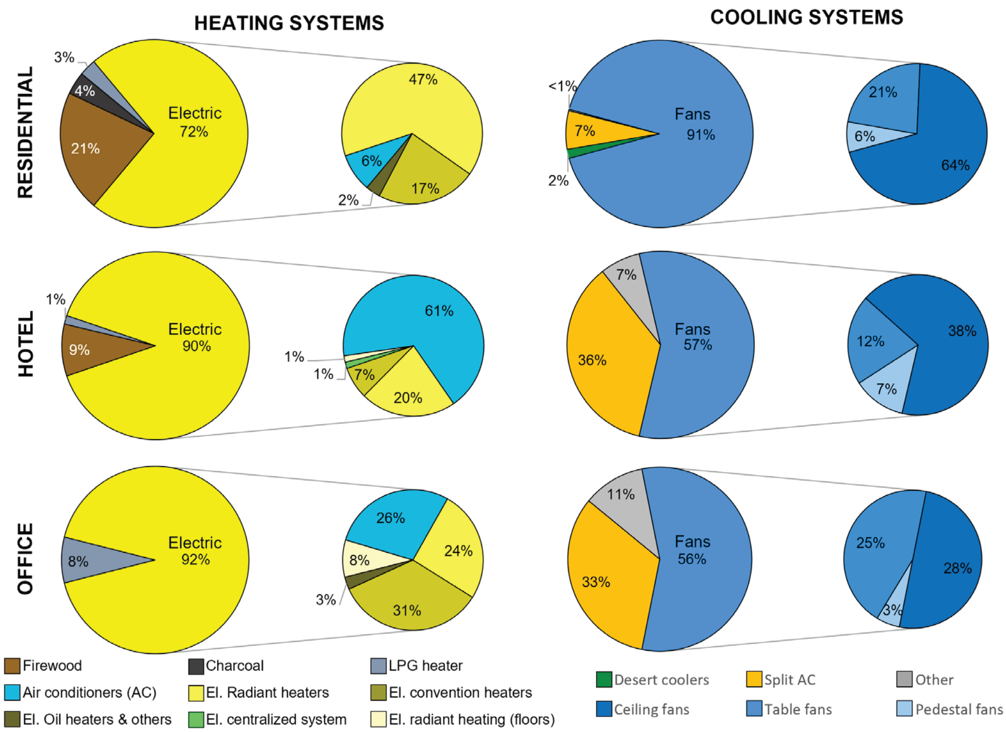


Figure 2 shows the distribution of individual technologies for heating and cooling. Heating is mostly electric driven, whether it is AC, radiant heater or convection heater. The most applied technology for cooling purpose are fans, mostly ceiling fans.

Figure 2: Distribution of HVAC systems for heating and cooling among different buildings types. Source: BEEN Project, 2024



1.2 Objective of the Manual

Technical systems and equipment can be a great benefit to the quality of a building and increase the user comfort. However, the correct selection, sizing, and application of products for heating, ventilation, and air conditioning (HVAC) are very important. Incorrect planning, design, and installation can cause discomfort, high investment costs and energy bills and even damages to the building.

This manual provides information for MEP consultants, architects, engineers, and installers on the basics of commonly used HVAC systems and ways to achieve energy-efficiency in these systems to make the building energy efficient.

1.3 Outline of the Manual

This manual provides general information on the comfort criteria, description and differences of systems and what to focus on when planning and installing systems. It is divided in the following chapter:

- **Chapter 2:** Comfort criteria

This chapter describes the different comfort parameters and their influence on the human thermal comfort and what the potential of HVAC systems is.

- **Chapter 3:** Outdoor climate

The relevance and implications of the outdoor climate on the HVAC system selection and design are described in this chapter.

- **Chapter 4:** Energy demand and load definition

The energy demand and energy load need to be calculated for proper planning of the HVAC systems. This chapter provides a basic understanding on the calculation of these indicators.

- **Chapter 5:** Overview of HVAC technologies and available systems

Here different technologies and system for heating, cooling and ventilation are described and their advantages and disadvantages are presented.

- **Chapter 6:** Overview of selected simulation and calculation software you may use for HVAC system design.

02 Comfort Criteria

In order to guarantee that building occupants are in a comfortable interior environment, it is crucial to have a clear understanding of comfort criteria and a method to calculate the indicators of comfort. Usually, these requirements include temperature and humidity control, noise levels, and indoor air quality. You can find supplementary information in:

- Manual for Energy-Efficient Building Design (BEEN, 2025)
- ASHRAE Standard 55 (ASHRAE, 2023)
- ISO 7730: Ergonomics of the thermal environment (ISO, 2005)
- A Review of Recent Literature on Systems and Methods for the Control of Thermal Comfort in Buildings (Grassi, Piana, Lezzi, & Pilotelli, 2022)

2.1 Thermal Comfort

The state of mind that conveys subjective satisfaction with the thermal environment is referred to as thermal comfort. Radiant temperature, air temperature as well as humidity and air velocity are important variables that affect thermal comfort. The parameters for appropriate thermal settings of a Heating, Ventilation and Air Conditioning (HVAC) system are outlined in ASHRAE Standard 55 (ASHRAE, 2023) and in ISO 7730 (ISO, 2005).

Among others, the type of clothing affects the thermal comfort. Wearing long pants and a pullover allows to reach comfort at lower temperatures than just wearing shorts and a T-Shirt. The clothing factor, expressed as *clo*, indicates the level of clothing and covering. A *clo* value of 0 corresponds to a person being naked whereas a *clo* value of 1 indicates a person being fully clothed, such as in a business suit. The clothing factor is composed of the combination of individual clothes and their specific insulation impact I_{clo}. These values are defined in the ASHRAE Standard 55-2010, Table 5.2.2.2B. A short-sleeve dress has an I_{clo} of 0.19, whereas a long-sleeve think sweater has an I_{clo} of 0.36.

A second aspect to be considered is the type of typical activity of a person in the room/ building. This aspect, expressed as *met (short form of metabolic rate)*, indicates the metabolic rate of waste heat. The ASRHAE standard 55 defines the *met* for a person sitting as 1, sleeping as 0.7 and walking about of 1.7. A higher activity of a person, expressed with a higher *met* value, allows comfortable conditions at lower temperatures compared a low *met* value.

Additional and complementary information can be found in BEEN Manual for Energy-Efficient Building Design.

Figure 3: Acceptable ranges of operative temperature and humidity with air speed ≤ 0.2 m/s for people wearing 1.0 and 0.5 clo clothing primarily seated with activity (≤ 1.1 met). Source: ASHRAE Handbook Fundamentals, 2009

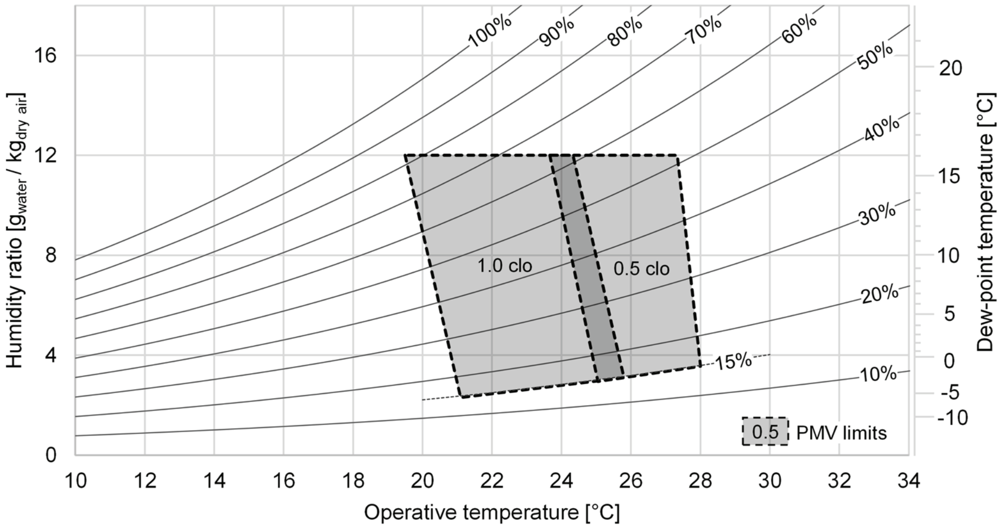


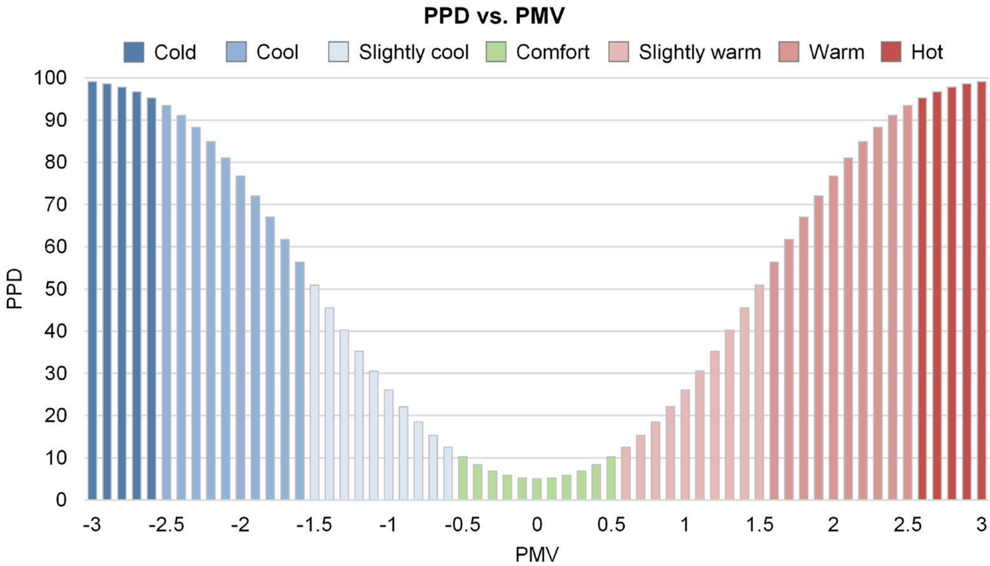
Figure 3 shows the comfort region adapted from ASHRAE Handbook 2009 for normal (1 *clo*) and summer clothing (0.5 *clo*). The left y-axis shows the absolute humidity g_{water}/kg_{dry_air}, the inclined and bended lines show the relative humidity in %.

- **Air Temperature:** The Dry Bulb Temperature (DBT) is the temperature of air measured by a thermometer which is freely exposed to the air but shielded from radiation. DBT is usually thought of as air temperature and does not indicate the amount of moisture in the air. It is usually expressed in °C or °F. It determines whether heat loss can occur through evaporation and convection.
- **Mean Radiant Temperature:** It is the mean temperature of surfaces facing to the room/building interior. The mean radiant temperature should be similar to the air temperature to prevent discomfort (this means insulation of walls and at least 2 pane windows).
- **The Operative Temperature:** It (shown in Figure 3) is the average of air and radiant temperature, if the air velocity is below 0.1 m/s. It should ideally be between 20-24°C during winter (active heating below 20°C, higher temperatures are allowed when achieved through solar radiation) and 24-27°C during summer (active cooling above 27°C, but at night/morning colder temperatures, <24°C, are allowed). Air Velocity should be low to avoid drafts, typically under 0.2 m/s (40 ft/min).
- **Relative Humidity:** Relative Humidity (RH) is the ratio of the amount of water present in the air to the maximum amount of water that the same volume of air can hold at the same temperature. It signifies the moisture content of the air. Relative humidity should be maintained between 20-70%. Despite ASHRAE is going down to 0% relative humidity, in this manual a relative humidity above 20% is recommended. Below this value problems with the trachea, the eyes

and the skin may arise. The absolute humidity, also called humidity ratio, describes how much mass of water is given per mass of air [g_{water}/kg_{dry_air}]. It is given on the left axis in Figure 3. The warmer the air, the more water it can hold.

- **Condensation:** The graph shows that warm air capable to hold more humidity. Cold air may have a higher relative humidity [%], but as its capability to hold the absolute humidity [g_{water}/kg_{dry_air}] is still low. Thus, especially for hot and humid climates where cooling is required, it is important to take the level of condensation into consideration. If hot and humid air gets in contact with a surface, condensation appears and water droplets form on that surface. You can experience this physical phenomenon when you take a cold bottle of water from the fridge and it gets wet.
- **Air speed/air movement:** Air speed is the average speed of air, indicating its movement within a space. It is usually expressed in terms of m/s. It is averaged over time intervals between one to three minutes due to the continuous variation in air speed. The recommended maximum air velocity for thermal comfort is at 0.2 m/s. It can be higher when the indoor temperature is above 27°C to support the cooling via sweating.
- **The PMV (Predicted Mean Vote) value,** shown in Figure 4, is a worldwide measure (ISO, 2005) that shows how many persons in average feel comfortable in a room. The PMV ranges from -3 (people feel too cold) to 3 (people feel too hot). A value of 0 means that most people feel comfortable, a value of ±0.5 means slightly too warm/cold. Here the Percentage of Persons Dissatisfied (PPD) are at 10%. Even if the PMV is at 0, still 5% of people on average will feel discomfort, as they personally prefer hotter or colder conditions.

Figure 4: Percentage of Persons Dissatisfied (PPD) vs. Predicted Mean Vote (PMV). Source: Kumar, 2019



The indoor comfort conditions are not always the very same for different climates. Instead, the outdoor climate also influences the indoor air comfort. In general, people in cold climates (such as Mustang) are ok with indoor air temperature of around 18°C. In hot climates on the other side (such as in Butwal), people are ok with indoor air temperature of 26°C. Otherwise, people might experience thermal stress when the thermal conditions between indoor and outdoor are too diverse.

Example: Thermal comfort is ensured in an office area by an HVAC system that keeps the air at between 20°C and 26°C and 20% – 70% relative humidity. Seasonal adjustments are possible, such as a few degrees warmer in the summer and colder in the winter. A higher flexibility and adaptiveness of users allows to operate a HVAC system unstrained and to lower the heating/ cooling and humidification/ dehumidification demand.

Table 1: Overview of recommended indoor conditions in different climates and HVAC requirements.

Region	Outdoor conditions		Recommended indoor conditions	
	Temperature	rel. humidity	Temperature	rel. humidity
Cold	-11–18°C	40-75%	16-20°C	20-50%
	HVAC requirements: Heating is required most time of the year, whereas cooling is not required. The outdoor temperature is generally low and the air holds less humidity, even though relative humidity of ambient air can be high. When heating, the relative humidity decreases as the total humidity is constant. Thus, humidification is recommended when heating is in use to prevent extreme dry air.			
Cool temperate	2-24°C	60-85%	16-22°C	20-70%
	HVAC requirements: Heating is required most time of the year, whereas cooling is not required. Humidification may be required, to prevent from extreme dry air.			
Temperate	5-30°C	60-85%	18-22°C / 25-27°C	20-70%
	HVAC requirements: Heating systems are required to maintain indoor temperature during cold season, whereas in summer time cooling devices may be required. In cold season, 18-22°C is comfortable, whereas in hot season 25-27°C is recommended. Dehumidification in summer time is often required, whereas humidification is not necessary.			
Warm	8-36°C	45-85%	22-28°C	60-80%
	HVAC requirements: Cooling is required during hot and rainy season whereas heating is not required. When cooling the air, the relative humidity increases as cooler air can hold less water than warm air. Thus, dehumidification is necessary to prevent extreme wet air.			

2.2 Humidity Control

It's critical to maintain appropriate humidity levels for both comfort and health. While dryness and respiratory problems can result from too low humidity, mould development and discomfort can come from too high humidity and too little insulation. The more humid the air is, the hotter it feels for the humans, as sweating for temperature control is less effective.

- Relative Humidity: Should be kept between 20-70%.

- Dehumidification: Use of dehumidifiers or air conditioners to reduce humidity levels in humid climates.
- Humidification: Use of humidifiers in very cold dry climates to increase humidity levels.

Example: The HVAC system of a museum should keep the relative humidity between 40% and 60% to avoid material deterioration, since maintaining artifacts is crucial. You can use dehumidifiers and humidifiers to keep this level consistent all year long.

2.3 Indoor Air Quality (IAQ)

To maintain a healthy atmosphere, indoor air quality requires limiting pollutants and keeping ventilation at a sufficient level. Particulate matter (PM), carbon dioxide (CO_2), and volatile organic compounds (VOCs) are examples of common pollutants.

- Ventilation Rate: The recommended ventilation rate is 8.5 litres per second per person (30 m^3/(h·person)). ASHRAE Fundamentals standards, chapter 16: Ventilation and Infiltration evaluates a ventilation rate of 10 litres per second and per person as very likely to provide acceptable indoor air quality. Examples for the very minimum ventilation rates Examples according to ASHRAE standard 62.1

Category	l/(s· Person)	m^3/(h· Person)	ft^3/(min Person)	l/ (s·m^2)	m^3/ (h·m^2)	ft^3/ (min m^2)
Classroom	5	18	10.6	0.6	2.2	1.3
Library	2.5	9	5.3	0.6	2.2	1.3
Daycare	5	18	10.6	0.9	3.2	1.9
Bar	3.8	13.7	8.1	0.9	3.2	1.9
Coffee station	2.5	9	5.3	0.3	1.1	0.6

- CO_2 Levels: Should be kept below 1,500 ppm to avoid stuffiness and support cognitive function.
- Filtration: Use of general filters, see Table 2 in special situations HEPA (High Efficient Particulate Air) filters to capture airborne particles and improve air quality. (AHSRAE 2023)

Example: Students and teachers can breathe clean air in a classroom that has an HVAC system that provides a ventilation rate of 10 litres per second per person (36 m^3/(h·person)) and is equipped with Bag Filters (F7) filters. This lowers the risk of respiratory issues and improves concentration.

Table 2: Comparison of filter grades for Asia/US and Europe for typical applications, including the filter arrestance based on EN 779. Source: (AirProControl, 2024), (A.D.D. Filtration, 2025), (MVHR, 2024)

Asia/US	Europe				
MERV Rating	US/ IN Filter Grade	EU Grade	Arrestance / Efficiency	Filter Types	Typical Applications
MERV 1	G1	EU1	50-65% Avg. Arrestance	Wire Frame Filters	Window units, heat exchangers
MERV 2 MERV 3 MERV 4	G2	EU2	65-80% Avg. Arrestance	Wire Frame Filters	Low level pre-filtration. Fan coils, refrigeration & equipment cabinets.
MERV 5 MERV 6	G3	EU3	80-90% Avg. Arrestance	Wire Frame Filters, Glass Panel Filters	Medium level pre-filtration. Simple ventilation for garages & factories.
MERV 7 MERV 8	G4	EU4	90% Avg. Arrestance	Wire Frame Filters, Glass Panel Filters	Higher level pre-filtration. Air-conditioning of paint booths & kitchens.
MERV 9 MERV 10	M5	EU5	40-60% Avg. Efficiency	Bag Filters, Pleat Pack Filters	Air-conditioning of restaurants, gyms, shops & workshops.
MERV 11 MERV 12	M6	EU6	40-60% Avg. Efficiency	Bag Filters, Pleat Pack Filters	
MERV 13	F7	EU7	80-90% Avg. Efficiency	Bag Filters, Pleat Pack Filters	Air-conditioning of schools, offices, theatres, computer rooms & spray booths.
MERV 14	F8	EU8	90-95% Avg. Efficiency	Bag Filters, Pleat Pack Filters	Air-conditioning of schools, offices, theatres, computer rooms & spray booths.
MERV 15 MERV 16	F9	EU9	≥ 95% Avg. Efficiency	Bag Filters, Pleat Pack Filters	Air-conditioning of clean rooms, pharmaceutical, animal health & laboratories.
	H10	EU10	> 95% Efficiency @ 0.3 μm	HEPA Filters	Highly effective against bacteria & smokes. Used in operating theatres, pill production, electronics & sterilisation applications.
	H13	EU13	> 99.997% Efficiency @ 0.3 μm	HEPA Filters	Highest air quality applications. Used in sterile areas, class 1000 clean rooms, bacteriological, animal health & isolation.

2.4 Noise Level

For the comfort and productivity of the residents, noise management is essential. An excessive amount of noise can be stressful and distracting.

- **Sound Levels:** Measured in decibels (dB). ASHRAE Handbook – HVAC Applications recommends following values:
  - 35-40 dB for classrooms,
  - 40-45 dB for office spaces,
  - 25-35 dB for hotel conference rooms,
  - 35-45 dB for hotel service and support areas,
  - 25-35 dB for apartment rooms,
  - 30-40 dB for hospital corridors and public areas
  - 45-55 dB for laboratories for testing/ research and minimal speech communication
- **Equipment Noise:** HVAC components like fans and compressors should be designed or installed to minimize noise. (ASHRAE, 2023)

Example: The HVAC system in a library should run silently, keeping noise levels at or below 35 dB to create a comfortable atmosphere for studying and reading. This can be achieved by using sound absorbing furniture like carpets, fabric covered chairs, curtains, duct liners, sound attenuators, and vibration isolators.

2.5 Additional Comfort Criteria

- **Air Distribution:** Ensuring even air distribution to avoid low air quality spots for ventilation systems or hot or cold spots for air conditioners.
- **Zoning:** Dividing a building into zones with separate temperature controls to accommodate differed individual comfort requirements.
- **Natural Ventilation Integration:** To improve interior air quality and save energy, use natural ventilation whenever it is possible.

Example: A multi-zone HVAC system in a modern office building would enable individual control over different spaces, including meeting rooms, private offices, and open-plan offices. This guarantees that, given its unique usage and occupancy, each zone may maintain the highest level of comfort.

03 Outdoor Climate

The design, operation, and performance of HVAC systems are heavily influenced by the outdoor climate. Understanding the specific conditions of the outdoor climate is essential for optimizing HVAC systems to ensure indoor comfort and energy efficiency (Roger and Myers 2010).

Factors Influencing Outdoor Climate:

- **Temperature:** The surrounding air temperature affects both heating and cooling demands.
- **Humidity:** The moisture level in the air impacts indoor air quality and occupant comfort.
- **Solar Radiation:** Solar heat gained through windows and building surfaces reduce space heating load but increases cooling loads.
- **Wind:** Wind speed and direction influence heat loss/gain and natural or mechanical ventilation.
- **Precipitation:** Rain, snow, and ice can affect the performance and maintenance of HVAC systems.
- **Seasonal Changes:** Fluctuations in weather throughout the year impact the design and operation of HVAC systems.

