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Ministry of Energy and Minerals

SOHAR PORT / FREEZONE

Energy Efficiency Guideline for SOHAR Industrial Buildings

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i. List of Abbreviations and Acronyms

Acronym	Full Form
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMS	Building Management System
CDD	Cooling Degree Days
CSPF	Cooling Seasonal Performance Factor
COP	Coefficient of Performance
DHW	Domestic Hot Water
DX	Direct Expansion
DOAS	Dedicated Outdoor Air System
ECM	Energy Conservation Measure
ECI	Energy Cost Index
EER	Energy Efficiency Ratio
EPC	Energy Performance Contract
EUI	Energy Use Intensity (or Energy Utilization Index)
FDD	Fault Detection and Diagnostics
GFA	Gross Floor Area
HDD	Heating Degree Days
HVAC	Heating, Ventilation, and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
IEER	Integrated Energy Efficiency Ratio
IPMVP	International Performance Measurement and Verification Protocol
IPLV	Integrated Part Load Value
ISO	International Organization for Standardization
LED	Light Emitting Diode
PV	Photovoltaic
RT	Refrigeration Tons
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SPFZ	SOHAR Port and Freezone
U-value	Thermal Transmittance Value
VFD	Variable Frequency Drive
VRF / VFV	Variable Refrigerant Flow / Variable Flow Volume
VSD	Variable Speed Drive
W/m^2	Watts per square meter

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1. Introduction

SOHAR Port and Freezone is one of Oman's most dynamic and diverse industrial clusters, where energy use plays a major role in competitiveness, operational efficiency, and sustainability performance. While industrial processes consume a large share of energy, buildings remain a critical - yet often underestimated -contributor to total demand. Offices, warehouses, workshops, and support facilities operate continuously, and without active management, their energy use typically rises over time due to equipment ageing, operational drift, and outdated systems.

Optimizing building operations is therefore not a luxury but a necessity - both for reducing energy costs and for maintaining a comfortable and productive working environment. Retrofitting existing buildings has been proven to deliver substantial results, achieving energy savings of up to 15–20% compared to baseline consumption levels. Recognizing this opportunity, SOHAR Port and Freezone has developed this Energy Efficiency Guideline to provide a structured framework for improving building performance and driving sustainable operations.

This guideline aims to help tenants, industries, and facility managers to:

- **Identify and quantify** energy and water **savings potential**,
- **Evaluate technical and financial viability** of retrofit measures, and
- Implement effective solutions that enhance operational efficiency performance.

This guideline has been developed to provide a structured, step-by-step approach for identifying savings potential in existing buildings, assessing practical measures, and implementing effective solutions. It draws upon internationally recognized standards and best practices, including:

- **ASHRAE Standard 90.1** – Energy Standard for Buildings Except Low-Rise Residential Buildings
- **ASHRAE Standard 105** – Standard Methods of Determining, Expressing, and Comparing Building Energy Performance
- **ISO 6946** – Building Components and Building Elements — Thermal Resistance and Thermal Transmittance
- **IPMVP** – International Performance Measurement and Verification Protocol
- **AHRI 550/590** – Performance Rating of Water-Chilling Packages
- **AHRI 340/360** – Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment
- **NFRC** – National Fenestration Rating Council Standards for U-values and SHGC
- **IEC 61724** – Photovoltaic System Performance Standard

In addition, the guideline incorporates national regulations, such as Ministerial Decree No. 286/2008 - Occupational Safety and Health Regulation for Lighting Requirement, Oman Building Code and Oman Plumbing Code ensuring that recommendations are tailored to the local regulatory framework.

The energy efficiency improvement methodology, illustrated in Figure 1, outlines a systematic process that begins with data collection and baseline development, progresses through benchmarking and identification of energy conservation measures, and concludes with savings assessment, feasibility analysis, and implementation with measurement and verification. By following the principles and methodologies outlined, industries and tenants can unlock cost savings, reduce carbon footprints, and contribute to a more sustainable and resilient built environment. This guideline explains each process in more detail in the upcoming sections.

