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GREEN BUILDING DESIGN GUIDEBOOK FOR ARMENIA

YEREVAN 2025

Green Building Design Guidebook for Armenia

Advisory manual

Yerevan 2025

The Green Building Design Guidebook was developed with the technical and financial support of the World Bank through its Global Facility for Disaster Reduction and Recovery (GFDRR) and in collaboration with the International Finance Corporation (IFC).

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The Guidebook is an advisory document.

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Acronyms and Abbreviations

AAC	Aerated Autoclaved Concrete
AASF	Average Annual Shading Factor
AC	Air Conditioning
ACH	Air Changes per Hour
AFUE	Annual Fuel Use Efficiency
AHU	Air Handling Unit
AI	Artificial Intelligence
ANPP	Armenian Nuclear Power Plant
BEMS	Building Energy Management Systems
BIPV	Building Integrated Photovoltaic
BOD	Basis of Design
BREEAM	Building Research Establishment Environmental Assessment Methodology
CFL	Compact Fluorescent Light
CMU	Concrete Masonry Unit
CO	Carbon Monoxide
CO2	Carbon Dioxide
COP	Coefficient of Performance
CoUD	Committee of Urban Development
CRI	Colour Rendering Index
CVD	Chemical Vapour Deposition
DCV	Demand Controlled Ventilation
DHW	Domestic Hot Water
DX	Direct Expansion
EDGE	Excellence in Design for Greater Efficiencies
EER	Energy Efficiency Ratio
EIFS	Exterior Insulation Finishing System
EPD	Environmental Product Declarations
EPDM	Ethylene Propylene Diene Terpolymer
EPI	Energy Performance Index
EPS	Expanded Polystyrene Insulation
ETHICS	Exterior Thermal Insulation Composite System
FCU	Fan Coil Unit
GBG	Green Building Guide
GHG	Greenhouse Gas
GHP	Geothermal Heat Pumps
GGBS	Ground Granulated Blast-furnace Slag
GoA	Government of the Republic of Armenia
GSHP	Ground Source Heat Pumps
GWP	Global Warming Potential
HPP	Hydroelectric Power Plants
HRW	Heat Recovery Wheel
HSA	Horizontal Shading Angle
HSPF	Heating Season Performance Factor
HVAC	Heating, Ventilation, and Air Conditioning
IEC	Indirect Evaporative Cooling
IEER	Integrated Energy Efficiency Ratio

IFC	International Finance Corporation
IoT	Internet of Things
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
LPD	Lighting Power Density
LPG	Liquefied Petroleum Gas
MEP	Mechanical, Electrical, and Plumbing
MSVD	Magnetron Sputter Vacuum Deposition
NC	New Construction
NDC	Nationally Determined Contribution
NIS	Newly Independent States
OHSC	Occupant Health, Safety, and Comfort
OPR	Owner’s Project Requirements
OTTV	Overall Thermal Transfer Value
PFC	Power Factor Correctors
PHE	Public Health Engineering
PIR	Passive Infrared Sensors
PPC	Pozzolanic Portland Cement
PSC	Portland Slag Cement
PUF	Polyurethane Foam
PV	Photovoltaic
RCC	Reinforced Cement Concrete
RES	Renewable Energy Sources
SBS	Styrene-Butadiene-Styrene
SC	Statistical Committee of the Republic of Armenia
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SR	Solar Reflectivity
SRI	Solar Reflectance Index
STP	Sewage Treatment Plants
TE	Thermal Emittance
TFC	Total Final Consumption
TPP	Thermal Power Plant
TTE	Temperature Transfer Efficiency
UN	United Nations
UPS	Uninterrupted Power Supply
VFD	Variable Frequency Drives
VLT	Visible Light Transmission
VOC	Volatile Organic Compounds
VRF	Variable Refrigerant Flow
VSA	Vertical Shading Angle
VSD	Variable Speed Drives
VT	Visible Transmission
WC	Water Closet
WWR	Window-to-Wall Ratio
XPS	Extruded polystyrene insulation

Measurement Abbreviations

C	celsius
Cm	centimetre
K	kelvin
Kg	kilogram
Km	kilometre
kW	kilowatt
kWh	kilowatts per hour
kWh/m^2	kilowatts per hour per square metre
lpm	litres per minute
l/s/m^2	litres per second per square metre
m^2	square metre
m^3	cubic metre
MJ	megajoules
mln.m^3	million cubic metre
Mtoe	metric tonne equivalent
Ppm	parts per million
Psi	pounds per square inch
W	watt
Wp/kWp	watt-peak / kilo-watt-peak
W/m^2	watts per square metre
W/mK	watts per metre kelvin
W/m^{2}K	watts per square metre kelvin

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About this document

This Green Building Design Guidebook demonstrates that is possible to achieve the Paris Agreement goals and foster Climate Change Mitigation through the Building Sector. Armenia is very well positioned to make this change happen. Integrating green measures into the design and construction of new buildings, as well as though the retrofitting of existing facilities, helps reducing GHG emissions and fosters the establishment of more sustainable and resilient built environment.

The Green Building Design Guidebook for Armenia is structured around 4 sections:

- **Section A** – provides an introduction to the topic and describes the objectives and background for the guidebook.
- **Section B** – gives the Armenian country context, including climate and natural resources, the typologies of buildings across different periods, and the current building normative.
- **Section C** – presents the green building measures, as further explained below.
- **Section D** – compiles some additional resources to expand on the topic.

The **Green Building Measures** in Section C are organized around 7 areas:

1. **Site and Context:** The selection of the site for the construction of new buildings needs to include a thorough analysis of the context - or ecosystem - to ensure that the new buildings are integrated into the environment and ecosystem minimising negative impacts on those. Locating new buildings near public transportation networks and facilitating the use of green transport, such as bicycles, helps reducing the carbon footprint of the building's users.
2. **Energy efficiency:** The installation of energy systems should integrate research and analysis about the climate in the area and the patterns for energy consumption, so buildings' design can take advantage of local conditions, and ensure high degree of efficiency through the combination of different measures. From passive design (such as building orientation to maximize the availability of natural light) to the implementation of energy efficiency equipment (such as lighting and heating, ventilation, and air conditioning (HVAC) systems) and the use of renewable energy sources (such as solar photovoltaic panels and wind turbines), the list of options to ensure the development of green buildings is long and effective. Energy-efficient technology consumes less energy while providing the same performance.
3. **Water efficiency:** Considering the scarcity of water resources in several regions of the planet, and the variability of climate patterns, affecting the water cycle, the establishment of an efficient water system starts with reducing demand by increasing the efficiency of equipment. Reducing the water demand in buildings, combined with measures such as harvesting rainwater or using recycled water, and fostering a responsible and sustainable water use among building users, help reducing the consumption of natural resources, such as rivers and lakes.
4. **Green building materials:** The materials used for the construction or retrofitting of buildings should better be local, suitable for the local context, and environmentally friendly, in addition to be combined with sustainable construction practices. The reuse or recycling of buildings components (such as steel) and the integration of materials with low embodied energy and carbon (i.e., materials that consume less energy and produce less carbon emissions during their extraction, fabrication, transport, and disposal), highly contribute to the consolidation of a green and sustainable building sector.
5. **Construction:** The construction site and process need to keep the levels of pollution as lower as possible - both dust and noise pollution, since those can lead to additional pollution related problems in the area - as well as to ensure a proper waste management, fostering recycling of materials as much as possible.
6. **Indoor environmental quality (IEQ):** The measures to ensure the health, safety, and comfort of the occupants of the buildings can be aligned with green and environmentally sustainable practices, even if they do not directly contribute to GHG emissions. IEQ measures have been coopted as good practice in green building design.
7. **Solid waste management (SWM):** The management and treatment of solid waste is one of the most critical aspects in cities worldwide, therefore, including solutions for segregation of solid waste into buildings' design greatly contributes to the environmental sustainability and efficiency of the building and their occupants. SWM is inherently connected with the larger environmental systems around the building.

Within these 7 areas, each measure includes detailed aspects, such as design approach, methodology, and potential technologies. The measures are organized by subtopics, as follows:

1. Site and Context

1.1 Ecology and Environment:

- 1.1.1 Integration of project with local ecosystem
- 1.1.2 Exterior Light Pollution and Controls
- 1.1.3 Storm water attenuation

1.2 Building and Transport:

- 1.2.1 Proximity to public transportation
- 1.2.2 Preferential parking for electric vehicles
- 1.2.3 Bicycle storage and changing rooms

2. Energy Efficiency Measures

2.1 Demand side measures – Passive Design:

- 2.1.1 Building orientation
- 2.1.2 Window-to-Wall Ratio (WWR)
- 2.1.3 Shading
- 2.1.4 Glazing Properties
- 2.1.5 Air infiltration
- 2.1.6 Thermal Breaks
- 2.1.7 Thermal transmittance of Building Envelope (U-value)
- 2.1.8 Wall and Roof reflectivity
- 2.1.9 Green roofs
- 2.1.10 Daylighting
- 2.1.11 Natural ventilation

2.2 Demand Side Measures - Energy Efficient Equipment Design:

2.2.a Lighting

- 2.2.1 Energy efficient lamps
- 2.2.2 Lighting Controls

2.2.b Heating, Ventilation and Air-conditioning (HVAC) Systems

- 2.2.3 Cooling System Efficiency
- 2.2.4 Heating System Efficiency
- 2.2.5 Ceiling fans
- 2.2.6 Economizers
- 2.2.7 Variable Speed Drives, Variable Frequency Drives
- 2.2.8 Fresh Air Pre-conditioning System
- 2.2.9 Refrigerant Management
- 2.2.10 Demand Control Ventilation using Carbon Monoxide (CO) and Carbon Dioxide (CO2) Sensors
- 2.2.11 Thermostat Controls

2.2.c Other Equipment

- 2.2.12 Domestic Hot Water System Efficiency
- 2.2.13 Domestic Hot Water Preheating System
- 2.2.14 Power factor correctors (PFC) and Regenerative Braking of Lifts

2.3 Energy / Supply side measures:

- 2.3.1 Renewable Energy

2.4 Knowledge and Behaviour management:

- 2.4.1 Smart Meters for Energy
- 2.4.2 Building Energy Management System
- 2.4.3 Building Commissioning
- 2.4.4 Energy Efficient Appliances

3. Water Efficiency Measures

3.1 Demand side measures:

- 3.1.1 Water-efficient fixtures
- 3.1.2 Water-efficient irrigation system
- 3.1.3 Swimming pool covers

3.2 Supply side measures:

- 3.2.1 Condensate recovery
- 3.2.2 Wastewater Treatment and Re-use
- 3.2.3 Roof rainwater harvesting

3.3 Knowledge and Behaviour management:

- 3.3.1 Water use submetering

4. Green Building Materials

- 4.1 Recycled building materials
- 4.2 Building materials with low embodied energy and carbon

5. Construction Site Measures

- 5.1 Construction pollution control
- 5.2 Construction waste management

6. Indoor Environmental Quality Measures

- 6.1 Indoor air quality
- 6.2 Indoor sensory comfort

7. Solid Waste Management Measures

- 7.1 Segregation of solid waste

Section A – Introduction

Climate Change is a global phenomenon that is affecting countries around the world, and a concerted action to reduce their respective greenhouse gas emissions (GHG) footprints is crucial to keep the planet liveable for future generations. Globally, buildings account for about 34% of the energy consumption and 37% of GHG emissions[1], and the building sector has major role to play in achieving the Paris Agreement's goal.

The building sector in Armenia is a nationally significant consumer of resources, especially energy, water, and building materials that result in GHG emissions causing global warming and climate change. Like other countries worldwide, Armenia has pledged its Nationally Determined Contributions (NDCs) towards reducing its GHG emissions, as per the Paris Agreement[2]. And since buildings form an important part of this contribution, it is therefore in the national and global interest that buildings are designed to be resource efficient.

Green buildings can be promoted through different policy levers, mainly classified under four key areas: Regulations, Building Controls and Monitoring, Market Mechanisms, and Capacity Building. One of the key initiatives is to build the capacity of the market. There is a general lack of awareness of how green buildings can be built. This spans across all the areas of the building sector ranging from government decision makers, architects and other engineering professionals, developers, building owners and operators, etc.

Objective of the Guidebook

This green building guide (GBG) aims to complement existing regulatory norm on green buildings and to help construction design professionals in Armenia to design green buildings appropriate for Armenian climate and built environment characteristics. This document provides practitioners with a comprehensive list of green building/resource efficiency measures. This Guidebook is intended mainly for design and construction professionals in Armenia, to help them incorporate greener design measures in their buildings. The intended audience of this guidebook includes, but is not limited to, the following professionals:

- Architects
- Structural Engineers
- Electrical Engineers
- Plumbing and Sanitary Systems (i.e., Public Health Engineering, PHE) Engineers
- Heating, Ventilation, and Air Conditioning (HVAC) (i.e., Mechanical) Engineers
- Quantity Surveyors
- Project Managers
- Contractors
- Teaching/training professionals in the construction industry

Overall, this Guidebook aims to provide insights and resources to achieve a greener building sector and serve as a knowledge resource for practitioners in the building industry, to reinforce the transition to a more sustainable and greener built environment in Armenia.

Background: Greening the Built Environment in Armenia

GHG reductions from the building sector can be achieved primarily through two methods: (i) building new structures using green building principles, and (ii) systematically retrofitting existing buildings. Green buildings are a part of long-term decarbonization plans to achieve low carbon society. Armenia's ongoing efforts in promoting green buildings must continue simultaneously constructing new buildings with low GHG footprints and retrofitting existing building stock to be able to meet its emission reduction targets.

To create an enabling environment for a green built environment, following four fundamental components (figure 1) works in tandem:

a) green building codes and regulations under a legislative framework;

b) monitoring and control mechanism as part of the regulatory compliance mechanism;

c) market mechanisms that encourage construction industry stakeholders and building owners to invest in a green built environment, including green building certification, financial and non-financial incentives, green bonds and mortgages, among others; and

d) knowledge dissemination and capacity building for industry professionals to equip appropriate knowledge to design and operate green buildings.

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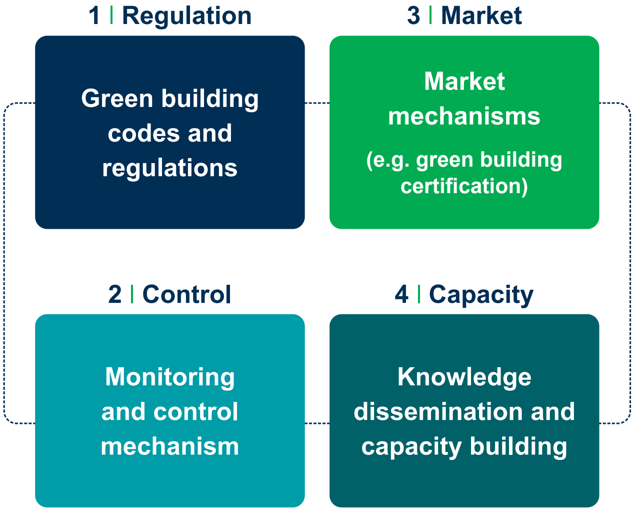
[1]Global Status Report for Buildings and Construction - Beyond foundations: Mainstreaming sustainable solutions to cut emissions from the buildings sector: wedocs.unep.org/handle/20.500.11822/45095

[2]The Paris Agreement is a legally binding international treaty on climate change adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015: unfccc.int/process-and-meetings/the-paris-agreement

Figure 1. The four fundamental components that contribute to a green built environment



Source: Building Code Checklist for Green Buildings (World Bank, 2023)

a) Green building code and regulations

Green building code is a set of mandatory regulations and voluntary provisions that establish minimum standards for energy efficiency, water conservation, and other sustainability measures in new construction and major retrofits. This can be part of an overall building code or a separate code. In Armenia, the Committee of Urban Development (CoUD) is mandated to develop these regulations, which are designed to facilitate that all new buildings and, in some cases, existing buildings meet a minimum level of energy and water performance. Green building regulations are designed to cover major building functions and building typologies, aiming to achieve significant impacts on improved energy and water efficiency in the overall built environment.

b) Monitoring and control mechanism

A monitoring and control mechanism of implementation of the legislative framework usually serves as an accountability mechanism to facilitate the compliance. To support functioning control mechanism, a building asset database and a methodology for building resource audits play important roles in recording a building's performance on water and energy efficiency. In Armenia, building passports being deployed includes data on building energy audits. Similar data can be measured and registered as part of the building permit process as well as the building maintenance process in the future.

c) Market mechanisms (e.g. green building certification)

To connect the regulatory framework and investments in green buildings, there are green building labelling and certification systems that encourages building owners and developers in the private sector to adapt green building practices. In some countries, these green building certification systems are part of a regulatory system that the government manages; in other countries, it is a voluntary program that the private sector leads that provides third-party verification of sustainability features. Green building certification programs such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Methodology (BREEAM) and Excellence in Design for Greater Efficiencies (EDGE) among others, provide rating systems that assess a building's performance in areas such as energy efficiency, water conservation, and indoor air quality. These certification systems are often aimed at the upper end of the market and incorporate innovative practices to demonstrate exemplary cases for the wider market. Green building certification is usually voluntary and provides additional recognition for buildings that exceed minimum local standards. Despite being voluntary, green building certification can encourage a green built environment by stimulating the market to promote green buildings and demonstrate best practices. In Armenia, there are only few buildings certified through these mechanisms at the timing of this guidebook's development. For easy use, the International Finance Corporation's EDGE is an affordable certification system, which hosts climate data for 11 major cities in Armenia, namely, Yerevan Zvartnoc, Yerevan Arabkir, Gyumri, Vnadzor, Kapan, Goris, Jermuk, Hrazdan, Artashat, Ijevan, and Dilijan.

Green building codes and green building labelling / certification mechanisms work in tandem. Although codes and regulations set minimum standards and have a greater influence on emissions reductions for the overall built environment as a bottom-up approach, green building labelling and certifications stimulate top-tier investors and building owners in investing more in green buildings.

d) Knowledge dissemination and capacity building

Capacity building is critical in transforming the market by disseminating knowledge and foster capacity to design and construct buildings with green building solutions. Training programs must be provided for professionals involved in the building industry (e.g., architects, engineers, energy auditors, developers) to keep them up to date on global best practices and trends as well as locally appropriate green measures in changing climate.

Section B – Climate and Buildings' Energy Use in Armenia

Buildings in Armenia account for around 40% of electricity demands and 25% of natural gas demands[3]. Armenia ratified the Paris Climate Agreement treaty in February 2017[4]. Towards achieving the Paris Agreement, the Armenian government also approved an updated NDC for 2021-2030 where it sets a country-wide target of reducing GHG emissions by 40% (compared with the baseline year 1990) by 2030.

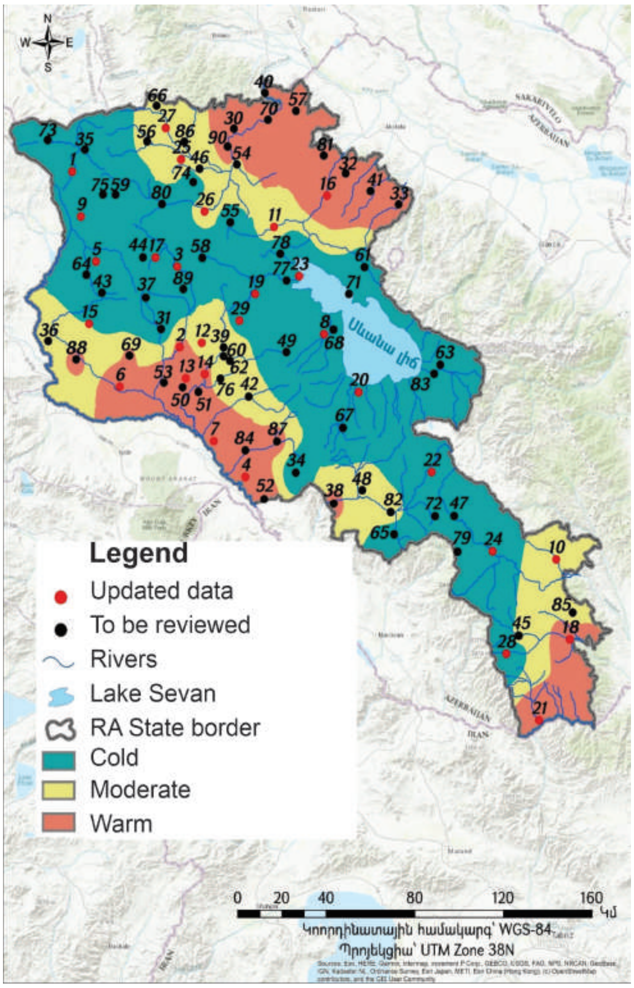
Armenia has a relatively long winter period which results in a high heating demand. It's critical to equip building professionals with appropriate knowledge on effective energy efficiency strategies for the built environment to expedite the transition to more energy efficient heating systems, resulting in lower demands for electricity and gas, which create positive environmental impacts as well as cost saving for the community. Other aspects like water efficiency, embodied carbon footprints of building materials, solid waste management, and indoor environmental quality have not received adequate attention yet, and require focused actions.

Climate and Natural Resources

Climate:

The climate in Armenia is sharply continental with very hot summers and extremely cold winters (see figure 2). The average temperature and the duration of winter period vary significantly for different regions. The average air temperature is low (e.g. 4.6°C in Amasia), and the duration of the heating season is long in northern highlands, while the temperature is higher (e.g. 14.5°C in Meghri), and the heating season is shorter in southern valleys. The outside air design mean temperature varies between -8°C to -25°C through the country. Therefore, extensive space heating is required for the entire territory. Considering the duration of the heating season and the outside average air temperature, the territory of the Republic of Armenia can be divided into three climatic zones: cold, moderate, and warm.

Figure 2. Climate map for Armenia.



Source: RACN 22-01-2024 Construction Climatology

Energy

Armenia imports all its fossil fuels from Russia via Georgia, and from Iran. About 80% of its fuel import consists of natural gas and the rest are oil products[5].

Armenia's electricity is produced from three sources; nuclear, hydro, and thermal. While nuclear fuel and hydroelectricity is sourced locally, the predominant amount of electricity is from thermal power plants powered by natural gas. Russia is the main supplier of natural gas (87%) with the rest coming from Iran[6].

According to the data of Armenia's Statistical Committee (SC), a total of 8.9 billion kWh (billion kilowatt hours) of electricity was produced in Armenia in 2022[7]. The largest part of it was provided by thermal power plants (TPP) - 43.5%. Armenian nuclear power plant (ANPP) produced 32%, hydroelectric power plants (HPP) - 21.8%. The government is trying to develop the solar energy market. However, solar plants still only have a small impact, only 2.7%. Wind farms have zero impact[8].

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[3] Armenia 2022 Energy Policy Review, International Energy Agency (iea.org/reports/armenia-2022)
[4] DECISION OF THE GOVERNMENT OF THE REPUBLIC OF ARMENIA «22» April 2021 N 610 - L
[5] Armenia Energy Profile, International Energy Agency (https://www.iea.org/reports/armenia-energy-profile/overview)
[6] Ilbid
[7] Armenia Energy Factsheet 2022, World Bank (https://armstat.am/file/doc/99544448.pdf)
[8] Ilbid

Heading

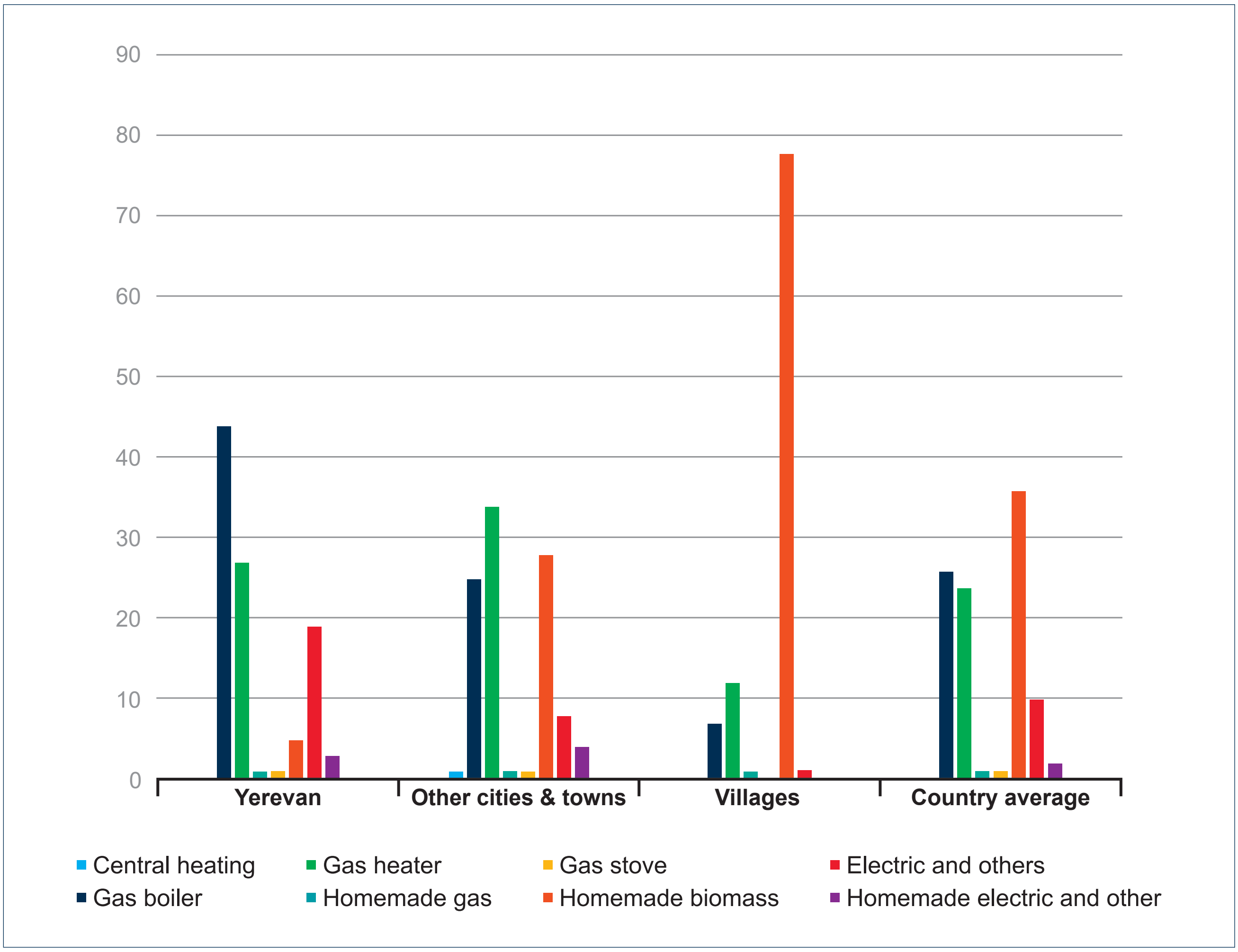
Heating

The first central heating system in Armenia goes back to early 1930s'. It utilized coal-fired boilers supplying hot water to building-level heating systems. Each building had its own boiler house located in the basement and was connected to the building's internal heating system. The boiler houses were equipped with low efficiency boilers working at 70-75% of their capacity[9]. The main fuel, used in the boilers was coal imported from Russia and other Newly Independent States (NIS) countries. After 1960, when the first natural gas supply pipeline was completed, the boilers were converted to use natural gas as the fuel. In 1963-1966 the cogeneration Thermal Power Plants (TPPs) in Yerevan, Vanadzor and Hrazdan were put into operation. The households not connected to these heat supply systems were supplied with heat from low-capacity boiler houses.