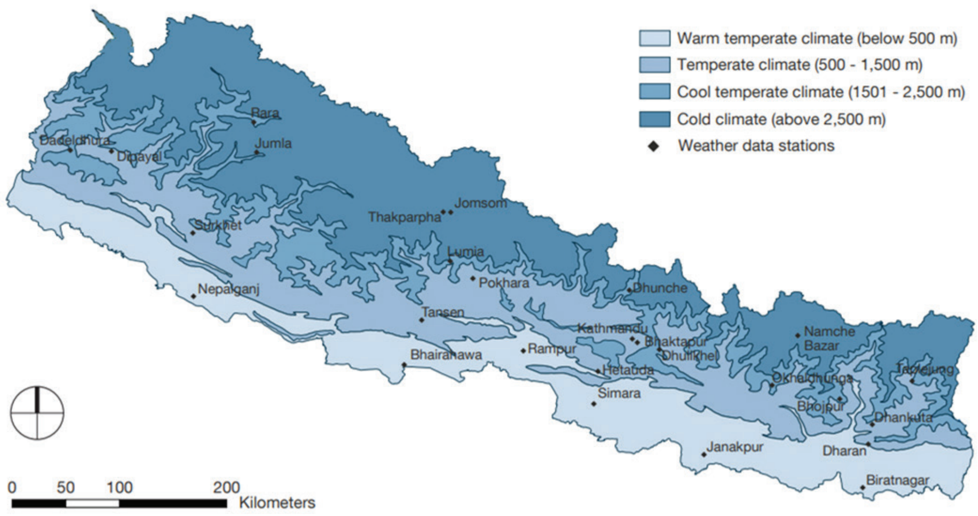
Table 3: Overview of four climate zones in Nepal and their typical characteristics.

Climate Zone	Climate Characteristics	Temperature		Avg. Relative Humidity range (%)
		Avg. Max. (°C)	Avg. Min. (°C)	
1-Warm Temperate	Dec-Feb: Cold & dry season with clear skies Mar: Moderately cold & dry season Apr-Jun: Hot & dry season with clear skies Jul-Sep: Warm & humid season Oct-Nov: Moderately warm & moderately humid season	33-36	8-10	45–85
2-Temperate	Dec-Feb: Cold & dry season with clear skies Mar: Moderately cold & dry season Apr-May: Warm & dry season Jun-Oct: Moderately warm & humid season Nov: Cool & moderately humid season	27–30	5-7	60-85
3-Cool Temperate	Nov-Mar: Cold & dry season with clear skies Apr: Cool & dry season May-Sep: Moderately warm & dry season Oct: Cool & dry season	22–24	2-4	60–85
4-Cold Climate	Cold & dry season for most of the year Jun-Aug: Moderately warm day-time temperature	16-18	-11–7	40-75

Types of Outdoor Climate

- **Warm Temperature:** Hot summers, dry winter, high humidity and temperature during rainy season.
  Impact on HVAC: No space heating needed. High cooling demands require efficient cooling systems and effective shading solutions.
- **Temperate:** Mild temperatures, moderate humidity, and clear seasonal changes.
  Impact on HVAC: Balanced heating and cooling needs with opportunities for natural ventilation and passive solar heating.
- **Cool Temperate:** Cold and dry winter and moderately warm and dry summer.
  Impact on HVAC: Demand for heating is given for all winter. No cooling demand.
- **Cold Climate:** Low temperatures, potential snow and ice, and considerable temperature variations.
  Impact on HVAC: High heating demands necessitate robust insulation and efficient heating systems. No space cooling needed.

Figure 5: Climate Zones in Nepal. Source: Bodach, Lang, & Hamhaber, 2014



04 Demand and Load Definition

To maintain a certain level of indoor temperature, at different outdoor weather conditions, can lead to a thermal energy demand (heating) in winter time, and to a thermal energy surplus, a cooling demand, in summer time. The heating/ cooling demand depends on the quality of the building and on the local climate.

This chapter presents the fundamental and advanced materials on heating and cooling demand and load calculation. Additionally, the ventilation load and the demand and load for domestic hot water are described.

There are two main calculations:

- The Heating/Cooling Load [kW] defines the needed size (power) of the HVAC components and the space needed in the building (e.g. technical room in large buildings) and therefore, the investment costs. Here the worst case assumptions are made for the system sizing calculations, which is not a good practice. However, these approaches are very similar in Europe, the USA (ASHRAE, 2021) or India (ISHRAE, 2017).
  - Space Heating Load: Calculated based on the lowest ambient temperature with transmission and ventilation losses and no solar and internal gains for heating. This can be a stationary calculation.
  - Cooling Load: Calculated based on the hottest day with transmission and ventilation gains/losses, internal and solar gains as well as thermal mass of the building. This can be a stationary calculation with transient elements or a dynamic simulation, as there are different solar gains in different directions over the day, no sunshine at night and the thermal masses cool down and need some time to heat up during the day.
- The Heating and Cooling Energy Demand [kWh/a or kWh/m^{2}a] indicates the energy demand based on heat losses and heat gains over the year. This energy demand refers to heat or cool the space, not the electricity consumed by HVAC appliances. Here average monthly (or hourly) climate conditions and all building energy flows (transmission, ventilation, solar gains, internal gains and the thermal mass of the building for the calculation time step) have to be taken into account. The energy demand is responsible for the annual operating costs for heating and cooling systems. Like in the cooling load, either a stationary calculation with transient elements or a dynamic simulation are used for the calculation.

4.1 Heating/ Cooling Load

The heating/ cooling load expresses the thermal load to achieve/ maintain desired air temperature at a given boundary condition (for design: worst case assumptions as explained above). The load is dependent on different aspects, such as thermal losses through ventilation and transmission (through walls and windows), the desired indoor air temperature, the internal and external (solar) heat gains and the thermal capacity of the building. The thermal capacity of a building governs how much heat can be the building construction absorb and indicates how fast a building cools down / heats up.

The correct and proper estimation of heating and cooling load is very important, not only for reasons of energy efficiency. Correctly estimated loads are the base for the suitable design and layout of heating and cooling appliances. If the load is underestimated, the HVAC systems will not be able to provide comfortable indoor air conditions, which can lead to cold indoor climate in winter and too hot indoor climate in summer times. On the other side, if the system is overestimated, it will cost a lot of money and will always run in on/off or part load conditions. Also, due to higher capacity, uncomfortable conditions can occur by too high air velocity in the rooms or too much cooling and heating. An overestimated HVAC system causes both, investment and operational costs unnecessarily high.

Benefits of proper heating/ cooling load estimation:

- Comfortable indoor conditions in summer/ winter
- Allows correct layout of heating/ cooling units, saving space and financial investment in appliances and installation
- Allows correct layout of system components, such as pumps and pipes
- Saves money in investment and operation

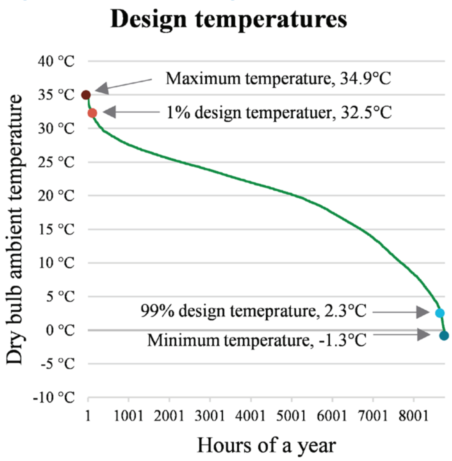
There are different standards applicable to calculate the heating/ cooling load of a building, such as ISHRAE, ASHRAE or EN12831/ISO 52016-1. All equations and standards are based on physical correlation to picture the different heat fluxes (gains/ losses) between indoor and outdoor.

All equations in this manual only serve the purpose to principally show the physical correlation between parameters and variables. Complementary equations can be found in Annex I – Formulas. For more information on the heating and cooling load calculation, please refer to the named standards or use proven and recognized software tools, such as EnergyPlus, TRNSYS, etc.

The heating load calculation requires the calculation of a design (maximum) temperature difference between indoor and outdoor. The indoor set point temperature for heating load calculation is defined as 20°C. The outdoor temperatures for the heating and the cooling load calculation are dependent on the local climate. Thus, the annual course of the outdoor climate must be known (see ASHRAE Fundamentals, chapter 14 or CBE Climate Tool - https://clima.cbe.berkeley.edu/)

In general, not the lowest hourly temperature for heating load or the highest hourly temperature for cooling load of a year is used in the calculation of

Figure 6: Example of design temperature definition.



the temperature difference, but the 99% and 1% design dry-bulb temperature, respectively. This temperature is defined as 99% of the time the outdoor temperature or 1% is above this value and accounts with this approach for thermal masses of the building and solar radiation and avoids oversizing of the system. If no national values are available, climate data (1% coldest and 1% hottest day temperatures) can be taken also from the free CBE Climate Tool. Benefits of proper heating/ cooling load estimation: shows the exemplary outdoor temperature for a place close to Kathmandu, listed from hottest to coldest temperature. The minimum temperature at a location is -1.3°C. But 99% of the time in the year, the temperature is above 2.3°C. Thus, the 99% design temperature is at 2.3°C, which will be used for heating system sizing calculations. Accordingly, the design temperature of 32.5°C will be used for cooling system sizing calculations

Depending on the climate and the building design, the planner is free to use the 99.6% temperature which is even closer the minimum temperature of the year.

4.1.1 Heating Load

Heating load must be calculated when the internal room temperature can drop below the comfortable temperature and a heating system is required to be designed.

ASHRAE Fundamentals[1] chapter 17 gives a comprehensive overview and detailed guidance in the calculation of heating and cooling loads. Following this standard, the heating load is influenced and calculated using the following parameters:

Table 4: Overview of parameters relevant for heating load calculation in ASHRAE Fundamentals Handbook (2021)

Parameter	Equation	Short description
Exterior surfaces above grade	$q = U \cdot A \cdot \Delta t;$ [W] $\Delta t = t_{in} - t_o$ [°C]	Walls, roofs and windows that directly face outdoor air, t_{in}: indoor temperature [°C], t_o: design outdoor temperature (99% hotter), U : U-Value [W/(m²K)] A : Area of surface, every surface needs to be calculated separately and the q values have to be added u [m²]
Partitions to unconditioned buffer space	$q = U \cdot A \cdot \Delta t$ [W]	Walls, roofs and windows that do not face outdoor, but unconditioned spaces, such as garages or storage halls Δt: temp. difference across partition [°C]
Walls below grade	$q = U_{avg,bw} \cdot A \cdot (t_{in} - t_{gr})$ [W]	Walls that face not outdoor air, but ground. This refers to walls in the basement $U_{avg,bw}$: Average U-value of all ground bordering walls [W/(m²·K)] t_{gr}: Temperature ground [°C]
Floors on grade	$q = F_p \cdot p \cdot (t_{in} - t_{gr})$ [W]	Floor slabs of ground floor F_p: heat loss coefficient per meter of perimeter, [W/(m·K)], p: perimeter (exposed edge) of floor, [m] (ASHRAE Fundamentals, Chapter 18)

1 The ASHRAE Fundamentals Handbook is a comprehensive guide for HVAC professionals, providing essential information on heating, ventilation, air conditioning, and refrigeration systems design and analysis. Here the edition 2021 was used.

Parameter	Equation	Short description
Floors below grade	$q = U_{avg,bf} \cdot A \cdot (t_{in} - t_{gr})$ [W]	Floors labs of basements, considering all heat fluxes, also to the side. $U_{avg,bf}$: Average U-value of ground slab [W/(m^{2}K)] *A*: Area of ground slab [m^2]
Ventilation/ Infiltration	$q_{v,i} = C_s \cdot Q_v \cdot \Delta t$ [W] $Q_v = 0.15 \cdot A_{cf} + 3.5 \cdot (N_{br} + 1)$ $Q_i = A_L \cdot \text{IDF}$	Air input from ventilation and infiltration via doors and windows and mechanical ventilation systems (controlled). C_s: air sensible heat factor, [W/(L·s·K)] (1.23 at sea level), Q_v: actual air volumetric flow rate, [L/s] for ventilation and infiltration. N_{br}: Number of bedrooms
	C_s = air sensible heat factor, [W/(L·s·K)] (1.23 at sea level), Q = air volumetric flow rate, [L/s.for ventilation and infiltration Q_v = required ventilation flow rate, [L/s] A_{cf} = building conditioned floor area, [m^2] N_{br} = number of bedrooms (not less than 1), ca 1 person / bedroom. Qi = infiltration airflow rate, [L/s] A_L = building effective leakage area (including flue) at reference pressure difference = 4 Pa, assuming discharge coefficient C_D = 1, [cm^2] IDF = infiltration driving force, [L/(s·cm2)]	
Distribution losses	Values from Table	Thermal losses/ gains in the HVAC systems, such as in ventilation ducts
Total sensible heating load	$q_s = \Sigma q$	Total sensible heating demand, including the distribution losses [W]

In addition to the parameters listed in the table above, thermal bridges can be taken into account in the heating load calculation. For further information on thermal bridges, please check the BEEN Manual on Application of Insulation Materials.

The sum of all parts is the whole heating load. The heating load calculation does not take solar gains and internal gains into consideration because it focuses on worst case calculation.

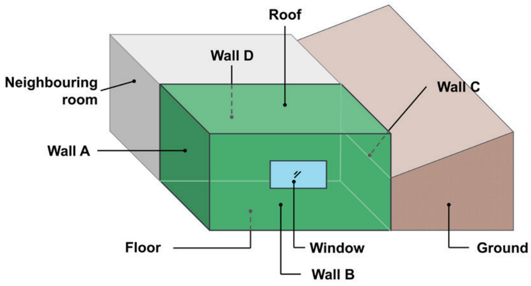
$$q_{Heating} = q_{Trans} + q_{v,i} + q_{Thermal\ Bridges} + q_{dis} \qquad (1)$$

$q_{Heating}$	Heating load
q_{Trans}	Heat losses through transmission (walls, glass, floors, above and below grade, ...)
$q_{v,i}$	Heat losses through ventilation and infiltration (open window, cracks, ...)
$q_{Thermal\ Bridges}$	Heat losses through thermal bridges
q_{dis}	Heat losses through distribution

Example of Heating Load Calculation

In the following example, heating load will be calculated for one exemplary room. The room is characterised by a 5m-by-5m footprint and a height of 2.8m. Except for one wall, all surfaces of the building are exposed to the ambient. One wall is partly below ground and the floor is directly placed on the ground slab.

Figure 7: Sketch of example room (green). Source: University of Innsbruck, Unit of Energy Efficient Building



The building is located in Kathmandu, with a coldest 99% design temperature of 0°C and a ground temperature of 15°C. The desired indoor temperature is set as 20°C. Thus, the resulting temperature difference (Δt) is 20 K for surfaces exposed to air and 5 K for surfaces exposed to ground.

Heat losses through transmission – q_{Trans}

This involves the transmission through all envelope construction: walls, windows, roof and floor. The regular U-value for each surface towards ambient air can be directly used. The U-value of ground-facing surfaces must be individually defined, based on the depth of floor below ground. This information is presented in ASHRAE Handbook Fundamentals, chapter 18.

Construction	Area	U-value	to	Δt	
Wall A	14 m²	2.0 W/m²K	Air	20 K	560 W
Wall B	12.2 m²	2.0 W/m²K	Air	20 K	488 W
Window (Wall B)	1.8 m²	5.7 W/m²K	Air	20 K	205 W
Wall C	14 ²	1.075 W/m²K	Ground, 1.8m	5 K	75 W
Wall D			other room	-	
Roof	25 m²	2.4 W/m²K	Air	20 K	1,200 W
Floor	25 m²	0.202 W/m²K		5 K	25 W
qTrans =					2,528 W

Heat losses through ventilation and infiltration – $q_{v,i}$

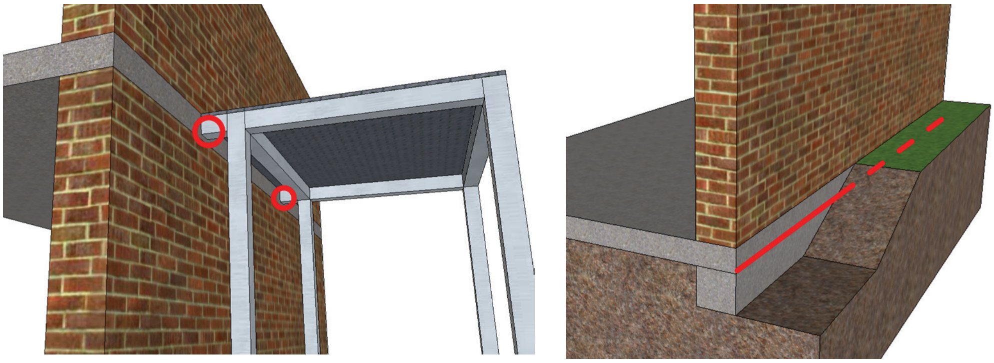
Heat lost through exchange of warm air leaving the building and cold air from ambient entering the building. The room is being used as a bedroom with 2 occupants. The heat factor is adapted for the elevation of Kathmandu (compare ASHRAE Handbook – Fundamentals, chapter 18 section 3.1).

Type	Elevation	Cs,1300m	Acf	Nbr	Noc	Qv	Δt	
sensible	1,300 m	1.05	25 m²	1	2	10.75	20 K	226 W
qv,i =								226 W

Heat losses through thermal bridges – $q_{Thermal\ bridges}$

Thermal bridges are for example the connection of a balcony or a non-insulated wall foundation. Thermal bridges cause additional thermal losses in addition to the transmission losses through surfaces. There are punctiform and linear thermal bridges, and their transmittance is given either as χ [W/K] for punctiform or as Ψ in [W/(mK)] for linear thermal bridges as additional heat loss compared to the plain surface. The transmittance must be calculated in a software upfront to the heating load calculation.

Figure 8: Graphic representation of punctiform and linear thermal bridges. (a) Two punctiform thermal bridges linked to the connection of ankers from the balcony into the wall/ RCC slab. (b) Linear thermal bridge linked to the uninsulated ground slab. Source: University of Innsbruck, Unit of Energy Efficient Building



(a) Punctiform thermal bridge (b) Linear thermal bridge

Thermal Bridge	Ψ	χ	Length/ number	boundary	Δt	
Balcony ankers		0.4 W/K	2	Air	20 K	16 W
Wall foundation ground	0.11 W/(m·K)		20 m	Ground	5 K	11 W
				qThermal Bridges =		27 W

The total heating load is accumulated from all the heat losses mentioned above, plus an additional heat loss based on heat losses in the distribution system qdis. Distribution losses can be estimated using chapter 17 of the ASHRAE Handbook Fundamentals. For simplified reasons, the distribution losses are fixed at 10%. The distribution losses can reach values of 50% and higher, depending on the location of ducts and pipes and whether they are insulated or not.

Heat losses	
q_{Trans}	2,528 W
$q_{v,i}$	226 W
$q_{Thermal\ Bridges}$	27 W
subtotal	2,782 W
q_{dis} (+10% back-up)	278 W
Required heating load $q_{heating}$	3,060 W

4.1.2 Cooling Load

At hot and warm weather conditions a building may heat up to uncomfortable indoor air conditions. This causes a need for cooling; in other words, the need to release/ reject heat from the building to the ambient.

The need for cooling may occur only in daytime or for the entire day, depending on the climate and the building design. The cooling depends on the heat losses / gains through transmission, ventilation, infiltration, internal heat gains from people, equipment and lighting, heat gains through solar radiation and also due to the dampening effect of thermal masses on the indoor temperature. The calculation of the cooling demand should follow a dynamic approach to take the effect of the thermal mass of the building into account. Nevertheless, the dynamic effect of heat storage is accounted for in lumped values in the following to yield a quasi-stationary approach.

The cooling load is the thermal power that has to be removed from of the building to achieve a defined indoor air temperature while the outdoor air is hot and humid.

It is essentially dependent on climate, building envelope quality and design, and user behaviour. ASHRAE Fundamentals chapter 17 highlights following parameters for the cooling load calculation. Opaque surfaces are treated in principle same as for the heat load, but Δt is adjusted by the factors "OF" representing the incident solar gain and the heat storage effects.