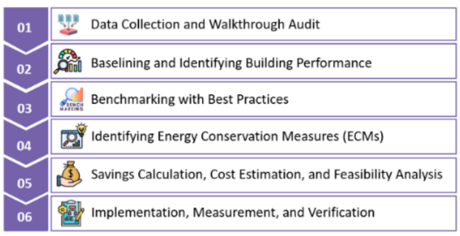


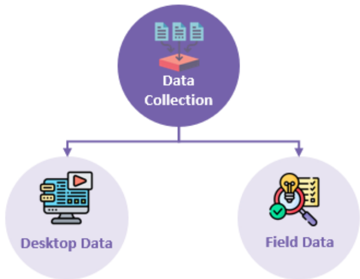
Figure 1:Energy efficiency improvement process

2. Data Collection

Data collection is the foundational step in any energy efficiency assessment. The process must be reliable, consistent, and accurate to ensure that subsequent analysis reflects the true performance of the building. In practice, obtaining high-quality data is often a challenge: desktop records may be incomplete due to limited monitoring frameworks in existing facilities, while short-term field measurements may fail to capture the building's annual operational profile.

To address this, data should be collected from two complementary sources:

1. **Desktop data** – records maintained by the facility management team.
2. **Field data** – on-site measurements and observations used to validate and complement desktop records



Desktop data is typically owned and managed by the facility manager. The following information should be obtained:

Facility information	Building type, **gross floor area** (GFA).
Energy consumption & bill	At least 12–24 months of **electricity consumption and bills**.
Water consumption & bill	At least 12–24 months of **water consumption and bills**.
Asset list	Complete list of equipment, including **year of installation, capacity**, and **nameplate power**. This should cover air conditioning and ventilation systems, lighting, renewable energy installations, water heaters and other significant loads (e.g., motors).
Operating hours	Detailed **operational profile** for both the building and individual systems, including daily and annual working hours.
Operational practices	**Maintenance schedules**, existing energy management policies, occupancy profiles, and occupant behavior patterns.
Weather data	**Weather data** – Monthly mean dry-bulb temp & CDD at base 21 °C.

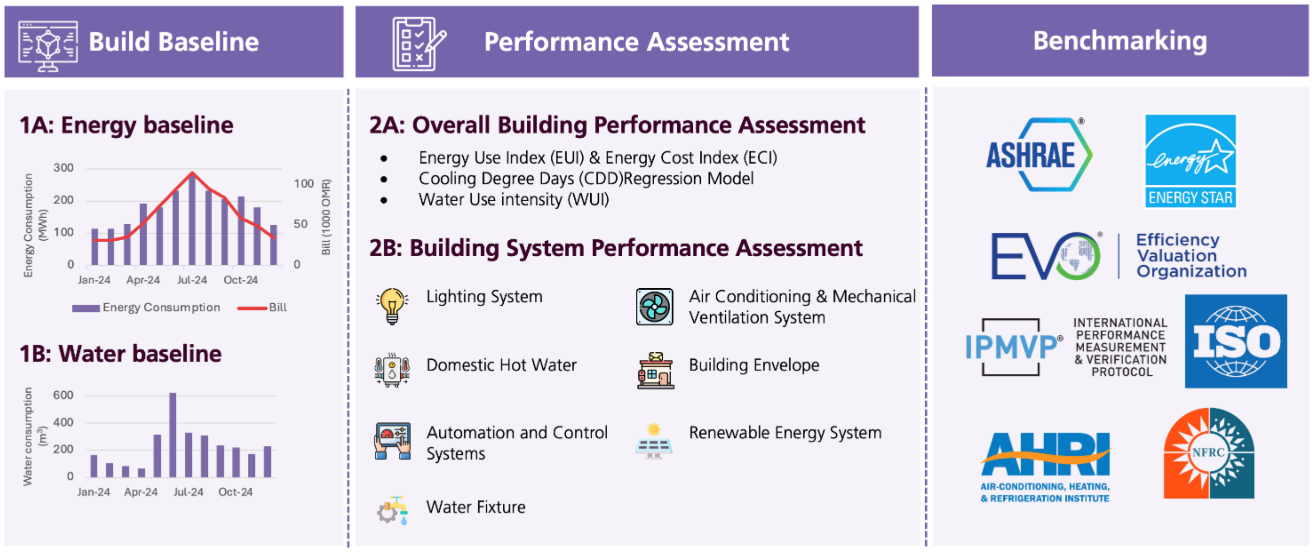
Desktop data is essential for recording and analyzing performance trends. However, it alone is not sufficient to provide a fully reliable picture of building performance. To gain confidence in the performance status, desktop data must be validated through **field data** collection. This involves site inspections to verify records and identify inefficiencies not visible in billing data. Typical activities include:

- Inspecting the building envelope for leaks or infiltration.
- Checking for energy-consuming loads operating in unoccupied areas.
- Observing equipment age, efficiency, and general condition.
- Recording the type of lighting systems in use.
- Identifying wasted lighting (e.g., burnt-out lamps, over-lit areas, or unnecessary lighting in bright spaces).
- Distinguishing between constant and variable load operations.
- Reviewing the nature of operational issues or recurring occupant complaints.
- Assessing maintenance practices.

Together, desktop and field data establish the evidence base needed to understand current performance, validate assumptions, and build confidence in the building's saving potential.

3. Data Simulation and Assessment

A structured methodology is required to assess a building's energy and water performance. This process begins with establishing accurate baselines, followed by evaluating overall building performance and system-level efficiency. The analysis provides a foundation for benchmarking performance against best-practice standards and quantifying potential savings. The key stages include:



3.1 Building baseline

Developing a building baseline is fundamental to understanding the existing consumption profile. The baseline represents the reference level of energy and water use that reflects the building's current operating conditions, systems, and equipment efficiency. It acts as a benchmark against which future performance improvements can be measured.

To establish **Energy Baseline**, follow the steps below after collecting at least 12 months of energy bills:

1. **Identify the Billing Period:** for each month, determine the number of days covered by the bill. This is calculated as:

$$Billing\ Period = Bill\ end\ date\ -\ Bill\ start\ day + 1$$

2. **Normalize Monthly Consumption:** Normalize the energy consumption to account for varying billing cycle lengths. For each month divide total consumption to number of days and then re-distribute consumption for each month.

3. **Calculate the Tariff:** For each billing month, calculate the average tariff as:

$$Energy\ Tariff\ \left(\frac{OMR}{kWh}\right) = \frac{Billed\ Amount\ (OMR)}{Energy\ Consumption\ (kWh)}$$

4. **Visualize the Data:** plot the normalized monthly consumption data over the year.

Table 1 below shows the normalized energy baseline data for the building while Figure 2 illustrates the monthly energy consumption alongside the corresponding bills.

Table 1: Energy bill analysis

Month/Year	Bill Start Date	Bill End Date	Billing Period (Days)	Energy Consumption (kWh)	Billed Amount (OMR)	Energy Tariff (OMR/kWh)
Jan-24	1/01/2024	31/01/2024	31	114,000	3,112	0.027
Feb-24	1/02/2024	28/02/2024	28	113,000	3,085	0.027
Mar-24	1/03/2024	31/03/2024	31	129,000	3,522	0.027
Apr-24	1/04/2024	30/04/2024	30	192,000	5,242	0.027
May-24	1/05/2024	31/05/2024	31	180,000	7,371	0.041
Jun-24	1/06/2024	30/06/2024	30	231,000	9,459	0.041
Jul-24	1/07/2024	31/07/2024	31	281,000	11,507	0.041
Aug-24	1/08/2024	31/08/2024	31	232,000	9,500	0.041
Sep-24	1/09/2024	30/09/2024	30	205,000	8,395	0.041
Oct-24	1/10/2024	31/10/2024	31	214,000	5,842	0.027
Nov-24	1/11/2024	30/11/2024	30	180,000	4,914	0.027
Dec-24	1/12/2024	31/12/2024	31	126,000	3,440	0.027