Hot water supply to buildings was realized individually through gas water heaters in each apartment. Due to low energy and economic efficiency, as well as for the purposes of environmental protection, replacement of individual boilers with district heating and centralized boiler heat supply systems was introduced in the early 1970s. In 1972-1986, the new district heating systems were built in various parts of Yerevan and other towns in Armenia. After Armenia became an independent country in 1991, majority of district, central and individual heat supply systems in the country were shut down due to lack of natural gas. Due to financial and technical issues during the transition period, heat generation by district heating systems in 2005 fell to about 2.5% of that in 1990[10]. Along with installations of individual boilers starting from 2000s, some developers started to introduce centralised boilers located in newly constructed apartment buildings.

Figure 3 shows a comparation between the energy consumption of different heating systems across the country.

Figure 3. Diagram of energy consumption for heating technologies used in Armenian households.



Source: International Energy Agency

[9]Heat Supply Option for Armenia, Advanced Engineering Associates International - Armenia (https://pdf.usaid.gov/pdf_docs/Pnacx795.pdf)
[10]Heat Supply Option for Armenia (https://pdf.usaid.gov/pdf_docs/Pnacx795.pdf)

Water

There are 14 large river basins within Armenia, with 400 rivers with a total length of over 10 km. They are mostly small, quick mountainous rivers. Average annual total river runoff is 6.250million m^3, from which 3.029million m^3 is formed from springs and ground waters[11]. About 940million m^3 is formed from frontier rivers Araks and Akhuryan[12]. Lakes in Armenia are mostly mountainous and small except Sevan Lake. There are more than 80 water reservoirs built in different times with useful capacity 988million m^3.[13] Natural water resources amount for 4.017million m^3/year from which 1.595million m^3 comes from springs, 1.434million m^3 from drainage outflow and 0.988million m^3 from ground water[14]. There are more than 700 natural and artificial sources of mineral water[15].

Building Typologies – A Historical Review

19th Century to 1920: Stone Masonry Buildings

Constructed throughout the mid-19th century and up to 1920s, these buildings are mainly preserved in Gyumri, Goris, central part of Yerevan and some other cities. These buildings are built with local stone masonry like tufa and basalt. The standard thickness of the external walls

Figure 4. Examples of buildings from mid-19th/early-20th centuries.
From left to right: 1) Aram Street, 3; 2) Aboyyan Street, 8; 3) Coal Furnace.

Source: Vazgen Sedrakyan

[11]GOVERNMENT OF THE REPUBLIC OF ARMENIA Decision No. 549 dated May 29, 2008 Appendixes 1 to 34 (https://www.arlis.am/DocumentView.aspx?DocID=44390); and Water Resources Management in Armenia National Report, Global Water Partnership (https://www.gwp.org/globalassets/global/gwp-cacena_files/en/pdf/armenia.pdf)
[12]Ibid
[13]Ibid
[14]Ibid
[15]Institute of Geological Sciences, National Academy of Science of Republic of Armenia (https://geology.am/en/museum-mineral-water/)

ranges between 40 and 80 cm, depending on the level of the floor. The walls have exterior lime-cement render with paint finish or exposed masonry. They typically feature hip/gable roofs made from metal sheeting. These buildings are typically 1 to 2 storeys in height, and in some cases an additional floor has been added later at the rooftop. See figure 4 for some examples.

Heating: Usually, buildings were heated by coal furnaces built in the wall mass.

Ventilation: The fresh air supply was provided by air infiltration through gaps in double layer split wooden frame windows and the extract air through oven chutes, exhaust ventilation shafts and toilet air exhausts.

1921-1955 and 1956-1970: Stone Masonry Buildings

Constructed between 1940s and 1970s, these buildings form the urban fabric of Armenian towns. These structures comprise around 70% of multiapartment residential buildings in Armenia[16]. The walls are built

Figure 5. Examples of buildings from mid-20th century.
From top to down and left to right: 1) Khorenatsi Street, 14; 2) Teryan Street, 62; 3) Hanrapetutyan Street, 76; 4) Nalbandyan street, 25; 5) Coal furnace converted into gas.

Source: Vazgen Sedrakyan

[16]The Socio-Economic Situation of the Republic of Armenia in 2022. JANUARY-JUNE. 5.16. Housing stock in 2021 (https://armstat.am/file/article/sv_06_22a_5160.pdf)

of the local tufa stone with thickness ranging from 60 to 100cm. The sloped roofs are also constructed from metal sheeting with attics that have an insulating layer of volcanic slag. The buildings typically have 4 to 5 storeys, averaging floor heights of 3.5 to 5.5 meters in the ground floors and 3 to 4 metres in the upper floors. Since 1955, industrialization of the construction began in Armenia to achieve efficiency of construction works (e.g. use of prefabricated structural members). See figure 5 for some examples.

Heating. In the initial part of the Soviet era, buildings were heated by coal furnaces built into the walls. However, from the mid-30s, central hot water heating was introduced to major Armenian towns supplied from centralized boilers using charcoal and then oil fuel or natural gas as the fuel. Nowadays individual apartment level heating is supplied with circuit combi gas boilers or gas ovens.

Ventilation. The fresh air supply was provided by air infiltration through gaps in double layer split wooden frame windows and the extract air through oven chutes, exhaust ventilation shafts and toilet air exhausts.

1971-1990: Prefabricated Reinforced Cement Concrete Buildings

Constructed between 1971 and 1991, these buildings are found throughout Yerevan and other towns. They comprise about 23% of the multiapartment residential buildings in Armenia[17]. The walls are built of Reinforced Concrete (RC) Panel Walls with typical thickness 20 to 32 cm. They are often built using standardised plans either as 9, 14 or 16-storey single-entrance buildings. They usually have 18 x 18 metre footprints or rectangular 9/10-story multi-entrance high-rises measuring 14 meters in width. The floor-to-floor height of all intermediate floors is typically 3 meters. The roofs are made of RC slabs with insulated with layer of volcanic slag, and some buildings have attics or technical floors at the roof level. See figure 6 for some examples.

Figure 6. Examples of building from 1971-1990. From left to right: 1) Aghayan Street, 7; 2) Aghayan Street, 9.

Source: Vazgen Sedrakyan

[17]Ilbid

Heating: Since the second half of 1950s', district heating was supplied from centralized boilers using oil fuel or natural gas[18]. Nowadays individual (apartment level) heating is supplied with a combination of gas boilers or gas heaters.

Ventilation: The fresh air supply was provided by air infiltration through gaps in double layer split wooden frame windows and the extract air through oven chutes, exhaust ventilation shafts and toilet air exhausts.

1991 TO PRESENT: Cast in-situ RC Structures

Modern construction projects, adhering to the building codes after 1991, have been erected in various parts of Yerevan and account for about 7% of multiapartment residential buildings in Armenia[19]. These buildings are characterized by diverse shapes and varying heights, ranging from 7 to 22 storeys. The gross height of the ground floor (in some buildings also second and third floors) usually varies from 3.6 to 5 meters and upper floors measure about 3.3 meters. The structure is usually made of RC Frames (columns, slabs and beams) with infill concrete masonry units (CMUs) for walls. Usually, the walls are insulated with 5 to 10 cm thick expanded polystyrene insulation (EPS)/extruded polystyrene insulation (XPS) or Mineral Wool/Rockwool insulation and then finished on the exterior with dry clad natural stone or fibre cement or ceramic tiles (ventilated facades). Roofs are made of RCC and then insulated with volcanic slag/EPS/XPS. See figure 7 for some examples.

Heating. Individual apartment-level heating system with a combination of gas boilers is used in most buildings. Some buildings have heating supplied from centralized natural gas-fired boilers located either on the rooftop or on the building site.

Figure 7. Examples of buildings from late-20th to 21st centuries. From left to right: 1) Sayat-Nova Avenue, 19/1; 2) Teryan Street, 77.

Source: Vazgen Sedrakyan

[18] Interview article with CoUD (https://www.1lurer.am/hy/2023/02/12/4-%D6%80%D5%A4-%D5%AF%D5%A1%D6%80%D5%A3%D5%AB-%D5%BE%D5%A9%D5%A1%D6%80%D5%A1%D5%B5%D5%AB%D5%B6-%D5%B7%D5%A5%D5%B6%D6%84%D5%A5%D6%80%D5%AB%D6%81-%D5%A1%D5%A6%D5%A1%D5%BF%D5%BE%D5%A5%D5%AC%D5%B8%D6%82-%D5%B0%D5%A1%D5%B4%D5%A1%D6%80-%D5%80%D5%80-%D5%BF%D5%A1%D6%80%D5%A2%D5%A5%D6%80-%D6%84%D5%A1%D5%B2%D5%A1%D6%84%D5%B6%D5%A5%D6%80%D5%B8%D6%82%D5%B4-%D5%B6%D5%B8%D6%80-%D5%A9%D5%A1%D5%B2%D5%A1%D5%B4%D5%A1%D5%BD%D5%A5%D6%80-%D5%A5%D5%B6-%D5%AF%D5%A1%D5%BC%D5%B8%D6%82%D6%81%D5%BE%D5%B8%D6%82%D5%B4/879898)

[19] The Socio-Economic Situation of the Republic of Armenia in 2022. JANUARY-JUNE. 5.16. Housing stock in 2021 (https://armstat.am/file/article/sv_06_22a_5160.pdf)

Current Normative

The first normative related to energy efficiency for the built environment in Armenia was *RACN II-7.01-95 "Construction Physics of Building Envelope" published in 1995,* which describes calculation methodologies and design guidance for thermal protection for building envelopes with consideration of different climatic conditions. This normative was updated in 2016 as *RACN-24-01-2016 "Thermal protection of buildings". Following this effort to improve thermal protection of buildings, a new normative RACN 24 02 2022 "Ensuring energy efficiency of buildings: Energy efficiency assessment indicators"* was adopted in 2022, introducing the calculation methodology for energy efficiency for buildings and labelling buildings with different energy efficiency levels. This methodology accounted to address various energy consumptions in a building, such as primary or final energy consumptions through heating, ventilation, air conditioning, hot water supply, lighting systems and so on. Besides these normative documents, the guidebooks *"Technical solutions for thermal insulation of enclosing the structures of the new residential, public and industrial buildings under construction and reconstruction in the Republic of Armenia"(UNDP, Yerevan 2013)* and *"Green Architecture"(UNDP—GEF, Yerevan 2015)* were adopted in Armenia. To further improve the energy efficiency of built environment and roll out green building practices on the ground, it requires design guidance of green buildings for building professionals to take up green building design practices and achieve different sustainability levels indicated in the normative adopted in 2022.

Table 1 presents a list of the normative documents and standards currently in force in Armenia, which contain certain clauses related to the discipline of Green Buildings.

Table 1. Summary of the normative and standards in Armenia related to green buildings.

Energy Efficiency Measures		
Normative number	**Normative title (English translation)**	**Descriptions**
RACN-24-01-2016	Thermal protection of buildings.	A regulation that guides the design of heat-retaining structures of building envelops. It addresses heating and ventilation aspects of building's energy saving issues by linking heat losses and building envelope components with established energy limits.
AST ISO 23045-2012	Building environment design. Guidelines for the assessment of energy efficiency of new buildings.	Guidelines for the assessment of energy efficiency of new buildings.
RACN 22-01-2024	Construction climatology.	A regulation that establishes climatic parameters that should be used in the design of buildings and structures, as well as in the planning and development of urban and rural settlements.
RACN II-7.01-95	Construction physics of building envelope constructions. Building Physics for Envelope Design. Design norms SHNDS II-7.102-98. (manual SHNDS II-7.01-95 building codes).	Updated by RACN-24-01-2016, but some manuals are still applicable.
AST 305-2008	General Specifications for Renewable energy. Solar energy. Solar collectors.	Renewable energy products and systems standards for domestic, industrial, agricultural, service, and other facilities.
AST 306-2008	Testing Methods for Renewable energy. Solar energy. Solar collectors.	
AST 307-2008	Types and Basic Parameters of Renewable energy. Solar energy. Solar photovoltaic modules.	
AST EN 12975-1-2019	General Requirements for Solar thermal systems and their components. Solar collectors. Part 1.	

AST EN 12977-1-2016	Solar thermal systems and their components. Custom-made systems. Part 1. General requirements for solar water heaters and combined systems.	
Water Efficiency Measures		
RACN 40-01.01-2014	Internal water supply and sewage of the buildings.	A regulation applicable to the design of constructed and reconstructed systems of internal cold and hot water supply, wastewater and rainwater disposal generated in buildings.
Materials		
06.11.2013 N343	Order of the Minister of Urban Development of the Republic of Armenia Technical solutions for thermal insulation of envelopes of residential, public and industrial buildings in construction and reconstruction in the RA.	
23.12.2013 N394	Order of the Minister of Urban Development of the Republic of Armenia Catalogue of Replicable Energy Efficient Individual Residential Houses in Communities of the Republic of Armenia.	
Construction Process Measures		
RACN I-3.01.01-2008	Execution of works on the organization of construction production. Order of construction production organization works.	A regulation that establishes general requirements for organizational works during new construction, major repairs (reconstruction, restoration, reinforcement), expansion, modernization (hereinafter referred to as construction) of existing buildings and structures.
Indoor Environmental Quality Measures		
RACN IV-12.02.01-04	Heating, Ventilation and Air Conditioning.	A regulation that is applicable to the design and construction of heating, ventilation and air conditioning systems in the premises of newly constructed and reconstructed buildings and structures.
GOST 30494-2011	Indoor microclimate parameters of Residential and Public Buildings.	A standard establishes parameters of the microclimate of residential, preschool, public, administrative buildings premises.
RACN 22-03-2017	Artificial and Natural Lighting.	A regulation that establishes standards of average illumination indoor and outdoor areas.
RACN 22-04-2014	Protection from Noise.	A regulation that establishes mandatory requirements of the sound (acoustic) environment for the design, construction and operation of buildings and structures for various purposes.
Solid Waste Management Measures		
-	There are general laws on solid waste management including: “Law on waste” adopted in 2004 and law “About Garbage and Sanitation” adopted in 2011 regarding waste management.	

Section C – Green Building Measures

The definition of green buildings can vary, but the World Green Building Council[20] defines them as *buildings that reduce or eliminate negative impacts on the climate and natural environment during their design, construction, and operation while also creating positive impacts and that help preserve natural resources and improve quality of life*. The council identifies several features that can make a building green, including efficient use of energy, water, and other resources; use of renewable energy sources such as solar; use of measures to reduce pollution and waste and enable re-use and recycling; good indoor air quality; consideration of occupants' quality of life during design, construction, and operation; use of nontoxic, ethical, sustainable materials; consideration of the environment during design, construction, and operation; and a design that enables adaptation to a changing environment. Residential, office, educational, health care, institutional, or any other type of structure can be a green building, provided it includes these features.

Based on the international good practices regarding green building codes and the various green building certification systems, the proposed Green Building Measures for Armenia in this document are divided into the following seven segments:

1. **Site and Context:** Buildings are integral to the site on which they are built. A building affects its surroundings, such as the flora and fauna, the way rainwater is absorbed into the ground, and the microclimate around it. Factors such as public transport connectivity will also affect the carbon footprint of its occupants.
2. **Energy Efficiency Measures:** Energy efficiency is a key aspect of green buildings. Because climate varies from one region to another, buildings must be built for local climatic conditions. By understanding the local building stock, architects and designers can analyse the performance of existing buildings in terms of energy consumption, thermal comfort, and natural ventilation. This knowledge can inform the design of new green buildings, incorporating passive design strategies that leverage local climate conditions such as solar orientation, shading, natural ventilation, and insulation.
3. **Water Efficiency Measures:** Water efficiency affects the finite water resources of a region and the energy efficiency of the building. With shifting climate patterns, access to water is becoming difficult in many regions around the world, so water efficiency is critical.
4. **Green Building Materials:** Incorporating green building measures involves using sustainable materials with low embodied energy, along with sustainable construction practices. Understanding the local building stock helps identify materials that can be locally sourced and that are environmentally friendly and optimal for the local context, which reduces the carbon footprint associated with transportation and supports the local economy.
5. **Construction Site Measures:** The construction process creates local pollution and generates significant waste, including debris, packaging, and unused materials. Implementing construction processes that control pollution and prioritize waste management strategies such as sorting, recycling, and responsible disposal reduces waste.
6. **Indoor Environmental Quality Measures:** Refers to the occupant health, safety, and comfort (OHSC), which do not directly affect GHG emissions, but there are codes mandating some of these measures.
7. **Solid Waste Management Measures:** Solid waste management is becoming critical in most cities globally. A building that provides for segregation of solid waste will enable its occupants to manage waste proactively and responsibly.

The following sub-sections provide explanations of the various measures supported by illustrations and photographs. Each measure is presented including the following points:

- **Design Approach/Methodology:** This will provide a step-by-step understanding of how the measure needs to be designed into the building. Where necessary information like tabular columns, diagrams, etc. will be incorporated.
- **Potential Technologies:** This will share a listing of technologies already available in the country and in the larger Central Asia/Europe region.

[20] https://worldgbc.org/

1. Site and Context

The approach to new green buildings begins with the selection of the site and the context where it is situated in. As a design professional, one can sometimes participate and influence decision making process during the selection of a site for purchase. In such an event, it is important to keep a few important aspects in mind.

The site of a building needs to be examined through two distinct prisms.

- **Ecology and Environment**
  Buildings are an integral part of the ecosystem and the environment. Care must be taken to ensure that adverse effects of the buildings are minimized.
- **Building and Transport**
  Location of buildings in the larger surroundings of urban areas plays an important role in determining the carbon footprint of its users.

1.1. Ecology and Environment

Buildings are an integral part of the ecosystem and the environment (see figure 8). Care must be taken to ensure that adverse effects of the buildings are minimized. The existing ecosystem can be analysed in terms of many sub-systems – flora which encompasses the plants and trees, fauna that includes animals of all species, the geology of the region comprising of the soil characteristics, the water ecosystem that comprises the drainage and collection of water in the immediate vicinity, the land-use in the region, among others. It is critical to understand the adverse or beneficial impact that the project we are constructing will have on the immediate ecosystem. This could be in terms of effluent treatment, the need to cut down trees, the need to change the soil profile, the impact of the building on the people that live/work in the locality, etc.

If the proposed project site is in an ecologically fragile region, then care must be taken to mitigate any adverse effects that the building may have on the environment.

Figure 8. Mount Ararat and the Yerevan skyline.

Source: Creative Commons License.
Photo credit: Serouj Ourishian.

The following measures may help to achieve this:

1.1.1 Integration of project with local ecosystem

1.1.2 Exterior Light Pollution and Controls

1.1.3 Storm water attenuation

1.1.1 Integration of project with local ecosystem

This measure is one of the first aspects that needs to be assessed before starting the design process. It is critical to ensure that the design of the building or property responds appropriately to ecological factors such as flora, fauna, presence of water bodes (lakes, rivers, sea). Figure 9 shows an example from South Africa.

Design Approach/Methodology

Knowledge of the current ecology of the land and its surrounding is paramount. This will include understanding of how water flows on the site, the nature of soil – whether it is strong enough for the construction planned on site, the type of vegetation and the impact of the building(s) on the same, etc. It is essential to understand the negative effects the planned building(s) will have on the various aspects of the site.

Ideally the design must create least harm to the ecology of the land and its surroundings.

Some examples of this integration may be as follows:

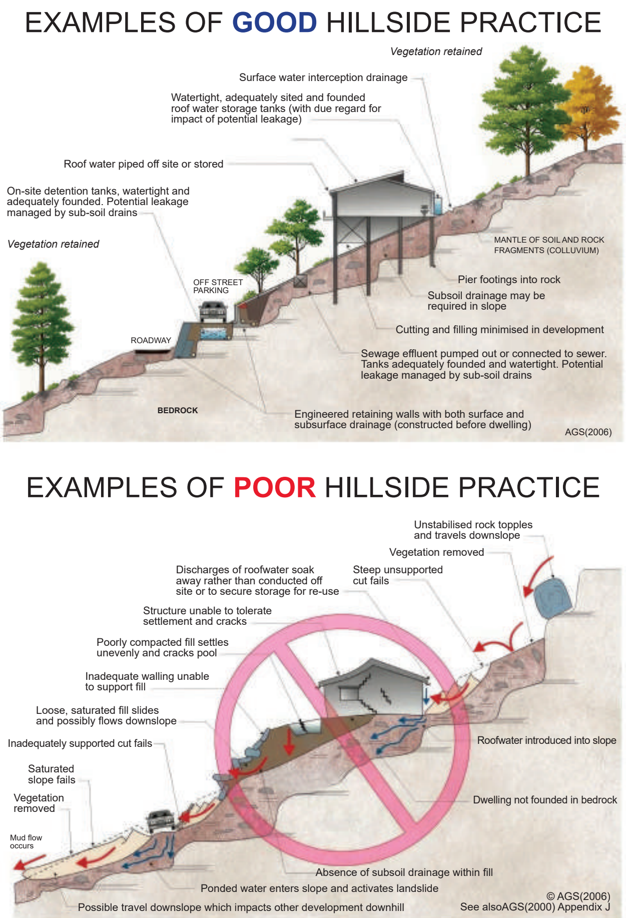
- To provide adequate buffer zones near water bodies (lakes/ponds/rivers/streams/sea, etc.) to ensure that the water bodies' catch basins are not negatively impacted by the building construction. Elements like heavy impermeable paving, untreated effluents, etc., will degrade and pollute the basin which will then pollute the water body. This will have downstream effects on other areas in the region.

Figure 9. A view of the Biodiversity Showcase Garden, Cape Town, South Africa.

Source: Creative Commons License.
Photo credit: Abu Shawka.

- To ensure that only native tree and shrub species are grown so that local fauna habitats are not affected. This will ensure that the native flora and fauna are conserved while also being resilient to the natural variations in climate and other aspects of the region.
- In a sloping site, to ensure that the design of the building is done in consonance with the slope in such a manner that it does not destabilise the soil in the surroundings. In such cases, adequate space needs to be provided for stable flow of water that will not result in soil erosion (see figure 10).

Figure 10. Schematic examples of good and poor practices of building on sloped terrace.



Source: Albedo Graphics.

Potential Technologies

- This is a design approach and may require a combination of different solutions.

1.1.2 Exterior Light Pollution and Controls

Nighttime light pollution from excessive lighting (especially in urban areas) affects the biological and circadian rhythms of birds, animals, and plants. This can be mitigated by ensuring that all exterior light fittings around and on buildings have shades on top so that light is directed down to the pathways as required for way finding.

Design Approach/Methodology

Embark on the exterior lighting design exercise. Exterior lighting will have two major components:

- **Exterior facade lighting:** Facade lighting is a way to beautify the building during the night. It is critical that this light does not face upwards into the sky. The lights must be focussed on the walls and downwards. If there are trees near the building, it would be ideal that the light does not fall on the trees – this will avoid disturbing birds and other animals who shelter in the tree.
- **Exterior pathway and landscape lighting:** Exterior pathway lighting is a safety and security requirement for people who use the outdoor spaces around the building. It is important that the top of the light fittings is covered thereby only spreading light on the ground. As for landscape lighting, it is best to avoid lighting up the trees as is sometimes the practice. A tree can be subtly highlighted by providing some down lighting at the base. It is important that the lumen output of the lamp is not excessive.

Potential Technologies

- Bollards with top cover
- Concealed and indirect lighting

1.1.3 Storm water attenuation

Storm water must be attenuated so that as much rainwater as possible is retained within the boundaries of the property. This has two effects. It primarily reduces chances of downstream flooding outside the property. It improves the level of water table of the property.

Design Approach/Methodology

It is important to understand the slope and topography of the land while carrying out the site planning. The best approach would be to minimise the amount of paved area to the necessary functional minimum. Conventional paving materials like reinforced cement concrete (RCC), asphalt and RCC pavers do not allow absorption of water into the soil. Instead, it increases the rate of water flow and potentially can create a flooding situation in another location in and around the site. The intent must be to keep as much of the land under *soft scaping* (with trees, plants, lawns) for the land to be able to absorb the rainwater into the ground. In addition, the drains can be detailed as swales (depressions with grass lining) rather than with concrete. This will further slowdown the run-off rate of water.

Potential Technologies

- **Perforated/Pervious pavers (grass pavers):** Perforated pavers can be an effective replacement for light traffic situations (cars and light commercial vehicles) where asphalt or conventional RCC pavers are used. These can be laid on a sand bed and then the gaps may be either planted with grass or filled with gravel or pebbles. (See figure 11)
- **Swales:** Swales are a replacement for concrete drains and usually natural or artificial depressions in the landform that transport run-off water. Concrete drains cannot absorb water. They just transfer it ahead. A swale also absorbs water as it is just soil with grass over it. (See figure 12, left image)
- **Soakaway crates:** A soakaway is a space created underground that is connected to the surface run-off water through a network of pipes. Crates made of high-grade durable plastic can be stacked in the required dimensions underground after lining the pit with gravel. This will help in the run-off water being collected within the crates during a heavy downpour of rain and then slowly let off into the surrounding soil. (See figure 12, right image)

Figure 11. Example of pervious paving.