Table 5: Overview of parameters relevant for cooling load calculation in ASHRAE Fundamentals Handbook (2021)

Parameter	Equation	Short description
Exterior opaque surfaces	$q_{opq} = A \cdot CF$ [W] $CF_{opq} = U \cdot (OF_t \cdot \Delta t + OF_b + OF_r \cdot DR)$ [W/m²]	Walls and roofs that directly face outdoor air. CF can be viewed as CF = *U*·CLTD. (Cooling Load Temperature Difference)
	Δt	$= T_o$ *(1% hotter)* $- T_i$ *(indoor design temperature)* [K]
	OF_t, OF_b, OF_r	= opaque-surface cooling factors (see ASHRAE Fundamentals Handbook p.17.8 Table 7) [-]
	DR	= average daily range of outdoor dry-bulb temperature, [K] (from CBE Climate Tool, e.g. 6 K in Kathmandu for June, July)
Exterior transparent surfaces	$Q_{win} = A \cdot CF_{win}$ [W] $CF_{win} = U(\Delta t - 0.46DR) + PXI \cdot SHGC \cdot IAC \cdot FF_s$ [W/m²]	Heat gains by windows to ambient with solar radiation and its shading functions [W]

Parameter	Equation	Short description
	SHGC = fenestration rated or estimated NFRC solar heat gain coefficient [-] IAC = interior shading attenuation coefficient [-], FF_s = fenestration solar load factor [-], Table 13 PXI = peak exterior irradiance, [W/m²]; calculated via *Eq.(a.1)* or *Eq.(a.2)* PXI = $T_x E_t$ (unshaded fenestration) [W/m²] - *Eq. (a.1)* PXI = $T_x [E_d+(1-F_{shd})E_D]$ (shaded fenestration) [W/m²] - *Eq. (a.2)*, where: E_t, E_d, E_D = peak total, diffuse, and direct irradiance in dependence of latitude and orientation (Table 9 or 10), [W/m²] T_x = transmission of exterior attachment (insect screen or shade screen) [-] F_{shd} = fraction of fenestration shaded by permanent overhangs, fins, or environmental obstacles [-] IAC = $1 + F_{cl} (IAC_{cl} - 1)$ - *Eq. (a.3)*. where: IAC shade = interior attenuation coefficient of fenestration with partially closed shade F_{cl} = shade fraction closed (0 to 1) IAC_{cl} = interior attenuation coefficient of fully closed configuration (see ASHRAE handbook Fundamental p.17.10 Table 14)	
Partitions to unconditioned buffer space	$q = U \cdot A \cdot \Delta t$ [W]	Walls, roofs and windows that do not face outdoor, but unconditioned spaces, such as garages or storage halls (see heat load) [W]
Ventilation/ Infiltration	$q_{vi} = C_s \cdot Q \cdot \Delta t$ [W]	Air input from ventilation and infiltration via doors and windows and mechanical ventilation systems (controlled) (see heat load) [W]
Occupants, lighting and appliances	$q_{ig,s} = 136 + 2.2A_{cf} + 22N_{oc}$ [W]	Internal heat gain from persons and appliances such as computers or printers [W]
	$q_{ig,s}$ = sensible cooling load from internal gains, [W] A_{cf} = conditioned floor area of building, [m²] N_{oc} = number of occupants (if unknown, estimate number of bedrooms (N_{br}) +1) [-]	
Distribution losses	$q_d = F_{dl}\, \Sigma_q$ [W]	Thermal losses/ gains in the HVAC systems, such as in ventilation ducts. Values from Table [W]
Total sensible cooling load	$\mathbf{q_s = q_d + \Sigma q}$ [W]	Total sensible cooling demand, including the distribution losses [W]
Latent load (ventilation/ infiltration)	$q_l = q_{vi,l} + q_{ig,l}$ [W] $q_{vi,l} = C_l \cdot (Q_{vi} + Q_{bal}, o_{th}) \cdot \Delta W$ $q_{ig,l} = 20 + 0.22A_{cf} + 12N_{oc}$	Gains in humidity from outside air via ventilation and infiltration [W]
	C_l = air latent heat factor, 3,010 [W/(L·s)] at sea level $q_{vi,l}$ = latent ventilation/infiltration load, [W] Q_{vi} = combined infiltration/ventilation flow rate (not including balanced component), [L/s] $Q_{bal,oth}$ = other balanced ventilation supply airflow rate, [L/s] ΔW = indoor/outdoor humidity ratio difference [-] $q_{ig,l}$ = latent cooling load from internal gains, [W]	
Latent load (internal gains)	$q_{ig,l} = 20 + 0.22A_{cf} + 12N_{oc}$ [W]	Gains in humidity from internal activities, such as breathing, showering or cooking [W]

The sum of all parts is the whole cooling load.

$$q_{Cooling} = q_{T,opq} + q_{win} + q_{v,i} + q_{Int,gains} + q_{latent} + q_{dis} \quad (2)$$

$q_{Cooling}$	Cooling load
$q_{T,opq}$	Heat flux through transmission (Walls and roofs that directly face outdoor air)
q_{win}	Heat gains by windows to ambient with solar radiation and its shading functions
$q_{v,i}$	Heat gains through internal activities (people, lighting, ...). Also referred to as $q_{ig,s}$
$q_{Int,gains}$	Gains in humidity from outside air via ventilation and infiltration
q_{dis}	Heat gain through distribution

Which application to be used and what variables to be considered in the calculation of heating/ cooling calculation is up the expert and technical planner.

Example of Cooling Load Calculation

In the following the cooling load for an exemplary room is calculated following the previously described methodology.

Given data and information: The room is used by 2 persons, has a footprint of 5 m by 5 m and a height of 2.8 m and is located in Kathmandu. The room is located in the upper corner of a building with 3 walls and the flat roof being exposed to the ambient. The building represents the state of the art, with single brick walls, no insulation and single glazed windows.

The desired indoor temperature *(T_i)* is set as 26°C, the hottest 1% design temperature *(T_o)* (compare Figure 6) is 32°C. Thus, the temperature difference *Δt* to be taken into account is 6K.

Transmission heat gain through opaque construction – $q_{T,opq}$

The heat gain through opaque construction results as the sum of all the individual construction parts exposed to the ambient. Wall D and the floor of the room are adjacent to other sections of

Construction	length	Height/ width	Area	U-value	Δt	OF_t	OF_b,K	OF_r	
Wall A	5 m	2.8 m	14 m^2	2.0 W/(m^2·K)	6 K	1	8.2	-0.36	337 W
Wall B	5 m	2.8 m	12.2 m^2	2.0 W/(m^2·K)	6 K	1	8.2	-0.36	294 W
Wall C	5 m	2.8 m	14 m^2	2.0 W/(m^2·K)	6 K	1	8.2	-0.36	337 W
Wall D									
roof	5 m	5 m	25 m^2	2.4 W/(m^2·K)	6 K	1	20	-0.36	1,419 W
Floor/ ceiling									
q_{Trans} =									2,387 W

Heat gain from transparent surfaces – q_{win}

This includes both the transmission and the radiative heat gains through windows. The investigated room has one window in Wall B, characterised by 1.5 m by 1.2 m and correspondingly 1.8 m² area.

The window is south-west oriented and no exterior attachment is installed. The peak exterior irradiation for south-west orientation calculated to be 318 W/m². The interior attenuation coefficient of fully closed configuration (IAC_{cl}) of the clear glazed window with medium blinds is defined by ASHRAE as 0.74. The closed shade fraction (F_{cl}) is fixed at 0.6. Following the equation in Table 5 this results in an IAC of 0.844. Due to the south-west orientation, the fenestration solar load factor FF_s is set at 0.58.

Construction	Area	U-value	SHGC	DR	IAC	PXI	FF_s	Δt	
Window (wall B)	1.8 m²	5.7 W/(m²·K)	0.8	6 K	0.844	318 W/m²	0.58	6 K	143 W
q_{win} =									143 W

Heat gain from ventilation and infiltration – $q_{v,i}$

The calculation of heat gain through ventilation and infiltration is defined as qv,i, taking the room area, the number of occupants (N_{oc}) air heat factor (C) into account. In this example, only the sensible heat gain from ventilation and infiltration is presented. The sensible heat factors (C_s) is adapted for the Kathmandu elevation of 1,300 m. The room is used as bedroom (N_{br} = 1) and is used by two persons (N_{oc} = 2).

Type	Elevation	$C_{s,1300m}$	A_{cf}	N_{br}	N_{oc}	Qv	Δt	
sensible	1,300 m	1.05	25 m²	1	2	10.75	6 K	68 W
$q_{v,i}$								68W

Heat gain from internal activities – $q_{Int,gain}$

Internal heat gains from people, lighting and other appliances contribute to the cooling load. Using the equation from Table 5 for heat gain from occupants, lighting and appliances, only the two parameters of room area and number of occupants is required.

Type	A_{cf}	N_{oc}	
sensible	25 m²	2	235 W
$Q_{Int,gain}$			235 W

Gains in humidity/ Latent load – q_{latent}

The cooling demand is affected by the gains in humidity. These gains can be generated from internal or external. Internal humidity gains are directly or indirectly caused by activities of the occupants, such as showering or cooking. External humidity gains can be generated through ventilation and infiltration. In this example, only the humidity gains from internal are calculated, considering the room area of 25 m² and two occupants.

Type	A_{cf}	N_{oc}	
Internal humidity gains	25 m^2	2	50 W
$Q_{Int,gain}$			50 W

The total cooling load is calculated via merging the different sections together and adding the additional cooling demand through distribution losses. In this example, the ventilation ducts are all placed within the conditioned space of the building. However, it is recommended to add a little surplus to be on the safe side.

Heat gain	
$q_{T,opq}$	2,387 W
q_{win}	143 W
$q_{v,i}$	68 W
$q_{Int,gain}$	235 W
q_{latent}	50 W
subtotal	2,882 W
q_{dis} (+10% back-up)	288 W
$q_{cooling}$	3,170 W

ASHRAE CLTD/SCL/CLF Cooling Load Calculation Method

This method derives from ASHRAE Fundamentals 1997 and is a simplified approach used to estimate the sensible cooling load from solar heat gain through windows and other transparent surfaces.

CLTD **Cooling Load Temperature Difference**

SCL **Solar Cooling Load**

CLD **Cooling Load Factor**

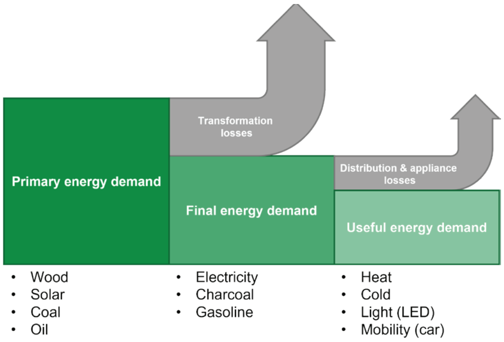
It calculates the temperature rise inside a building due to solar radiation, considering factors like window orientation, shading, and geographic location. The method uses a base CLTD value, adjusted by a Cooling Load Factor (CLF) for time-of-day and seasonal variations, and a Solar Heat Gain Factor (SHGF) for different glazing types.

Unlike more detailed methods, such as those using energy simulation software or hourly calculations, the CLTD method is less complex and more practical for quick, approximate estimations. It doesn't account for latent heat gain or dynamic variations in heat flux over time.

4.2 Heating/Cooling Energy Demand

The total heating/ cooling energy demand refers to the sensible and latent energy demand for a whole year. This energy demand represents the demand in useful energy, which is heat and cold that is provided through the heating and cooling system. The energy to drive appliances, such as electricity, is defined as final energy, that includes any losses from appliance and distribution side. The final energy is part of the primary energy demand. For example hydropower running a turbine which in turn powers a generator providing electricity. 4.2 Heating/Cooling Energy demand shows the relation between primary, final and useful energy and lists examples.

Figure 9: Comparison and examples of primary energy, final energy and useful energy. Source: University of Innsbruck, Unit of Energy efficient Building



The heating and cooling demand is an indication on the energy performance and the operating costs for heating and cooling of a building.

ASHRAE Fundamentals (Chapter 19) either suggest the use of simulation tools or a simplified Degree Day or BIN method (sorted ambient temperature ranges). EN ISO 52016-1 describes a whole simulation scheme using either hourly or monthly steps. The hourly procedure is very close to the approach of simulation tools.

Power-to-Energy Conversion

The basic equation for calculating the heat output of an electric heater is:

$$Q = P \cdot t \qquad (3)$$

- Q energy [Wh]
- P power/ thermal capacity rating [W]
- t time of operation [h]

4.2.1 Heating Energy Demand

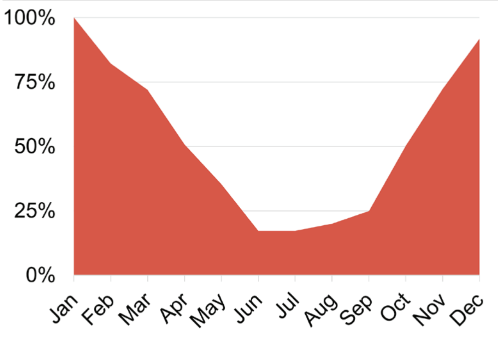
The heating demand describes the sum of sensible and latent heat demand accumulated over a whole year. The heating demand refers to the useful energy demand (the energy that flows over the boarder of the building) that a building or a room requires to fulfil the required indoor air temperature and quality. It is dependent on the use of a building/ room, on the building design the envelope quality and the thermal mass as well as the climate (temperature, solar radiation).

Latent heat demand may occur in cold climates, where the inlet air needs to be humidified to keep the relative humidity in the building above 20%.

It is given either in [kWh/year] or [MWh/year] for total buildings. It is common to express the specific heating demand in [kWh/(m²·year)] to give a relation to the building area.

The course of heating demand varies throughout the year with peaks in the coldest month and lows in the summer months, when the weather conditions are warmer and the building experiences less heat losses. Figure 10 shows an exemplary course of annual heating demand for a moderate climate.

Figure 10: Exemplary course of annual heating demand for a building in Mustang. Source: University of Innsbruck, Unit of Energy efficient Building



There are different methods to calculate and estimate the heating energy demand of buildings or zones. EN ISO 52016-1 follows a monthly or an hourly approach using a utilization ratio (η) for gains from internal activity and solar radiation. ASHRAE on the other hand uses a more detailed and dynamic method based on hourly calculation, the ASHRAE Heat Balance Method (HBM). Thus, a simulation software is required to perform the ASHRAE calculation. Calculating the annual heating demand is crucial for an expressive evaluation of a building and for a better understanding on the system's requirements. The monthly or hourly balance between heat losses and the useful heat gains (not leading to overheating) of EN ISO 52016-1 describes the heating energy demand.

$$Q_{Heating} = Q_{Trans} + Q_V - \eta \cdot (Q_{Int,gain} + Q_{Sol}) \quad (4)$$

$Q_{Heating}$	kWh/month	Heating energy demand
Q_{Trans}	kWh/month	Heat energy losses through transmission (walls, glass, ...)
Q_V	kWh/month	Heat energy losses through ventilation
η	kWh/month	Utilization ratio of internal and solar gains
$Q_{Int,gain}$	kWh/month	Heat gains through internal activities (people, lighting, ...)
Q_{Sol}	kWh/month	Heat gains through solar radiation

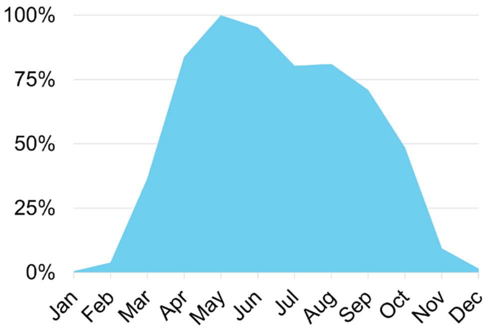
When the thermal losses through pipes or ducts and the efficiency of the heating appliances are taken into account, you get the final energy demand. This final energy demand represents the amount of energy which needs to drive the heating system in order to answer the final energy demand.

4.2.2 Cooling Energy Demand

The cooling energy demand describes the sum of cold needed by a building/room accumulated for a whole year to keep the indoor temperature at the required cooling setpoint (e.g. 26°C).

The cooling demand refers to the useful energy demand that a building or a room requires to fulfil the required indoor air temperature and quality. It is dependent on the use of a building/ room, building design, envelope quality, thermal mass as well as the climate (temperature, solar radiation). For the cooling demand, the latent cooling is very important because in hot (and even more hot and humid) climates dehumidification is most often needed. The sensible cooling demand refers to the temperature difference between the actual and the desired indoor air temperature. The latent cooling demand refers to the level dehumidification. As presented in chapter 2.2, the humidity has a crucial impact on the indoor comfort and on the temperature a user feels. Reducing only the temperature of ambient causes the relative humidity to rise. Additional dehumidification or subcooling to expel water from the air is necessary. The required energy of this step is the latent part of the cooling demand.

Figure 11: Exemplary course of annual sensible cooling demand for a building in Terai. Source: University of Innsbruck, Unit of Energy efficient Building



The total cooling demand is given either in [kWh/year] or [MWh/year] for total buildings. It is common to express the specific cooling demand in [$kWh/m^2 \cdot year$] to give a relation to the building area.

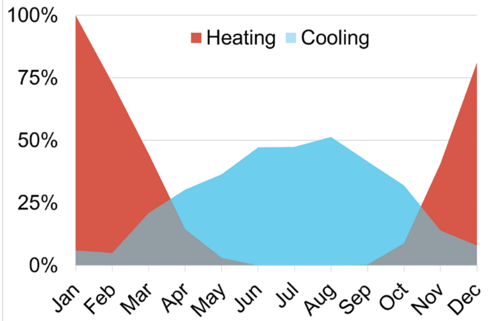
The course of cooling demand varies throughout the year with peaks in the hottest month, like May before monsoon, and lows in the winter time, when the weather conditions are colder. The diagram on the right shows an exemplary course of annual cooling demand.

Because of the many parameters and the transient approach, the calculation of heating/ cooling calculation is up to experts and technical planners.

4.2.3 Demand in Temperate Climate

The given description of both heating and cooling demand works in principles for all climates and building. For temperate climates, it is very important to check the heating and cooling demand simultaneously. Some measures that may reduce cooling demand, may increase heating demand. Thus, an optimisation of both demands must be in focus. However, even within a month, there might be hot and cold days that raise demand on heating or cooling.

Figure 12: Exemplary course of annual sensible cooling demand for a building in Kathmandu. Source: University of Innsbruck, Unit of Energy efficient Building



The optimisation of the building envelope can already decrease and shorten the shown demand. For more information, please check the BEEN manuals on building design, insulation, and doors and windows.

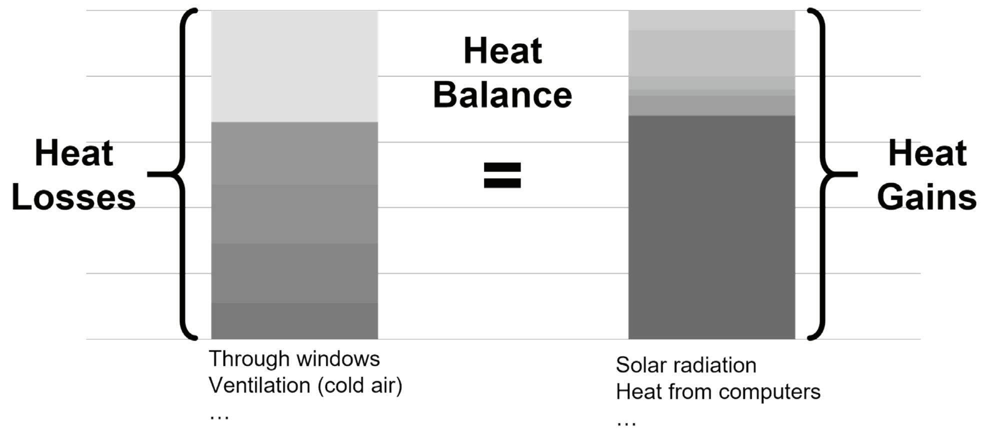
Hotel buildings are also a special case, as heating and cooling demand are also given in the same months, and sometimes even at the very same time. Reason for this is the individual thermal comfort of guests, that prefer warmer or colder indoor air condition.

4.3 Heat Balance

Heat Balance Definition

Every building has an individual heat balance. The heat balance includes all thermal losses and thermal gains of a building. Both losses and gains will level out, creating the heat balance. Any thermal losses are balanced by the thermal gains, as the other way round.

Figure 13: Characteristics of the heat balance, being the equilibrium of the combined heat gains vs. all combined heat losses. Source: University of Innsbruck, Unit of Energy Efficient Building



If there was no balance of incoming and outgoing heat fluxes, the total building would either heat up or cool down. The heat balance represents the thermal equilibrium, as each heat loss is substituted by a heat gain. If there is less heat available (less heat gains), then the heat losses are automatically less. Otherwise, a building would magically cool down below the ambient temperature.

Parameters Considered

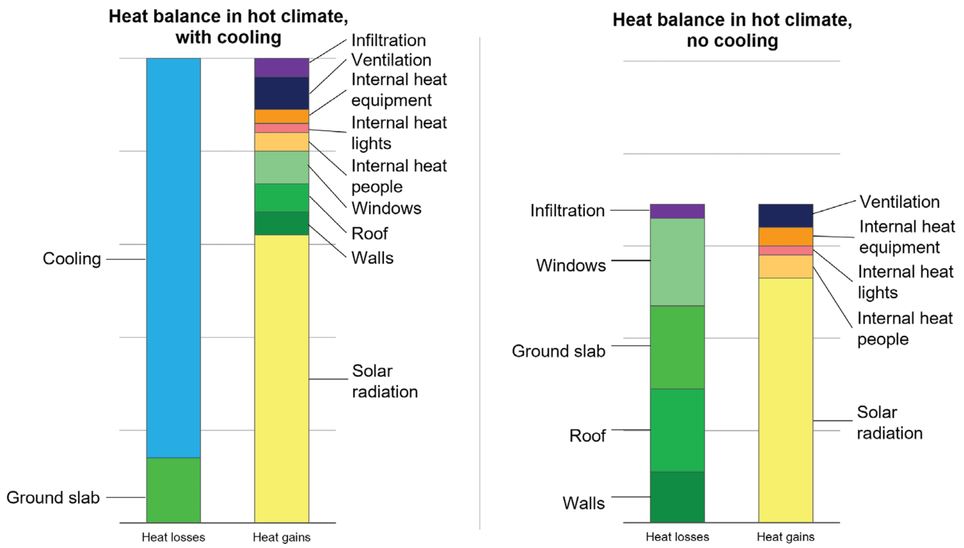
- Solar radiation
- Convective heat fluxes through building envelope
- Ventilation
- Internal heat gains
- Heating & Cooling

Examples: The heat balance looks very different not only for each individual building, but also for different climates. In the following, examples for different climates are presented for business as usual (BAU) buildings.

Hot Climate

In hot climate, a heat gains result from several sources, such as through solar radiation, warm air, heat gains through the envelope of course from internal heat sources, such as electric equipment, lights, and people. Heat is distributed and lost through the ground slab into the ground. Figure 14 shows the heat balance of a building in a hot climate, with cooling activated on the left and no cooling on the right. In this case, a lot of cooling es required to maintain comfortable indoor air conditions. If the cooling is off, the distribution within a heat balance may change, and the envelope serves rather as heat losses than heat gains, as their thermal mass has potential in absorbing heat during the day and releasing it when the ambient is colder, such as during the night time. But in this case the indoor air becomes uncomfortable hot. Checking the heat balance, the main contributors for heat loss/ heat gains can be easily identified, as in this case the heat input from solar radiation. Thus, a promising measure would be to retrofit the windows and install outer shading elements.

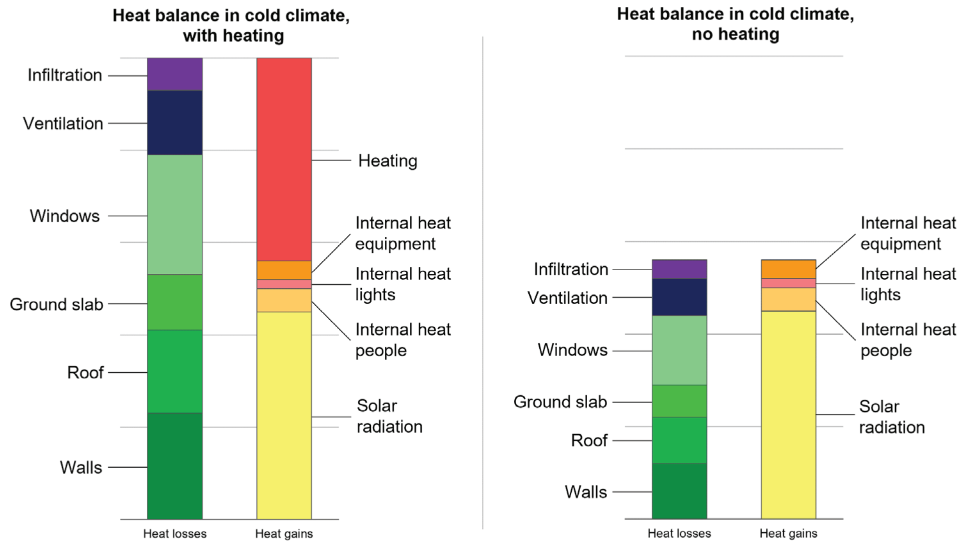
Figure 14: Example of a heat balance for a building in hot climate. On the left, the building is actively cooled, on the right, no cooling is considered. Source: University of Innsbruck, Unit of Energy Efficient Building.