Source: Creative Commons License.
Photo credit: Michael Trolove.

Figure 12. Examples of Water Sensitive Landscape practices.
Left: example of swales to drain water. Right: pervious paving with soakaway crates.

Source: Left photo - Creative Commons License. Photo credit: Didiunsw.
Right photo: Roads Application. Photo credit: Image courtesy of Hoensoey.

1.2. Building and Transport

Location of buildings in the larger surroundings of urban areas plays an important role in determining the carbon footprint of its users. If the building is in proximity of a mass transit station (bus, train, metro, ferry, etc.), then there is a greater chance of people using public transport over private transport thereby reducing the carbon footprint of the building's users (figure 13). Hence the siting of the building is extremely important.

The following measures may help to achieve this:

1.2.1 Proximity to public transportation

1.2.2 Preferential parking for electric vehicles

1.2.3 Bicycle storage and changing rooms

Figure 13. View of Kolkata Metro, India

Source: Creative Commons License.
Photo credit: Arnab Saha.

1.2.1 Proximity to public transportation

Public transport has lower per capita GHG emissions potential compared with private transport (cars/ motorcycles). Access to the property in terms of public transport connectivity is an important aspect of site selection. It will reduce the carbon footprint of those who use or visit the building. Ideally, public transport systems such as bus, metro, suburban and light rail will be within walking distance of the proposed development, which will reduce private vehicle use to access the building.

Design Approach/Methodology

Ideally, a property owner must endeavour to develop those properties that are in proximity (ideally within 10-15 minutes of walking distance) to a public transport stop. This will ensure that the building users will have the choice of using the public transport to travel to and from the building.

In many fast-growing cities new public transport networks and modes keep getting added or extended (see figure 14). It would be useful for potential site purchasers to understand plans of public transport expansion.

Figure 14. Example of Electric Bus Charging Station

Source: Creative Commons License.
Photo credit: MTA of State of New York.

Potential Technologies

There are no technologies needed at the building level. However, the building owner can consider establishment of a shuttle (preferably non-polluting electric or hybrid fuel vehicles) service to and from the building in case the distance to public transport stop is far to be covered on foot.

1.2.2 Preferential parking for electric vehicles

Electric vehicles reduce vehicular pollution. Preferential parking for electric vehicles makes it easier for drivers of electric vehicles to use the building. An example of a preferential provision may be that parking spots for electric vehicles are closest to the building entrance.

Design Approach/Methodology

While designing car parking, the designers can earmark the slots closest to the building entrance or lifts/staircase access core for electric vehicles. Alternatively, car charging points may be provided in slots across the parking areas building (figure 15).

Figure 15. Example of EV Car Charging Ports in Public Car Parks

Source: Creative Commons License.
Photo credit: Ivan Radic.

Potential Technologies

Fast charging points: The building could provide for fast charging points for electric vehicles. The building owner may prefer to have these points usable on a metered charge basis.

1.2.3 Bicycle storage and changing rooms

Encouraging building users to use bicycles instead of cars reduce vehicular congestion and pollution. Cyclists need changing rooms to change into and out of official workwear (in workplace situations) and secure storage facilities for their bicycles (see figure 16).

Design Approach/Methodology

Designers may incorporate bicycle racks in their parking design. Additionally, showers, changing rooms and lockers can be designed into the building, especially in workplaces. This will facilitate employees to ride to work in cycles and have the option of changing into official workwear.

Figure 16. **Examples of Bike Infrastructure in Buildings. Left: Bike Storage. Right: Lockers for Employees.**

Source: Creative Commons License. Photo credit: Snowmanradio (left) and Realpublicdomain2004 (right).

Potential Technologies

There are no special technologies needed for this measure.

2. Energy Efficiency Measures

Energy efficiency is a key aspect of green buildings. Because climate varies from one region to another, buildings must be built for local climatic conditions. By understanding the local building stock, architects and designers can analyse the performance of existing buildings in terms of energy consumption, lighting thermal comfort, and natural ventilation. This knowledge can inform the design of new green buildings, incorporating passive design strategies that leverage local climate conditions such as solar orientation, shading, natural ventilation, and insulation.

Energy efficiency measures can be divided into three broad areas. They are as follows:

- **Demand side measures:** Demand side accounts for energy that the building will need for optimal functioning. The aim of a design professional must be to reduce the energy demand of the building by first ensuring that the building is optimally designed for thermal performance. The next step is to ensure design and deployment of energy efficient equipment. This section therefore gets sub-divided into two portions:
  - **Passive Design:** This is typically achieved by a combination of designing the building envelope so that it may not gain heat (in summer conditions) and lose heat (in winter conditions).
  - **Energy Efficiency Equipment Design:** Broadly, this would mean energy efficient lighting, energy efficient HVAC systems and other energy efficient equipment like pumps, elevators, etc.
- **Supply side measures:** Supply side measures involve relying on renewable energy sources (RES) such as solar photovoltaic panels and wind turbines that enable building owners to generate their own energy, reducing reliance on fossil fuel–based energy sources.
- **Knowledge and behaviour management:** Knowledge of how energy is used is critical in managing behaviour regarding energy use. This will help in increasing awareness in the users as to how energy is consumed in the building which will in turn result in them taking steps towards conserving energy.

2.1. Demand Side Measures – Passive Design

Passive design includes features that are integral to the construction of the building, for example types of walls, windows, and roof. Energy demand is first reduced by ensuring that the building is designed to reduce the need for occupants to rely on artificial means of achieving human comfort (e.g., air conditioning, ceiling fans).

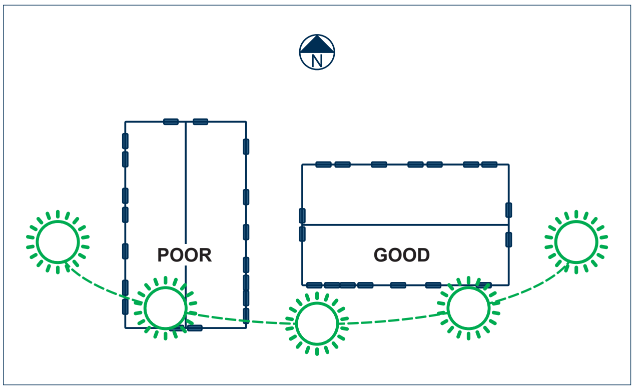
The following measures may help to achieve this:

2.1.1. Building orientation
2.1.2. Window-to-Wall Ratio (WWR)
2.1.3. Shading
2.1.4. Glazing Properties
2.1.5. Air infiltration
2.1.6. Thermal Breaks
2.1.7. Thermal transmittance of Building Envelope
2.1.8. (U-value)
2.1.9 Wall and Roof reflectivity
2.1.10. Green roofs
2.1.11. Daylighting
2.1.12. Natural ventilation

2.1.1 Building orientation

Building orientation affects building heating and cooling loads. Orienting a building optimally considering geographic location and local climate can reduce cooling load in warm climates and heating load in cold climates, as shown in figure 17. For example, in cold climates in northern hemisphere, it is desirable for the long facades of a building to face south, to maximize incident solar irradiation and solar gains. This is a difficult provision to make compulsory, but guidance can be provided on orientation.

Figure 17. Diagram showing good and poor building orientation.



Source: Albedo Graphics.

Design Approach/Methodology

In larger plots, understand the orientation of the sun path. Armenia requires heating for eight months or more annually. Hence, it would be advisable to orient the longer face north and south. By placing large windows on the south facade, the building would be able to absorb solar radiation during the day in winter. However, it is advisable to design horizontal shading devices on the southern facade to block the summer sun. It would also be advisable to plant deciduous trees on the southern side of the building, that will shade the building from the summer sun while the shedding of leaves during winter will let in the much-needed winter light.

Potential Technologies

This is a design intervention and hence does not need specific technologies.

2.1.2 Window-to-Wall Ratio (WWR)

Windows and structural glazing provide light and ventilation, but in warm climates, they also bring in unwanted heat, increasing the load on air conditioning systems and thus increasing energy use. In cold climates, it is important that the glazing and windows are sized to optimise heat gain into the climate. Having the optimum window-to-wall ratio (WWR) helps balance the two opposing requirements (see figure 18).

Design Approach/Methodology

Window to Wall Ratio (WWR) is the ratio of the total area of the window or glazing (inclusive of window frames, mullions, etc.) area divided by the total gross external wall area.

The equation is as follows[21]:

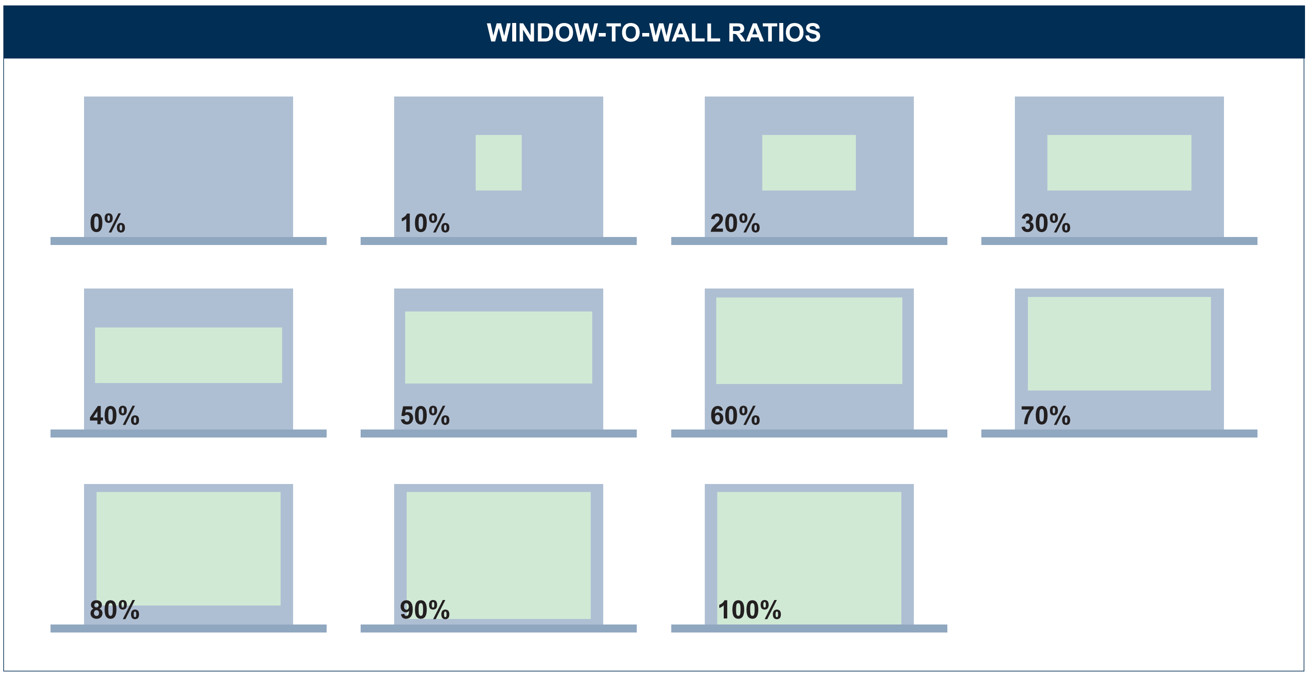
$$\text{WWR (\%)} = \frac{\text{Total Glazing Area (SqM)}}{\text{Gross Exterior Wall Area (SqM)}}$$

It is best to separate out the WWR for each orientation of the building. This is because different orientations will have different amounts of solar exposure. Windows and walls facing internal courtyards or gaps between buildings (any space that is open to outside air) must be included in the WWR calculations.

In Armenia, following recommendations can be considered:

- WWR in northern facade can be low as direct incident sunlight is less. However, care must be taken to use a high-performance glass (low U-value)[22] to prevent ambient heat gain during summers.
- WWR in southern facade can be high provided horizontal shading is used to block the summer sun and high-performance glass (low U-value and higher solar heat gain factor (g-value)) to prevent ambient heat gain during summers.
- WWR on eastern and western facades glazing must be low to prevent radiant and ambient heat gain during summers, where vertical shading elements are to be incorporated for reducing the heat gains in summer.

Figure 18. Visual representation of facades with different WWR.



Source: Albedo Graphics.

[21]EDGE User Guide Version 3.0a

[22]For explanation about U-value, please refer to the points: 2.1.4 Glazing Properties, and 2.1.7 Thermal transmittance of Building Envelope (U-value).

Potential Technologies

This must be read along with the glazing in upcoming pages. It is prudent to use high-performance glazing that is characterised by a low U-value and low solar heat gain coefficient (SHGC) for summer climate and low U-value and higher SHGC for winter climate. Additional information will be provided in the measures under glass.

2.1.3 Shading

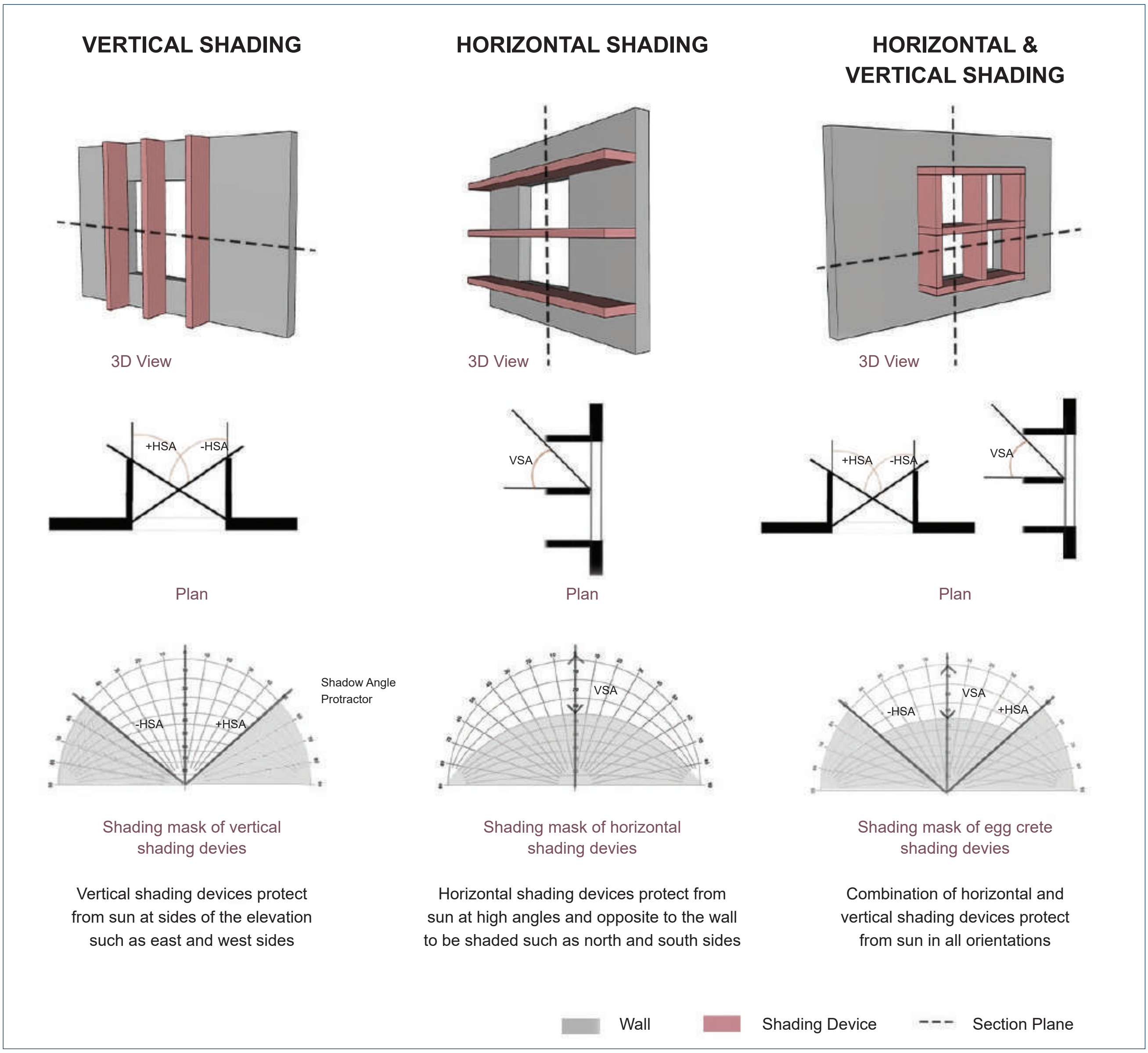
Horizontal shading reduces solar radiation on windows and glazing when the sun is high in the sky. Vertical shading reduces solar radiation on windows and glazing when the sun is low in the sky. A combination of vertical and horizontal shading is usually recommended to reduce solar radiation from various sun angles. Shading also allows for controlled natural light and results in better and pleasant quality of indoor light.

Design Approach/Methodology

Shading helps in reducing the solar heat gain into the building.

Horizontal Shading: This is the shading along the facade the of the building, perpendicular to the wall in the horizontal plane. Horizontal shading is used when the sky is high up in the sky and its size is measured by a parameter called “Vertical Shading Angle” (VSA). The VSA is the angle that is derived between the horizontal line drawn outwards from the sill of an opening (door or window) and the line drawn from the windowsill to the outer edge of the shading device (see figure 19). No shading would mean a VSA of 90 degrees.

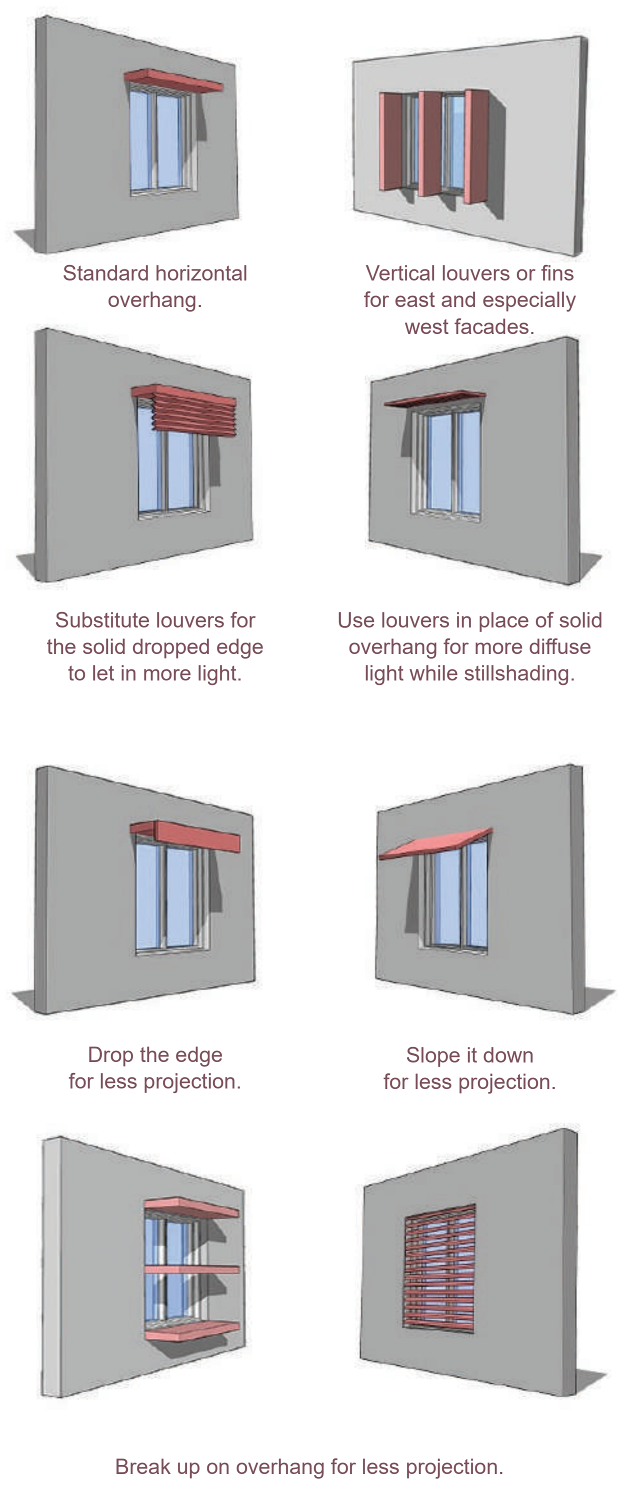
Figure 19. Representation of different types of shading.



Source: Adapted from the Net Zero Energy Buildings (NZEB) Knowledge Portal.

Horizontal shading is used usually on the northern or southern sides of a building. For buildings in the northern hemisphere, it is important to shade the southern walls while for those in the southern hemisphere, it is important to shade the northern walls.

Figure 20. A few ideas of types of shading that could be used.



Source: Adapted from Autodesk.com

Vertical Shading: This is the shading along the facade the of the building, perpendicular to the wall in the vertical plane. Vertical shading is used when the sky is low in the sky and its size is measured by a parameter called "Horizontal Shading Angle" (HSA). The HSA is the angle that is derived between the horizontal line drawn outwards from the opposite edge of an opening (door or window) and the line drawn from the wall to the outer edge of the shading device. (Refer image). No shading would mean an HSA of 0 degrees.

Vertical shading is usually used on walls that receive sun from a low angle (see figure 20). This usually occurs on the eastern (during early to mid-morning) and western (during mid to late afternoon) walls. As the angle of the sunrise and sunset shift every day with respect to the eastern and western walls, it is expected that a well-designed vertical shading device will keep the openings shaded.

Approach in Armenia: The core intent must be to shade the windows in such a way that limits the exposure to direct sunlight during summers and to maximise it during winter.

New emerging technologies like automated solar shading devices may also be used on the façade. These shades can open up during the winters letting in the much-needed heat and can protect openings from sun's heat during the summers.

Potential Technologies

The most common type of shading is done with civil construction components like RCC and masonry blocks. However, various types of metal assemblies (aluminium, steel, etc.) and composite materials are also being used.

2.1.4 Glazing Properties

This sub-section includes Thermal transmittance of glass (U-value), Glass Solar Heat Gain Coefficient (SHGC), and Visible Transmission (VT).

Thermal transmittance (known also as U-value) is the amount of heat that a material transfers by conduction from outdoors to indoors to raise the temperature by 1°Kelvin. This is called U-value. The lower the U-value, the greater the insulating properties of the material (figure 21). The SI Unit of U-value is Watts per Square meter Kelvin (W/m^2K). The inverse of U-value is R-value, which is the measure of how well an insulation resists the flow of heat.

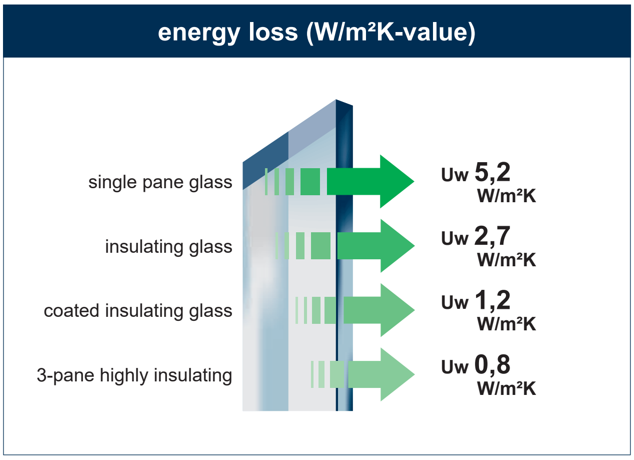
Solar Heat Gain Coefficient (SHGC) is the amount of heat that glass admits from direct solar radiation incident on the surface of the glass. It is expressed as a fraction or a percentage (e.g., 0.1=10%, 0.65=65%). Shading the window reduces the SHGC, as does tinting the glass.

Design Approach/Methodology

Thermal Transmittance of single glazing (approx. 5 W/m²K) is twice as much compared to a 200mm thick wall of solid dense concrete block used for masonry (approx. 2.5 W/m²K). This would mean that for summer climates, it is advisable to reduce the WWR to reduce the heat gain thereby reducing the need for energy intensive cooling systems. Conversely, in a predominantly winter climate it would be advisable to increase the WWR to increase the solar heat gain thereby reducing the need for energy intensive heating systems.

The alternative would be to use thermally efficient glazing like double glazing (approx. 2.5 W/m²K) or triple glazing (approx. 1.3 W/m²K). Many of the double and triple glazing assemblies have a noble gas like argon, krypton or xenon. Noble gases are heavier and denser than air and therefore slows down the transfer of heat.

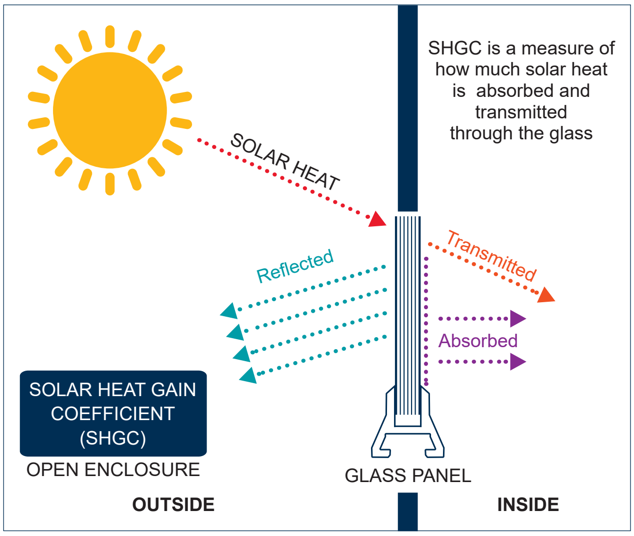
Figure 21. U-values of various types of glazing assemblies.



Source: Albedo Graphics.

Solar Heat Gain Coefficient (SHGC) is the next important parameter to consider while selecting glass (see figure 22). Irrespective of the external air temperature, glass transfers heat through direct radiation. The radiant transfer of heat is measured as a comparison of heat incident on the outer surface of the glass and that which is transferred inside and is measured as fraction of 1 or a percentage. So SHGC of 1 would mean 100% of radiant heat being transferred while SHGC of 0.1 would mean only 10% of radiant heat being transferred. The SHGC property is controlled by tinting the glass.

Figure 22. Heat transfer pattern on glass.



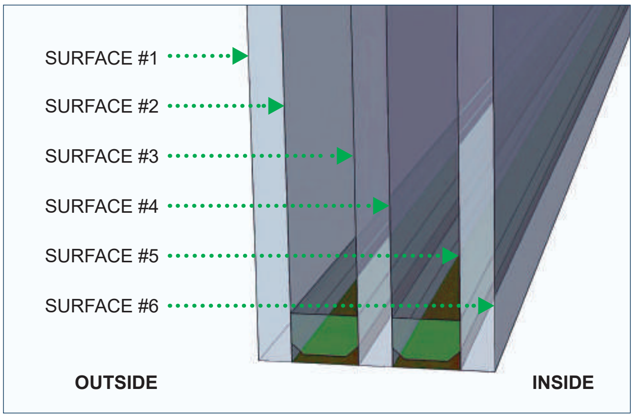
Source: Albedo Graphics.

Visible Light Transmission (VLT) or **Visible Transmission (VT)** is the amount of daylight admitted by the glass to the internal space. The tinting that reduces the SHGC also reduces the visible transmitted light. Hence, it is important to balance the Visible Transmission (VT) with SHGC to ensure a balance between heat protection and adequate daylight.

Glass surfaces numbering is as follows (see figure 23):

- In single glazing, the outer surface of the glass is 1 and the inner surface is 2.
- In double glazing, the numbering of the outer glass remains the same as single glazing. The outer surface of the inner glass is 3 and the inner surface is 4.
- In triple glazing, the numbering of the outer 2 glasses is the same as double glazing. The outer surface of the innermost glass is 5 and the inner surface is 6.

Figure 23. Surface nomenclature.



Source: Albedo Graphics.

Low-e coatings

Low emissivity coating is a microscopically thin coating applied on glass and it enhanced the ability of the glass to reflect the heat carrying infrared and ultraviolet spectra of the light wavelengths that cause heating. Usually, the darker surfaces have a higher emissivity and lighter and more reflective surfaces have a lower emissivity. Lower the emissivity value, higher the ability of the glass to block out heat. Hence Low-e coatings on glass is useful for both summer and winter climates. For a largely summer climate, it is best to have the low-e coating on the surface 2 of a double paned window as it prevents the glass from transmitting the heat inwards. In the case of largely winter climates, it is preferable to have the low-e coating on the surface 3 as it aids in preventing the loss of internal heat.

There are 2 types of low-e coatings done:

Hard Coating: Also called as the pyrolytic process or chemical vapour deposition (CVD), this is done during the manufacture of glass where the coating is sprayed into the glass at a high temperature. The chemicals used include silicon, silicon oxides, titanium dioxide, aluminium, tungsten and many others. The process is such that the coating is hard-wearing.

Soft Coating: This is done after a glass is cut to size before it's assembly into a window. The coating is done in a vacuum chamber at room temperature and is also called as Magnetron Sputter Vacuum Deposition (MSVD). It consists of a series of layers of transparent silver sandwiched between layers of metal oxides. This is highly susceptible to damage and hence is recommended only in double or triple glazing units where the coating is applied on the inner surfaces.

Potential Technologies

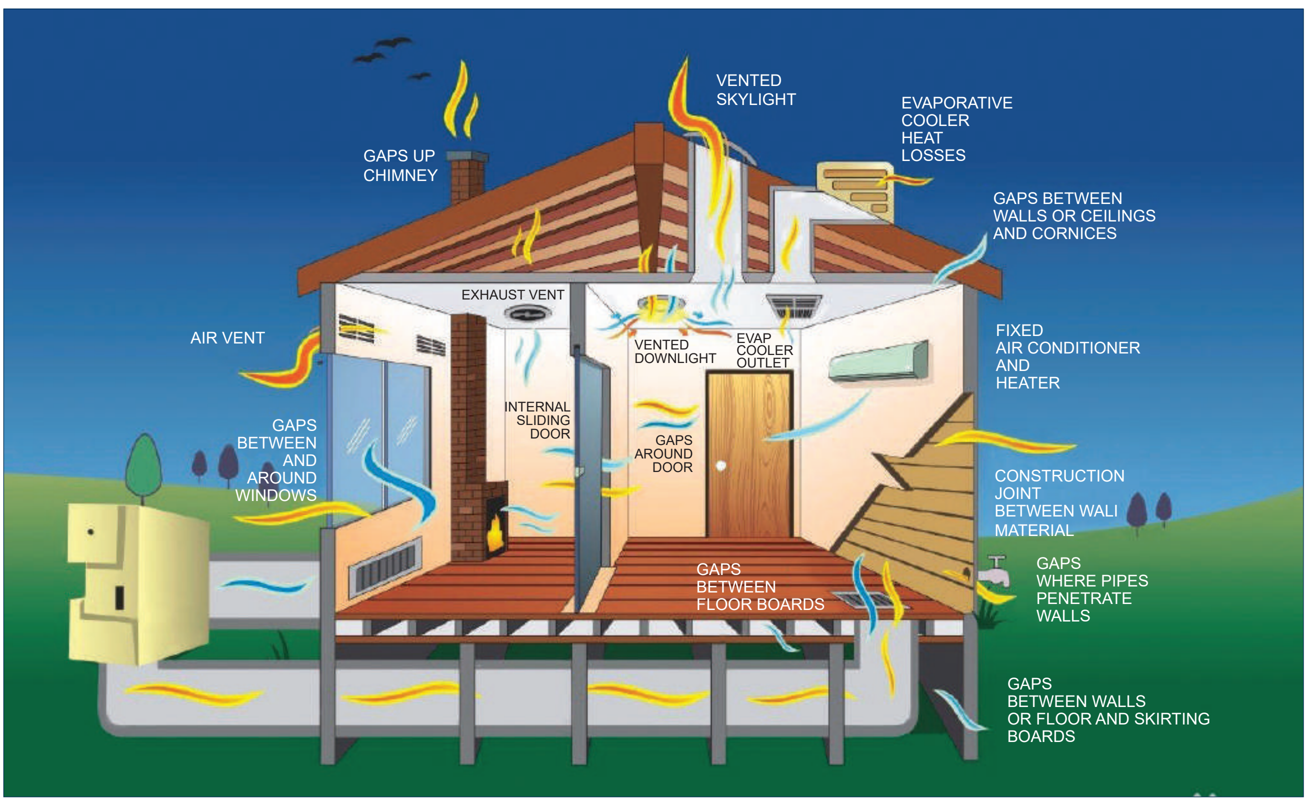
There are many glazing solutions available. Glazing assembly contractors will be able to provide you with a range of solutions with measurements like U-value, SHGC and VLT values. This would empower professionals to take quantitative decisions.

2.1.5 Air infiltration

Air infiltration is the phenomenon of uncontrolled air leakage from one space to another thereby reducing cooling or heating effectiveness of the space. This may happen between adjacent spaces inside a building or between the internal spaces of a building and the exterior air. Typically, this happens through improperly sealed or unsealed construction joints or between gaps in doors and windows (see figure 24).

Air infiltration causes the air-conditioning system to work harder to keep up the set temperature. This happens both in cooling and heating conditions, though usually more critical in the heating conditions as the temperature differential between the outside and inside are usually

Figure 24. Areas in a building prone to air-infiltration.



Source: Courtesy of Efficiency Matrix Pty Ltd (www.efficiencymatrix.com.au) large in extreme winters. Air infiltration also affects indoor air quality because unfiltered outside air can carry pollutants and allergens into the building which can affect health and comfort. The moisture in the air can also condense on colder surfaces leading to growth of mould and potential damage to the building.

Design Approach/Methodology

Air infiltration in a building energy model can be measured in terms of air changes per hour (ACH). It can also be measured based on the volume of air per unit time per unit floor area of the space (SI units – litres/second/square metre – l/s/m^2)[23].

In addition to poorly sealed joints and gaps, walls and roof surfaces are pervious to molecules of air and water. However, as air molecules are smaller than water molecules even waterproof barriers can be pervious to air. Hence good air barriers must have a higher permeability compared with vapour barriers.

Potential Technologies

- Joints between the door or window frame and the wall must be properly sealed.
- Joints or abutting surfaces among the various components of a window or a door (hinges, rebates, jambs, shutters, frames, etc.) must be properly sealed.
- Joints between a walls and roofs need to be sealed.
- In case of dry walls, the joints between the dry cladding components and its framework must be sealed properly.
- A vestibule at the entrance helps reduce the air leakage.
- Self-closing entrance doors/automatic door shutters.
- Joints where pipes, ducts and cables enter the walls must be effectively sealed.
- Caulking, skirting, or architraves at various joints will help seal the joints.
- After the completion of the building, blower tests may be conducted to ensure minimal air leakage.

2.1.6 Thermal Breaks

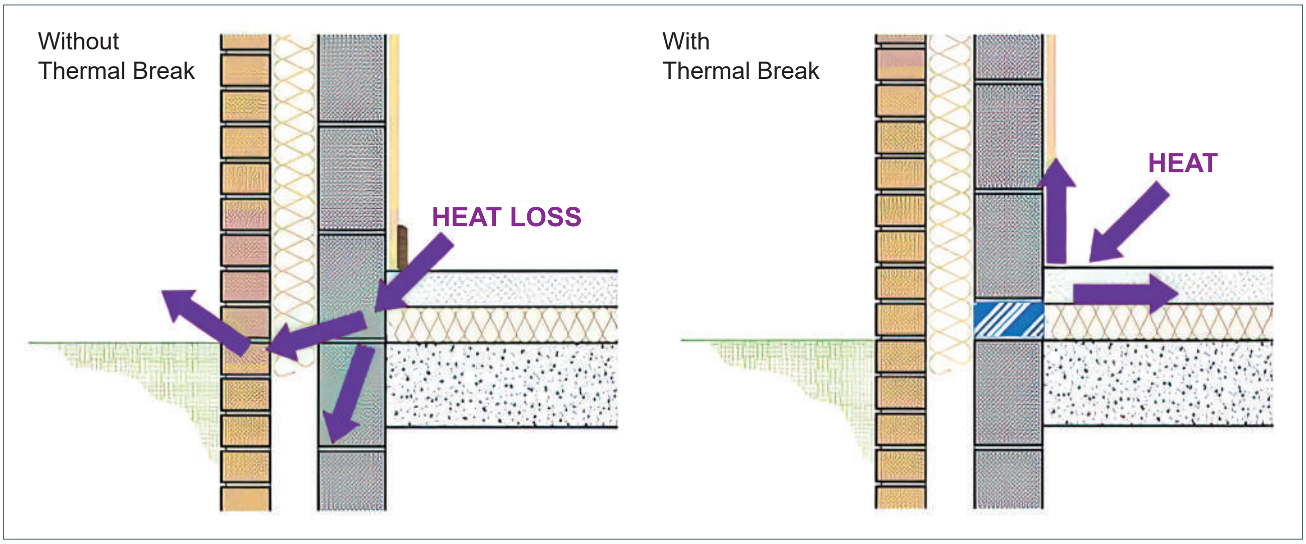
Intent

Thermal bridges are elements of a building that leak heat between the outdoors and indoors, possibly because of poorly insulated joints (e.g., exposed floor slabs, uninsulated window frames or glazing). This is especially critical for winter climates where there is a large difference between the desired indoor temperature and the outside ambient temperature. Thermal breaks are insulation insertions made at these thermal bridges (see figure 25).

Design Approach/Methodology

There are many joints that can leak heat out of a building. An architect needs to be mindful of these joints and provide the appropriate thermal breaks.

Figure 25. A typical section of wall and floor showing the joint without thermal break (left) and with a thermal break (right)



Source: Albedo Graphics.

[23] EDGE User Guide Version 3.0

Potential Technologies

Some of the common thermal break joints are:

1. Civil works joints

a. Wall to foundation joints
b. The floor slabs that extend out to an external balcony.
c. Floor slabs that extend out as portico roofs
d. Sunshades
e. The joint between the roof slab and parapet.
f. Pillars and internal basement walls

2. Window and Doors

a. Window frames
b. Door frames
c. Thresholds
d. Lintels

3. Metal Attachments on external walls

a. The joint between the wall and the framework of dry cladding.
b. Storefront signage
c. Curtain walls
d. Portico roof attachments in metal
e. Metal sunshades

4. Metal Buildings

a. The joint between the wall and the foundation
b. The joint between the columns and their bases
c. Purlin attachments to the roofing sheet
d. Purlin attachments to the siding sheet

The above list is only indicative. Thermal imaging inspections can be done to examine existing buildings and bridges can be identified for further rectification.

It is important for the architect and the structural engineer to identify all the joints that require a thermal break and work in conjunction with the HVAC consultant to pick the right insulation material. The structural engineer will also need to ensure that the seismic resilience of the building is not compromised in any manner.

2.1.7 Thermal transmittance of Building Envelope (U-value)

The building envelope consists of the walls, roofs, floor and the glazing. We have already covered glazing in the earlier section. A low U-value for a wall, roof and floor helps keep the building warm or cool. This can be achieved by choosing the right wall and roof assembly materials or insulating the wall surface. The SI Unit of U-value is Watts per Square meter Kelvin (W/Sqm. K). The inverse of U-value is R-value, which is the measure of how well a material resists the flow of heat.

Design Approach/Methodology

It is recommended to use low U-value wall and roof materials in both warm and cold climates. In warm climates, low U-value walls and roofs will prevent the interiors in getting heated up thereby saving on space cooling bills and in cold climates, it will prevent the interiors from losing heat thereby saving on space heating bills.

U-value is derived from the thermal resistance (R) of the material. R-value is the inverse of U-value, and its SI unit is Square Metre Kelvin/Watts (m^2K/W).

The formula for deriving U-value of a wall assembly is as follows[24]:

$$\text{U-Value} = \frac{1}{Rsi+Rso+R1+R2+R3 \text{ etc}}$$

Where: R_{si} = Resistance of air layer on the inner side of the external wall

R_{so} = Resistance of air layer on the external side of the external wall

R_1, R_2, etc. = Resistance of each layer of material within the wall assembly.

The Resistance in turn is derived from Thermal Conductivity also called K-value, which is the amount of heat a material transfers independent of its thickness. This is represented by the Greek symbol Lambda (λ).

Thermal Resistance[25] is derived as follows:

$$\text{R-value} = \frac{d}{\lambda}$$

d = material thickness in metres

λ = thermal conductivity in W/mK

Potential Technologies

Walls:

Some of the common technologies for low U-value wall assemblies are as follows:

- Traditional stone wall masonry: In Armenia, traditional buildings kept out the cold by making external walls with at least 600 mm thick stone masonry walls. However, this technology is difficult to construct because the area the walls occupy, the time it takes to build and its inability to be used in buildings higher than 5 or 6 storeys.
- Low U-value masonry: Materials like Aerated Autoclaved Concrete (AAC) Blocks and Cavity Clay

[24] EDGE User Guide Version 3.0a
[25] Ibid.

Blocks can be used; however, the U-value of such materials is not low enough to be used in isolation.

- Composite Wall 1 (outside to inside) - Dry Cladding + Insulation (mounted on a metal framework) + low U-value Masonry Wall/RCC wall + Internal Plaster: This is a good technology as it can be applied in high rise buildings as well. The required U-value can be achieved by selecting the right type and thickness of insulation and masonry block.
- Composite Wall 2 (outside to inside) - Painted External mortar on glass mesh with EPS/XPS/ Rockwool slab insulation glued on the RCC wall (Exterior insulation finishing system (EIFS)/Exterior thermal insulation composite system (ETHICS)).
- Composite Wall 3 (outside to inside) - Dry Cladding + Plasterboard + Insulation + Internal Plaster Board (mounted on a wooden or metal framework). This technology also provides good options to the architects to provide the optimum U-value.
- Thermal Mass & Trombe Wall – utilize materials with high thermal mass to store heat. An example of this is to create a Trombe wall which is essentially a wall of heavy thermal mass with a glass façade. The glass façade captures the solar heat and then facilitates the wall to absorb heat. This wall in turn will heat the interiors.

The above list is not exhaustive but provides a good idea of the principles involved in creating a low U-value wall assembly.

Roofs:

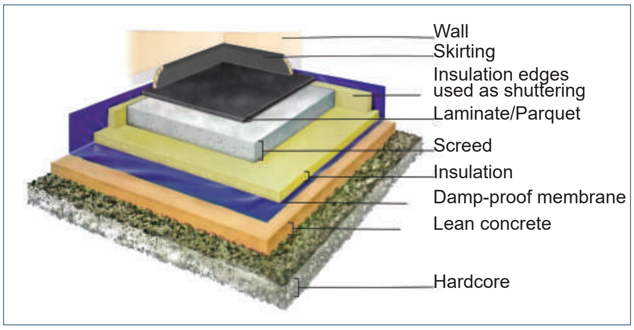
- Overdeck Insulation on Concrete Slabs (outside to inside) - Insulation protection + Insulation + vapor barrier/damp proof membrane + RCC Slab + Internal finish. This is the most thermally effective manner of insulating the roof. However, the over deck insulation must be well protected from the wear and tear as some people movement will be unavoidable on the roof. Also, the required slopes for water drainage needs to be provided on a flat roof assembly.
- Underdeck Insulation on Concrete Slabs (outside to inside) – Waterproofing/weatherproofing coat + RCC Slab + Insulation + False Ceiling. While less effective than the over deck insulation, this is also useful in lowering the U-value of the roof assembly. The advantage is that the insulation will be protected from wear and tear as it's not exposed to the elements or human traffic.
- Insulated metal roofs/Sandwich panel roofs (outside to inside) have the following layers – corrugated galvalume roof + polyurethane foam (PUF) insulation + flat galvalume sheet. Such roofs must be mounted on a metal truss.
- Metal roofs with in-situ insulation: In cases where conventional galvalume metal roof is used, the insulation can be fixed underneath the roof surface. The insulation must be protected below with a false ceiling and also must not have any gaps in the joints to ensure insulation effectiveness.

Floors:

Underfloor insulation: In cold climates, floors that are in direct contact with the earth or floors that are raised on stilts are susceptible to heat loss. Therefore, it is important to insulate the floors.

- Concrete Floors: It is recommended to lay the insulation under the concrete. In such a case, ensure that a damp proof material is applied on the base before laying the insulation and then the concrete is poured over. In the case of insulating existing concrete floors, then the existing flooring needs to be removed until the concrete layer. A damp proofing material must be applied and then the insulation is installed over which the floor finish is laid. (See figure 26)

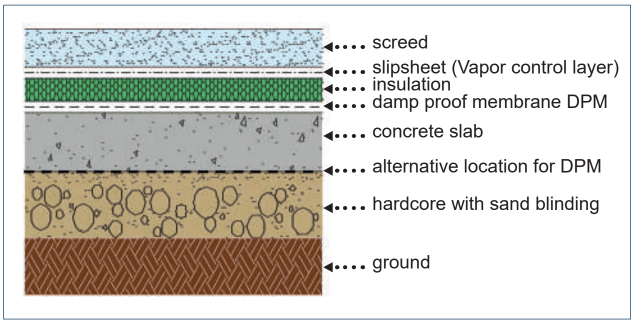
Figure 26. Scheme of floor assembly with insulation.



Source: Albedo Graphics.

An alternative scheme is presented in figure 27.

Figure 27. Scheme of alternative floor assembly with insulation.



Source: Albedo Graphics.

- Wooden Floors: Many old buildings may have wooden floors. It is recommended to remove the floors to expose the joists. If there is no space below the joists, it is best to damp proof the joists and lay insulation between the joists. In the case of some crawl space beneath the joists, then it is recommended to lay a damp proofing layer below the joists and a layer of insulation under and between the joists. The wooden flooring can then be re-fixed.

A general comment would be that fire safety norms must be adhered to the use of the materials and the assemblies.

2.1.8 Wall and Roof reflectivity

The capacity of a wall for heating or cooling through the direct solar radiation is connected to its colour and texture. Using walls with high reflectivity (i.e., clearer colours) in warm climates reduces the heat gain of the building. In the case of cold climates, it would be preferable to have darker colours on the walls and the roofs.

Design Approach/Methodology

The Wall and Roof reflectivity is measured by the Solar Reflectance Index (SRI – also called Albedo). It is arrived at by calculating two aspects namely the Solar Reflectivity (SR) and Thermal Emittance (TE). The higher the SRI the greater the reflectivity of the surface.

Solar Reflectivity is the fraction of sunlight (0 to 1, or 0 percent to 100 percent) that is reflected from a surface. SR typically ranges from about 0.04 (4%) for charcoal to 0.9 (90%) for fresh snow.

Thermal Emittance is the efficiency (0 to 1) with which a surface emits thermal radiation. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all non-metallic surfaces have high thermal emittance, usually between 0.90 and 0.85. Uncoated metal has low thermal emittance, which means it will stay warm. By this logic, an uncoated metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation.

Solar Reflectance Index is a composite value accounting for a surface's solar reflectance and thermal emittance. SRI is defined so that a standard black surface (SR 0.05, TE 0.90) is 0 and a standard white surface (SR 0.80, TE 0.90) is 100. SRI values for highly reflective roofs have been engineered to go above 100.

The SRI for roofing materials or wall paints can be acquired from the product manufacturer. In case SR and TE of a material are known but the SRI is unknown, it can be calculated using this calculator[26] by the Lawrence Berkeley National Laboratory, Berkeley, CA, USA.

Potential Technologies

There are many materials available to enhance roof and wall reflectivity. Below is a table that shows the SRI of various materials. This data has been taken from the EDGE User Guide Version 3.0.a.

Table 2. Materials to enhance roof reflectivity.

Roofing Materials	SRI
Bitumen	
Smooth Bitumen	0
Firestone SBS Bitumen on White	28
White Granular Surface Bitumen	28
Asphalt Shingles	
White Asphalt	26
Light Grey	22
Light Grey - with cool coating	44
Grey	4
Beachwood Sand	19
Light Brown	18
Saddle Tan	14
Black or Dark Brown	1
Black - with cool coating	41
Blue	16
Blue - with cool coating	50
Coral	14
Terracotta - coloured	36
Terracotta - coloured - with cool coating	56
Green	18
Green - with cool coating	53
Chocolate	9
Chocolate - with cool coating	46
Metal Roof	
Metal Roof - uncoated	68
Bare Aluminium	56
New, Bare Galvanised Steel	46
Metal Roof - with cool coating	92
White Metal Roof	82

[26] https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fcoolcolors.lbl.gov%2Fassets%2Fdocs%2FSRI%2520Calculator%2FSRI-calc10.xls&wdOrigin=BROWSELINK

Built-up Roof	
Dark Gravel on Built-up Roof	9
Light Gravel on Built-up Roof	37
White-coated Gravel on Built-up Roof	79
Roof Tiles	
Red Clay Tile	36
Red Concrete Tile	17
Unpainted Concrete Tile	25
White Concrete Tile	90
Light, Beige-coated Concrete Tile	76
Light, Brown-coated Concrete Tile	48
Earth Brown Fibre Cement Tile	27
Pewter Grey Fibre Cement Tile	25
EPDM	
EPDM - Grey	21
EPDM - White	84
EPDM - Black	0
T-EPDM	102
Roof Coatings	
White Coating (2 coats, 20 mils*)	107
White Coating (1 coat, 8 mils*)	100
No Pigment Coating (1 coat, 18 mils*)	40
No Pigment Coating (2 coats, 36 mils*)	64
*** mil = 0.001 inches or 0.2254 mm**	

Wall Materials	SRI
Metal - with cool coating	92
White Metal	82
Red Clay Brick	36
Red Concrete	17
Unpainted Cement Finish	25
White-painted Concrete	90

Source: EDGE User Guide Version 3.0.a.

2.1.9 Green roofs

Green roofs have vegetation on them, along with structural and waterproofing safeguards, reducing the transfer of heat into and out of the building. Green roofs also increase biodiversity in densely built urban environments and are becoming increasingly popular.

Design Approach/Methodology

It is recommended that the base slab is designed to bear the load of the growing medium (soil or other alternatives) and the plants. The slab should also be treated to ensure proper waterproofing.

The landscape architect on the project will need to coordinate with the architects and other service consultants to ensure a well detailed green roof. The client in turn needs to be prepared to understand the maintenance aspects of a green roof and makes the adequate preparations for the same. Green walls are also a potential technology that can help in regulating the temperature while also increasing the biodiversity in an urban environment. Typically, plants can be placed in specially designed balconies. These balconies need to be structurally designed to bear the load of the plantation and also need to be water proofed. Another method of planting is installing vertical planter boxes specially designed to hold the plants.

Potential Technologies

There are 3 types of green roofs.[27]

- Extensive Green Roofs: These are green roofs with 10-15 cm of lightweight growing medium and low-maintenance ground cover plants. (See figure 28)

Figure 28. Example of an extensive green roof: Jesuit Center Garden Roof at Fairfield University in Fairfield, Connecticut, USA.

Source: Creative Commons License.
Photo credit: Stagophile.

- Intensive Green Roofs: Compared to extensive green roofs the growing medium is about 20-30 cm deep and can be planted like a regular garden on the ground. However, plants with invasive and deep roots must not be planted. The plants require regular maintenance. (See figure 29)

[27] Green Roof Frequently Asked Questions - BCIT (https://www.bcit.ca/centre-for-architectural-ecology/courses-education/resources/frequently-asked-questions/)

Figure 29. Example of an intensive green roof: Chicago City Hall pilot green roof project.

Source: Creative Commons License.
Photo credit: Conservation Design Forum.

- Semi-intensive Green Roofs: These roofs combine elements of both the systems and results in a diverse garden.

2.1.10 Daylighting

Abundant daylight in a building reduces the need for artificial lighting, thereby reducing energy use during the daytime. Artificial lighting consumes energy and in addition to that the heat caused by the light fixtures that adds to the air-conditioning load.