Cold Climate

In a cold climate, the potential heat gains are limited to the solar radiation and internal heat gains from electric equipment, light, and people. Heat on the other hand is lost through all building envelope construction and through ventilation and infiltration. The required total heating demand is added to the heat gains, showing how much heat is required to make sure that comfortable indoor conditions are met for the building users. If the heating is off, the total heat balance is also reduced as less heat can be lost through the envelope or through infiltration but the indoor air becomes uncomfortable cold. Thus, the heat losses through envelope are reduced. Based on the climate and the building performance, it may change whether a component is a net heat loss or heat gain.

Figure 15: Example of a heat balance for a building in cold climate. On the left, the building is actively heated, on the right, no heating is considered. Source: University of Innsbruck, Unit of Energy Efficient Building.



4.4 Domestic Hot Water (DHW)

Hot water is an essential criterion for user comfort. Demand for hot water is primarily given for showering and cleaning and depends on the climate, number of users and dwellings in a building.

Demand Estimation

To estimate the heat demand for DHW generation the most relevant aspect is the number of use cases, such as the number of showers or number of sinks and the number of end-users. Additionally, it is important to consider the planned hot water temperature.

The following Table 6 gives an indication of hot water consumption per use case, depending on the hot water temperature. While the cold water supply temperature will depend on the climate; here, it is assumed at 10°C for calculating the energy consumption.

Table 6: Overview of hot water demand in litres and heat demand for different use cases and hot water temperatures.

Use case	Consumption of hot water dependent on hot water temperature in litres		Energy consumption in kWh
	40°C	60°C	
Hot bath	120–150	72–90	4.3–5.4
Shower	30–50	18–30	1.1–1.8
Washing hands	2-5	1–3	0.1–0.2

This demand assumption is helpful for the estimation of the hot water demand and the corresponding capacity of DHW system. While, it can be used by a single family house having individual systems; large buildings with a centralised DHW system must be planned considering the 'diversity factor'. A diversity factor needs to be considered not to over-estimate the hot water demand, because not all resident will shower at the exact same time. Therefore, for large buildings with several dwelling the energy for hot water demand must not be planned by just adding up the individual maximum domestic hot water of the individual dwelling.

4.5 Ventilation Load

The indoor air quality is an essential aspect of user comfort. This does not only refer to the level of air temperature, but also to the humidity, CO_2 concentration and smell/ olfaction and dust particles of the air. Each person has an impact on the air quality.

- First of all, each person emits heat to the air. The amount of heat depends on the level of activity (lying, sitting, standing, moving, ...).
- Second, each person emits humidity to the air. This happens through direct emission via breathing and sweating. Indirectly humidity is increased via cooking or washing.
- Third, a person consumes oxygen and emit CO_2 to the air. The increase of CO_2 in the air causes reduction of air quality and leads to a reduced level of concentration, makes tired and may cause headache.
- Fourth, a person emits dust and affects the olfactory air quality. This is due to cloth and skin abrasion as well as breathing and sweating, but also due other activities such as cooking.

These impacts on the indoor air quality cause a need of fresh air supply. Thus, oxygen is supplied to the user and CO_2, humidity and smell is released to the ambient. The required fresh air depends among others on the activity and age of the users. The general fresh air requirements to consider is between 25–35 $m^3/(h·person)$ and in average 30 $m^3/(h·person)$.

Like in heating and cooling, the design of the ventilation system is based on worst case assumptions. The energy demand of the system depends on design conditions and the required ventilation rate according to the current needs.

Worst case assumptions for the size of the system components (investment costs):

The approach described in the paragraph above can be used for rooms where the maximum number of persons is known (e.g. lecture rooms, school class rooms, offices, theatres, cinemas, etc. ...). For other rooms, an approach based on room size and type of usage can be applied.

The required ventilation flow rate Qv according ASHRAE was given in Table 4. It yields similar values as stated above.

If dehumidification (hot and humid climate in summer/raining season) or humidification (cold climate winter) occurs the energy demand has to be calculated accordingly (see Table 4, q_{vi}, = latent ventilation/infiltration load, W).

Yearly Energy Consumption (Operating Costs)

The yearly operating cost depends on the capability of ventilation systems to reduce the ventilation rate according to actual needs of the different number of persons in the room (e.g. CO_2 sensor in classrooms where the content of CO_2 should be kept below 1,500 ppm). The air flow rate $\dot{V}$ represents the required fresh air based on the use cases. The energy demand of a fan is given by:

$$P_{el} = \frac{\dot{V} . \Delta p}{\eta} \quad (5)$$

P_{el} Electric demand of the fan [W]

$\dot{V}$ Volume flow of the air [m^3/s]

Δp Pressure difference in the compressor [Pa]; 100.000 Pa = 1 bar [N/m^3]

η The efficiency of the fan [-]

As

$$\Delta p = \Sigma\xi \frac{\varrho v^2}{2} \quad (6)$$

and

$$v = \frac{\dot{V}}{A} \quad (7)$$

$\Sigma\xi$ Sum of resistances/ pressure loss coefficients in the air flow due to bends, ducts, and filters [-]

ϱ Density of the air [kg/m^3]

V Velocity of the air [m/s]

A Cross section of the air duct [m^2]

It can be concluded that P_{el} is related to $\dot{v}^3$

$P_{el} \sim \dot{v}^3$

This means if the volume flow can be halved due to only half of people in the room the electricity demand is reduced by the factor of 8. Therefore, a control of the fan speed according to the actual needs can reduce the energy demand of the ventilation system by far.

Air Change Rate Calculation:

The air change rate, measured in air changes per hour (ACH), is a key parameter in ventilation design. It represents the number of times the air within a space is replaced per hour.

$$ACH = \frac{Q}{V} \, 3{,}600 \qquad (8)$$

ACH	Air change rate [1/h]
Q	Air flow rate [m^3/s]
V	Volume of the space [m^3]
3,600	Seconds per hour [s/h]

If the maximum number of persons cannot be said in advance, as is in residential buildings (are there 1 or 6 persons residing in the apartment) an agreement of the number has to be taken by standards. In Europe normally something like 3.5 persons per 100 m^2 are taken for residential buildings which is above average and therefor is estimated on the more densely inhabited side.

With this 30 m^3/(h·person) · 3.5 persons = 105 m^3/h are needed. If this is related to the volume of the room with 100 m^2 · 2.5 m height = 250 m^3 volume an air exchange rate of 105 (m^3/h) / 250 m^3 = 0.42 per h results. Such air exchange rates (ACH) for rooms or buildings, where the maximum number of people is not fixed can be found in standards.

The housing density in Nepal is higher compared to Europe. The average household size is assumed to be between 4 and 5 persons. The dwelling area is expected to be between 80 m^2 and 135 m^2 (UN-HABITAT, 2010). Assuming a household of 5 persons for a dwelling of 100 m^2 and a height of 2.5 m, you end up with a fresh air supply of 30 m^3/(h·person) · 5 persons = 150 m^3/h, and an ACH of 150 m^3/h / 250 m^3 = 0.60 per hour.

The Indian standard ISHRAE recommends in its Handbook 2017 comfortable indoor design conditions (ISHRAE, 2017). This includes essentially dry bulb air temperature, relative humidity, but also ventilation and noise levels. The mentioned air temperature and humidity for both summer and winter case, as well as ventilation, exhaust air stream, filter efficiency and Noise RC level.

Following this handbook, the lobbies, conferences rooms, and meeting rooms of hotels can have a lower dry bulb temperature compared to the guest rooms itself. The ventilation demand for guest rooms is given in total (30 – 60 cf (ft^3) per minute (cfm) or 51 – 102 m^3 per hour), whereas the demand for the other rooms is always depending on the expected number of persons in the rooms (15 – 20 cf per minute and person or 25.5 – 34 m^3 per hour and person).

Table 7: Overview of design conditions and recommended ventilation qualities for different use cases. Source: ISHRAE, 2017.

Category	Inside Design Conditions				Ventilation	Exhaust	Air Filter Efficiency	Noise RC level
	Winter		Summer					
	Temp.	Relative humidity	Temp.	Relative humidity				
Guest rooms	74–76°F	30–35%	74–78°F	50–60%	30–60 cfm per room	20–50 cfm per room	6–8 MERV	25-35
Lobbies	68–74°F	30–35%	74–78°F	40–60%	15 cfm per person	-	8 MERV or better	35
Office	70–74 °F	20–30%	85–88 °F	50–60%	0.75–2 cfm/ft^2	-	-	30-45

Following conversion factors between IP units (Imperical units) and SI units (Système International d'Unités) must be considered:

Table 8: Conversion examples for temperature, volume flow and air velocity from IP unit to SI unit.

Field	IP unit	SI unit
Temperature	68°F	20.0°C
	74°F	23.3°C
	78°F	25.6°C
Ventilation volume flow	1 cfm	1.7 m^3/h
	30 cfm	51.0 m^3/h
Air velocity	1 fpm	0.0051 m/s
	39.4 fpm	0.2 m/s
	197 fpm	1 m/s

The ISHRAE table includes following categories:

- Hotel
- Dining and Entertainment
- Office Building
- Museum, Libraries and Archives
- Bowling Centres
- Communication Centres
- Warehouses
- Industrial use cases
    - Brewery, Ceramics, Candy chocolate, ...

The given information and recommendations from the standard serve as a orientation and good design framework in the further planning. Final design conditions are established by individual boundaries, climate and customer requirements.

Wind Velocity

The wind velocity in a room has direct impact on the user comfort. A light breeze increases the comfort when the temperature is hot, but decreases the comfort when it's cold in a room. Turbulent mixed ventilation can reach an air velocity of 2 – 5 m/s at the outlets, often installed in the ceiling. The resulting air velocity experienced by the user should not exceed 0.2 m/s, about 40 fpm. Thus, the decision making of the position of ventilation outlets should take the design of the interior into account.

Infiltration

Uncontrolled air flow into the building is defined as infiltration, given in ACH. The infiltration is an indicator for the air tightness of a building. The target is to minimise the uncontrolled air flow into the building, as this affects the heating and cooling load. Infiltration is reduced when sealings bands are installed in windows and doors, connections of constructions such as between roof and wall are executed gap free and openings for technical pipes and wires are closed. The infiltration increases the higher the air pressure difference between inside and outside the building. The standard procedure to measure the quality in air tightness of the building is the Blower-Door test. An artificial pressure difference of 50 Pa is created between indoor and the ambient using fans. The measured air flow indicates the ACH at 50 Pa, resembling the n_{50} value.

Rough calculation estimates for infiltration rates can be found in chapter 5.3.1.

05 Systems and Technologies

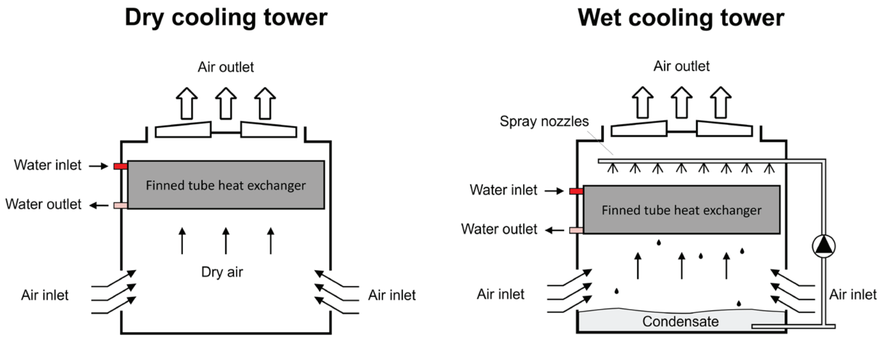
5.1 Technology Overview

This chapter shortly presents an overview of wet and dry cooling towers, portable air conditioning systems, heat pumps and other technologies and gives a short explanation of the thermodynamic processes. There are different ways to generate heat (heat pumps, electric heater, wood stove) and cold (most often heat pumps). Every heat exchanger of electric heaters, heat pumps, and stoves is based on the heat transfer from high temperature to a lower temperature (2nd law of thermodynamics). Heat pumps reverse this direction (take heat from cold side and release it on the hot side) by the use of electricity. It lifts thermal energy from low temperature to high temperature.

5.1.1 Wet and Dry Cooling Towers

Cooling towers are technical components to dissipate heat from a HVAC system to the ambient. A hot medium (water, or refrigerant) is directed to a cooling tower where heat is transferred to air directly (dry cooling) or to water to increase the cooling effect via evaporation (wet cooling). If the ambient air temperature is very hot, higher temperatures in the heat transferring medium are necessary to be able to dissipate heat.

Figure 16: Schematic comparison of dry cooling towers and wet cooling towers. Source: University of Innsbruck, Unit of Energy Efficient Building



Dry cooling towers rely on ambient air to cool the fluid. Hot fluid circulates through heat exchangers, and the heat is transferred to the air via fans. These towers use no water, making them suitable for water-scarce areas but are generally less efficient in high-temperature conditions.

Wet cooling towers use water to cool hot fluids through evaporation. One possibility to reduce the air temperature entering the condenser, or the cooling tower, or to cool an air stream directly, is to inject water droplets that evaporate. Cooling towers using this effect are called wet cooling towers.

As warm water is sprayed or circulated over fill media, it loses heat to the air, and the resulting vapor is expelled. These towers are efficient but can require significant amount of water and may be prone to issues like scaling or biological growth.

Of course, this process increases the relative humidity of the air, that is taking up the evaporating water vapor. The energy needed for the evaporation is taken from the air (no other energy source is available) and cools down but humidifies thereby the air. As no energy from outside is included it is called an adiabatic or isenthalpic process (no change of total energy content of air and water).

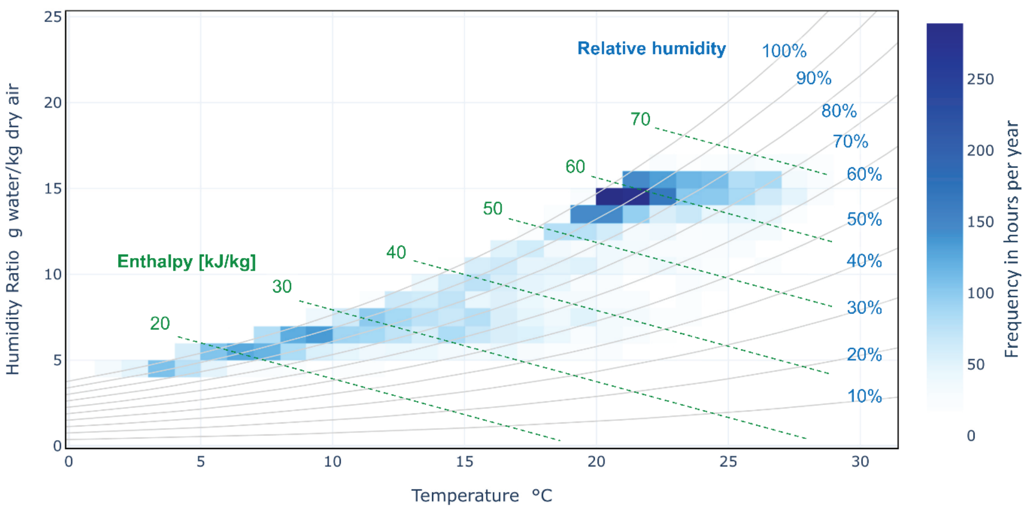
The sprayed in water must be deionized in order to prevent limestone building blocking the nozzles and not be used in a recycling loop of not evaporated droplets back to the spraying nozzles, as there is a danger of legionella bacteria growing and spreading into the air.

This process only works, when the air around the water droplets can take up water vapor. If the relative air humidity is already 100%, no water can be evaporated and no cooling effect occurs.

In dry climates, cooling of air by spraying in droplets works quite well. In hot and humid climates, the air cannot take much more water, so the cooling effect via spraying is quite low. Figure 17 shows the example for Kathmandu climate in a psychrometric chart for hourly values including the enthalpy lines. As can be seen for the hot period, the humidity is most often already quite high (70 – 100%). Many hours in the year, the outdoor air condition is between 20°C and 23°C with a high humidity between 90% and 100% (dark blue area in the diagram). During that time the potential via spray cooling technology is expected to be very low, only between 0 and 3 K of cooling. For very hot hours (27°C and higher) the humidity goes down to 65% and the cooling effect is larger (up to 5K for some hours). The diagram also shows that most often the relative humidity is at least 70%, often in the range of 90%.

In dry cooling towers, this effect is not used and the non-humified air is taking the rejected heat.

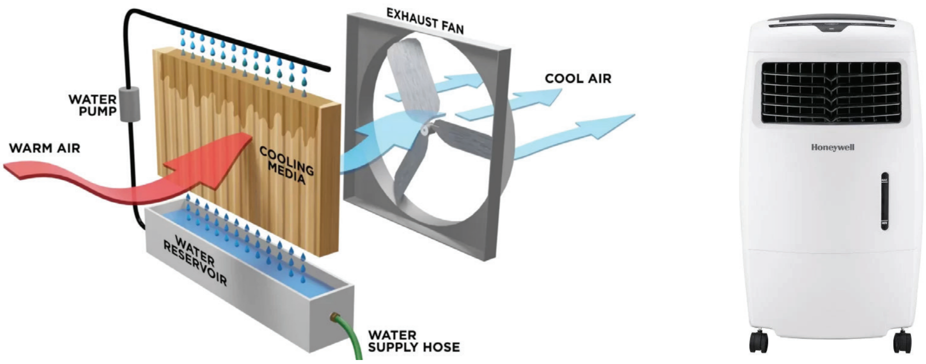
Figure 17: Psychometric chart for the climate of Kathmandu, using ASHRAE climate data, 2009-2023. Source: Betti, Tartarini, Nguyen, & Schiavon, 2023



5.1.2 Evaporative Cooler or Desert Cooler

Portable air conditioning devices as shown in Figure 18 seem to be a very cheap solution for air cooling. In principle they are wet cooling towers for the indoor air. Nevertheless, the cooling effect in humid climates like in Kathmandu is quite low as shown above, while it works very well in the hot-dry conditions. When the water is circulated over several days, the danger of legionella growth is quite high. The water should be changed at least once every week. The felt cooling effect is even lowered further, as 100% relative humidity are never reached due to leakage of air without humidifying and the air feels warmer with higher humidity. Cooling of the body by sweating is working less (sticky air).

Figure 18: Left: Air coolers by direct evaporation, Sketch (Power Breezer, 2023). Right: Example of an apparatus (Honeywell, 2022)

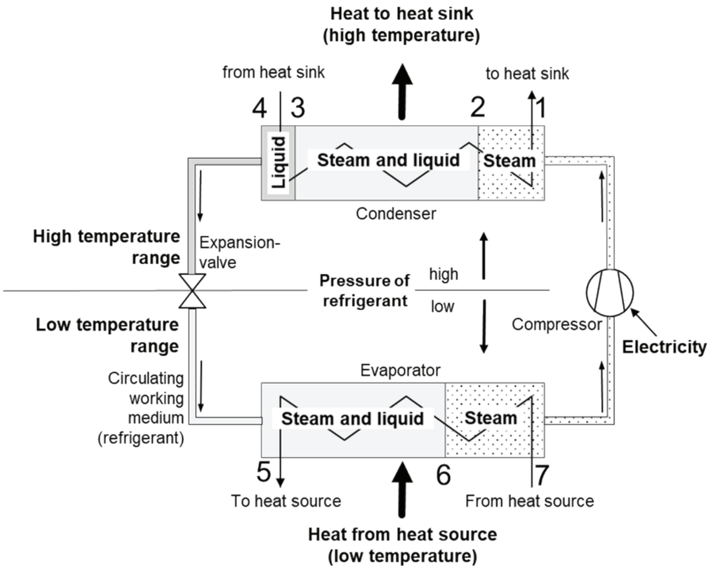


5.1.3 Vapor Compression Heat Pump Cycle

A vapor compression cycle is an electric driven process which can provide simultaneously heating and cooling at two different temperature levels at the same time. It is widely applied in single split AC units, vapor compression chillers and even in refrigerators and freezers.

A compressor runs and creates a pressure lift and therefor also a temperature lift of an evaporated refrigerant. The pressure difference leads to different temperatures of condensation (releasing heat) and evaporation (absorbing heat) side. The refrigerant evaporates at lower pressure and lower temperature, absorbing heat at lower temperature. Heat is dissipated at higher temperature by desuperheating and condensation of the refrigerant. The essential electric power consumption is the compressor to increase pressure.

Figure 19: Schematic of the process of a vapour compression cycle. Source: Kaltschmitt, Streicher, & Wiese, Erneuerbare Energien, 2020



The heat output is 2-5 times higher than the electricity input (heating COP). The cooling COP is slightly lower. Both are dependent on the temperature lift (pressure lift) between cold and hot side. The higher the temperature lift the lower is the COP and also the thermal powers delivered by the heat pump.

The heat rejection in heat pumps can be done directly from the condenser to the air (direct cooling as e.g. in a split AC, section 5.3.1) or with a secondary liquid filled cycle, when the heat pump is not standing in the ambient or the air stream cannot be directed to the heat pump by ducts (which are far larger than water pipes). In cold climates the secondary cycles must be filled with an antifreeze/water mixture, in non-freezing climates pure water is sufficient. Nevertheless, the secondary cycle needs an additional heat exchanger from refrigerant to liquid so the condensing temperature has to be even higher, which reduces the COP of the cooling machine compared to a direct cooled heat pump. The heat rejection to the air can be done as dry or wet cooling tower (see 5.1.1).