Design Approach/Methodology

Daylight is an important component of building design. Adequate daylight in a building not only saves energy but also positively impacts the physical and mental health of the users. Daylight requirements depend on the use of space. While designing the building, there is a tendency to assume that larger the opening size, better the amount of daylight. However, it is critical that glare is avoided. Glare is the phenomenon when a large amount of light falls directly into the eyes of the user on onto the work plane causing visual discomfort. This can be controlled by a variety of ways at the design stage. One could introduce light shelves, change the proportion of the windows, introduce blinds, manage internal reflectivity by choosing appropriate colours and finishes for internal spaces among other measures.

Potential Technologies

Some of the strategies to ensure good daylighting are as follows:

- Windows: Windows are the single most important source of daylight. However, window orientation and shading are important to keep glare out.
- Light shelves: As a thumb rule, daylight from windows penetrate about 6m at the most. For better penetration of daylight, light shelves are installed on top of the window at the lintel level with a strip of window above it. The light shelf helps in reflecting light onto the ceiling resulting in deeper penetration of light into the room. (See figure 30)

Figure 30. Example of light selves reflecting the light deeper into the room

Source: Albedo Graphics.

- Skylights: Skylights are fixed on the roofs and generally provides a much higher intensity of light. One needs to be mindful of the size of the skylight and the location. It can bring in unwanted heat in warm climates.
- Solar Tubes: Solar tubes capture daylight through a rooftop collector and transmits the light through a reflective tube into lower floors. (See figure 31)

Figure 31. Example of solar tubes that transmit

Source: Creative Commons License.
Photo Credit: Mimi Kotter

2.1.11 Natural ventilation

Natural ventilation in a building is when ventilation occurs without use of artificial systems such as fans and air conditioning. It is the process of supplying and removing air through an interior space without the use of mechanical systems. It relies on natural forces such as wind and thermal buoyancy to move fresh air into buildings and remove stale air. If a building is designed in a manner where occupants can be comfortable without the use of artificial ventilation systems, then the energy footprint of the building reduces. As a strategy, natural ventilation is useful in warmer climates.

Design Approach/Methodology

Natural ventilation is usually possible when the weather outside is moderate in terms of temperature. It could be utilised during warmer weather but would not be possible during times of extreme cold. Aligning the walls and window openings of a building to the direction of prevailing winds would be useful to maximize natural ventilation during summers.

There are four types of room arrangements that can facilitate natural ventilation.

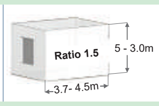
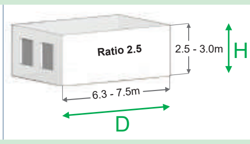
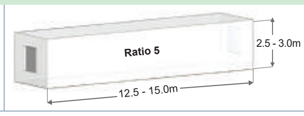
- **Single Sided Ventilation:** Single sided ventilation is when only one wall in a room has windows opening to the exterior environment. The ventilation coming through such openings relies on the pressure differences between the different openings within a space. The ventilation is usually driven by turbulence.
- **Cross-ventilation - Single Spaces:** Cross-ventilation of single spaces is a very effective approach. It is driven by the pressure differences between the windward and leeward sides of the space.
- **Cross-ventilation - Double-banked spaces:** Cross-ventilation between two adjacent spaces can be designed in the case when the ownership of both spaces is with the same user. This may typically happen in an educational institution or a hostel where an exterior room either provides or derives ventilation from adjacent corridor. Ventilation openings needs to be designed into the intermediate partition wall. It is possible that noise will travel between the two spaces.
- **Stack Ventilation:** Stack ventilation occurs vertically inside a building. This is facilitated by temperature difference between the upper levels (usually warmer) and the lower levels (cooler). As warm air rises, this sets up a draught of air that can then be vented out by using of an opening on the uppermost floor.

Potential Technologies

There are certain important room proportions that must be followed for successful natural ventilation. Room size (width, depth and height) is the most important aspect of the ventilation strategy. Some important aspects to be considered for natural ventilation:

- Maximum ratio of floor depth to ceiling height. (See figure 32)
  - Single-sided single opening: Maximum depth to height ratio must be 1.5. That means for effective ventilation in a space of 3.0m height, the maximum depth of the room can only be 4.5m.
  - Single-sided multiple openings: Maximum depth to height ratio must not be more than 2.5.
  - Cross-ventilated spaces: Maximum depth to height ratio must not be more than 5.0.

Figure 32. Scheme of the maximum room depths to ensure effective natural ventilation, based on windows size and configuration.

Room/Opening Configuration	Image/Example	Minimum D/H Ratio
Single-sided, single opening		1.5
Single-sided, multiple openings		2.5
Cross ventilation		5.0

Source: Designing for Greater Efficiencies, Green Building Course provided by IFC.

- Natural ventilation is calibrated as a percentage of window area to the total floor area of the space. Total area of window with respect to the floor area of the space.
  - The minimum area of opening required depends on the expected heat gains in a space. Figure 33 below shows the typical area percentage of windows compared with the floor area.

Figure 33. The area of windows required as a percentage of the floor area for effective ventilation

Building Type	Space Type (Heat Gain)	Minimum Area of Opening Required as a Percentage of Floor Area
Homes	Bedrooms (15-30 W/m2)	20%
	Living Room (15-30 W/m2)	20%
	Kitchen (>30 W/m2)	25%
Hospitality	Corridors (<15 W/m2)	10%
	Guest Rooms (15-30 W/m2)	20%
Retail	Corridors, Atrium & Common Areas (<15 W/m2)	10%
Offices	Offices (15-30 W/m2)	20%
	Corridors and Lobby (<15 W/m2)	10%
Hospitals	Corridors (<15 W/m2)	10%
	Lobby, Waiting and Consultation Areas (15-30 W/m2)	20%
	Patient Rooms (15-30 W/m2)	20%
Education	Corridors (<15 W/m2)	10%
	Classrooms (15-30 W/m2)	20%

Source: EDGE User Guide Version 3.0a

2.2. Demand Side Measures – Energy Efficient Equipment Design

Broadly, this sub-section refers to energy efficient lighting, energy efficient HVAC systems, and other energy efficient equipment like pumps, elevators, etc.

Artificial lighting consumes a significant portion of the energy used in a building. Energy-efficient lighting reduces the amount of energy required for lighting. Heating, Lighting and Ventilation are important aspects of human comfort that consume a significant amount of energy in the building. There are other important components like hot water systems, power correctors and regenerative braking technologies in lifts that also need to be worked for their efficiencies.

The following measures may help to achieve this:

2.2.a) Lighting

- 2.2.1. Energy efficient lamps
- 2.2.2. Lighting Controls

2.2.b) Heating, Ventilation and Air-conditioning (HVAC) Systems

- 2.2.3. Cooling System Efficiency
- 2.2.4. Heating System Efficiency
- 2.2.5. Ceiling fans
- 2.2.6. Economizers
- 2.2.7. Variable Speed Drives, Variable Frequency Drives
- 2.2.8. Fresh Air Pre-conditioning System
- 2.2.9. Refrigerant Management
- 2.2.10. Demand Control Ventilation using Carbon Monoxide (CO) and Carbon Dioxide (CO2) Sensors
- 2.2.11. Thermostat Controls

2.2.c) Other Equipment

- 2.2.12. Domestic Hot Water System Efficiency
- 2.2.13. Domestic Hot Water Preheating System
- 2.2.14. Power factor correctors (PFC) and Regenerative Braking of Lifts

2.2.a) Lighting

2.2.1 Energy efficient lamps

Lighting consumes between 15% and 40% of the total electrical energy in a building depending on the type of building use. Hence energy efficient laps contribute significantly towards building energy efficiency.

Design Approach/Methodology

Lighting efficiency can be measured in two ways:

- Light power density is defined as the total power that all lighting in a building consumes divided by the total area of the building. It indicates the energy efficiency of lighting. The unit is W/m2.
- Luminous efficacy refers to the amount of light output per watt of electricity used in a particular lamp. The unit is lumens per Watt.

Quality of light is another measure that does not concern the energy efficiency of lighting. This is measured by Colour Rendering Index (CRI) and Colour Temperature. CRI indicates the lamp's ability to show natural colours and is measured a scale of 0 to 100. Colour Temperature is measured in degrees Kelvin where warm lighting (yellow) is in the range of 2,700 to 3,000 K while 4,000 to 6,000K is closer to daylight (see figure 34).

Figure 34. Lights of varying colour temperatures.

Source: Albedo Graphics.

The design approach is to work out the best luminous efficacy for a particular function when each individual lamp is being considered for selection. In addition to this, it is important to control the Lighting Power Density (LPD) values without compromising on the functionality.

Information on luminous efficacy and the wattage is provided by the manufacturer.

Potential Technologies

Light-emitting diode (LED) lighting is at least six times as efficient as incandescent lighting and at least twice as efficient as linear and compact fluorescent lighting (CFL). LEDs are also available in all colours and for most types of lighting applications. They provide a luminous efficacy in the range of 50 – 100 lumens/Watt. LED lamps have a significantly longer service life (LED lamps last an average of 30,000 to 50,000 hours compared with around 10,000 hours of CFL and 1,000 hours of incandescent lamps) thereby resulting in cost reductions in maintenance and lamp replacements.

2.2.2 Lighting Controls

Lighting controls help in reducing lighting usage. While manual controls are used extensively, use of following type of automated lighting controls can be used in a building:

- Daylight Sensors
- Occupancy Sensors

Design Approach/Methodology

Daylight sensors: They are used on light fixtures that are close to windows. In large-occupancy spaces, they switch off lights when sufficient daylight is available, reducing energy use. They are usually used in large, open plan offices, classrooms, and lecture halls, where workstations near windows receive adequate daylight. Daylight sensors can be fitted to exterior lights (e.g., street and pathway lights, garden lights, bulkheads on buildings) to switch them on at dusk and off at dawn. They may be based on photoelectric sensors or timers.

In interior spaces, the space close to the window is called Daylight Zone. The thumb rule for a daylight zone is 1.5 times the head height of the window. If the window lintel is at 2.1m, the daylight zone is 3.15m. Daylight sensors can be fixed on lamps in this zone.

Occupancy sensors: There are many types of sensors that can be used to control lights. The basis of an occupancy sensor is to ensure that lights are on during the period that a space is occupied. There are many technologies in occupancy sensors; Motion sensors will switch on when motion is detected. Passive infra-red (PIR) sensors detect a person's heat signature and switch on the lights. There are also timer-based switches that switch on and off based on the settings fed in by the building owners.

Sensor based lights can be used in spaces such as corridors, office areas (especially after hours), toilets and garages where low levels of light are sufficient for one to enter the space. When someone enters the space, the remaining lights switch on for full functionality. The extra lights then switch off after the occupant exits the space.

Occupancy sensors can be designed into the lighting system after ascertaining the modality of space use. For e.g., if an office space has fixed working hours where the employees' clock-in and clock-out at set times, then a timer-based control may be more appropriate. However, if the office has flexible work schedules where certain people may use the office space after "regular" work hours, then an occupancy sensor would ensure that only occupied spaces would be lit fully.

Potential Technologies

There are different types of sensors available. Below is an extract from the EDGE User Guide 3.0a.

Table 3. Types of sensors.

Timer Controls	The two types of timer controls are: time delay switches and actual timer controls. Time delay switches are manually switched on and then automatically switch off after a set time, which can be adjusted. Time delay or time lag switches can either be mechanical (pneumatic time delay) where the lighting requirement is less than 30 minutes, or they can be electronic, which can be programmed to provide a longer delay. A time delay switch is most appropriate in spaces where lighting is only used for short periods of time, such as bathrooms in common areas or rarely used corridors. Timer controls use a built-in clock function to switch on and off at preset times. They can either be used to switch lights off when the lighting is unlikely to be required (such as security lighting during daylight hours), or to switch lights on at a set time (such as decorative lighting). Timer controls should always be fitted with a manual override, so that out-of-hours use is still possible if required.
Occupancy or Presence Detectors	Occupancy or presence detectors can be used to switch lights on when movement or presence is detected and switch them off again when no movement or presence is detected. These may be used in areas of infrequent use by staff and public. Some technologies are as follows: **High frequency ultrasonic sensors**, detect occupancy by emitting a high-frequency signal, which they receive back as a reflected signal using the Doppler effect, and interpret change in frequency as motion in the space[28]. They can work around obstructions. These are first generation occupancy sensors and not very reliable as they get triggered by any movement including undesirable triggers. **Passive Infrared Sensors (PIR)**, detect human body temperature by sending out infrared beams to detect temperature differences. These are an advancement on ultrasonic sensors. However, PIRs do not always work well in very hot climates, as the background temperature is like human body temperature. They also require a direct line of sight[29]. **Microphonics sensors**, utilize a microphone inside of the sensor to hear sounds that indicate occupancy. They can learn to ignore background noise such as air conditioners and do not rely on the line of sight. So, they are especially useful in rooms with obstructions such as bathrooms with stalls. **Dual technology sensors**, use a combination of technologies described above to reduce the chances of false-on and false-off. As each type of presence-detecting technology has different limitations, many controls use a combination of the three technologies.
Daylight Sensors	Daylight sensors can be used to switch lights on or off, alone or in conjunction with dimmers. Daylight sensors sense the availability of daylight and can switch lights off or trigger lighting dimmers to produce reduced lighting levels to maintain a comfortable level of light.

Source: EDGE User Guide 3.0a.

[28]Source: http://www.ecmweb.com/lighting-amp-control/occupancy-sensors-101
[29]Source: https://www.acuitybrands.com/brands/lighting-controls/-/media/abl/acuitybrands/files/sensor-switch/occupancy-sensor-technologies-white-paper-pdf.pdf

2.2.b) Heating, Ventilation and Air-conditioning (HVAC) Systems

In warm climates, the HVAC system can account for 60 to 70% of energy use in a fully air-conditioned building. In cold climates, heating accounts for 40 to 60% of the energy use in a building.

Energy efficiency of HVAC technologies used in a building are key drivers towards bringing down the energy consumption of a building. Many components of HVAC systems can be made more efficient to decrease this energy use.

In this section, we will start with simple technologies like ceiling fans and progressively move to the more complex components of a full-fledged HVAC system.

2.2.3 Cooling System Efficiency

The cooling system efficiency is measured in various ways.

Coefficient of Performance (COP) is the ratio of the amount of cooling energy achieved to the amount of electrical energy consumed. It can also be expressed as energy efficiency ratio (EER), seasonal energy efficiency ratio (SEER) and/or integrated energy efficiency ratio (IEER). All manufacturers include one of these values in their technical data sheet.

Design Approach/Methodology

The COP[30] can also be defined as the amount of heat removed from a space compared with the amount of electrical energy consumed by the system. The formula is as follows:

$$COP = \frac{(Q\ out)}{(W\ in)}$$

Where:

Q out = heating energy removal (kW)

W in = electrical energy input (kW)

Potential Technologies

There are many types of cooling systems available in the market with varying COP. It is important to understand and specify the best possible system considering not just the COP but also the application and the maintenance aspects of the system. Some of the key types of AC systems are explained below.

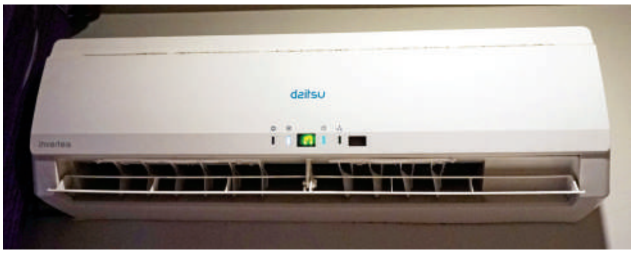
- **Window air-conditioners:** These are simple air-conditioners fitted into an opening in the wall with the condenser portion that projects out of the building while the air delivery system faces the internal space. These are the least efficient types of systems and are not very popular. (See figure 35)

Figure 35. Example of window air-conditioner.

Source: Creative Commons License.
Photo credit: Rsrokanth05.

- **Spilt air-conditioners:** This is commonly used for small spaces. It contains two portions – a condenser unit that is installed outside the building and an internal fan coil unit (FCU) that delivers the cool air inside the building (see figure 36). The technology is called direct expansion (DX) mechanical refrigeration system. The inner and outer units are connected by a small tube that carries the refrigerant and the electrical and sensor cables. They do not require extensive ducting and are more efficient than ducted systems. The system has a limitation that the distance between the condenser unit and the FCU cannot be too large.

Figure 36. Example of split air-conditioner.

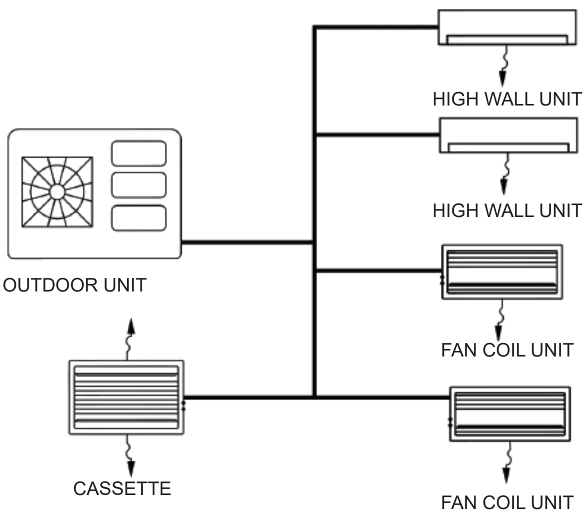


Source: Creative Commons License
Photo credit: Tia Monto.

[30] EDGE User Guide Version 3.0a

- **Multi-split air-conditioners:** This system is like the spilt air-conditioners. The key difference is that the outside condenser is connected to multiple FCUs (see figure 37). However, the limitation is that the internal temperatures of various spaces need to be similar.

Figure 37. Scheme of multi-split air-conditioners unit.

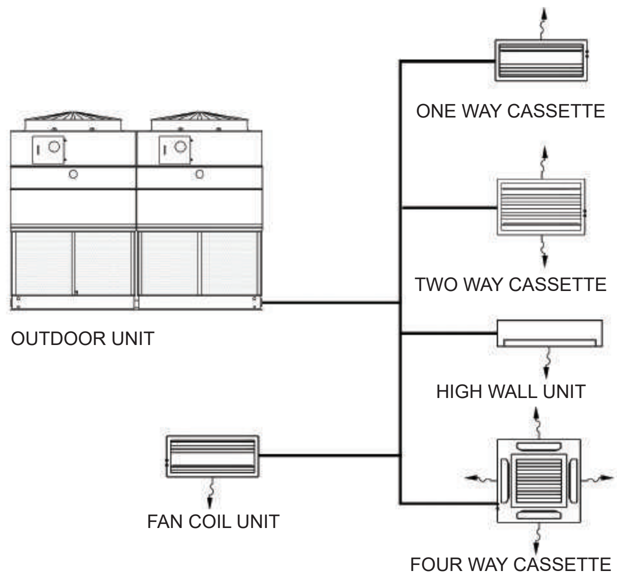


Source: Albedo Graphics.

- **Variable Refrigerant Flow (VRF):** Like the multi-split air-conditioners, this system also has one outdoor unit connected to multiple indoor FCUs (see figure 38). The key difference in this system is that the outdoor unit can support internal FCUs can have varying indoor temperature requirements. The system runs by modulating the amount of refrigerant that is sent to each evaporator, running only at the rate needed to deliver the cooling required by each internal unit. This system can also take care of cooling and heating requirements simultaneously – in other words, the system can serve one zone that requires heating while simultaneously serving another zone that requires cooling. The mode of heat transfer is through refrigerant flow and the compressors are equipped to deal with a variety of thermal loads from 6% to 100% load. Every FCU must have has its own thermostat to realize energy savings. There are 3 types of VRF systems:

- VRF - cooling only system
- VRF with Heat Pump – provides both heating and cooling but not simultaneously
- VRF with Heat Recovery – provides both heating and cooling simultaneously.

Figure 38. Scheme of VRF system



Source: Albedo Graphics.

- **Chillers:** Chillers deliver cooling through chilled water which has much higher heat capacity than air, allowing heat to be transferred more efficiently. Chilled water is circulated to provide comfort cooling throughout a building. The system has four components: i) Compressor, ii) Condenser, iii) Thermal expansion valve, and iv) Evaporator. The compressor compresses the refrigerant and pumps it through the air conditioning system at a designed flow rate and pressure. The compressor technology is a way to distinguish the type of air-cooled chillers: Reciprocating chillers, rotary screw chillers, or scroll chillers. Selection must be made based on many factors including the size of the system; for example, reciprocating compressors are typically 3–510 refrigeration tons. The cycle begins in the evaporator where a liquid refrigerant flows over the evaporator tube bundle and evaporates, absorbing heat from the water circulating through the bundle. The refrigerant vapor is drawn out of the evaporator by the compressor. The compressor compresses the refrigerant raising its pressure and temperature and pumps the refrigerant vapor to the condenser. The refrigerant condenses in the condenser tubes, giving up its heat to the air or water that is cooling the condenser. The high-pressure, liquid refrigerant from the condenser then passes through the expansion device that reduces the refrigerant pressure and temperature as it enters the evaporator. The cold refrigerant again flows over the water coils absorbing more heat and completing the cycle.

Air-cooled chillers use air to cool the condenser and are suitable for climates where water supply is scarce or high humidity reduces the efficiency of the cooling towers (figure 39). **Water-cooled chillers** are like air cooled chillers except that water is used to provide the condenser cooling (figure 40). Air-cooled chillers cost significantly less per ton than water-cooled systems primarily because they require fewer components to build and operate and require less support equipment and plumbing. Installation of an air-cooled chiller is faster and easier than that of a water-cooled chiller. However, the efficiency of water-cooled chillers is typically higher because of the higher heat capacity of water compared to air. A water-cooled system is the best option when reducing operating costs is of paramount concern and the project can invest in a system with a longer payback period. Water cooling does involve a higher initial investment since both a chiller and a circulating tower system are required, which in turn require additional pumps, piping and tanks. Also, water cooling systems consume considerable amounts of water due to evaporation, purging and bleeding[31].

Figure 39. Example of air-cooled chiller.

Source: Creative Commons License.
Photo credit: Mori2000.

Figure 40. Example of water-cooled chiller (left) and Cooling Tower in a Water-cooled chiller system (right)

Source: Creative Commons License. Photo credit: Winfried Recker.

As seen above, there are different types of AC systems that have different uses with varying levels of energy efficiencies. For further guidance on the minimum energay efficiency requirements, please refer to figure 41.

- **Absorption chillers:** An absorption chiller is a type of air-cooling device that absorbs waste heat instead of electrical energy to provide cooling. An absorption chiller has a low COP. However, it can reduce operating costs because it is powered by waste heat. An absorption chiller is a much more cost-effective alternative to a traditional cooling system due to the use of waste heat as fuel and lower maintenance.

Waste heat is the result (byproduct) of building processes or industrial processes that is not being put to practical use. This waste heat is captured to generate cooling as an emission-free substitute for costly purchased fuels or electricity. It is thus a no-cost fuel source which can improve the overall energy efficiency in a facility. Absorption chillers are more cost-effective in large-sized buildings which are owned and operated by the same manager[32].

- **Ground source heat pumps:** Sometimes referred to as geothermal heat pumps (GHPs), are used to heat and cool buildings by absorbing naturally existing heat from the earth. A GSHP/GHP takes advantage of the more constant below-ground

[31]EDGE User Guide Version 3.0a
[32]Ibid

temperature within the earth (soil or water) compared to the more variable outside air temperature. Below-ground temperature is warmer than the air during the winter and cooler than the air in the summer. A GHP takes advantage of this by exchanging heat with the earth through a ground heat exchanger. A GHP can reach a high COP of 3 to 5.2 on the coldest winter nights, compared to air-source heat pumps that only reach up to a 1.5 to 2.5 COP on cool days. Ground source heat pumps are a clean alternative utilizing renewable and reliable sources of energy[33].

Four major types of ground source heat pump systems (GHPs) are available. Of these four types, three systems – the horizontal, vertical, and pond systems – are closed loop systems. The fourth major type of GHP is the open loop system. A closed loop system recirculates antifreeze or water through a loop of piping that is either buried in the ground or submerged under water. A heat exchanger transfers heat between the refrigerant in the heat pump and the antifreeze/water solution. An open loop GHP system pumps water from a ground or water source, circulates the water and then discharges it once the heat has been transferred into or out of the water. It draws fresh water instead of recirculating the same water again[34].

Figure 41. Minimum recommended COP of AC systems

Type of Cooling System (Air Conditioning)	COP
Through the wall, air-cooled, packaged and split ≤ 9 kW	3.51
Air-cooled, split < 19 kW	3.81
Air-cooled, single package < 19kW DX and heat pumps	4.10
Water-cooled, split and single package < 19kW	3.54
PTAC and PTHP, standard size, all capacities In equation, Capacity = 2.1 kW < Capacity < 4.4.kw	4.10 - (0.300 x Capacity/1000)
Variable Refrigerant Flow, air-cooled, cooling mode < 19 kW	3.81
Variable Refrigerant Flow, water source, cooling mode < 19kW	3.52
Variable Refrigerant Flow, groundwater source, cooling mode < 40kW	4.75
Variable Refrigerant Flow, ground source, cooling mode < 40kW	3.93
Air Cooled Chiller < 528 kW	2.985 at Full Load (FL) 4.048 at Part Load (IPLV)
Air Cooled Chiller > 528 kw	2.985 at Full Load (FL) 4.137 at Part Load (IPLV)
Water Cooled Chiller, positive displacement <264 kW (Positive displacement = reciprocating, screw and scroll compressors)	4.694 at Full Load 5.867 at Part Load (IPLV)
Water Cooled Chiller, centrifugal < 528 kW	5.771 at Full Load 6.401 at Part Load (IPLV)

Source: EDGE User Guide Version 3a.

2.2.4 Heating System Efficiency

In cold climates, space heating accounts for one of the largest energy uses within a building. Heating has traditionally relied on fossil fuels.

Design Approach/Methodology

Efficiency of boilers are measured in many ways. A few important parameters are explained below:

- Coefficient of Performance (COP): This is the ratio of the amount of heating energy achieved to the amount of electrical energy consumed for heating.
- Annual Fuel Use Efficiency (AFUE): AFUE is the total annual heating output provided by a heating system divided the total fuel input. It is measured in percentage terms. Higher the AFUE, higher the efficiency of the system.
- Heating Season Performance Factor (HSPF): This is derived by dividing the total space heating required during the heating season by the total electrical energy consumed during the same season. This factor is used to measure heating that uses electricity as the source of heating.

[33]Source: http://energy.gov/energysaver/articles/geothermal-heat-pumps
[34]EDGE User Guide Version 3.0a

Potential Technologies[35]

Conventional Technologies

- **Boilers:** A boiler heats water to provide hot water or steam for heating that is then distributed through a series of pipes. The fuels used are natural gas, propane, heating oil, biodiesel blends or electricity.
- **Furnaces:** Furnaces heats air and uses a blower motor to distribute warm air throughout the building. The fuels used are natural gas, propane, heating oil or electricity.
- **Electric Radiators:** Also called electric resistance heating, electric radiators are standalone units that generate heat by passing an electric current through a resistor.

Energy Efficient Technologies

- **Air-source Heat Pump:** Heat pumps pull heat from the surrounding air to warm the building. This can also be used for cooling. There are two types of heat pumps. They are 3-4 times more energy-efficient than fuel-based or electric resistance systems. This is because they move heat in and out of buildings instead of generating it.

- **Air to Air Heat Pump[36]:** Air-to-air heat pumps use heat from the outside air to heat your home through in-room blowers or vents. Air-to-air heat pumps are ideal for buildings without radiators or underfloor heating, and they can also provide space cooling. Some models can be combined with water tanks to provide hot water for bathrooms and kitchens.

- **Air to Water Heat Pump:** Air-to-water heat pumps use heat from outside air to heat water for radiators or underfloor heating. Air-to-water heat pumps are usually connected to a tank that provides hot water for heat distribution systems, bathrooms, and kitchens. Some models also provide space cooling.

- **Ground Source Heat Pump:** Explained in the chapter Cooling System Efficiency.
- **Solar Heaters:** Solar thermal heaters use solar collectors on the roof to produce hot water. While this hot water is mainly used in bathrooms and kitchens, it can also contribute to meeting space heating needs if combined with other heating systems such as heat pumps. This way they can lower the energy cost of the system with which they are combined and have a lifespan of 15-20 years.
- **Biomass Boilers:** Biomass boilers burn wood pellets, chips, or logs to heat water. This water then provides heat to radiators or underfloor systems. In addition to biomass boilers, there are other biomass heating systems such as stoves that heat a single room and that can be combined with a boiler for hot water for bathrooms and kitchens. Biomass heating systems can also be used in combination with solar thermal heaters or heat pumps. When installed in well-insulated homes, they can achieve significant energy bill savings – for example, up to 40% in France compared to gas boilers. They have a lifespan of 20-25 years.
- **District Heating**: Heat networks, available in some areas, are centralised systems distributing heat through underground pipes. District energy networks transfer heat to your radiators or underfloor systems and might also provide hot water for bathrooms and kitchens. Some systems can also cool connected homes. They run on various energy sources such as combined heat and power plants or large-scale heat pumps, depending on the network. In well-insulated homes they can achieve significant energy bill savings – for example, up to 25% in France compared to gas boilers. District heating networks have a lifespan of about 20-25 years, though the lifetime of the pipe network can exceed 30 years.
- **Radiant Heating:** There are three types of radiant floors – a). air heated radiant floors b). electric radiant floors c). hydronic radiant floors. While the first two are not very efficient the hydronic radiant floor is quite efficient. In this system, radiant heat is achieved by running hot water through pipes in the floor, roof slabs and also walls of the building. These pipes are then supplied with hot water which then heats the space. This does not require air as a means of transferring heat.

2.2.5 Ceiling fans

In climates where cooling is required, ceiling fans are the most energy-efficient of the various active cooling systems.

Ceiling fans are one of the simplest active cooling systems available. It is affordable, easy to procure and simple to install and operate. It is one of the most common cooling systems that is found in the warm climates across the world. Ceiling fans increase air movement, aiding human comfort by promoting evaporative cooling (evaporation of transpiration).[37]

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[35]Source: https://www.energy.gov/sites/default/files/2014/01/f6/homeHeating.pdf
[36]https://www.iea.org/energy-system/buildings/heating#home-heating-technologies
[37]EDGE User Guide Version 3.0a

Design Approach/Methodology

The design approach is a simple exercise. In smaller areas, one needs to position the fan either in the centre of the room or above the most used portion of the room (like the bed in a bedroom).

In larger spaces, one can use the table below to understand the size and number of fans required in a room. In the table below the 1st value is the diameter of the ceiling fan in metres and the 2nd value is the number of fans required.

For example, a room measuring 5m (width) and 8m (length) requires 2 numbers of 1.4m diameter fan. Figure 42 provides some recommendations regarding number and size, depending on the room dimension.

Figure 42. Recommended number and size of ceiling fans based on the room dimensions.

Room Width	Room Length										
	4m	5m	6m	7m	8m	9m	10m	11m	12m	14m	16m
3m	1.2/1	1.4/1	1.5/1	1050/2	1.2/2	1.4/2	1.4/2	1.4/2	1.2/3	1.4/3	1.4/3
4m	1.2/1	1.4/1	1.2/2	1.2/2	1.2/2	1.4/2	1.4/2	1.5/2	1.2/3	1.4/3	1.5/3
5m	1.4/1	1.4/1	1.4/2	1.4/2	1.4/2	1.4/2	1.4/2	1.5/2	1.4/3	1.4/3	1.5/3
6m	1.2/2	1.4/2	0.9/4	1.05/4	1.2/4	1.4/4	1.4/4	1.5/4	1.2/6	1.4/6	1.5/6
7m	1.2/2	1.4/2	1.05/4	1.05/4	1.2/4	1.4/4	1.4/4	1.5/4	1.2/6	1.4/6	1.5/6
8m	1.2/2	1.4/2	1.2/4	1.2/4	1.2/4	1.4/4	1.4/4	1.5/4	1.2/6	1.4/6	1.5/6
9m	1.4/2	1.4/2	1.4/4	1.4/4	1.4/4	1.4/4	1.4/4	1.5/4	1.4/6	1.4/6	1.5/6
10m	1.4/2	1.4/2	1.4/4	1.4/4	1.4/4	1.4/4	1.4/4	1.5/4	1.4/6	1.4/6	1.5/6
11m	1.5/2	1.5/2	1.5/4	1.5/4	1.5/4	1.5/4	1.5/4	1.5/4	1.5/6	1.5/6	1.5/6
12m	1.2/3	1.4/3	1.2/6	1.2/6	1.2/6	1.4/6	1.4/6	1.5/6	1.4/8	1.4/9	1.4/9
13m	1.4/3	1.4/3	1.2/6	1.2/6	1.2/6	1.4/6	1.4/6	1.5/6	1.4/9	1.4/9	1.5/9
14m	1.4/3	1.4/3	1.4/6	1.4/6	1.4/6	1.4/6	1.4/6	1.5/6	1.4/9	1.4/9	1.5/9

Source: EDGE User Guide Version 3.0a(referenced from the Indian National Building Code).

Potential Technologies

Ceiling fans can be used for both warm and cold climates. The blades of a ceiling fan usually will have a raised edge to pull or push the air up or down. In warm climates, the leading edge of the fan blade will be raised, and it pulls up the air. In cold climates, the heating requirement can be reduced by pushing down the warm air at the top of the room. In such cases, the raised portion of the fan blade will be at the trailing edge therefore pushing down the warm air.

Some fans come with both heating and cooling modes where the user can reverse the direction of rotation based on the need.

2.2.6 Economizers

Economizers are installed in air conditioning equipment to let fresh air into the system when the outdoor temperature matches the desired indoor temperature. This brings down the cooling energy consumed by the air-conditioning system shutting off the chiller operation.

They are an add-on feature to an HVAC air handling unit that draws in outdoor air and mixes it with return air from indoors. This is useful when the ambient temperature is within the human comfort range on many days in the year.

Design Approach/Methodology

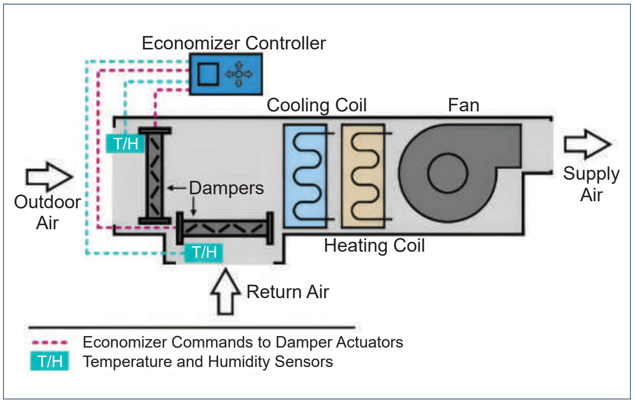
The HVAC consultant must assess from the local climate date, the number of days/hours that provide for ambient temperatures. If there are enough days/hours where the ambient temperature is lower or equal to the desired indoor temperature, then air-side economizers may be considered.

Potential Technologies

There are two types of economizers:

- **Air-side Economizers:** Air-side economizers is equipped with a sensor that measures the outside air temperature and humidity (see figure 43). Under comfortable ambient conditions, the outside air damper is fully opened, and the cooling compressors are turned off.

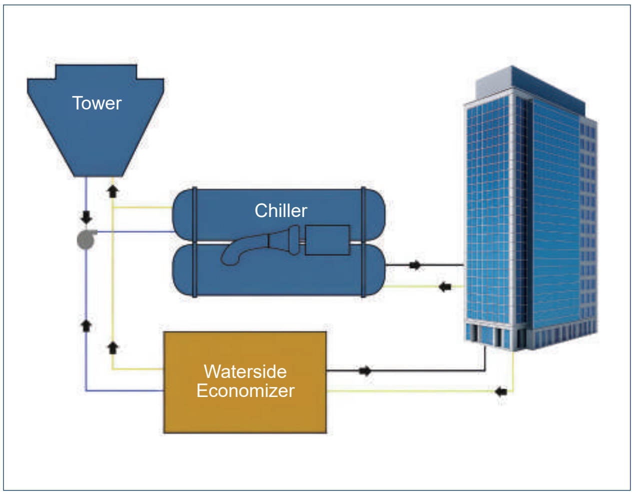
Figure 43. Diagram of a typical air economizer.



Source: Albedo Graphics.

- **Water-side Economizers:** A water-side economizer is used in a HVAC system that uses a water-based cooling system with a cooling tower (figure 44). The economizer enables the cooling tower to use the ambient cooler air to chill the water instead of using the chiller. This also aids in the case that the chiller undergoes a down-time for repairs and maintenance thereby increasing redundancy.

Figure 44. Diagram of a typical water-side economizer.



Source: Albedo Graphics.

2.2.7 Variable Speed Drives, and Variable Frequency Drives

The HVAC system consists of several fans and pumps. They also form a major source of the energy consumption. Variable Speed Drives (VSD) and Variable Frequency Drives (VFD) are electronic components that can vary the speed of the fans and pumps by varying the input voltage into the fans and pumps. They are in turn connected to sensors that gauge the amount of cooling or heating required for the various spaces.

Design Approach/Methodology

Cooling systems need to run at peak loads only at certain times. At most times they do run at part loads. The power demand of motors is directly proportional to the cube of the motor speed. So, even a 20% reduction in motor speed cuts down power consumption by about half[38, 39].

Potential Technologies

VSDs for Fans: Fans are used in chillers to pull air in to cool the water. These fans which are driven by electrically powered motors can be fitted with VSDs which regulates the input frequency and voltage.

VSDs for Pumps: Pumps are used to pump both water and refrigerants through the HVAC system. VSDs attached to the electrically powered motors that run the pumps adjust the flow of the refrigerant or water that flows through the system.

Figure 45, which has been adapted from the EDGE User Guide Version 3.0a, illustrates the benefits and limitations of VSDs for Pumps.

[38] EDGE User Guide Version 3.0a
[39] http://www.ecmweb.com/power-quality/basics-variable-frequency-drives

Figure 45. Benefits and limitations of VSDs for pumps.

Benefits and Limitations of VSDs for Pumps		
BENEFITS	Improved Process Control:	Provide regulation functions that improve the entire system and protect the other components of the system.
	Improved System Reliability:	Lower chance of failure
	Simplified pipe systems:	Elimination of control valves and by-pass lines
	Improved system lifetime:	Avoidance of soft start and stop, and resulting mechanical overload and peak pressures implied by on-off systems
	Reduced energy costs and maintenance:	Ability to modulate speed and torque at part-loads reduces energy use, and wear and tear
LIMITATIONS	Minimum speed may be required (typically 30%)	Manufacturers may require a minimum speed to avoid problems with overheating and lubrication

Source: EDGE User Guide Version 3a.

2.2.8 Fresh Air Pre-conditioning System

Pre-conditioning is the act of extracting heat (in a heating system) or the coolth (in a cooling system) of the outgoing air so that the difference of temperature between the outgoing exhaust air and the incoming fresh air is reduced. This reduction in temperature means that the HVAC system needs to heat/ cool the incoming fresh air to a lesser degree thereby saving precious energy.

Design Approach/Methodology

The measure of efficiency of the system is called Temperature Transfer Efficiency (TTE)40. The formula is as follows:

$$\mu_t = \frac{(T_2 - T_1)}{T_3 - T_1}$$

Where = Temperature Transfer Efficiency (%)

T_1 = Outside air temperature before heat exchanger (°C)

T_2 = Air temperature after heat exchanger (°C)

T_3 = Exhaust air temperature before heat exchanger (°C)

Potential Technologies

There are 2 types of preconditioning systems:

- **Heat Recovery Wheel (HRW):** Using a heat exchanger, these use a heat exchange wheel that extracts the heat from the outgoing air (in the case of a heating system) or cools down the incoming air (in the case of a cooling system). The fresh and exhaust air streams flow without getting in touch with each other. It is mostly used in heating solutions but can also be used for cooling.

- **Sensible heat recovery system:** In this type of HRW, the only the sensible heat (represented by the dry bulb temperature) is used. The moisture in the incoming or outgoing air remains unaffected.

- **Total heat recovery** (sensible and latent heat) also known as Enthalpy or Desiccant Wheel: In this type of HRW, the sensible and latent heat are both transferred. This is especially useful in low humidity environment, where it is advantageous to humidify the incoming air. The HRW has a desiccant that absorbs or adsorbs the humidity from the outgoing air and passes it on the incoming air.

- **Indirect evaporative cooling (IEC):** Evaporative cooling is the phenomenon of water or any liquid absorbing the latent heat from the atmosphere and changing state from liquid to gas. In the process, the air around becomes cooler. In the case of an IEC, the water used for the evaporative cooling process does not encounter the incoming or outgoing air as a heat exchanger is used and hence does not humidify the air. This is used for cooling solutions.

2.2.9 Refrigerant Management

Conventional refrigerants have a high global warming potential (GWP). At the end of life of an equipment, a leak of the refrigerant can cause a highly disproportionate impact on global warming.

Design Approach/Methodologies

GWP is measured using a 100-year value for comparison, where the 100-year GWP of Carbon Dioxide (CO2) is taken as 1[41]. The GWP of the most common refrigerant used today R-22, has a GWP of 1,810[42].

The design team must explore the following steps in their journey towards reducing the GWP of the refrigerants used.

[40]EDGE User Guide Version 3.0a

- Reduce the need for air-conditioning by designing the building to ensure passive cooling or heating.
- Reduce the air-conditioning area.
- Specify air-conditioning systems that use no refrigerants.
- Specify refrigerants with low GWP potential.

Potential Technologies

Some of the important alternatives of low GWP refrigerants are provided below.

Table 4. Alternatives of low GWP refrigerants.

Equipment Type	Common Refrigerants	Low GWP Alternative Refrigerants
Refrigerators and Freezers	HFC-134a	HC-600a (iso-butane), HFO-1234yf
Small room split air-conditioners	HFC-410A, HFC-407C	HFC-32 (R-32) HFC-446A, HFC-447A, HFC-452B
Ducted Air-conditioners	HFC-410A, HFC-407C	HFC-32, R-290, HFC-446A, HFC-447A, HFC-452B
Heating-only heat pump	HFC-410A, HFC-407C	HFC-32, HFC-446A, HFC-447A, HFC-452B
Multi-room VRF air-conditioners	HFC-410A	HFC-32, HFC-446A, HFC-447A, HFC-452B
Water chillers for central air-conditioners	HFC-134a, HFC-410A	HFO-1234ze, HFO-1234yf, HFO-1233zd, R-717 (ammonia)
District cooling	HFC-134a	HFO-1234ze, HFO-1234yf, HFO-1233zd, R-717 (ammonia)
Specialist refrigeration (ice rinks and ski centres)	HFC-134a, HFC-404A	HFO-1234ze, HFO-1234yf, HFO-1233zd, R-717 (ammonia), R-744 (CO2)

Source: Adapted from Fig 13, EDGE Guidance Document for Refrigerant Selection to Reduce Climate Impact based on the Montreal Protocol[43]

2.2.10 Demand Control Ventilation using Carbon Monoxide (CO) and Carbon Dioxide (CO2) Sensors

Large buildings with higher concentration of occupants require the Carbon Dioxide amounts in the air to be controlled. The conventional way of controlling CO_2 is by having constant or predetermined ventilation rates based on the maximum demand. However, this is not energy efficient as the fans tend to run at full capacity even during low occupancy periods.

Enclosed garages usually have exhaust systems that run continuously to prevent concentration of CO from vehicle exhaust.

Design Approach/Methodology

Demand controlled ventilation (DCV) consists of installing sensors in the HVAC system that measure CO or CO_2 at various locations. The sensors relay the information when gas levels measured in parts per million (PPM) exceed safe limits and switches on the fans to bring in fresh air.

This results in energy efficiency of the system while also extending the equipment life.

Potential Technologies

ASHRAE Standard 90.1-2004 recommends that the building incorporate any type of DCV when the building has a density greater than 100 people and when the AHU has an outdoor capacity greater than 3,000 ft^3/min (85 Cum/min). The following specifications are recommended in standard for the selection of the sensor:

- Range: 0 – 2,000 ppm
- Accuracy (including repeatability, non-linearity and calibration uncertainty): +/- 50 ppm
- Stability (allowed error due to aging): <5% Full Scale for 5 Years
- Linearity (maximum deviation between a reading and the sensor's calibration curve): +/-2% Full Scale
- Manufacturer recommended minimum calibration frequency: 5 years

2.2.11 Thermostat Controls

Use of thermostats is important in a heating or cooling systems. While use of thermostats is important it is also important to modulate behaviour around using thermostat temperature setting.

[41] EDGE User Guide Version 3.0a
[42] https://ww2.arb.ca.gov/resources/documents/high-gwp-refrigerants#:~:text=The%20most%20common%20refrigerant%20today,a%20ton%20of%20carbon%20dioxide.
[43] https://edgebuildings.com/wp-content/uploads/2022/04/170403-RefrigerantSelection_EDGE_MontrealProtocol.pdf

Energy can be conserved by programming thermostats to slightly higher temperatures in warm climates or lower temperatures in cold climates. Even a 1°C difference can make significant changes in the energy consumption of the HVAC system.

Design Approach/Methodology

Heating systems many times lack a thermostatic valve to control the amount of heat being transferred to various spaces. If the radiators in individual spaces do not have a thermostat, then the room can get over or under heated. In the case of overheating, the occupants will then need to open windows to cool the air down which results in loss of the heating energy.

The MEP consultant needs to integrate thermostatic valves in individual spaces in the heating system design.

Potential Technologies

Thermostatic valves fitted on radiators will aid the occupants to control the heat required in the room, thereby resulting in greater system efficiency.

As a part of behaviour management, users can set lower temperatures in a heating context and higher temperatures in a cooling context. The lower the difference between the external temperature and the internal temperature, the higher will be the energy efficiency of the system.

2.2.c) Other Equipment

2.2.12 Domestic Hot Water System Efficiency

Water heating has conventionally been done with either electricity or fossil fuel sources. Switching to more efficient or alternate systems of fuel would aid in reducing the resultant GHG emissions.

Design Approach/Methodology

The various measures for assessing the efficiency of a hot water system are like the space heating system. Coefficient of Performance (COP) or Thermal Efficiency can be used.

MEP consultants will need to understand the type of technologies available in the market and make recommendations. It would be useful also to explore a combination of technologies based on the varying climatic conditions around the year, the project requirement and pattern of use of hot water.

Potential Technologies

There are three technologies that can provide energy efficiency in hot water.

- **Solar Water Heaters[44]:** There are two types of solar hot water collectors namely flat plate and tubular (figure 46). The system consists of a flat panel that is laid exposed to the sun at an angle that is approximately equal to the latitude of the location and facing the equator. The cold water runs through the panel and then is stored in an insulated hot water tank. In the case of varying availability of direct sun, a second source of heating can be attached to the solar hot water system. It is common to use the solar heater as a primary system and a heat pump as a secondary system that gets activated when there is not enough sunlight.

Figure 46. A typical solar hot water system – collector plate with the cylindrical hot water tank.

Source: Creative Commons License. Photo credit: Solar Prince Hot Water.

- **Heat Pumps:** Heat pump water heaters (figure 47) take heat from the surrounding air and transfer it to the hot water. This is like the work done by the condenser unit in an air-conditioning system but in reverse.

Figure 47. Image of a typical air source heat pump.

Source: Creative Commons License.
Photo credit: Southend-on-sea City Council.

The EDGE User Guide Version 3.0a provides the various types of heat pumps in the table below.

[44] https://www.energy.gov/energysaver/solar-water-heaters?

Table 5. Types of heat pumps.

Type	Process
Heat Pump Water Heaters	A low-pressure liquid refrigerant is vaporized in the heat pump's evaporator and passed into the compressor. As the pressure of the refrigerant increases, so does its temperature. The heated refrigerant runs through a condenser coil within the storage tank, transferring heat to the water stored there. As the refrigerant delivers its heat to the water, it cools and condenses, and then passes through an expansion valve where the pressure is reduced, and the cycle starts over.
Air-source Heat Pumps	These systems are called "integrated" units because they integrate the heating of domestic water with a house space-conditioning system. They recover heat from the air by cooling and transferring heat to domestic hot water. Water heating can be provided with high efficiency with this method. Water heating energy can be reduced by 25% to 50%.
Ground-Source Heat Pumps	In some Ground-Source Heat Pumps, a heat exchanger, sometimes called a "desuperheater," removes heat from the hot refrigerant after it leaves the compressor. Water from the home's water heater is pumped through a coil ahead of the condenser coil, in order that some of the heat that would have been dissipated at the condenser can be used to heat water. Excess heat is always available in the summer cooling mode and is also available in the heating mode during mild weather when the heat pump is above the balance point and not working to full capacity. Other ground-source heat pumps provide domestic hot water (DHW) on demand: the whole machine switches to providing DHW when it is required. Water heating is easier with ground-source heat pumps because the compressor is located indoors. They generally have many more hours of surplus heating capacity than required for space heating, because they have constant heating capacity. Like air-source heat pumps, ground-source heat pumps can reduce water heating consumption by 25% to 50%, as some have a desuperheater that uses a portion of the heat collected to preheat hot water, and also can automatically switch over to heat hot water on demand.

Source: EDGE User Guide Version 3.0a

- **Boilers:** Boilers typically use fossil fuels like Liquefied Petroleum Gas (LPG) or Natural Gas. However, there are high efficiency boilers that provide good energy savings. A few of the examples are provided below.

Table 6. Examples of boilers.

Type	Description
Condensing boiler	The only boilers likely to achieve efficiency level of at least 90%. They extract latent heat from the waste gases' water vapor that is generated by the combustion process. To minimize the cost of a boiler installation, hot water demand should be minimized before sizing the system.
Combi boiler	This is a type of condensing boiler that provides both heating and hot water without needing a separate tank.
Low temperature hot water boilers	Produce hot water at around 90ºC, which is then distributed via pipework to a hot water storage tank. These boilers commonly run on Natural Gas but may also be LPG.
High-efficiency boilers	These generally have lower water content, larger heat exchanger surface areas and greater insulation of the boiler shell. They are suitable to applications where a higher water temperature is required, such as kitchens, laundry and showers.
"Staged" multiple-boiler system	Reduces the amount of time in which a boiler is running at less than peak load, since only few boilers run depending on the demand. So, in the peak times more boilers are in use while during the off-peak times only the boilers to cover a small demand will be active.
Modular boiler systems	Series of boilers linked together to meet different demands; they are suitable for buildings or processes with a significant variable hot water/heating demand. Modular systems are generally composed of several identical boiler units although a mix of condensing and conventional boilers could be used.

Source: The Carbon Trust[45]

[45]The Carbon Trust. UK: March 2012. https://www.carbontrust.com/media/7411/ctv051_low_temperature_hot_water_boilers.pdf

2.2.13 Domestic Hot Water Preheating System

In cold climates, heat can be extracted from wastewater through heat exchange which can then be reused for water heating. This will reduce the amount of electrical or fossil fuel energy used in the building for hot water.

Design Approach/Methodology

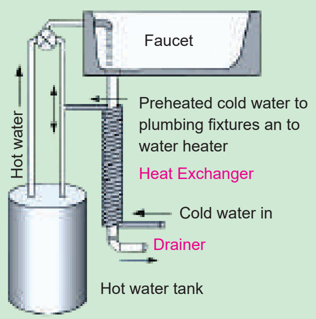
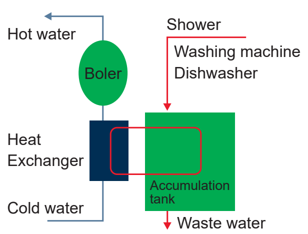
During the project design process, the mechanical, electrical, and plumbing (MEP) consultants can evolve an integrated approach involving hot water system design, HVAC system design and the electrical design. It is necessary to view the design holistically to explore what sources of waste heat can be used to pre-heat or heat the water.