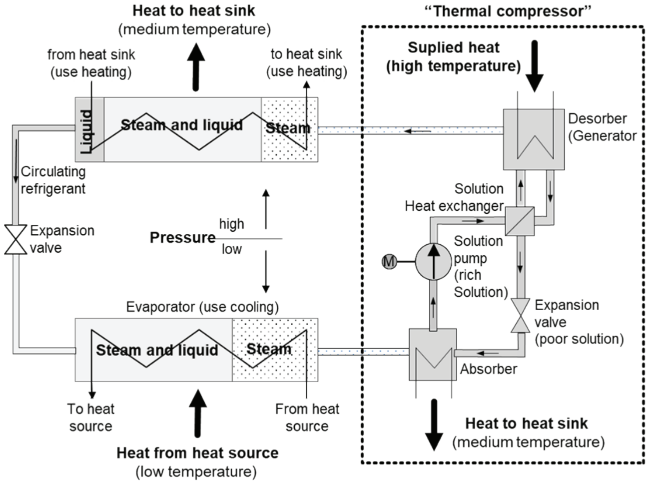
5.1.4 Absorption- and Adsorption Chillers

In contrast to vapor compression chillers, these chillers using an ab-or adsorption process driven by heat, not electric power. Their principle is based on the physical process of absorption (liquid-liquid) and chemical process of adsorption (liquid-solid) of a refrigerant (such as water or ammonia) and a sorbent. Heat is used for the regeneration and the extraction of the refrigerant from the sorbent. Due to the absence of a compressor, the only moving parts within the systems are small pumps. The thermal efficiency of ab-and adsorption chiller is in between 0.6 and 0.8.

Figure 20 shows the cycle of a process in a single-stage absorption chiller. The cycle has no compressor to increase the pressure, but only a pump for circulation of the refrigerant. An absorption chiller has four key-components:

- **Desorber/ Generator:** This is where the refrigerant is separated from the absorbent using an external heat source, such as steam or hot water. The heat causes the refrigerant to evaporate, leaving behind the concentrated absorbent.
- **Condenser:** The refrigerant vapour from the generator is then condensed into a liquid by releasing heat to the surroundings, typically through cooling water. This condensed refrigerant is now at a high pressure and ready to move to the next stage.
- **Evaporator:** The condensed refrigerant enters the evaporator, where it evaporates by absorbing heat from the chilled water that is to be cooled. This process cools the chilled water, which is then circulated through the building for air conditioning.
- **Absorber:** The refrigerant vapor from the evaporator is absorbed back into the concentrated absorbent solution (which has returned from the generator). This absorption process releases heat, which must be removed by cooling water. The diluted absorbent solution is then pumped back to the generator to restart the cycle.

Figure 20: Schematic of the process of an absorption process cycle. Source: Kaltschmitt, Streicher, & Wiese, Erneuerbare Energien, 2020



5.2 Heating Systems

5.2.1 Compression Heat Pumps

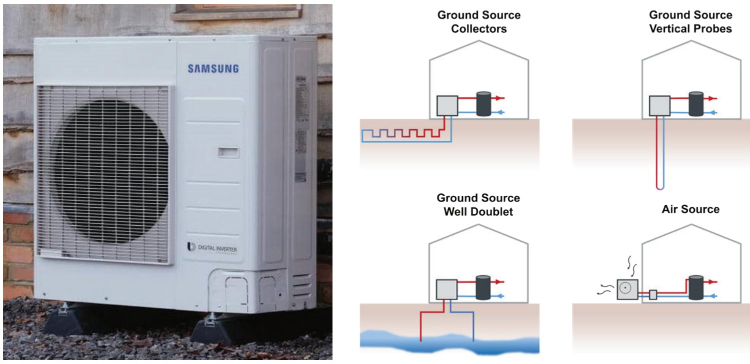
Compression heat pumps are systems that transfer heat from low temperature to hot temperature between different locations, offering both heating and cooling functionalities by using electricity or mechanical force. They operate based on the principles of thermodynamics (if a real gas is compressed it gets hot, if it is expanded it gets cold). For space heating or domestic hot water production the use is on the condenser side and not at the evaporator side as in the cooling process. The process involves four main steps (see Figure 19):

- **Compression:** The compressor receives low inlet pressure thus low temperature and increases the pressure and temperature at the outlet of the gaseous refrigerant via providing electric-driven mechanical power on the gas.
- **Condensation:** The high-temperature, high-pressure gas releases its heat to the indoor environment. By condensing back into a liquid, a high amount of heat can be released by constant high temperature.
- **Expansion:** The expansion valve lowers the pressure of the refrigerant thus cooling it down before it re-enters the evaporator. The refrigerant partly evaporates at the reduced pressure.
- **Evaporation:** The evaporating refrigerant receives heat from the outdoor environment, causing it to evaporate and become a gas. During evaporation a high amount of heat can be absorbed at constant low temperature.

Types of Heat Pumps

- **Air-source Heat Pumps (ASHP):** Extract heat from the outside air and transfer it indoors either to air or to water or vice versa for cooling (Figure 21 left). If also the room side is air based this unit is often called a split system, if heating and cooling is possible it is a reversible AC system.
- **Ground-based Heat Pumps (GSHP) or Geothermal Heat Pumps:** Extract heat from the ground via either bore holes or ground collectors (Figure 21 right).
- **Water-based Heat Pumps:** Extract heat from water sources such as ground water or rivers/ lakes (Figure 21 right).

Figure 21: Left: Heat source of heat pumps: left: typical outdoor unit of an air-source system (Glasgow Heat Pumps, 2021). Right: Different heat pump systems and components. Source: University of Innsbruck, Unit of Energy Efficient Building



Coefficient of Performance (COP)

The performance of a heat pump is measured by the Coefficient of Performance (COP), which is the ratio of the heating or cooling output to the energy input (electricity). This is not an efficiency, as the "free of charge" energy input to the evaporator is neglected. COPs are very much dependent on the cold temperature of the heat source (in case of heat pump ambient air, ground) and the temperature of the heat sink (to be heated room or hot water). The higher the difference of both the lower is COP and the more electricity is used. In normal operation COPS can vary between 2 and 5. (Kaltschmitt et al. 2020)

Seasonal Performance Factor (SPF)/ Seasonal Energy Efficiency Ratio (SEER)

The SPF allows an evaluation of a heat pump performance for a whole year. It is the average COP for all operating hours in a year. Thus, it expresses the annual conversion of required work to useful heat or cold generated and includes the variations in operating conditions (climate and outlet temperature) and the annual need of electricity (operating costs over the year). The following equation describes the calculation of the SPF.

$$SPF = \frac{Q_{output}}{Q_{input}} \qquad (9)$$

SPF	Seasonal Performance Factor [-]
Q_{output}	Total useful energy output [kWh/a]
Q_{input}	Total energy input [kWh/a]

Environmental Impact

Heat pumps are generally more eco-friendly than traditional heating systems such as furnaces and boilers as no local emissions like CO, Hydrocarbons etc. occur. They can substantially lower CO_2 emissions, particularly when used in conjunction with renewable energy sources for electricity production.

5.2.2 Direct Electric Heating

Direct electric heating involves converting electrical energy directly into heat. This method is simple, highly efficient in energy conversion, and offers easy control. These systems generate heat through electrical resistance. When an electric current flows through a resistive material, such as a metal heating element, it produces heat due to the resistance encountered. This heat is then transferred to the air or nearby surfaces. But the heat output cannot be higher than the electricity input. Therefor the COP of such a system is 1 or below (no free heat source is used). Therefore, they need 2 to 5 times more electricity than heat pumps.

Common Types:

- Furnaces: Utilize electric heating elements to warm air, which is then circulated through ducts.
- Baseboard Heaters: Installed along walls, these heaters use electric elements to warm the surrounding air
- Radiant Heaters: Employ infrared radiation to directly heat objects and people within a room.
- Space Heaters: Portable devices that use electric coils or ceramic elements to deliver localized heating.

Efficiency

Direct electric heating systems are typically close to 100% efficient as nearly all the electrical energy is converted into heat. The cost-effectiveness and environmental impact, however, depend on the electricity's source.

Advantages
▪ Easy and fast installation ▪ Low installation costs ▪ Technology widely applied and vendors and installers available
Disadvantages
▪ Low efficiency compared to heat pumps ▪ Due to low efficiency, the operational costs can be high ▪ Only affects air temperature, not air humidity ▪ Impact is very localised to the location of installation and operation

Environmental Impact

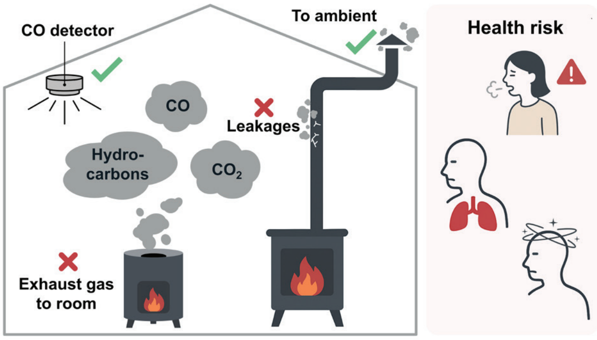
The environmental impact of direct electric heating depends largely on the source of the electricity. If the electricity is derived from renewable sources like wind, solar, or hydro, the environmental impact is minimal. Conversely, if the electricity comes from fossil fuels, the carbon footprint can be substantial. (IEA 2023)

5.2.3 Wood Stove

Wood stoves offer a traditional means of heating by utilizing wood as fuel. Frequently found in homes, they provide a dependable source of heat, especially in regions with plentiful wood supplies. A wood stove generates warmth by burning wood, and the heat produced is distributed into the surrounding area through radiation and convection. Additionally, not usable heat losses are exiting the house by the hot exhaust air of the chimney. The exhaust air MUST NOT be put in the room as there is a high content of CO_2 and especially contents of CO and Hydrocarbons which are extremely poisons.

The burning and heat exchange chamber and the chimney must be completely tight to the room. In the best case there is also under pressure in these chambers compared to the room created by the drought in the chimney, then no flue gas will exit into the room.

Figure 22: Health-relevant aspects in wood stove installations. Source: University of Innsbruck, Unit of Energy Efficient Building



Types of Wood Stoves

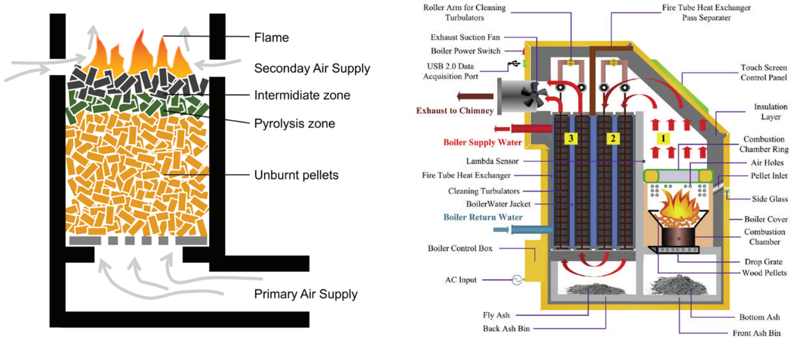
Traditional Wood Stoves: These have a basic design and primarily heat through radiation but also convection from the hot surfaces. As the surfaces are normally not big, the view factor of the radiation to the persons in the room is quite small. They are typically constructed from cast iron or steel.

- **Catalytic Wood Stoves:** Equipped with a catalytic combustor, these stoves burn biomass by staged combustion: first heating and drying (evaporating out the wood water content), then gasification (85 % of wood needs to be gasified before burning) and finally burn the gasses gases around the catalytic surface with lower flame temperature and low emissions of carbon monoxide (CO), hydrocarbons (HC) and particulates to enhance efficiency and lower emissions.
- **Non-Catalytic Wood Stoves:** Utilize a baffle or a secondary combustion chamber to improve efficiency and burn cleaner, without a catalytic combustor.
- **Pellet Stoves:** Burn compressed wood pellets and are known for high efficiency, featuring automated fuel feeding, staged combustion (primary air for pyrolysis, secondary air for final combustion), no cold water or cold surfaces around combustion chamber to keep temperature high for complete combustion and low emission, and thermostat controls.

Figure 23: Left: Wood burner, non-catalytic, Source: (geogphotos/Alamy). Right: Catalytic wood stove, Source: (Alsips, 2014)

Figure 24: Left: Portable wood-fired rocket stove, Source: (SSM, 2025). Right: Schematic of wood-fired rocket stove, Source: University of Innsbruck, Unit of Energy Efficient Building

Figure 25: Left: Stage combustion for pellets, Source: (Patel, Rathod, & Sapariya, 2022). Right: pellets burner, Wang, Nakao, Thimmaiah, & Hopke, 2019



Advantages

- Low investment
- No installation required, ready to use
- Biomass materials as fuel is easily to access
- Reduced risks when using outdoor

Disadvantages

- High in emissions, both gases (CO_2, CO, NO_x, ...) and dust particles
- Exhaust gas must be subtracted from indoor
- Risk for health
- Low efficiency
- Risk of uncontrolled fire
- Fresh air supply must be secured
- Impact is very localised to the location of installation and operation

Efficiency and Heat Output

The efficiency of wood stoves can range from 60% to 80%, with modern stoves typically falling within this range. The heat losses are leaving hot flue gas via the chimney and heat losses to the room of the stove (if this is not the heated house area). Heat output is commonly measured in kWh.

Wood stove – Maintenance and Safety

Proper maintenance and safe operation are crucial for wood stoves:

- Chimney is mandatory: never put exhaust gas into the room (danger)
- Chimney Cleaning: Regular cleaning of the chimney is necessary to prevent creosote build-up, which can lead to chimney fires.
- Firewood Storage: Wood should be stored in a dry area to ensure efficient burning (less water to be evaporated before burning) and reduce smoke production.
- Safety Precautions: Install smoke and carbon monoxide detectors in the room, maintain safe distances from flammable materials, and use a fire screen.

Environmental Impact

Wood stoves have a mixed environmental impact. Burning wood is considered greenhouse gas-neutral because the carbon dioxide released is balanced by the amount absorbed during the tree's growth. However, wood stoves can emit particulate matter, CO hydrocarbons and other pollutants. Certification bodies, such as the Environmental Protection Agency (EPA) in the United States assess wood stoves in their emissions and Modern, EPA-certified wood stoves are designed to reduce these emissions. (DOE 2025)

5.3 Cooling and Combined Heating/Cooling Systems

All cooling systems have in common that heat from inside the building is absorbed and released to the ambient or other heat sink. There are many different technical solutions to do this but they are all based on the heat pump system. The cold side of the evaporator takes heat from the inside of the room, the compressor reduces the pressure of the evaporator side and increases the pressure to a temperature above the ambient temperature and the condenser releases both (cooling heat plus electricity of the compressor) to the ambient. In the following, systems are divided into the two groups of air-based systems and water-based system.

5.3.1 Air-Based Systems

As the name indicates, air-based systems directly condition the fresh air supplied to a room or cools the room via air circulation.

Air Conditioner (AC) – Single Split and Window AC

AC single split units are state-of-the-art and most commonly used across the world. In 2024, around 140.6 million AC units were sold worldwide (IIFIIR / JARN Magazine, 2025). AC single split units do not supply fresh air from outside to the room, but circulate and cool down (or heat up as reversible heat pump) the indoor air. They consist of basically two components between a refrigerant circulates:

- **Indoor unit:** the room air is passed through a fan and pushed through a heat exchanger which is the evaporator of the cooling machine thus filled with evaporating refrigerant. Heat is transferred from the warm air to the colder refrigerant. Thus, the air is cooled down and blew back into the room. A fan is mounted to increase the air circulation around the evaporator to increase the heat exchange.
- **Outdoor unit:** The outdoor unit is relevant to release heat to the ambient. It consists of the condenser of the cooling heat pump, the compressor and possibly the expansion device. The evaporated refrigerant is compressed and its temperature is lifted. It then flows through a heat exchanger (the condenser) which is surrounded by ambient air. A fan is used to increase the air circulation around this heat exchanger and. The hot refrigerant releases heat to the ambient air, causing the refrigerant to cool down and condense. The cooled liquefied refrigerant then passes through a throttling device in which the pressure is reduced, its temperature is decreased and the refrigerant is partly evaporated (flash evaporation). The cold and liquid refrigerant is then passed back to the indoor unit.

Figure 26: Schematic design of indoor and outdoor unit of a single split air conditioner with components. Source: (Kaltschmitt, Streicher, & Wiese, Renewable Energy, 2007)

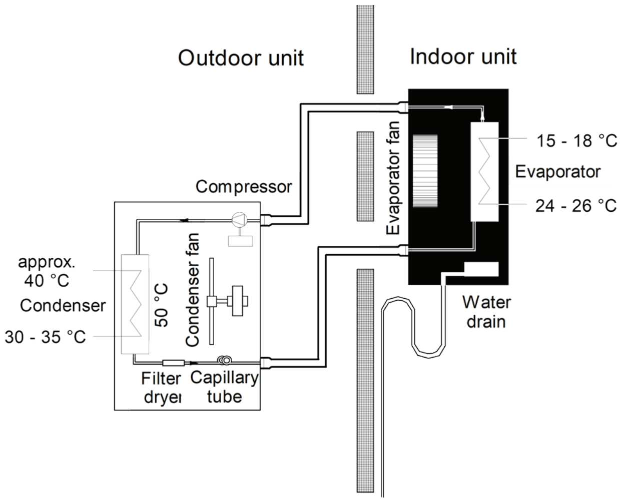


Figure 26 shows the two units of a single AC device. The indoor unit (black) is located in a room of the building and holds the evaporator. The evaporator absorbs heat and the evaporated refrigerant flows to the outdoor unit (white). The compressor increases the pressure and temperature and the refrigerant flows through the condenser and releases heat to the ambient. A fan is installed to increase the air mass flow around the condenser. The condensed refrigerant runs through a capillary tube and experiences a reduction in pressure before it flows back inside to the evaporator o the indoor unit. The piping from the outdoor unit back to the indoor unit must be insulated, to avoid heat input before the refrigerant reaches the evaporator.

In the window AC, both the indoor and outdoor unit are combined in one compact box. It is installed on the windows or the external walls. The working principle remains the same as the split unit.

Efficiency

The Coefficient of Performance (COP), of common single split or window AC units available in the market ranges between 2.5 and 3.5. This means that 1 kWh of electric energy input to the compressor is used to provide 2.5 to 3.5 kWh of cooling in a room. Modern and energy efficient units reach a COP of 4.0 and higher. The performance of a single split and window AC unit depends on the desired cold temperature and the outdoor temperature conditions. At hot outdoor temperature the refrigerant must be even hotter to be able to emit heat to the ambient. As a consequence, the compressor has to work a higher pressure lift, the electric energy consumption is increased thus decreasing the COP and the refrigerant volume flow of refrigerant through the compressor is decreased thus decreasing cooling power of the machine.

Reversible ACs can reverse the refrigerant flow. The evaporator becomes condenser and vice versa. When the flow is reversed, then the machine can heat the inside. Such machines can switch from a cooling to a heating machine. Therefore, nearly no additional costs are needed, if cooling in summer and heating in winter is needed.

Advantages

- Availability and market acceptance: this cooling system is available all over the globe and the installers and technicians are familiar with it.
- Prices are affordable
- Low Complexity
- Fast response on demand
- Can include a dehumidification option
- Indoor unit can include air filtration option

Disadvantages

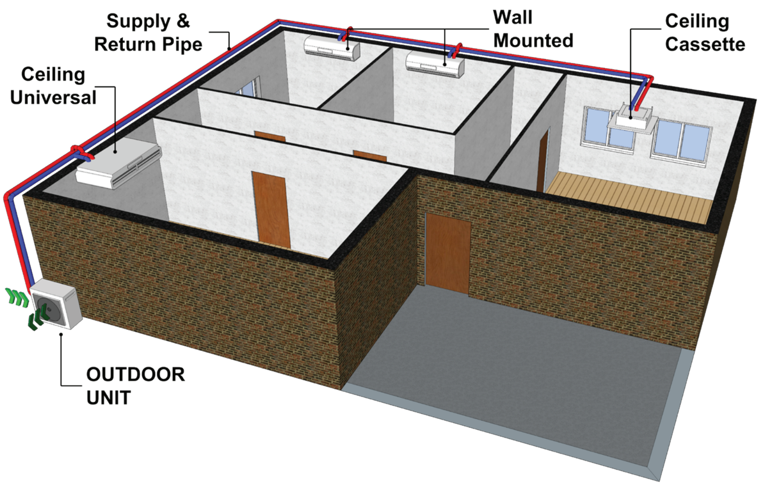
- Low efficiency in conventional products
- Outdoor unit can be noisy
- Indoor-and outdoor units should be installed close to each other to avoid thermal gains and heating of the cooled refrigerant
- No fresh air delivered to the room
- Today, F-gases1[2] are still used, which are harmful to the environment (Global Warming Potential). For new machined, they are continuously replaced by less global warming potential.

Air Conditioner (AC) – Multi Split

Multi split run on the same concept as single split units. The only difference is, that one outdoor unit is connected to multiple indoor units. Thus, one outdoor can provide cold energy to multiple rooms at once. Multi split units cool down the indoor air, not providing fresh air to the rooms. As reversible heat pumps system they can either heat or cool the rooms, but not heat one room and cool the other at the same time.

2 Fluorinated Greenhouse Gases (F-gases) are synthetic compounds used in refrigeration, air conditioning, and other industrial applications, known for their high global warming potential. They are critical because they trap significantly more heat in the atmosphere than CO_2, contributing to climate change.

Figure 27: Example of a Multi-split System, Source: University of Innsbruck, Unit of Energy Efficient Building



Advantages

- Only one outdoor unit, improved aesthetics
- Individual control of each indoor unit/ each room
- Free selection of indoor unit type
- No indoor ducts necessary

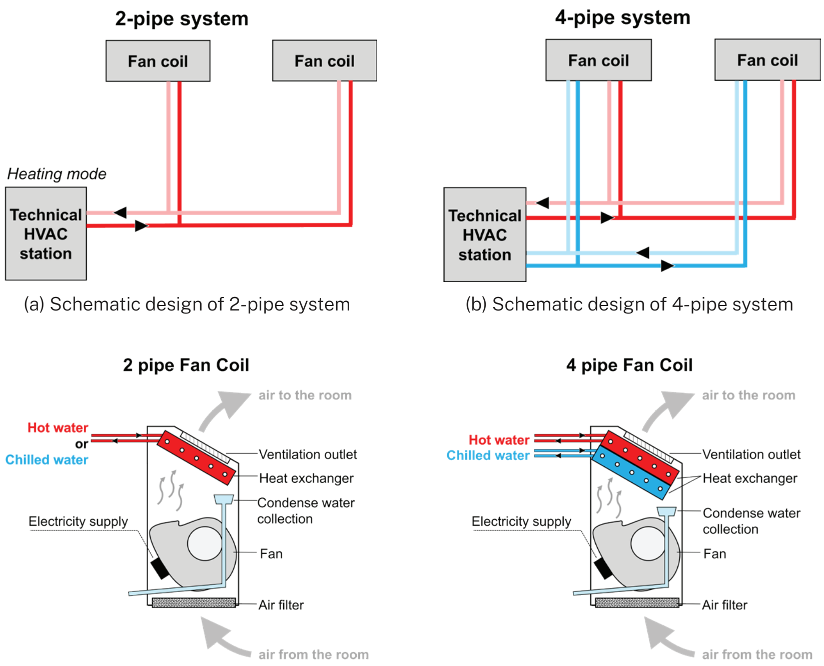
Disadvantages

- No heating and cooling at the same time in different rooms
- Total capacity of indoor units is limited to the capacity of the outdoor unit
- Installation requires more piping compared to single split and is more complex
- No fresh air supply

Difference Between 2-pipe and 4-pipe Systems

There are different design and methodologies that can be considered in planning a HVAC system. It is fundamental to understand the principles of both a 2-pipe system and a 4-pipe system and how the differentiate from each other. Both systems use water as working fluid. A 2-pipe system uses a single set of supply and return pipes, which are alternately used for either heating or cooling, depending on the season or central system configuration. This means that all zones or terminal units in the building must operate in the same mode at any given time — either heating or cooling — limiting flexibility, especially in buildings with diverse thermal loads. In contrast, a 4-pipe system includes separate supply and return lines for both hot and chilled water, allowing simultaneous heating and cooling in different parts of the building. This dual-network configuration enhances operational flexibility, as it enables individual zones to respond to their specific thermal needs regardless of the season or the mode of adjacent zones. However, the increased material cost, installation complexity, and space requirements for piping and control systems make 4-pipe systems more common in larger or high-performance buildings, such as commercial offices, hospitals, or hotels, where thermal zoning and precise indoor climate control are critical.

Figure 28: Presentation and comparison of 2-pipe and 4-pipe system. (a) shows the schematic design of a 2-pipe system in heating mode, supplying hot water to the fan coils. (b) shows the schematic design of a 4-pipe system, simultaneously supply hot water and chilled water to the required fan coils. (c) and (d) show the principle design of a fan coil for a 2-pipe system, respectively a 4-pipe system. Source: University of Innsbruck, Unit of Energy Efficient Building



(a) Schematic design of 2-pipe system

(b) Schematic design of 4-pipe system

(c) Design of a fan coil in a 2-pipe system

(d) Design of a fan coil in a 4-pipe system

Advantages	
For 2-pipe system ▪ Water instead of refrigerant is circulating through the pipes ▪ Simple installation, less pipes ▪ Lower installation costs compared to 4-pipe system ▪ Reduced power consumption for pumping ▪ Good for residential applications in apartments/ single family houses	For 4-pipe system ▪ Water instead of refrigerant is circulating through the pipes ▪ Heating and cooling available at the same time with one system only ▪ High flexibility and increased user-comfort ▪ Very suitable for hotels, hospitals and offices
Disadvantages	
For 2-pipe system ▪ No fresh air ventilation ▪ Only either heating or cooling ▪ Limited flexibility	For 4-pipe system ▪ No fresh air ventilation ▪ More piping, more complex installation ▪ Higher installation cost ▪ Increased space requirements ▪ Greater maintenance demand compared to 2-pipe system

VRF System

Variable Refrigerant Flow (VRF) systems are advanced HVAC systems used for both cooling and heating even simultaneously in different rooms. They work by circulating refrigerant at different flow rates, which makes them efficient for handling large spaces without needing traditional ventilation ducts. Instead, refrigerant pipes are installed directly to the rooms that need climate control.

Unlike standard split air conditioners, VRF systems can support multiple indoor units from a single system and can provide both heating and cooling at the same time. This is a key difference from multi-split units, which can only do one or the other.

VRF systems are more efficient due to inverter compressors, which adjust their speed to match the needs of each room. This is different from older systems that only run at full speed, leading to better energy use and lower operating costs.

Because VRF systems can be tailored to different needs and are very flexible, they are especially useful in commercial buildings and for facility managers looking for efficient climate control solutions.

Figure 29 shows the refrigerant flow in an VRF unit for mainly heating (including domestic hot water) and a smaller part for cooling (Kwon, Lee, Hwang, Radermacher, & Kim, 2014). The system is divided into four unit sections:

- Outdoor unit
- HR unit
- Indoor unit
- Water Heating unit

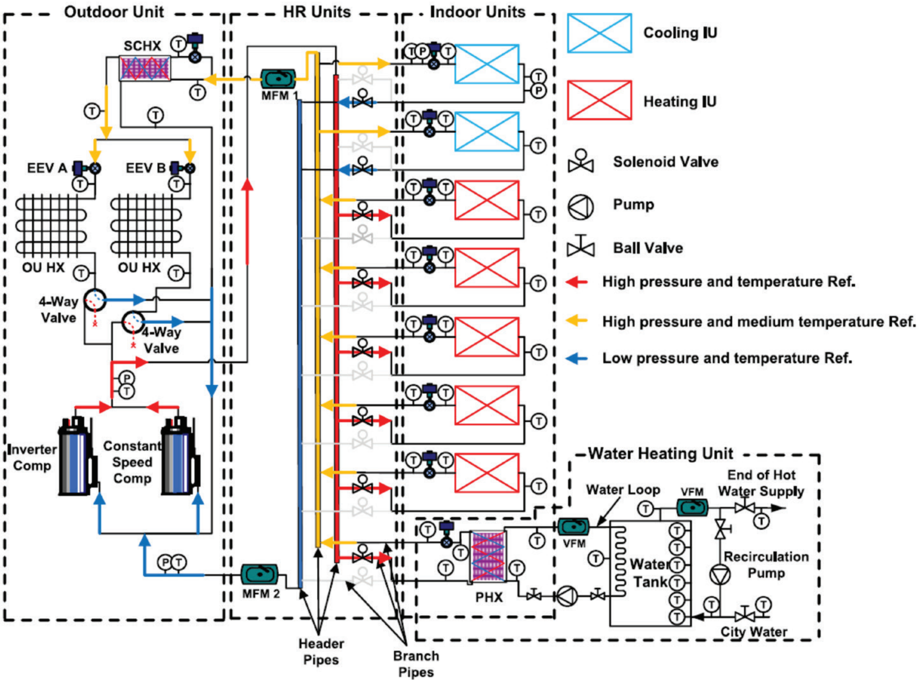
Outdoor Unit Section: In this case, the outdoor unit consists of two different compressors (constant speed and variable speed), two heat exchangers (OU HX), two propeller fans, two four-way valves, two expansion electric expansion valves (EEV), and a subcooling heat exchanger (SCHX). Depending on the overall heating and cooling demand of the system and its performance, heat can be released via the heat exchangers or heat can be generated using electric input through the compressors.

HR Units Section: Three individual pipes are running in parallel. A high pressure and high temperature pipe (red) supplies the units in heating indoor units with heat in form of vapour. The liquid return flow of those units has high pressure but medium temperature (yellow). This pipe directs the liquid working fluid either to the SCHX of the outdoor unit or to the indoor units operating in cooling mode. Their gaseous return flow is then of low pressure and low temperature (blue). This pipe is heading back to the outdoor unit.

Indoor Units Section: The individual indoor units supply either heat or cold to a room. They are equipped with finned-tube heat exchangers, an EEV for refrigerant control and a fan for forced convection and increased air exchange at the heat exchanger.

Water Heating Unit Section: A plate heat exchanger (PHX) serves as handover station between the pipes of the HR unit and the hot water supply circuit. Heat is transferred from high pressure and high temperature pipe (red) to an intermedium water loop delivering the heat to the hot water tank. From that tank, domestic hot water is supplied to the individual

Figure 29: Schematic of a VRF System with simultaneous heating, cooling and domestic hot water production. Source: Kwon, Lee, Hwang, Radermacher, & Kim, 2014



VRF Working Principle: The discharge gas is directed to the units in heating mode for condensation. The "cold" liquid high pressure outlet from the heating units can be partly directed to the units operated in cooling mode via an expansion device and partly to the outdoor units operating as evaporators. For a situation with more cooling than heating units the discharge gas of the compressor can partly be directed to the units used for heating for condensation or partly to the outdoor heat exchangers functioning as condensers when more cooling than heating is needed. Both are directed to the so cold liquid pipe with high pressure. A receiver (high pressure accumulator) has to be located behind the outdoor heat exchangers. The units used for cooling are fed from this pipe and expand the needed refrigerant mass-flow to low pressure/low temperature by expansion devices and use the units used for cooling as evaporator. The refrigerant is directed via the suction pipe and an accumulator (to avoid liquid droplets entering the compressor) to the compressor.

If heating and cooling occurs simultaneously in the house, which will not often occur, then the refrigerant flow for this part is used on the hot and cold side (double use) thus increasing the COP.

Advantages
▪ Simultaneous heating and cooling at the same time ▪ Hot water generation can be included in the same system ▪ Energy efficient system ▪ Through heat recovery mode, excess heat from indoor cooling units can be directly for either heating purpose or for DHW generation
Disadvantages
▪ More complex system, more effort in planning, maintenance and explicitly control ▪ Effort in piping, three parallel strings ▪ Due to complexity of control logic, system is sensitive to operational or control faults ▪ High content of refrigerant – application of inflammable refrigerants like Propane are not possible

Central Ventilation Systems with AC

Fresh air supply is important for the indoor air condition. If the outdoor air temperature is higher than the desired indoor air temperature, an integration of cooling technologies into the ventilation system is a solution to deliver some cold into the room. Nevertheless, if only the hygienic air exchange rate is used, the cooling power is very small:

With q_{vi} from Table 4 one can calculate for residential buildings:
Given information:

ACH = 0.42 1/h (chapter 4.4) and

H_{room} = Volume flow of the air [m^3/s]

V_{spec} = Pressure difference in the compressor [Pa]; 100.000 Pa = 1 bar [N/m^3]

Calculation

With this the specific needed air flow comes to
$ACH \cdot V_{spec}$ = 0.42 1/h · 2.5 m^3/m^2 = 1.05 $m^3/(m^2 \cdot h)$
(for the ease of calculation roughly 1 $m^3/(m^2 \cdot h)$)

If calculated to [$l/(m^2 \cdot s)$] it comes to
Q = 1.05 m^3/m^2,h · 1,000 l/m^3 / 3,600 s/h = 0.29 $l/(m^2 \cdot s)$

The fresh air temperature should not be below 18°C to avoid discomfort. Therefore, the Δt between inlet air of 18°C and room air (26°C) becomes Δt = 8°C or 8 K. With the formula of Table 4 to

$q_{vi} = C_s \cdot Q \cdot \Delta t$; the cooling power given to the room by cooling the ventilation air comes to

q_{vi} = 1.23 W/(l·s·K) · 0.29 L/m^2,s · 8 K = 2.85 W/m^2

$$q_{vi} = C_s \cdot Q \cdot \Delta t$$

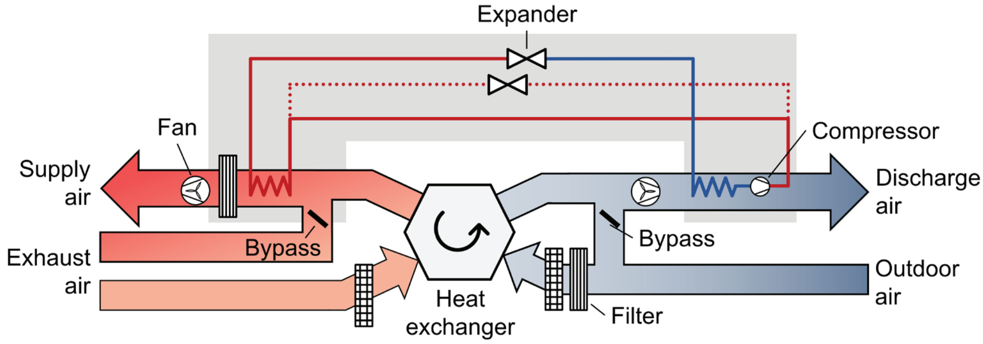
Air input from ventilation and infiltration via doors and windows and mechanical ventilation systems (controlled).

C_s = air sensible heat factor, [W/(l·s·K)] (1.23 at sea level)

Q = actual air volumetric flow rate, [l/s] for ventilation and infiltration.

which is a very low cooling effect. If more cooling is needed, normally either an additional cooling device is needed, or the ventilation system needs additional circulating air at evaporator and condenser thus coupling an AC Split Unit and a ventilation unit. Here Q in the above formula is only the hygienic air exchange, not the circulating air.

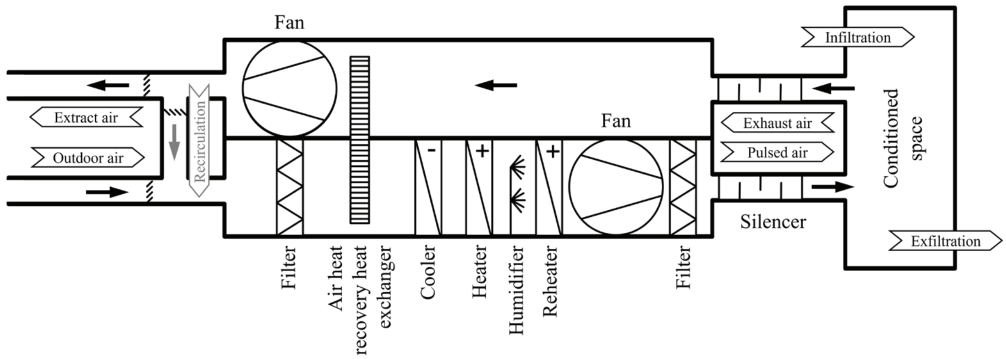
Figure 30: Coupled Ventilation /Split Unit System with hygienic air exchange, air heat recovery system, and circulating air for condenser and evaporator (heating example) Source: University of Innsbruck, Unit of Energy Efficient Building



The process of dehumidification can be installed in a central ventilation system, too. There are different components and designs available for integration, dependent on the use case and climate condition.

The hot outdoor air is drawn into a ventilation system using fans. It passes a heat exchanger (cooler) through which cold refrigerant runs. When the air is cooled below the dew point water is drained out and the air is dehumidified until the desired absolute humidity is reached. Then the air needs a reheating in order to avoid 100 % humidity entering the room. A full central AC ventilation unit has the possibility to fulfil all thermodynamic functions: filter, air heat recovery, cooling, heating, humidification and dehumidification. For the selection of filter types, refer to Table 2.

Figure 31: Full decentral ventilation air conditioning unit with air heat recovery, cooling, heating, humidification and dehumidification. Source: Roulet, Foradini, & Cretton, 1994



Advantages

- Increased user comfort
- Combination of technologies
- Central control
- Dehumidification easy to integrate

Disadvantages

- Hygienics must be monitored
- Filters need to be changed
- Cost-intensive

5.3.2 Heat/Cold Distribution Systems

In water-based systems, water is cooled in the evaporator and transported to the rooms, takes up heat there (and thereby cooling the rooms) and be transported back to the evaporator. Water-based systems cool down either material and construction (thermally activated concrete) or serve as lowered ceiling system.

Water-based systems can also be used for heating purpose by transporting hot water from the condenser of the heat pump to the rooms.

Chilled Suspended Ceiling

Chilled suspended ceilings provide cooling primarily via radiative heat transfer to a room, and only indirectly cool down the whole air volume of a room/ building. They are built as lowered ceiling in which pipes are installed. Cold water is running through these pipes. Figure 32 shows the construction of a suspended ceiling with water-running pipes that operates as a chilled ceiling.

Figure 32: Sketch of chilled ceiling as a lowered ceiling. Source: (GF Building Flow Solutions, 2025)

Advantages

- Installation after building construction possible
- The cold-water temperature can be down to 18°C (check to be above dew point)
- High efficiency of chillers, due to relatively high cold-water temperature and up to 80 W/m^2 cooling power
- The same system can be used for space heating (radiation, up to 40 W/m^2)
- Cold is provided to top and bottom of the suspended ceiling, increasing the conduction and cooling effect

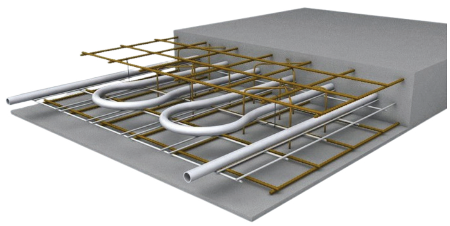
Disadvantages

- No dehumidification. Additional dehumidifiers systems must be installed if dehumidification is necessary.
- Temperature of the cooled surfaces must be above dew point temperature of the room air to avoid condensation and droplets falling down.
- They need a relative humidity sensor at the coldest place facing the ambient air (inlet of cold water) in order to avoid condensation and "raining" form the ceiling.
- A separate system for ventilation is required

Concrete Core Activation

Pipes are directly installed in construction elements, like RCC ceilings or walls. Cold water is running through the pipes, directly cooling down the construction. Materials like RCC have a high thermal energy storage capacity. Figure 33 shows the construction of a construction core activation in a RCC ceiling. The water-running pipes are placed between the steel reinforcement and embedded within the concrete. This leads to a high thermal conductivity form the heat transport medium (water) to the construction material.

Figure 33: Sketch of design and construction of thermally activated RCC ceiling with piping in between reinforcement steel. Source: GF Building Flow Solutions, 2025



Advantages

- The cold-water temperature can be 20°C
- High efficiency of chillers, due to relatively high cold-water temperature and up to 40 W/m² cooling power (less than the suspended colling ceiling because the high thermal mass needs far longer to heat up when the cooling is stopped due to high humidity and thus danger of condensation.
- Thermal mass of construction is helpful in reducing the cooling needs, the building doesn't heat up fast
- It can be used also for space heating up the 40 W/m²

Disadvantages

- Planning required at early stage of building design
- Inert system, not useful for quick cooling
- No dehumidification. Additional dehumidifiers systems must be installed if dehumidification is necessary.
- Temperature must above dew point temperature to avoid condensation (humidity sensor the coldest place).
- A separate system for ventilation is required

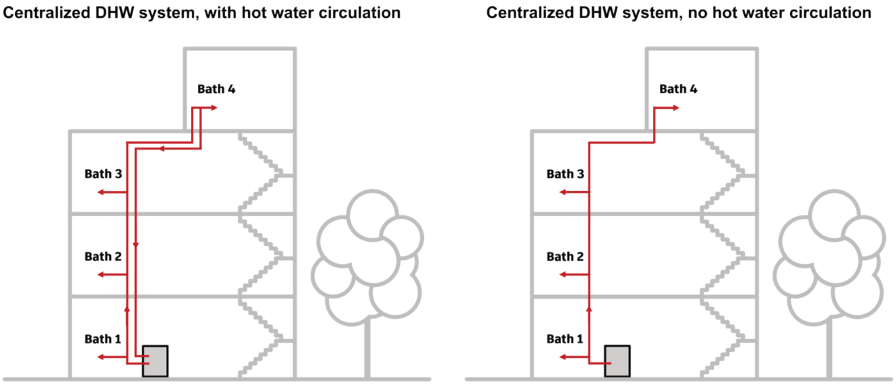
5.4 Domestic Hot Water Systems

There are different systems to choose for DHW generation. In the following three different systems are described in short.

5.4.1 Central System

A central domestic hot water system has only one central heating station to heat the water. This station may use different heat sources which are combined. For example, solar thermal collectors in combination with natural gas boilers. A central system requires a hot water storage. Depending on the size of the building and number of end users, a permanent hot water circulation might be useful, also to dismiss legionella.

Figure 34: Sketch of two options for a central domestic hot water heating system with hot water distribution to different rooms. Left: System with hot water circulation. Right: System without hot water circulation. Source: University of Innsbruck, Unit of Energy Efficient Building



Legionella are bacteria found in water systems that can cause Legionnaires' disease, a severe form of pneumonia. They are harmful because inhaling contaminated water droplets can lead to serious respiratory illness, especially in vulnerable individuals. In this case the whole circulation loop has the be permanently kept above 55°C. A central system requires a full system approach in planning and an insulation of the hot water pipes to reduce thermal losses in the hot water pipes. Hot water is always available with this system. Figure 34 shows two schematics of central domestic hot water system, with and without a hot water circulation. With a hot water circulation system, you can secure that hot water is available on demand, but installation and operational costs are higher. Without the hot water circulation, hot water cools down in the pipes and it may take a little bit of time until hot water is available.

Another solution in combination with a centralized space heating system is to have individual heat exchangers in the apartments. However, this requires to run the building heating system also in times of no space heating demand.

Advantages

- Efficient heating of all hot water
- Integration of hot water tank possible
- Only one unit for heating necessary

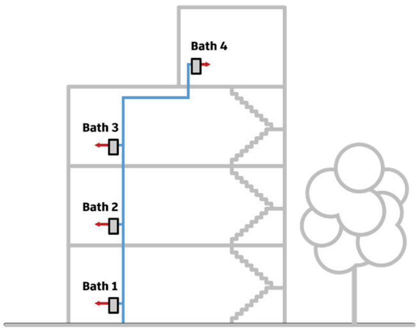
Disadvantages

- Circulation of domestic hot water required
- Heat losses from the hot pipes
- Danger of Legionella growth compared to decentral systems per apartment.

5.4.2 Decentralized System

The hot water in a decentralized system is generation at different points in the house using individual heaters. A common technology for this are electric instantaneous water heaters. Another commonly used technology are electric geysers, with a small hot water storage of 15-25 litres.

Figure 35: Sketch of a central domestic hot water heating system with hot water distribution to different rooms. Source: University of Innsbruck, Unit of Energy Efficient Building



Hot water is only generated when on demand. This requires installation of heaters at every point of demand in the building such as the shower or sinks, but the system does not require a hot water storage insulated hot water pipes in the building. Thus, decentralized hot water systems have no thermal losses, but require more electric power to heat the water. Figure 35 shows the schematic of a decentralised system. Single units provide hot water for each use case.

Advantages
▪ No piping and insulation of connecting additional hot water pipes in the building ▪ Low thermal losses ▪ Hot water generated only on demand ▪ If hot water pipe length is below 5 m there should be no problem of Legionella bacteria growth as they are washed out frequently, when hot water is used.
Disadvantages
▪ Multiple heaters required, more installation actions ▪ Less opportunities for individual heaters compared to central system

5.5 Ventilation Systems

5.5.1 Natural Ventilation

This chapter presents a brief overview and fundamentals on natural ventilation. Supplementary information are available in the BEEN Manual for Energy-Efficient Building Design (2025), chapter 6.