Potential Technologies

Broadly waste heat will have three sources:

- **Grey Water Heat Recovery:** Grey water is defined as wastewater from wash basins, showers, kitchen sinks, laundry, spa area, etc. This water will contain heat that can be then transferred to the incoming cold water (either directly to the faucets or to the hot water system) through a heat exchanger. Various commercial solutions are available ranging from non-storage systems to centralised heat recovery. EDGE User Guide Version 3.0a describes as few systems as in figure 48 below.

Figure 48. Grey water heat recovery systems.

Types		Description
Spiral design (non-storage)		Hot water runs through a series of narrow spirals in which it is forced to spin alongside the walls of the heat recovery pipe. The cold water then comes as a counter flow in a spiral pipe swirled around the outside. This design requires small gaps (2cm) to avoid plugging. It is commonly used in residential and small hotels or hospitals. Instead of a spiral system, tubular or rectangular heat exchanger systems can also be used.
Accumulation tank (centralized)		Gray water from different sources is accumulated in a tank, which has an electrical coil (close loop) that transfers the heat to the cold water passing through the gray-water heat recovery unit outside the tank.
Parallel heat exchanger (centralized)		This is ideal for larger buildings such as hospitals, as it collects the gray water in one pipe that passes through the heat exchanger. It is like spiral design but used centrally rather than in each unit.

Source: EDGE User Guide Version 3.0a.

- **Heat Recovery from Chiller:** Air-conditioning systems reject large amounts of waste heat during the space cooling process. This heat can then be captured by a heat exchanger and routed back to the water heating system.
- **Generator Waste Heat:** Diesel generators for electricity operate a low efficiency and typically generate large amounts of heat. This heat can be utilised using heat exchangers for heating water.

2.2.14 Power factor correctors (PFC) and Regenerative Braking of Lifts

Power quality is essential for efficient equipment operation, and power factor, which is the measure of how efficiently incoming power is used in an electrical installation, contributes to this. PFCs are electronic circuits that can increase the efficiency of equipment.

Another way to save energy is to use lifts that have a regenerative braking technology. Usually, when the lift descends, braking is applied and therefore kinetic energy in the form of heat is released. This can be converted to electrical energy and thus can bring down the energy used by the lift.

Design Approach/Methodology

The MEP/Electrical Consultant may include various PFCs into the overall design. The architect can specify lifts with regenerative braking.

Potential Technologies

Some of the PFCs that are available are as follows[46]:

- Voltage Regulators
- Isolation Transformers
- Noise Filters
- Power Line Conditioners
- Harmonic Current Solutions
- Uninterrupted Power Supply (UPS)

Lifts with Regenerative Braking: Most established lift companies manufacture lifts with regenerative braking system.

2.3. Supply Side Measures

Renewable energy technologies such as solar photovoltaic and wind turbines enable building owners to generate their own energy, reducing reliance on fossil fuel–based energy sources.

2.3.1 Renewable Energy

Electricity production from conventional sources of fossil fuels is responsible for a considerable amount of GHG emissions. As building electricity consumption makes up for a significant portion of electricity consumption in the country, it is important that building owners switch to renewable sources of energy.

Electricity produced from Solar Photovoltaic (PV) panels, wind turbines and biomass generators are considered to be "clean" energy and contribute very little to GHG emissions.

Design Approach/Methodology

The building owner has the following options of availing renewable energy.

- **On-site renewable energy:** In an ideal situation, a building should be able to produce its own energy. If there is sufficient space, a renewable energy plant could be set up within the site.
- **Off-site renewable energy:** If a building is unable to produce its own renewable energy, the next option would be able to contract with a renewable energy supplier. In many countries, this is now possible.
- **Carbon Offsets:** Carbon offsets are used when a building is unable to achieve the GHG emissions reduction through its design. Each carbon offset represents the mitigation of 1 ton of carbon dioxide or equivalent greenhouse gas. Carbon offsets can be purchased from recognized platforms and are sold by those who have achieved caron emissions reductions in their projects thereby incentivizing them to have followed the green path.
- **Net Zero Energy and Net Positive Energy:** Net zero energy can be achieved if the building is able to produce all the energy that it consumes from renewable sources. If the building produces more renewable energy than what it consumes, then it would become a net positive energy building.

  Net zero and net positive approach would bring down the carbon footprint of the building significantly.

Potential Technologies

The most prominent renewable energy technologies are as follows:

- **Solar PV Panels:** Solar photovoltaic (PV) panels have been the most popular source of renewable energy as sunlight is ubiquitously available in most seasons especially in the tropical and temperate zones. The panels are light and can be mounted easily on the rooftop or on the ground (see figure 49). There is a version of PV panel that can be integrated into the vertical glazing of a building. These are called Building Integrated PV (BIPV) panels and are more effective in higher latitudes where the sun angle is low.

  The output is measured in Watt-peak (Wp) or Kilo-Watt-peak (kWp). Each panel is typically 1m x 2m and can produce as much as 600 Watt-peak. The panel efficiencies have been consistently being increased over the years.

Figure 49. Example of Solar PV Panels.

Source: Creative Commons License.
Photo credit: Fernando Tom.

[46]https://electrical-engineering-portal.com/power-correction-devices

- **Wind Turbine:** Small wind turbines ranging from 400W to 20 kW can be operated on buildings. The important aspect is the make a survey of the wind speeds and patterns in the location.
- **Biomass:** Biomass is a collective term for plants, wood, food waste, animal waste and agricultural waste. It is an alternative to the fossil fuels as it is a renewable source of energy. Some organic material is also converted to biofuels that can be used in place of diesel or petroleum. Biomass is controversial as it still contributes to GHG emissions. Hence the entire supply chain needs to be studied to check if the source of biomass energy under consideration is carbon neutral or carbon negative. Biomass is considered a transitional fuel away from fossil fuels.
- **Bio-gas:** Bio-gas is a mixture of Carbon Dioxide and Methane that is released on the breakdown of organic matter. A bio-gas digester enables the collection of the organic matter and collects the gas which then is routed to a generator that produces electricity or it could be used as cooking gas. The waste used is usually animal waste, plant waste, kitchen leftovers, and human waste, among others.)

2.4. Knowledge and Behaviour management

Knowledge of how energy is used is critical in managing behaviour regarding energy use. As building systems are getting increasingly complex, the manner in which energy is used in a building have many nuances. The underlying reasoning in this section, is that data on how much, where and when energy is used should provide building owners and managers with information of how behaviour change of the users can increase or decrease energy usage. Some of the methods of managing knowledge and behaviour is explained below.

The following measures may help to achieve this:

2.4.1. Smart Meters for Energy
2.4.2. Building Energy Management System
2.4.3. Building Commissioning
2.4.3. Energy Efficient Appliances

2.4.1 Smart Meters for Energy

Smart metering enables the energy consumption of various components of the building to be measured, for example, lighting, pumps, and HVAC systems. Smart metering provides data that can be used to increase energy efficiency.

Design Approach/Methodology

The smart meter must show the readings across various time periods like last hour, last day, last 7 days or last 12 months. Smart meters (figure 50) must also be able to measure aspects like:

- Electricity use and real power1
- Analyse various measurements

With smart meters, the users must be able to analyse, appreciate, understand and act upon energy usage patterns towards creating substantial savings in energy consumption.

Potential Technologies

Smart metering is designed to provide real time information about their energy consumption patterns. It consists of a detection unit (the transmitter) that is fixed to an existing utility meter and tracks the energy use. The display unit receives a wireless signal from the transmitter and displays the consumption information in real time. Many companies offer online monitoring systems.

Figure 50. Example of smart meters

Source: Creative Commons License.
Photo credit: Mirko Tobias.

Smart meters can be fixed for different uses like cooling, lighting, hot water, plug loads etc. This will provide the user with granular data on their usage patterns.

2.4.2 Building Energy Management System

Building energy management systems (BEMS) monitor use of various resources in the building and provide data that can be used to reduce energy use (see figure 51). It can also automate various functions and can take over the controls of various energy consuming devices across the building.

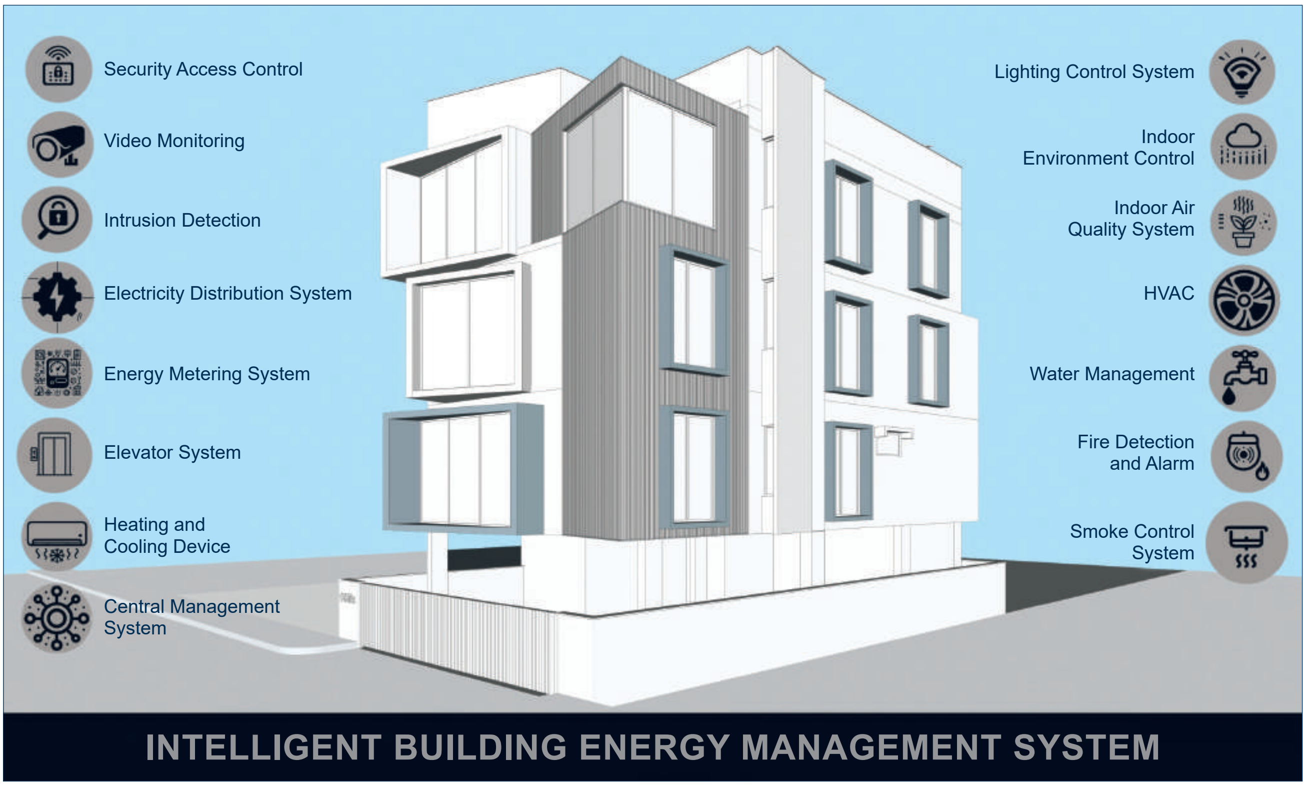
Design Approach/Methodology

A BEMS has several important components:

- **User Interface:** The user interface provides the building manager with all the information on the energy usage of the building. This could be through electronic dashboards on software applications on computers, tablets or mobile phones. By providing real time insights, the operators can optimize the building energy performance.

- **Central Management Software:** This is the central processing component of the system and analyses and stores data.
- **Sensors and Meters:** Sensors and meters are installed at critical locations throughout the building. They provide information on the status of performance of the various components of the building like the chiller, the Air Handling Units (AHUs), the lighting power, etc.
- **Controllers:** The system is connected to a series of controllers that can adjust settings in the HVAC and lighting by turning them on and off or modifying their performance based on the occupant load of the building.
- **Communication Networks:** The network is the backbone of the BEMS and helps transmit data between the various parts either in wired or wireless manner.

Figure 51. Diagram showing various components of a Building Energy Management System



Source: developed by authors, adapted from Solid Pro (solidpro-es.com).

Potential Technologies

The market contains different products and some of them have also started to harness the power of the Internet of Things (IoT). Artificial Intelligence (AI) and machine learning is also being used to learn patterns of building usage and adapt its responses according to the occupant behaviour.

2.4.3 Building Commissioning

Building commissioning is the practice that ensures that all building systems (HVAC, electricity, fire safety, water supply and waste management) are all functioning as per the original design intent. This is an important aspect in ensuring that the components of a building run smoothly in tandem with the use case of the building and that the minimum amount of energy is used.

Design Approach/Methodology

It is important to document the entire design, execution and operation process of the building to ensure a smooth and efficient performance of the building (see figure 52).

There are various stages in the process:

- **Pre-design stage:** The pre-design stage consists of development of the Owner's Project Requirements (OPR) and the basis of design (BOD).
- **Design stage:** This stage consists of the development of the design documents and the commissioning plan.
- **Construction stage:** This involves the installation, testing and verification of building systems.
- **Acceptance stage:** At this stage the buildings systems is accepted by the owner and the commissioning authority. At this stage various tests like thermal imaging to detect heat leakages, conducting blower door tests to check air tightness, checking the lighting levels, etc. may be carried.

- **Operations stage:** This stage involves the training of the owner's staff and the on-going commissioning of the building systems.

Figure 52. Image showing an engineering technician checking the systems.

Source: Creative Commons License.
Photo credit: Technicians Make It Happen.

As per LEED NC, the building commissioning authority must do the following:

- Review the OPR, BOD, and project design.
- Develop and implement a commissioning plan.
- Confirm incorporation of commissioning requirements into the construction documents.
- Develop construction checklists.
- Develop a system test procedure.
- Verify system test execution.
- Maintain an "issues and benefits" log throughout the commissioning process.
- Prepare a final commissioning process report.
- Document all findings and recommendations and report directly to the owner throughout the process.

Further LEED NC states that the commissioning authority must prepare and maintain a current facilities requirements and operations and maintenance plan that contains the information necessary to operate the building efficiently. The plan must include the following:

- a sequence of operations for the building;
- the building occupancy schedule;
- equipment run-time schedules;
- setpoints for all HVAC equipment;
- set lighting levels throughout the building;
- minimum outside air requirements;
- any changes in schedules or setpoints for different seasons, days of the week, and times of day;
- a systems narrative describing the mechanical and electrical systems and equipment;
- a preventive maintenance plan for building equipment described in the systems narrative; and
- a commissioning program that includes periodic commissioning requirements, ongoing commissioning tasks, and continuous tasks for critical facilities.

Potential Technologies

There is no specific technology involved. This is a process.

2.4.4 Energy Efficient Appliances

Energy efficient appliances are usually installed by the building users after the commissioning of the building. However, it is important that energy efficient appliances are used by the end users.

Design Approach/Methodology

Many countries now have a energy rating system for appliances. The appliances that need to be considered are:

- Refrigerators and Freezers
- Washing Machines
- Clothes Dryers
- Electric Water Heaters
- Microwave Ovens
- Domestic and Commercial Ovens
- Computers
- Televisions

It is suggested that the building design professionals orient and influence the clients/end-users towards selecting energy efficient equipment.

3. Water Efficiency Measures

Water efficiency affects the finite water resources of a region and energy efficiency. With shifting climate patterns, access to water is becoming difficult in many regions around the world, so water efficiency is critical.

3.1.Demand Side Measures

Demand signifies the amount of water that building users need for optimal functioning. The aim of a code must be to reduce the water demand of buildings.

The following measures may help to achieve this:

3.3.1. Water-efficient fixtures

3.3.2. Water-efficient irrigation system

3.3.3. Swimming pool covers

3.1.1 Water-efficient fixtures

Water use can be reduced by using the most water efficient fixtures available on the market that provide sufficient “wash feel” and hygiene. Water efficiency is measured according to flow rate, expressed in litres per minute.

Design Approach/Methodology

Water efficiency is measured by the flow rate of water and is expressed in litres per minute (lpm). Flow rates change with the pressure of the water supply. Usually, most manufacturers will quote the flow rate at 3 bar (43.5 psi) pressure.

Many countries have begun recommending or mandating the flow rates for various types of fixtures.

The Eco Label[47] programme from the European Union have a series of standards, as reflected in table 7.

Table 7. EU Eco Label Standards.

Product	Maximum allowed flow rate
Basin taps without flow limiting device	6.0 lpm
Basin taps with flow limiting device	8.0 lpm
Showerheads and showers	8.0 lpm
Kitchen taps without flow limiting device	6.0 lpm
Kitchen taps with flow limiting device	8.0 lpm

Source: the EU Ecolabel for Sanitary Tapware[48]

Likewise, the Bureau of Indian Standards[49] have a specific Water Efficiency Rating criteria, which is specified in the “Water Efficient Plumbing Products” document (IS17650:2021 -Part 1 and 2), as shown in table 8.

Table 8. Water Efficiency Rating criteria by the Bureau of Indian Standards.

Product	Unit of consumption	Rating Criteria		
		1-star	2-star	3-star
Water closet – full flush	Litres/flush	< 6.0	< 4.8	< 4.0
Water closet – half flush	Litres/flush	< 3.0	< 2.8	< 2.0
Urinal	Litres/flush	< 3.0	<2.0	< 1.0
Metered faucets for basin	Litres/use	1.0	0.8	0.6
Metered faucets for urinal	Litres/use	3.0	2.0	1.0
Wash basin faucets	Litres/Minute	8.0	6.0	3.0
Kitchen sink faucets	Litres/Minute	8.0	6.0	4.5
Over-head shower	Litres/Minute	10.0	8.0	6.8
Hand-held shower	Litres/Minute	8.0	6.0	4.0
Hand-held ablution spray	Litres/Minute	6.0	5.0	4.0

Source: Water Efficient Plumbing Fixtures[50]

[47]Sanitary Tapware Factsheet: ec.europa.eu/environment/ecolabel/documents/Sanitary%20Tapware%20Factsheet.pdf
[48]Ibid.
[49]Part-A-Chapter-15-Water-Efficient-Plumbing-Fixtures: mohua.gov.in/upload/uploadfiles/files/Part-A-Chapter-15-Water-Efficient-Plumbing-Fixtures.pdf
[50]bid.

Potential Technologies

Faucets: Faucets have aerators fixed at the mouth of the faucet that introduce air into the water stream thereby increasing the wash feel. Auto shut-off faucets also called self-metering or metered faucets are activated by a push action or electronic sensors that allow the water to flow for a set amount of time. It is usually 15 seconds. This type of a faucet is ideal for public toilets (see figure 53).

Figure 53. Examples of aerators fixed to faucets.

Source: Creative Commons License.
Photo credit: Leo Reynolds.

Showers: Flow rates in showers are controlled by introducing air into the water stream, thereby creating turbulence which increases the "wash feel" while conserving water.

Water Closets (WC): The flushing system in most water closets now are fitted with dual flow flushes containing a full flush button and a half flush button. This gives the user the choice to press the right button based on the nature of use. There are also electronic sensors that can be fitted to the WC system.

Urinals: Urinals can be flushed either using an electronic sensor or auto-shut off tap. Some auto-shut off taps come with a half and full flush choice.

3.1.2 Water-efficient irrigation system

Water efficient irrigation system for landscaping will reduce the requirement of water from the municipal water supply system or other sources of water that are traditionally used (see an example of drip irrigation in figure 54). It also saves the cost of fertilizers and maintenance while preserving the plant and wildlife habitat.

Design Approach/Methodology

According to studies, "up to 50% of the water applied to lawns and gardens is not absorbed by the plan. It is lost through evaporation, runoff or being pushed beyond the root zone because it is applied too quickly or more than the plants' needs.[51]"

Water efficient irrigation[52] is measured by the amount of water used per square metre of irrigated area per day. The water shall be measured excluding rainwater.

$$\text{Landscape water consumption} = \frac{(\text{Landscape Water Requirements} - \text{Rain Fall Volume})}{\text{Total Outdoor Landscaping Area}}$$

Where;

Landscape Water Requirements = Average amount of water needed per day for all the plants within the outdoor landscaped area (in Litres)

Rain Fall Volume = Daily average rain fall (in litres)

Total Outdoor Landscaping Area = Area of outdoor lawns, gardens and ponds (m^2)

Figure 54. Drip Irrigation.

Source: Creative Commons License.
Photo credit: Nanda Kishore Reddy.

[51]EDGE User Guide Verson 3.0a and US Environmental Protection Agency. http://www.epa.gov/WaterSense/docs/water-efficient_landscaping_508.pdf
[52]EDGE User Guide Version 3.0a

Potential Technologies

Some of the important interventions that needs to be done are as follows:

- Use native plans which require very little amount of water than normal rainfall received locally.
- Create different zones of landscaping that have different water requirements. This will allow the property owner to water plants based on the frequency of each set of plants.
- Use of drip irrigation[53] or under surface irrigation that requires much lesser water compared with conventional systems such as sprinklers.

3.1.3 Swimming pool covers

Covering pools when they are not in use prevents water from evaporating and also from heat losses in the case of heated pools in cold climates.

Design Approach/Methodology

The pool must be designed to be covered fully (see figure 55). The following benefits accrue from the usage of pool covers:

- Reduced water consumption: When the pool is covered, it minimises the evaporation losses from the pool.
- Reduced energy consumption:
- Reduced heat losses: In the case of heated pools, the pool will lose heat when exposed to atmosphere when the conditions outside are colder. A pool cover will insulate the pool from losing heat and hence the heater efficiency will be greatly improved.
- Reduced need for mechanical ventilation: In a covered pool context, the evaporation of the pool will cause area to humidify causing discomfort. This will reduce as the evaporation is limited and hence the need to run the mechanical ventilation to exhaust the space.
- Reduced maintenance
- Reduced treatment chemicals consumption: Usually an open pool will have debris from the surroundings like debris from leaves, dust from the environment, etc. When the pool is covered it remains clean and hence the need to treat the pool with chemicals reduces.
- In a covered space, the pool causes a great deal of humidity acceleration of rusting of metal parts and mould growth.

Figure 55. Example of swimming-pool cover.

Source: Albedo Graphics.

Potential Technologies

The pool cover must have the following characteristics:

- It should be fully fitted to the pool without any gaps where the water is exposed to the atmosphere.
- It should be of a thick and durable material.
- It should have resistance to the chemicals used for pool cleaning and treatment as well as to UV light from the sun.
- It must be insulating to prevent heat from escaping.

3.2. Supply Side Measures

Harvesting rainwater and using recycled water enable building owners to generate their own water supply, which reduces reliance on resources such as rivers and lakes.

The following measures may help to achieve this:

3.2.1. Condensate recovery

3.2.3. Wastewater Treatment and Re-use

3.2.4. Roof rainwater harvesting

3.2.1 Condensate recovery

Condensate, water that collects and drips out of the compressor of an air conditioner, can be captured and recycled.

Design Approach/Methodology

Air-conditioning systems usually dehumidify the air to the necessary levels while supplying the same to the indoor space (figure 56). This humidity is retained as condensate water that is usually wasted. The system can generate between 11 to 40 litres per day per 100

[53] https://www.microdrips.com/en/blog/drip-irrigation/choose-drippers-watering-time/?

SqM of conditioned space[54] depending on the HVAC system, operational hours and the atmospheric humidity.

However, this water needs to be treated as it could contain harmful bacteria like Legionella. After treatment, it can be used for various purposes such as irrigation, for cooling towers, for toilets and urinal flushing, laundry and washing and for landscape purposes.

Figure 56. Air-conditioning outdoor unit with condensate water collected in a plastic receptacle.

Source: Albedo Graphics.

Potential Technologies

The MEP Consultant must ensure that a condensate recovery system is fixed into the HVAC system. The water must be collected and them conveyed through pipes into the water storage tank or the rainwater collection tank, if present.

3.2.2 Wastewater Treatment and Re-use

About 80 to 85% of water consumed in a building is ejected as wastewater that must be treated for hygiene and safety before it can be disposed of. Most cities and towns have a centralized facility or require that buildings larger than a certain size have their own sewage treatment plants (STP) (see an example on figure 57).

Design Approach/Methodology

Wastewater can be categorised as two types:

- **Grey Water:** Grey water is the wastewater that originates from faucets, showers, laundry and spa.
- **Black Water:** Black water includes grey water along with solid waste from toilets and kitchens that require more intensive treatment.

The MEP consultant needs to create a water balance model to calculate the total water requirements of the building, the water that is generated, the water that can be treated and re-used. This will provide the basis for freshwater demand.

Treated water can be re-used in the following ways:

- Re-use for non-potable purposes: Most sewage treatment plants provide treated water that can be used for toilet flushing and landscaping. Such water usually has a biological oxygen demand of less than 10 parts per million of bacteria present in water.

Treated water standards must be in accordance with the requirements of Order No. 876 of the Minister of Health of the Republic of Armenia dated 25.12.2022.

Figure 57. View of a sewage treatment plant, at the Yenepoya Medical College Campus, Delarekatte, Mangalore, Karnataka, India.

Source: Creative Commons License.
Photo credit: India Water Portal.

Potential Technologies

Dual piping system must be included in the drawing. Dual piping consists of two supply pipes namely one pipe for freshwater supply and another for treated water supply.

There are several wastewater treatment technologies available in the market and needs to be decided on by the MEP consultant after studying the requirements of the project.

3.2.3 Roof rainwater harvesting

Harvesting rainwater reduces dependence on piped potable water. Rainwater can be harvested by collecting

[54] Alliance for Water Efficiency website. http://www.allianceforwaterefficiency.org/condensate_water_introduction.aspx

it and recharging it into the ground or can be collected and filtered and used to augment or replace conventional water supply sources.

Design Approach/Methodology

Rainwater harvesting can be done up at multiple levels (see an example on figure 58).

At the site level, the important consideration is to keep the hard surfaces to the minimum required. This has been dealt in the Site and Context chapter.

At the building level, open to sky surfaces will receive the rainwater which needs to be diverted to a storage tank and a treatment system.

On flat roof surfaces, a smooth well-maintained surface is desirable to maximise the amount of water collected. Rainwater down-take pipes need to be installed to convey the water to the treatment tank.

Figure 58. Example of rainwater harvesting with rainwater down take pipes from the roof in Kiribati.

Source: Creative Commons License.
Photo credit: Dept of Foreign Affairs & Trade, Kiribati.

On sloped roof surfaces, a gutter provided along the eaves (lower edge of the roof) shall convey the rainwater to the rainwater down-take pipes.

Important aspect to note is that the roofs should be cleaned well on a regular basis so that the filtration load on the treatment system load is reduced.

To calculate the amount of rainwater that can be collected, the following can be used as a rough guide[55].

Rainwater Harvesting (m3)
= (Catchment Area (m2) x Rain fall volume(m) x Run off coefficient)

where,

Catchment area = area of rooftop (m^2)

Rain fall volume= average annual rainfall (m)

Run-off coefficient = varies depending on the surface type

While designing the tank one must establish the following factors:

- Total daily requirement of water
- The number of days for which storage needs to be done.
- In an ideal situation, to be completely independent of any other source of water other than rainwater, once must calculate the tank size to store water for the maximum dry spell in a year. However, this is only possible if the rainfall amount and pattern suffices this demand.

Potential Technologies

The principles of rainwater collection and treatment is like the systems designed for other water sources. If the roof is not well maintained and clean, then the first 15 to 30 minutes of the rainwater must be diverted away from the rainwater system to surface drains. This will avoid the contaminated water being mixed with the cleaner water. There are some filters available that does not require manually diverting the rainwater[56].

3.3. Knowledge and Behaviour Management

Knowledge of how water is used is critical in managing behaviour regarding water use.

3.3.1 Water use submetering

Submetering enables the water consumption of various components of the building to be measured, for example, sinks, toilets, showers. Supply-side inlets such as water from the city, town, or village authority; water from rainwater harvesting; and treated water from a sewage treatment plant can also be sub metered. Submetering provides data that can be used to increase water efficiency.

Design Approach/Methodology

The smart meter (figure 59) must show the readings across various time periods like last hour, last day, last 7 days or last 12 months. Smart meters must also be able to measure aspects like:

- Measure water use
- Analyse various measurements

[55] EDGE User Guide Version 3.0a
[56] https://www.rainyfilters.com/products/rainy-filters

Figure 59. Typical smart meters for water.

Source: Creative Commons License.
Photo credit: Dmitry G.

With smart meters, the users must be able to analyse, appreciate, understand and act upon water usage patterns towards creating substantial savings in water consumption.

Potential Technologies

Smart metering is designed to provide users real time information about their water consumption patterns. It consists of a detection unit (the transmitter) that is fixed to an existing utility meter and tracks the water use. The display unit receives a wireless signal from the transmitter and displays the consumption information in real time. Many companies offer online monitoring systems.

Smart meters can be fixed for different sources and different uses. This will provide the user with granular data on their usage patterns.

4.Green Building Materials

Incorporating green building measures involves using sustainable materials with low embodied energy, along with sustainable construction practices. Understanding the local building stock helps identify materials that can be locally sourced and that are environmentally friendly and optimal for the local context, which reduces the carbon footprint associated with transportation and supports the local economy.

4.1. Recycled Building Materials

Many buildings components, such as steel, can be recycled and reused, reducing dependence on virgin resources.

Some codes require that a certain percentage of building components be of recycled raw materials. For example, Pozzolanic Portland cement (PPC) contains a significant percentage of fly ash, a by-product of coal power production and Portland Slag Cement (PSC) contains ground granulated blast furnace slag ((GGBS) - a by-product of steel production.

Design Approach/Methodology

Recycling of building materials can be done in the following ways:

1. Direct reuse: Reusing various building components like stone blocks (from walls), old doors and windows, etc. is an effective way to recycle building materials. However, this can be done only for select projects and may be difficult to implement in most projects.
2. Using materials with recycled content: Many manufacturers routinely use recycled content or waste substitutes in building materials. For e.g. PPC and PSC cements, secondary steel that contains a significant amount of recycled steel.

Potential Technologies

There are many materials that have recycled content. An exhaustive list may not be possible in the purview of this guide. It would be best to use the guidelines provided in the methodology.

4.2. Building Materials with Low Embodied Energy And Carbon

Manufacturing building materials consumes a significant amount of energy in its extraction, processing/ manufacture, transportation and disposal. This is called embodied energy. For example, producing burnt bricks for a 230 mm thick wall of for a given building area consumes 4 times as much energy as producing 200 mm thick concrete blocks for the same building area. Using materials with less embodied energy reduces the carbon footprint of a building. As a thumb rule local materials have lesser embodied energy as transportation adds to the embodied energy of a material. This also has an added advantage of encouraging local economy.

Embodied carbon is the amount of carbon emissions that is caused by the extraction, processing/manufacture, transportation and disposal of the building materials.

While both provide a good comparative indicator of greenness of a material, embodied carbon is more holistic in its approach as it deals with GHG emissions. An example of low embodied carbon masonry is illustrated in figure 60. This snack manufacturing facility was built with Stabilised Soil Blocks which has one of the least embodied carbon among various masonry alternatives.

Design Approach/Methodology

It is necessary for the architecture design team to explore various options available for various materials. The most important materials that need to be considered are:

- Walls – Internal and External
- Slabs – Ground level, upper levels and roofs
- Windows Frames & Glazing
- Insulation – Walls, Floor and Roofs
- Floor Finishes

Figure 60. Construction with Stabilised Soil Blocks.

Source: Photo courtesy OrgTree (www.orgtree.in) and Ecumene Habitat Solutions Pvt. Ltd. (www.ecumene.in)

In typical office buildings, walls and slabs contribute to about 75 to 80% of the total embodied energy of a building. Windows and floor finishes contribute approximately 18% to 20%. These figures are indicative and will vary based on the building type and design.

Embodied Energy can be measured as follows:

- Energy divided by unit weight of the material – MJ (megajoules)/Kg
- Energy divided by the useful internal area of the building - MJ/SqM

Data provided by the 2nd measure is easier to use by practising building professionals.

Embodied Carbon is measured as follows:

- GHG emissions divided by the useful internal area of the building - $kgCO_2e/SqM$

In addition to using low-embodied carbon materials, it is also important for the designers to employ designs that require lesser materials. For example, certain cantilevered designs (RCC slabs and beams) will require more reinforcement steel compared with avoiding the cantilever or by providing column supports. Clients can also be encouraged to think about evaluate their needs and to reduce spaces that will be sparsely used.

Potential Technologies

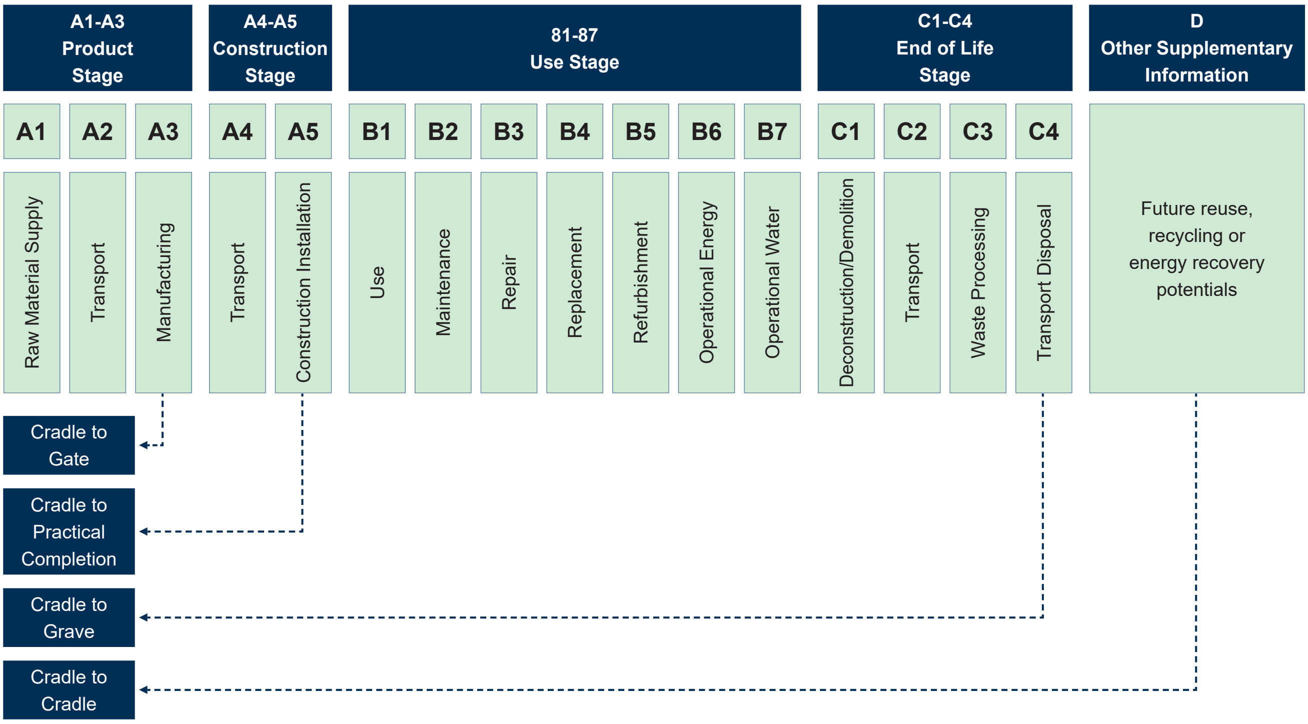
Environmental Product Declarations (EPD) is a procedure mandated across European Union. EPDs are akin to nutrition labels on processed foods. EPD provided the environmental impact of a product through its lifecycle. The lifecycle of a product stretches from the time it was extracted in the raw material form all the way to manufacturing, use at site, end of life disposal or re-use and is defined by the European standard EN 15804:2012+A2:2019. Figure 61 shows the modules that breaks down the various stages of the product lifecycle.

EPDs are divided into the following broad system boundaries[57]:

- **Cradle to Gate:**
- Product Stage
  - Module A1 - Raw Material Supply
  - Module A2 - Transport
  - Module A3 - Manufacturing
- **Cradle to Practical Completion**
- All earlier modules and the following:
- Construction Stage
  - Module A4 - Transport
  - Module A5 - Construction Installation
- **Cradle to Grave**
- All earlier modules and the following:
- Use Stage
  - Module B1 - Use
  - Module B2 - Maintenance
  - Module B3 - Repair
  - Module B4 - Replacement
  - Module B5 - Refurbishment
  - Module B6 - Operational Energy
  - Module B7 - Operational Water
- End of Life Stage
  - Module C1 - Deconstruction/Demolition
  - Module C2 - Transport
  - Module C3 - Waste Processing
  - Module C4 - Disposal
- **Cradle to Cradle**
- All the above modules and the following
  - Module D - Future re-use, recycling or energy recovery potentials

[57] https://circularecology.com/en-15804-a2-epd-update.html#:~:text=In%202019%20the%20standard%20was,for%20all%20EN%20 15804%20EPD.

Figure 61. System boundaries of Environmental Product Declarations (EPD) as defined by European Standard EN 15804:2012+A2:2019



Source: Albedo Graphics.

Among the various locations on the internet, samples of EPDs can be seen at https://getgreenbadger.com/environmental-product-declaration-examples/.

There is no single registry for embodied carbon information. One of the well trusted sources is the "Inventory for Carbon and Energy" developed by the University of Bath, UK. Another source is the Built Environment Carbon Database (https://carbon.becd.co.uk/) developed by the Building Research Establishment, UK.

5. Construction Site Measures

Construction sites are major sources of pollution. Dust pollution occurs during activities like soil excavation, laying of flooring, etc. Noise pollution occurs during floor tile cutting, concrete pours, cutting of reinforcement steel, etc. In the event of rain, if the site is not correctly drained, many of the pollutants from the site can get mixed with stormwater that can flow into waterbodies around. Hence it is important that measures are incorporated during the construction process.

5.1. Construction pollution control

Construction process generates pollution (e.g., dust, noise, materials leeching into the water table). It is critical to control and manage the pollution.

Design Approach/Methodology

Construction dust: Construction dust is a huge problem, especially in fast developing urban areas. It is possible to control it using various methods such as spraying water (figure 62) and ensuring that the site is well covered on the sides.

Figure 62. Watering the ground to prevent dust rising from the soil.

Source: Creative Commons License.
Photo credit: - NASA/Amber Watson.

Soil retention during stormwater discharge: Excavated soil is normally heaped in piles around a construction site. When it rains, the soil can mix with runoff, clogging streets and stormwater drains. Care must be taken to cover the soil properly or dispose of it safely. The soil can be covered by waterproof sheets or can be covered with temporary turf planting to avoid soil runoff.

Construction Noise: Adequate measures need to be taken to minimise noise arising from construction sites. Appropriate side barricades (figure 63) and temporary enclosures in buildings will be useful to reduce the construction noise. Timing of works can also play a significant role in reducing the disturbance to neighbours.

Figure 63. Protection around the construction site

Source: Creative Commons License.
Photo credit: Madhav Pai.

Potential Technologies

This is a design and execution related item. There are no specific technologies that can be used for this measure.

5.2. Construction waste management

Waste generated from construction goes into landfills. However, with proper management it can become a resource for recycling into other uses (see figure 64).

Construction sites generate considerable waste. For example, pieces of tile, cardboard, polystyrene foam, paper, all types of plastics, leftover insulation, materials containing asbestos, and scraps of steel must be segregated, stored temporarily, and disposed of responsibly. Waste generated during construction goes into landfills, but with proper management, it can be recycled for other uses.

Design Approach/Methodology

It is important to minimise construction waste. This can be done to a certain extent by designing in an appropriate manner. For example, flooring tiles can be chosen that best fits a room size. Usually, smaller size tiles will have lesser wastage.

Construction waste generated at site must be properly segregated and stored. It must be stored in a manner that the waste does not leach into the ground and gets blown into the wind.

Figure 64. Segregation of construction waste.

Source: Albedo Graphics.

The disposal should be done with responsible recyclers who would ensure that the materials would get re-used or recycled appropriately.

Potential Technologies

This is a design and execution related item. There are no specific technologies that can be used for this measure.

6. Indoor Environmental Quality Measures

Indoor environmental quality measures do not directly affect GHG emissions, but there are codes mandating some of these measures.

6.1. Indoor Air Quality

Indoor air quality is critical to the health of occupants and can be controlled with good design and selection of materials. Carcinogenic volatile organic compounds (VOCs) in paints, carpets, and adhesives used for fixing wood and wood products decrease indoor air quality. Low VOC materials are widely available.

Design Approach/Methodology

Volatile organic compounds (VOC) are found in various building materials like paints, carpets, adhesives, solvents and wood preservatives. They are also found in household materials like air fresheners, nail polishes, cleaning materials, pesticides among others. Prolonged exposure in unventilated or poorly ventilated conditions can affect the health of the occupants with symptoms like headaches, fatigue, eye irritation, irritation in nasal passages, swollen/itchy throat, nausea, etc.

Potential Technologies

Some of the potential methods is to:

- Use low VOC materials; e.g. Low VOC paints, low VOC carpets, etc. (See figure 65, left)
- Increase space ventilation – either with larger windows or by changing the rate of air changes per hour or by increasing fresh air intake in HVAC systems.
- Air purifiers: Air purifiers can be installed in the spaces. (See figure 65, right)

Figure 65. Examples of VOC paints (left), and air purifiers (right).

Source: Left: Albedo Graphics. Right: Albedo Graphics.

6.2. Indoor Sensory Comfort

Indoor sensory comfort includes such factors as lighting and exterior views.

Design Approach/Methodology

- Indoor Lighting: Adequate indoor lighting (figure 66) is important for physical and mental health. We have covered daylighting and energy efficient lighting in the project. It is recommended to adhere to the prescribed local/international standards.

Figure 66. Example of indoor lighting.

Source: Creative Commons License.
Photo credit: Commerzbank AG.

- Nature connected spaces: Spaces connected with nature (windows overlooking a garden or the city skyline) help occupants have a sense of connection with the outdoors, which improves overall well-being. Figure 67 shows an example of this.

Figure 67. Example of nature-connected spaces

Source: Creative Commons License.
Photo credit: Bezik.

- Acoustic protection: Urban settings have become noisy. Some codes require measures such as well-sealed windows and doors to prevent undue amounts of noise from coming inside. Prolonged exposure to loud noise is harmful to health.

7. Solid Waste Management Measures

Solid waste management is becoming critical in most cities globally. A building that provides for segregation of solid waste will enable its occupants to manage waste proactively and responsibly. Building designs that enable the segregation of waste is the first step towards responsible handling of waste.

7.1. Segregation of Solid Waste

Responsible solid waste management is extremely important for local ecosystems. Spaces within a building that provide for safe segregation and storage until disposals are important (see figure 68). Wet waste can be composted on site and used as fertilizer for landscaping.

Figure 68. Example of Solid Waste Segregation in a building.

Source: Creative Commons License.
Photo credit: Lukasz Katlewa.

Design Approach/Methodology

Every city has its own rules regarding waste segregation. Typically following categories are provided for:

Dry Waste: This includes paper, plastic and other items like cardboard boxes, etc.

Wet Waste/Organic Waste: Wet waste is usually anything that composts – food waste is the largest component.

Hazardous and Household Waste: This could be breakable items like glass, sharp objects like razor blades, syringes, asbestos, mercury, etc.

Household Medical Waste: This would include diapers, sanitary napkins, used wound dressings, etc. (Note that medical waste is defined by Order No. 03-N of the Minister of Health of the Republic of Armenia dated 04.03.2008 as waste generated as a result of patient examination, treatment, medical and preventive work or scientific research in organisations.)

E-waste: This would include all unusable electronic and electrical items.

The above list is not exhaustive and every urban local body will issue waste segregation rules as per the local conditions.

Section D – Further Resources on Designing and Construction Green Buildings in Armenia

This section aims to provide some additional resources to expand knowledge and strengthen the development of Green Buildings in Armenia.

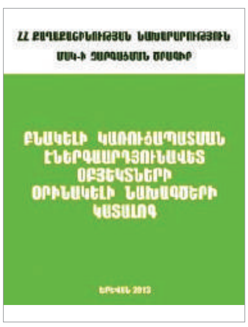
Publications

To complement this Guidebook on Green Building Design, the following studies and handbooks could be of help for professional practitioners on the field.

Amirkhanyan, A., Sokoyan, T., Hambartsumyan, R., Hamarian, A. (2015); **Green Architecture: Energy Efficiency and Renewable Energy;** Yerevan: UNDP Armenia

(Available at: https://dspace.aua.am/xmlui/handle/123456789/2290) Accessed 11 July 2024

This is the first-ever bilingual (Armenian and English) textbook. It was commissioned and published by the United Nations Development Programme under their Improving Energy Efficiency in Buildings project. The textbook aims to present multiple solutions and approaches contributing to the wider application of green architecture practices in construction. These include renewable energy, passive solutions, energy audit, integrated building design approach, etc. The authors demonstrate interdisciplinary approaches and refer to the latest sectorial developments, relying on the most recently available literature and online resources. The textbook is intended for a wide range of interested professionals, including faculties and students of architecture and engineering.



Catalogue of energy efficient replicable design options for five types of individual residential houses, July 2013

(Available at: https://nature-ic.am/en/publications/catalogue-of-energy-efficient-replicable-design-options-for-five-types-of-individual-residential-houses) Accessed 11 July 2024

This catalogue includes replicable (typical) designs of five energy efficient individual residential houses based on the designs provided by the Project. The goal of the catalogue is to promote energy efficient construction and resource saving, application of advanced construction technologies and materials, as well as to present design practices of energy efficient residential houses (16MB. pdf, available in Armenian language only).

Advisory Handbook on technical solutions for thermal insulation of building envelopes, May 2013

(Available at: https://nature-ic.am/en/publications/advisory-handbook-on-technical-solutions-for-thermal-insulation-of-building-envelopes) Accessed 11 July 2024

This Handbook on Technical Solutions for Thermal Insulation of Envelopes of Residential, Public and Industrial Buildings in Construction and Reconstruction in the Republic of Armenia was developed and published in the frames of the Project. The Handbook was endorsed by the Minister of Urban Development of the Republic of Armenia (order #343 of November 6, 2013.)

(This manual is available in Armenian language only.)

2021 International Green Construction Code (IgCC), 2022

(Available at: https://codes.iccsafe.org/content/IGCC2021P2) Accessed 11 July 2024

A Comprehensive Solution for High-Performance Buildings.

A whole systems approach to the design, construction and operation of buildings, the IgCC contains measures that result in better indoor environments, lower impact on natural resources, better neighborhood connections, and improved walkability. It includes ANSI/ASHRAE/USGBC/IES 189.1-2020 Standard the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings. The IgCC provisions allow the seamless coordination with either the IECC® or ASHRAE Standard 90.1 for ease of adoption in any jurisdiction.

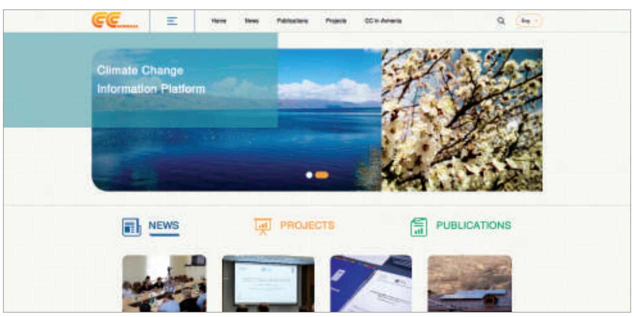
Websites

A couple of online platforms are of particular interest for those interested on implemented green measures in the building sector in Armenia:

Link: https://mershenq.am/en
[Accessed 11 July 2024]

This is website for the **UNDP – GCF "De-risking and Scaling-up Investment in Energy Efficient Building Retrofits" project.**

Using an integrated suite of de-risking interventions, the Project seeks to systematically de-carbonise the existing building stock in Armenia to reduce greenhouse gas (GHG) emissions while achieving sustainable development benefits. The Project, addressing both public and residential buildings, focuses on creating a favourable market environment and a scalable business model for investment in energy efficiency retrofits by addressing market barriers. These barriers to energy efficient building renovation are addressed through a combination of policy and financial de-risking instruments and targeted financial incentives to key market players.



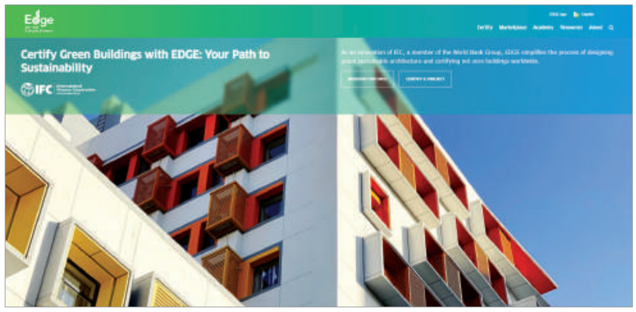
Link: https://nature-ic.am/en
[Accessed 11 July 2024]

This is the **Climate Change Information Platform**, established in 1996 in the frameworks of "Armenia-Country Study on Climate Change" UNDP-GEF Project.

The Program along with other goals is aimed at strengthening of the climate change related information exchange and ensuring transparency in the context of obligations of the Ministry of Nature Protection as a UNFCCC coordinating entity in Armenia.

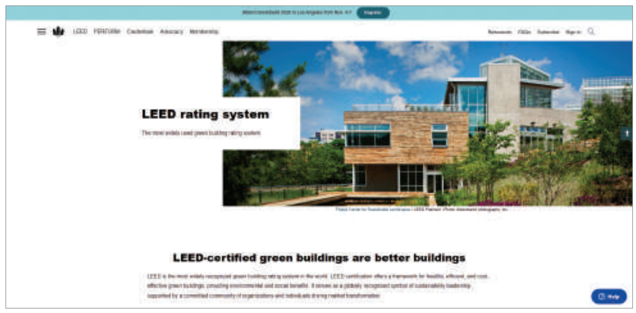
Green Building Certification Systems

Finally, those are the main Green Building Certification Systems referenced along the document.



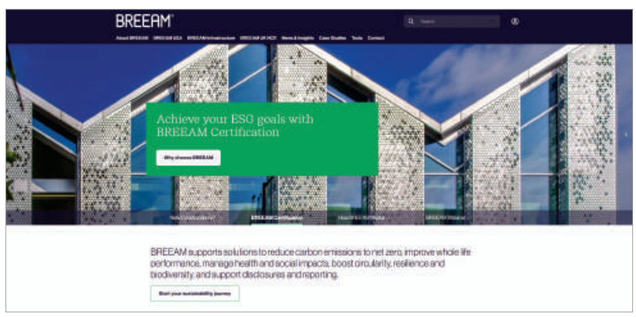
EDGE (https://edgebuildings.com/)
[Accessed 11 July 2024]

By bringing together those who design, develop, finance, and incentivize green buildings, EDGE unlocks collaboration and provides a new paradigm for the future.



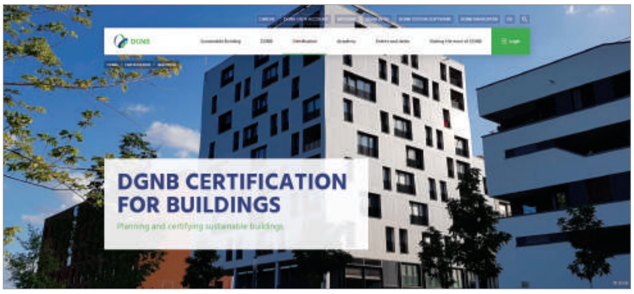
LEED (https://www.usgbc.org/leed)
[Accessed 11 July 2024]

The U.S. Green Building Council (USGBC)'s mission is to transform how buildings and communities are designed, built, and operated to create thriving, healthy, equitable, and resilient places that advance human and environmental wellbeing.



BREEAM (https://breeam.com/)
[Accessed 11 July 2024]

BREEAM is used to specify and measure the sustainability performance of buildings. Using this framework helps projects to meet their sustainability goals and achieve optimal performance over time.



DGNB (https://www.dgnb.de/en/certification/buildings) [Accessed 11 July 2024]

The overriding goal of this non-profit association is to actively shape the transformation of the construction and real estate industry, to promote understanding of the need for sustainable building and to anchor it in the consciousness of the general public.

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