Natural ventilation relies on natural forces like wind and buoyancy to move fresh air through buildings, promoting indoor air quality and thermal comfort sustainably and energy-efficiently.

The Primary Mechanisms Include:

- Wind-driven Ventilation: Utilizes pressure differences created by wind to circulate air through openings like open windows or leakages of the building.

- Buoyancy-driven Ventilation (Stack Effect): Uses temperature differences between indoor and outdoor air to drive vertical air movement. (Jakob, 2024)

Types of Natural Ventilation:

- Cross Ventilation: Air flows straight through a building using openings on opposite sides, driven by wind pressure.
- Stack Ventilation: Warm air rises and exits through higher openings, drawing cooler air in from lower levels.
- Single-sided Ventilation: Effective for shallow spaces, with openings on one side of the building.
- Atrium Ventilation: Combines stack and cross ventilation using a central atrium to facilitate air movement. You can find it often in malls.

Additional and extensive information on elements and types of natural ventilation are available in the BEEN Manual for Energy-Efficient Building Design (BEEN, 2025).

$$Q = C_d \cdot A \cdot V \qquad (11)$$

Q	Air flow rate [m^3/s]
C_d	Discharge coefficient (typically 0.6 – 0.7 for fully open windows)[3]
A	Area of the opening [m^2]
V	Wind speed [m/s]

Advantages

- Energy Efficiency: Reduces reliance on mechanical ventilation and cooling systems and therefor the electricity demand.
- Improved Air Quality: Regular air exchange enhances indoor air quality.
- Cost Savings: Lowers energy bills avoiding HVAC system use by night cooling by open windows (mosquito nets and rain and burglar safe shudders with enough hoes to let the air pass are needed) .
- Environmental Benefits: Decreases carbon footprint by reducing energy consumption.

Disadvantages

- Weather Dependency: Effectiveness varies with outdoor conditions.
- Control and Predictability: Less predictable and controllable compared to mechanical systems.
- Design Complexity: Requires thoughtful architectural design to maximize effectiveness.

Design Considerations:

- Building Orientation: Align openings to maximize wind exposure.
- Opening Size and Placement: Optimize size and position of windows, vents, and other openings.
- Internal Layout: Ensure unobstructed pathways for airflow within the building.
- Climate Adaptation: Design to accommodate local climatic conditions, such as prevailing wind directions and seasonal temperature variations.

3 Depends on window geometry, opening angle, and air velocity. For more information, please refer to ASHRAE standard 62.1

- Use lockable shutters and mosquito nets in order to prevent rain coupled with wind coming in, assure safety (burglary), prevent mosquitos and flies coming in, still have enough air opening that the air flow behind shutters through open windows is assured.
- Use natural ventilation at night for natural night cooling and reducing mechanical cooling demand by the HVAC system (Pont, 2018).

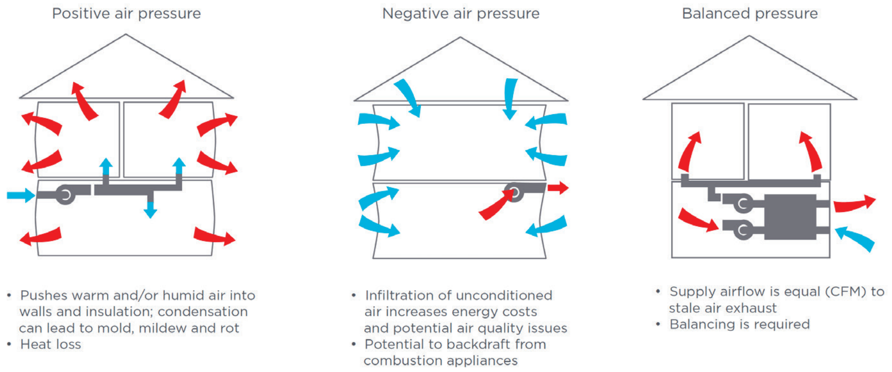
5.5.2 Mechanical Ventilation

Mechanical ventilation employs systems to circulate air within buildings, ensuring controlled air exchange, improved air quality, and consistent thermal comfort regardless of outdoor conditions. These systems use inlet/outlet openings with filters, fans, ducts, and controls to move air and can function independently or as part of an HVAC system.

Types of Mechanical Ventilation

- **Exhaust Ventilation Systems:** Use exhaust fans to remove stale air from the building, creating a negative pressure that draws fresh air in through vents and leaks. An exhaust fan installed in a kitchen removes air to eliminate cooking odours and moisture. The outlet air is replaced by ambient air through leakages of the building or open windows. The building has slight negative pressure.
- **Supply Ventilation Systems:** Use fans to bring fresh air into the building, creating a positive pressure that forces stale air out through vents and leaks. Air is pressed out of the building by leakages (slight overpressure). This can yield moisture problems in colder climates (condensation of humid warm air in the wall), however, this can be minimised with sufficient provision of vents.
- **Balanced Ventilation Systems:** Use both supply and exhaust fans to bring in fresh air and remove stale air, maintaining balanced pressure. A balanced system in a residential home uses both supply and exhaust fans to provide fresh air and remove the same amount of stale air, maintaining a neutral pressure environment.
- **Energy Recovery Ventilation (ERV) Systems (also Enthalpy Recovery Ventilation):** Exchange heat and humidity between incoming and outgoing air streams to improve energy efficiency. An ERV system provides fresh air while recovering 70% of the heat and about 50% of humidity from the exhaust air, improving energy efficiency. Humidity recovery is needed in both cold climates in winter or in hot climates in summer. In winter times it humidifies the fresh air, whereas in hot and humid climates a dehumidification is necessary
- **Heat Recovery Ventilation (HRV) Systems:** Similar to ERV systems but focus on exchanging heat without humidity exchange.

Figure 36: Supply ventilation (left), exhaust ventilation (middle), balanced ventilation (right). Source: (Efficiency NS, 2025)



Advantages

- Control: Provides precise control over air exchange and indoor air quality.
- Consistency: Operates effectively regardless of outdoor conditions.
- Energy Efficiency: ERV and HRV systems recover heat, reducing heating and cooling loads.
- Air Quality: Filters and controlled ventilation rates ensure high indoor air quality.

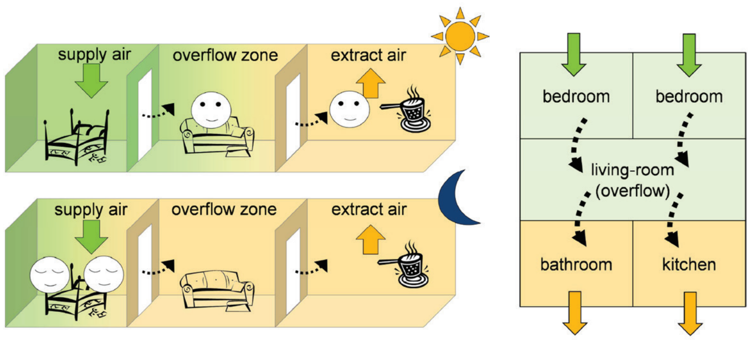
Disadvantages

- Energy Consumption: Mechanical systems consume energy, increasing operational costs.
- Maintenance: Require regular maintenance to ensure proper operation and efficiency.
- Installation Cost: Initial cost can be higher compared to natural ventilation systems.

Cascade Ventilation (Passive Overflow)

"Saving of supply air ducts and components through zoning of the floor plan in supply air, overflow and exhaust air zones: Normally the supply air zones are living rooms and bedrooms. The air is routed from this supply air zones via the overflow zone (e.g. corridor) to the exhaust air zone (e.g. kitchen, bathroom). This air routing principle is called cascade ventilation. Compared to a system with supply and extract air for each room, this principle already saves a lot of space and money. By means of the extended cascade ventilation, the supply air may be restricted to bedrooms. In this case, the living room is regarded as overflow zone as shown in the next graph." (Sinfonia Project, 2019).

Figure 37: Cascade ventilation (passive overflow). Source: (Sibille, 2015)



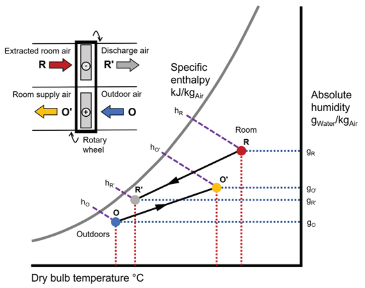
The pictures in Figure 38 show the possibilities for HRV (Heat Recovery Ventilation) and ERV (Enthalpy Recovery Ventilation) systems. They can be either built as plate heat exchanger, rotary wheel or, when no connection between inlet and exhaust air is allowed (e.g. in hospitals) as run around coil systems.

In the plate heat exchanger energy is driven by temperature difference from hot to cold. The plates allow water vapor to diffuse form high partial pressure to low partial pressure, thereby exchanging moisture. This is also working for dehumidifying outlet air, when the vapor partial pressure of the outside air is higher than the one of the room air exhausted.

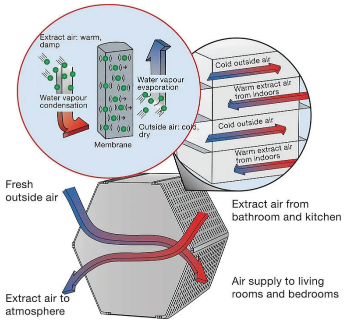
For the rotary wheels, the wheel consists of small air channels with metal or other wall rotates slowly from hot side to cold side of the air flow. On the hot air stream the material of the wheel is heated up and releases the heat at the cold air stream. When the surface of the channels is coated with e.g., Lithium chloride, it takes up water vapor at the higher partial pressure side and releases the vapour at the lower partial pressure side. Also, this system can humidify the inlet air in winter and dehumidify the inlet air in summer. This wheel has always some leakage from outlet to inlet air due to incomplete bearings between wheel and inlet and outlet air ducts.

If such a leakage has to be avoided on any chance (e.g. hospitals) then run around coil systems are used with to heat exchangers and a connecting pipe circuit fille with liquid. Here only heat recovery is possible (HRV), see Figure 38 (d).

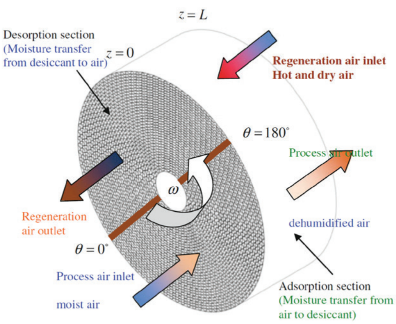
Figure 38: Upper left (a): Psychometric diagram for the moisture recovery in cold climates, Source: (Dwyer, 2020); Upper right (b): Enthalpy Plate Heat Exchanger, Source: (Zehnder Group UK Limited, 2025); Lower left (c): Rotary Desiccant Wheel, Source: (Muthu, Talukdar, & Jain, 2016); Lower right (d) Run Around Coil system, Source: (Mahmoud, Filipsson, Brunninge, & Dalenbäck, 2022)



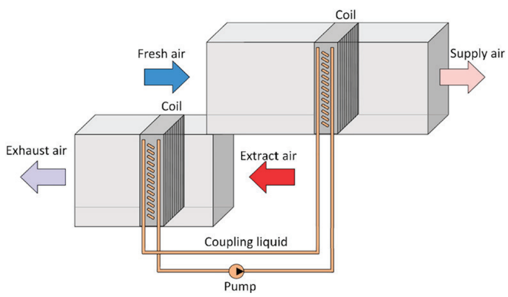
(a) Psychrometric diagram of temperature and moisture recovery



(b) Enthalpy plate heat exchanger



(c) Rotary Desiccant Wheel



(d) Run Around Coil system

5.6 Solar PV

Solar PV systems convert sunlight into electricity using semiconductor materials, providing a renewable energy source for all electric appliances in a building or even electric vehicles, thus reducing energy consumption and reliance on non-renewable sources. The PV cells generate electricity through the photovoltaic effect, where sunlight excites electrons, creating an electric current. This direct current (DC) electricity is then converted to alternating current (AC) with inverters, making it compatible with most electrical systems in homes and businesses. The optimal operation by maximising the power output of a PV Panel (max current multiplied with voltage, $U \cdot I = P_{el}$) is performed by a so-called Maximum Power Tracker, MPT.

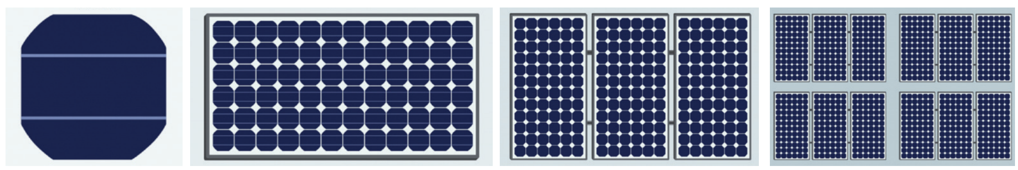
Types of Solar PV Systems

- **Monocrystalline PV Panels:** Made from a single continuous crystal structure, these panels are highly efficient (about 20% efficiency of electricity production related to solar irradiance on the PV-pane) and durable but costlier to produce.
- **Polycrystalline PV Panels:** Comprising multiple crystal structures, these panels are less efficient but cheaper to manufacture than monocrystalline panels.
- **Thin-Film PV Panels:** Created by layering photovoltaic material on a substrate, these panels are less efficient but are lightweight and flexible, suitable for various uses.
- **Building-Integrated PV (BIPV):** PV materials integrated into building materials, such as roof shingles or facade elements, serving both structural and energy-generating purposes. Mainly mono-and polycrystalline cells are used.

Figure 39: Different type of PV cells. Source: Maysun Solar, 2022

MONO POLY THIN FILM

Figure 40: From PV cell to PV array. Source: Olayiwola, Hyun, & Choi, 2024



Photovoltaic (PV) Cell Module Panel Array

Example for Sizing a PV System for a House

- Calculate the total electricity consumption of the house in kilowatt-hours (kWh). For example, the house consumes 5,000 kWh per year.
- Calculate the amount of energy a solar panel produces per day.
  - Panel peak power rating (P): 300 W (0.3 kW) rated to 1,000 W/m^2 global irradiation.
  - Average full sunlight hours (1,000 W/m^2) per day (H): 5 hours during the full year. This amounts to 1,780 kWh/a sunshine which is occurring in Kathmandu for a 45° tilted south orientated surface.
  - System efficiency (E): 0.8 (accounting for losses)
  - Daily energy production per panel:

$$\text{Daily Energy} = P \cdot H \cdot E$$

$$\text{Daily Energy} = 0.3\ \text{kW} \cdot 5\ \text{hours} \cdot 0.8$$

$$\text{Daily Energy} = 1.2\ \text{kWh/day}$$

  - Calculate the total number of panels required to meet the annual energy consumption.

$$\text{Total panels} = \frac{\text{Annual energy consumption}}{\text{Daily energy production per panel} \cdot 365\ \text{days}}$$

$$\text{Total panels} = 5{,}000\ \text{kWh} / (1.2\ \text{kWh/day} \cdot 365\ \text{days})$$

$$\text{Total panels} \approx 11.4$$

$$\text{Total panels} = 12$$

Advantages

- Renewable Energy Source: Reduces dependence on fossil fuels.
- Reduced Electricity Bills: Generates free electricity from sunlight.
- Low Maintenance: PV systems have few moving parts and require minimal maintenance.
- Environmentally Friendly: Produces no greenhouse gases during operation.
- Energy Independence: Can provide power in remote locations without access to the grid.

Disadvantages

- High Initial Cost: Significant upfront investment for panels and installation.
- Intermittent Energy Production: Solar energy is not available at night or during cloudy weather.
- Space Requirements: Requires sufficient roof or ground space for installation.
- Efficiency Decline: PV panels gradually lose efficiency over time.
- Dust formation: PV-Panels must be cleaned periodically, when dust is not washed away by rain. Otherwise, the solar radiation can only partly reach the PV cells and is partly reflected (absorbed) by the dust.

Solar PV Integration with the Electrical Systems

Solar PV systems can be integrated with electrical systems (including electric driven HVAC) to supply renewable energy for most of the application including lighting, appliances, heating, cooling, and ventilation, in several ways:

- Direct Power Supply: PV systems can directly power electrical systems/appliances during daylight hours, reducing grid electricity usage.
- Battery Storage: Storing excess solar energy in batteries allows electrical systems/ appliances to run on solar power even when sunlight is not available.
- Grid-Tied Systems: PV systems can be connected to the grid, allowing excess electricity to be fed back into the grid, potentially earning credits from the utility company (Pont, 2018).

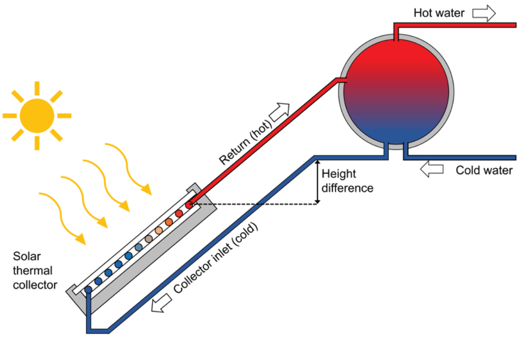
5.7 Solar Thermal Systems

This section focusses on solar thermal systems. It is divided into thermosyphon systems where no pumps are required, and pumped solar thermal systems.

5.7.1 Solar Thermosiphon System

Solar thermosiphon systems are hot water system of great application. The system is reduced in its complexity and does not need any pump, but uses the difference in density between hot and cold water only. There are direct and indirect thermosiphon systems. The picture on the right shows a direct system with the use water running directly through the solar thermal collector pipes. The heat-transfer medium is separated from the use water in an indirect system, with a pocket heat exchange in the upper tank (see chapter 5.7)

Figure 41: Sketch of a solar thermosiphon system. Source: University of Innsbruck, Unit of Energy Efficient Building



Advantages
▪ No operation costs ▪ Simple and proven system ▪ Easy to install
Disadvantages
▪ Hot water generation only during daytime when sun is available ▪ Indirect systems required to avoid calcification in hard water areas ▪ Insulation and auxiliary heating required in climate with freezing temperatures ▪ It is impossible to shut off the collector – Stagnation above 100°C with boiling in the collector (or DHW) loop can occur, especially if there is no need during one or two sunny days (weekend, travel of occupants…). Water needs to be drained by the pressure safety valve and to be refilled afterwards.

5.7.2 Pumped Systems

Solar thermal systems use solar energy to generate heat rather than electricity. This heat is utilized directly for purposes such as space heating, water heating, and even cooling when combined with absorption chillers. These systems play a crucial role in sustainable HVAC strategies, providing substantial energy savings and lowering carbon emissions. Solar thermal systems capture and convert sunlight into thermal energy, which is then transferred to a circulating fluid, commonly water or a glycol solution, to deliver heating to a water filled storage tank to be used for heating purposes. The hot absorber has heat losses to the ambient via the insulation on the back (flat plate collector) and via the glazing by convection, conduction and radiation. The heat losses are directly proportional to the temperature difference between absorber and ambient, the higher the absorber temperature, the higher the heat losses. Therefore, the useful heat and the efficiency of the thermal collector becomes lower with increasing absorber temperature. Depending on the needed application temperature, less insulation or a strong insulation is needed for high efficiencies at varying operating temperature. On the other hand, with low thermal losses due to better insulation, the stagnation temperature (no pump flow because no heat is needed any more) becomes high. Flat plate collectors can reach 180 – 200°C, evacuated tubes even higher temperature. This can lead to boiling of the collector circulation fluid or of the water in the storage tank depending on the pressure on both sides. Boiling results in an enormous volume increase from fluid to vapor. This effect has to be dealt with by the construction of collector, collector loop and storage tank.

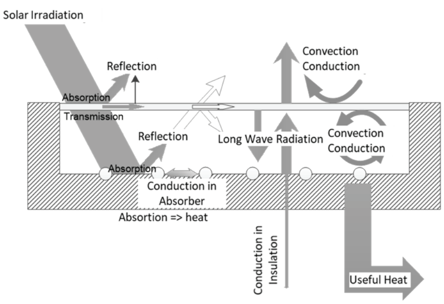
The circulation of the heat transfer medium is controlled via electric driven pumps. Pumps allowing variable flow control can be used to adapt the mass flow in response to the solar radiation to harness heat at a constant temperature.

Types of Solar Thermal Collectors

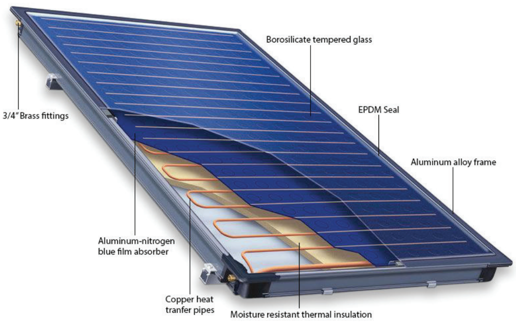
- **Flat-Plate Collectors:** These consist of an insulated, flat box with a transparent cover and a dark absorber plate. The absorber plate absorbs solar radiation and transfers the heat to a fluid circulating through attached tubes. This type is effective for water heating and space heating in cold and moderate climates.
- **Evacuated Tube Collectors:** These collectors feature rows of transparent glass tubes, each containing an absorber tube within a vacuum. The vacuum reduces convective heat loss, enhancing efficiency, particularly in colder climates. These collectors are suitable for high-temperature applications and areas with lower solar radiation. As heat pipe collectors with evaporating refrigerant at the absorber and condensing refrigerant at the heat exchanger to the heated water, there is no stagnation problem with boiling water.
- **Swimming Pool Collectors:** as swimming pools need a temperature close to the ambient temperature there is no high temperature lift needed. Therefor they have a excellent efficiency and are very cheap systems without glazing and insulation.

- **Solar Air Collectors:** Similar to flat-plate collectors, these systems heat air instead of liquid. They are designed to directly heat air, which can be circulated for space heating and ventilation preheating.
- **Concentrating Collectors:** Using mirrors or lenses, these systems focus sunlight onto a small, high-intensity area to generate high temperatures. They are ideal for industrial processes, large-scale power generation, and certain HVAC applications requiring high temperatures. Examples include parabolic troughs, solar towers, and dish concentrators.

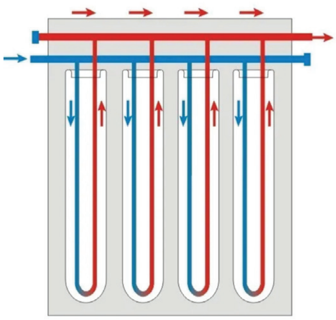
Figure 42: Upper left (a): Energy flow in solar thermal collector (Kaltschmitt, Streicher, & Wiese, Erneuerbare Energien, 2020); Upper right (b) Flat plate collector, Source: (Northern Lights Solar Solutions, 2024); Middle left (c), evacuated tube Sidney collector, Source: (Jiaxing Passion New Energy Technology Co. Ltd., 2025); Middle right (d): Evacuated tube heat pipe, Source: (Elsheniti, Kotb, & Elsammi, 2019); Lower left (e): non-covered swimming pool collector, Source: (Yznahre), Lower right (f): Parabolic trough collector, Source: (Tagle-Salazar, Nigam, & Rivera-Solorio, 2020)



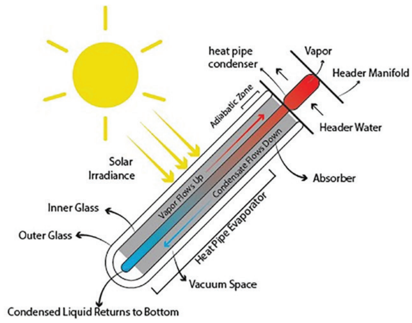
(a) Heat fluxes in solar thermal collectors



(b) Flat plate collector

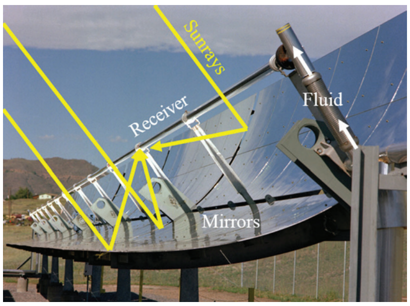


(c) Evacuated Tube Sidney collector



(d) Design of evacuated tube heat pipe

(e) Non-covered swimming pool collector



(f) Parabolic trough collector

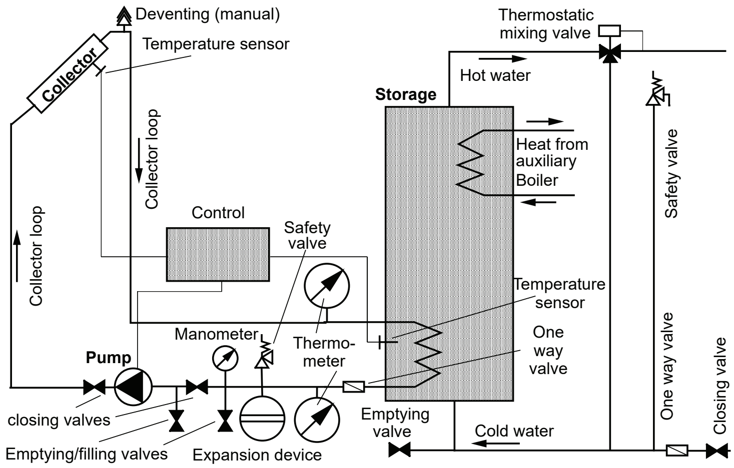
Advantages

- High energy efficiency
- Products are already well proved and available on the market, many vendors
- Easy in maintenance

Disadvantages

- Based on the collector-type, cost for invest can be high
- Hydraulic systems (pumps, pipes, expansion valve, storage, ...) must also be installed

Figure 43: Forced circulation solar thermal plant for domestic hot water production (Kaltschmitt, Streicher, & Wiese, Renewable Energy, 2007)



Example

Sizing the system (Pont, 2018):

- Calculate the total energy required for space heating or water heating.

  Example for Domestic Hot Water:

  - Daily hot water requirement: 200 liters = 0.2 m^3
  - Temperature rise required: 50°C (from 10°C to 60°C)
  - Specific heat capacity of water: 4.18 kJ/(kg·K)
  - Density of water: 1,000 kg/m^3
  - The last two values can be multiplied and set from J to kWh /divide by 3,600 s/h and 1,000 to get kJ/s (kW) instead of J/s (W). This gives a volumetric thermal capacity of 1.16 kWh/(m^3·K) which can be easily used for rough and calculations

- Energy required per day:

  Q = mass · specific heat capacity · density · temperature rise

  Q = volume · volume-specific heat capacity · temperature rise

  Q = 0.2 m^3 · 1.16 kWh/(m^3·K) · 50 K

  Q = 11.6 kWh/day

- Estimate Solar Collector Area:
  - Solar insolation: Average daily solar energy per unit area (assumed 5 kWh/(m^2·day))
  - Collector efficiency: Assumed to be 50% (0.5)

  Collector area required:

  Area = Energy required / Solar insolation × Efficiency
  (Given the solar insolation is 5 kWh/(m^2·day) and the collector efficiency is 0.5, this value represents the effective solar energy captured by the collector per unit area per day, accounting for the efficiency of the collector)

  Area = 11.61 kWh/day / 5 kWh/(m^2·day) · 0.5

  Area ≈ 4.64 m^2

Advantages

- Renewable Energy Source: Uses abundant and free solar energy.
- Reduced Energy Bills: Lowers dependency on fossil fuels and cuts energy costs.
- Low Operating Costs: Requires minimal maintenance and has low operating expenses.
- Environmental Benefits: Reduces greenhouse gas emissions and lessens environmental impact.
- Most of cheap collectors with low efficiency achieve the same amount of energy (low temperature rise compared to ambient needed) bit have less or no boiling of the collector fluid during stagnation (no heat need, nobody at home ...)

Disadvantages

- High Initial Cost: Requires a significant initial investment for installation and equipment.
- Weather Dependency: Performance varies with sunlight availability, necessitating backup systems.
- Space Requirements: Needs adequate space for collector installation.
- Complexity: Systems can be complex and need professional design and installation.
- Dust formation: Collector must be cleaned periodically, when dust is not washed away by rain. Otherwise, the solar radiation can only partly reach the absorber and is partly reflected (absorbed) by the dust.

5.8 Summary and Overview of Technologies

Chapter 5 Systems and Technologies presents multiple technologies that provide heating or cooling as well as technology to distribute the heating/ cooling to the room, apartments, or office spaces.

This section summarises the presented information in a concentrated form. Table 9 presents an overview of the heating/ cooling technologies described in this manual.

Table 9: Overview of different heating and cooling technologies

Heating / cooling technology	Characteristics	Typical application fields
Direct electric heating	Easy to install but low efficiency. Impact of heaters is very limited.	Buildings that are part-time used, or heating is only required few times a year.
Single split AC and window AC	Easy to install, widely available and less investment-intensive. Must be correctly sized for its application and room. Less efficient units will cause high operational costs. COP ranges between 2.5 and 4.5, based on desired cooling temperature and outdoor conditions. As a reversible unit it can provide heating and cooling.	Individual rooms in apartments, single family houses, or commercial buildings
Multi split AC	The system provides either cooling or heating. Once circuit of refrigerant connects one outdoor unit with several indoor units. Total cooling/ heating capacity is based on the outdoor unit. Indoor units can be adapted for individual rooms.	Hotels, hospitals, multi-family houses, or large office buildings.
VRF	Heating and cooling at the same time is possible, providing high user comfort. Three strings of refrigerant circulate between one outdoor and several indoor units. Installation is complex and investment costs are high.	Hotels, hospitals, multi-family houses, or large office buildings.
2-pipe system	The system can provide only either heating cooling, but not simultaneously. The system includes only one loop of working fluid. Water instead of refrigerant is piped between indoor and outdoor unit. Typically, one outdoor unit the includes a vapour compression process is connected to multiple indoor units.	Apartments, single family houses.
4-pipe system	Water instead of refrigerant is piped between indoor and outdoor unit. Typically, one outdoor unit the includes a vapour compression process is connected to multiple indoor units. The system can provide heating and cooling at the same time. Two loops of working fluid are required.	Hotels, hospitals, multi-family houses, or large office buildings.
Wood stove	Simple and inexpensive products, widely available. There are different kinds of wood stove, all being fired with wood or biomass products. In catalytic stoves, wood is partly gasified a second combustion takes place, reaching a higher efficiency of the stove. When installed indoors, exhaust gas extraction must be planned and considered. Wrong installation and missing ventilation are risks for health and safety.	Residential homes, cabins, and off-grid locations.
Vapour compression chiller	Works on the same concept as a single split AC but on a larger scale. Uses refrigerant in a vapor-compression cycle to cool a working fluid (water) that is then circulated to other units.	Large commercial buildings, industrial applications, and centralized district cooling systems.
Heat Pump	Works on the same concept as a single split AC but treats water instead of air. Potential heat sources are either ambient air, ground, or water. Can provide both heating and cooling.	Apartments, single family houses, commercial buildings
Ab-/ Adsorption chiller	Driven by a heat source instead of electricity. The working fluid is evaporated and absorbed by a solid or liquid. Integration is complex as it requires a heat source and a rejection unit.	Hospitals, large office buildings, and industrial applications with waste heat.

Heating / cooling technology	Characteristics	Typical application fields
Solar thermal	Uses solar radiation to heat a working fluid. Different types of solar thermal collector types are available, based on the desired outlet temperature.	Useful for heating and DHW applications for residential buildings.
Solar PV	Uses solar radiation to generate electricity. Electric efficiency is in the range of 15%-20%. A transformer is required to transfer direct current (DC) to alternating current (AC) power.	Roof top applications, façade integration, open field solar PV farms

The heat and/ or cold provided a technology listed in Table 9 must be distributed to the indoor room(s). There are different ways to distributed heat/ cold to the rooms. Table 10 presents an overview of available distribution technologies divided into air-based and water-based systems. Each distribution technology is shortly described and linked heating/ cooling technologies are mentioned.

Table 10: Overview of heating/ cooling distribution technologies

	Heating / cooling distribution technology	Characteristics	Linked heating / cooling technology
Air-based	Distribution to indoor air directly	Air is heated or cooled and then recirculated within the space without introducing fresh outdoor air. Can be simple but lacks fresh air.	Single split AC, window AC, multi-split AC, VRF, 2-pipe system, 4-pipe system
Air-based	Mechanical ventilation with fresh air supply	Uses fans to bring in filtered outdoor air and distribute it. Can be combined with heating/cooling coils. Provides good indoor air quality.	Centralized or decentralized Air Handling Units (AHUs) linked to chillers, boilers, VRF systems
Water-based	Convectors / radiator	Used for heating only. Hot water circulates through coils or panels, transferring heat by convection (convectors) and radiation (radiators) to the room air. Often visible and can be controlled per room. Supply temperature ranges from 40°C-80°C	Boilers (for heating), chillers (for cooling), heat pumps, 2-pipe system, 4-pipe system
Water-based	Suspended ceiling	Panels within a suspended ceiling contain water pipes to heat or cool the room. Provides even temperature distribution and is aesthetically discrete.	Chillers, heat pumps, 2-pipe system, 4-pipe system
Water-based	Concrete core actviation	Useful for both heating and cooling. Water pipes are embedded directly within the ceiling structure (e.g., plasterboard or concrete slab). Offers highly uniform heating/cooling and is completely invisible.	Chillers, heat pumps, 2-pipe system, 4-pipe system
Water-based	Floor heating	Used for heating only. Water pipes are embedded within the screed (wet system) or in an insulation layer (dry system). A warm floor grants high user comfort and the heat is evenly distributed. Supply temperature ranges between 25°C and 35°C.	Boilers, heat pumps, solar thermal collectors
Water-based	Wall heating	Water pipes are embedded within wall panels or plaster. Offers heating and cooling from vertical surfaces, providing good comfort and being aesthetically discrete. Supply temperature ranges between 25°C and 45°C.	Boilers, heat pumps, solar thermal collectors

06 Energy Simulation Tools

Simulation software programs are just tools, no answer machines!

Any simulation software will just help you in decision making.
It will not decide for you, that is the duty of planners.

Simulation and calculation results are based on your input!

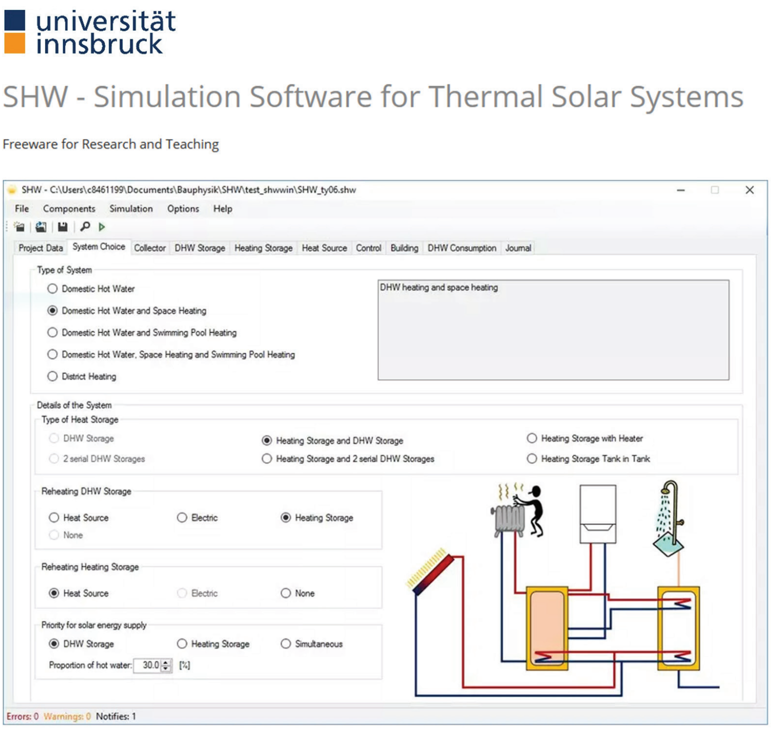
Any simulation and calculation software will provide results based on your input.
If your input data are not reliable, your results won't be either.

Free Simulation Software

Free software to design solar thermal systems is e.g. SHW. This tool is available at the website of University of Innsbruck:

https://www.uibk.ac.at/en/energy-efficient-building/research/software-and-tools/shw/

The SHW software can be used to calculate solar thermal systems for DHW heating, for combined DHW heating and (partially solar) heating and for the partial solar supply of district heating networks. Many hydraulic schemes and cylinder configurations are possible and pre-installed. SHW runs on Windows version 7 or higher. The user interface was completely modernised in 2016 and is constantly being improved. SHW is available as freeware for study, teaching and research.



PVWatts Calculator

PVWatts is a web-based application developed by the U.S. National Renewable Energy Laboratory (NREL) for estimating the energy production and cost savings of grid-connected photovoltaic (PV) systems. The tool is freely accessible online and designed for non-technical users such as homeowners, early-stage developers, and educators. It is widely used in North America and supports most global locations via a geographic selection interface.

The tool uses Typical Meteorological Year (TMY) weather data in combination with a simplified PV performance model to estimate monthly and annual electricity generation. Users enter basic inputs like location, system size, tilt, and module orientation, while default system losses and efficiency factors are automatically applied. The calculator also provides basic financial indicators such as annual savings and payback time. Though limited in technical depth and customization, PVWatts excels in accessibility and speed, making it an excellent first-step analysis tool. It does not account for shading or detailed component configuration but can serve as a reliable rough estimator for planning purposes.

Website: *https://pvwatts.nrel.gov*

PV GIS

PVGIS is a free web-based tool developed and maintained by the European Commission's Joint Research Centre (JRC). It is designed to estimate the solar energy potential and expected electricity generation of photovoltaic systems based on high-resolution geographical and meteorological data. PVGIS is openly accessible and does not require any installation or licensing, making it ideal for early-stage project development, education, and public-sector applications across Europe, Africa, Asia, and the Americas.

PVGIS uses detailed satellite-based irradiance data, historical weather datasets, and digital elevation models to calculate solar radiation and PV system performance at any given location. Users can input key system parameters such as tilt, orientation, peak power, technology type (standard crystalline, thin-film, bifacial), and system losses. The tool calculates monthly and yearly energy yield and provides output in both tabular and graphical formats. Additionally, PVGIS includes features such as optimal tilt estimation, hourly time series export, and comparison of fixed vs. tracking systems. Though it lacks advanced design capabilities (e.g., 3D shading, equipment selection), its high-quality climate data, transparency, and reliability make it one of the most widely used tools for solar resource assessment in Europe and beyond.

Website: *https/://pvgis.com/en*

RETScreen Expert

RETScreen Expert is a comprehensive software platform developed by Natural Resources Canada for the analysis and optimization of renewable energy and energy efficiency projects. It supports a wide range of technologies including solar PV, solar thermal, wind, hydro, and combined heat and power (CHP). RETScreen is available in both a free and a paid version, with the Expert version offering more advanced features such as performance tracking and benchmarking.

RETScreen employs a spreadsheet-based interface integrated with a global database of climate data, technology parameters, fuel prices, and emissions factors. The software enables users to conduct feasibility studies by modeling energy production, costs, savings, and greenhouse gas reductions. Additionally, RETScreen can be used for ongoing monitoring and verification (M&V) by importing actual system performance data for comparison against expected values. While it does not perform detailed system design or dynamic simulation, its strength lies in strategic-level decision-making, policy assessment, and portfolio-level analysis. Its versatility and wide range of applications make it popular among governments, utilities, energy managers, and consultants.

PV*Sol

PVSol is a powerful Windows-based simulation software developed by Valentin Software in Germany for the detailed planning and optimization of photovoltaic systems. It supports both grid-connected and off-grid installations and is available in various license levels, including Premium and Pro editions, with pricing depending on features and user type. PVSol is widely used by solar installers, engineers, and architects for commercial and residential projects.

The core methodology in PVSol is based on dynamic simulation using real hourly weather data and detailed component models. One of its standout features is its 3D shading analysis tool, which allows users to import and model buildings, trees, and other obstacles to assess shading losses precisely. The software includes extensive manufacturer databases with real-world PV modules, inverters, batteries, and other components. Users can simulate different system configurations and obtain detailed outputs such as energy yields, performance ratios, self-consumption rates, and economic metrics like LCOE and payback periods. PVSol offers a good balance of technical detail and usability, making it a go-to choice for professional system planners.

Polysun

Polysun is a dynamic simulation software developed by the Swiss company Vela Solaris for designing and analyzing complex energy systems that integrate solar PV, solar thermal, heat pumps, and other renewable technologies. It is a commercial tool available through a paid license, with pricing tailored to user needs (educational, professional, or enterprise). Polysun is particularly suited for planners and engineers designing hybrid and multi-technology energy systems.

The simulation engine in Polysun allows for time-step modeling with high temporal resolution, enabling the detailed analysis of system dynamics under real-world conditions. The software provides component libraries that include manufacturer-specific data for collectors, inverters, storage tanks, and controllers. Users can create and simulate custom system topologies, evaluate thermal and electrical energy flows, and perform parametric studies. Polysun supports integration with building load profiles, weather data, and district heating networks. Its major strength lies in its flexibility and ability to model interactions between multiple subsystems, making it ideal for projects involving both solar PV and thermal, as well as seasonal storage or advanced control strategies.

Additional Software Tools

Additional software tools for both solar thermal and solar PV application can be found on the following website:

https://photovoltaic-software.com/

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08 Annex – Formulas

Transmission through exterior surfaces above grade

$$q_{Trans,\,ext,\,i} = (U_i \cdot A_i) \cdot (T_{indoor} - T_{outdoor}) \quad (12)$$

$$q_{Trans,\,ext} = q_{Trans,\,1} + q_{Trans,\,2} + \ldots.. + q_{Trans,\,i} \quad (13)$$

$q_{Trans,\,ext}$	Total heat flux from exterior facing surfaces[W]
$q_{Trans,\,ext,\,i}$	Heat flux through transmission of construction i [W]
U_i	U-value of construction element I [W/(m²·K)]
A_i	Area of construction element I [m²]
T_{indoor}	Indoor temperature [°C], 20 °C
$T_{outdoor}$	Outdoor temperature [°C], 99% design temperature

Partitions to unconditioned buffer spaces

$$q_{Trans,\,b,\,i} = (U_i \cdot A_i) \cdot (T_{indoor} - T_{buffer}) \quad (14)$$

$$q_{Trans,\,b} = q_{Trans,\,1} + q_{Trans,\,2} + \ldots.. + q_{Trans,\,i} \quad (15)$$

$q_{Trans,\,b}$	Total heat flux from partition to unconditioned buffer spaces [W]
$q_{Trans,\,b,\,i}$	Heat flux through transmission of construction i [W]
U_i	U-value of construction element I [W/(m²·K)]
A_i	Area of construction element I [m²]
T_{indoor}	Indoor temperature [°C], 20 °C
$T_{outdoor}$	Outdoor temperature [°C], 99% design temperature

Walls below grade

$$q_{Trans,\,ground,\,i} = (U_i \cdot A_i) \cdot (T_{indoor} - T_{ground}) \quad (16)$$

$$q_{Trans,\,ground} = q_{Trans,\,1} + q_{Trans,\,2} + \ldots.. + q_{Trans,\,i} \quad (17)$$

$q_{Trans,\,b}$	Total heat flux from walls facing ground [W]
$q_{Trans,\,b,\,i}$	Heat flux through transmission of construction i [W]
U_i	U-value of construction element I [W/(m²·K)]
A_i	Area of construction element I [m²]
T_{indoor}	Indoor temperature [°C], 20°C
$T_{outdoor}$	Ground temperature [°C], 99% design temperature

Ventilation losses (ad latent part, Enthalpy includes sensible and latent for evaporation, condensation, at US mollier diagram)

$$q_v = \dot{V} \cdot \rho \cdot c_p \, (h_{indoor} - h_{outdoor}) \qquad (18)$$

q_v	Heat flux through ventilation [W]
$\dot{V}$	Volume flow of air between air between indoor and outdoor
ρ	Density of air [kg/m^3]
c_p	Thermal heat capacity of air [Wh/(kg·K]
h_{indoor}	Indoor temperature [°C]
$h_{outdoor}$	Outdoor temperature [°C]

Infiltration losses

$$q_{Inf} = ELA \cdot S \qquad (19)$$

$$S = \sqrt{f_s^2 \cdot (T_{indoor} - T_{outdoor}) + f_w^2 \cdot v^2} \qquad (20)$$

q_{Inf}	Heat flux through infiltration [W]
ELA	Effective Leakage area [m^2]
S	Specific infiltration [m/s]
f_s	Stack factor: 0.
f_w	Stack factor: 0.182 [-]
v	Wind speed [m/s]
T_{indoor}	Indoor temperature [°C]
$T_{outdoor}$	Outdoor temperature [°C]

BUILDING ENERGY EFFICIENCY IN NEPAL

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