$$Energy\ Tariff = \frac{Billed\ Amount}{Energy\ Consumption}$$

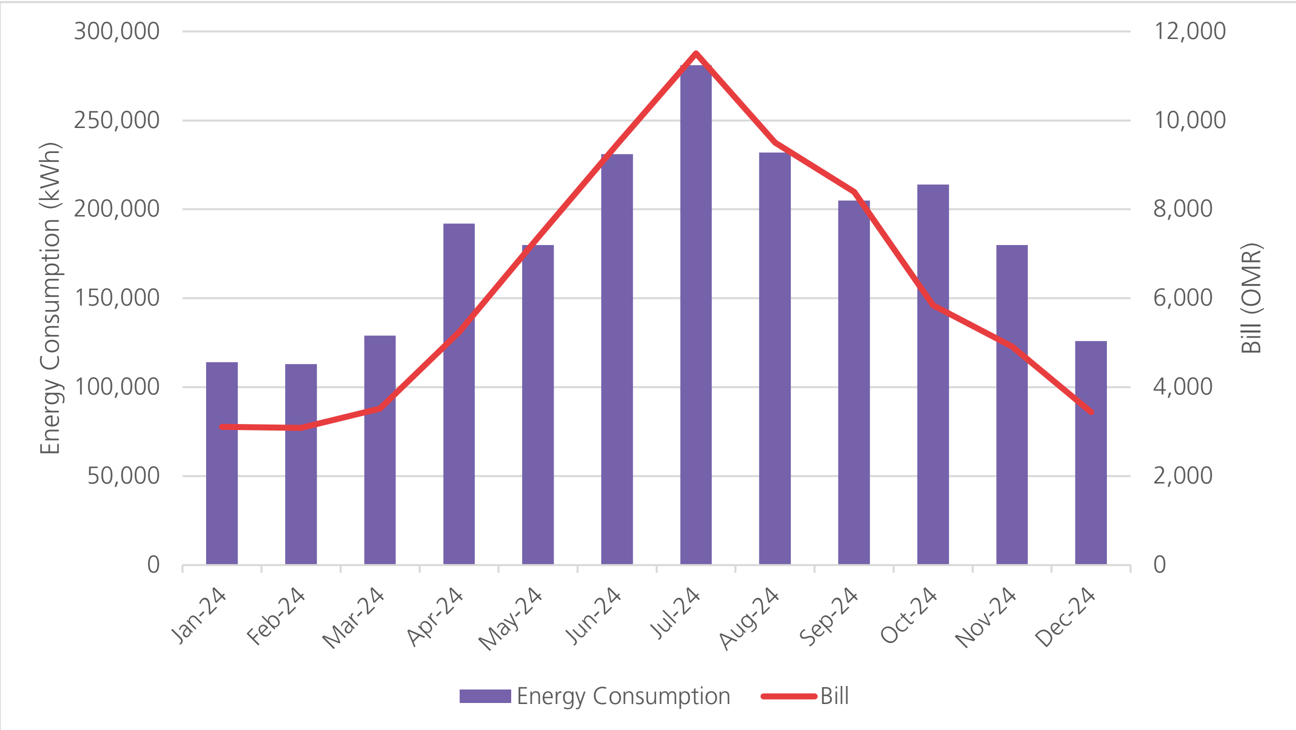


Figure 2: Monthly energy consumption & bill

As well as establishing a **Water Baseline** is essential for evaluating a building's water performance. Similar to the energy baseline, it represents a reference level of water consumption that reflects the building's current usage patterns. This baseline serves as a benchmark to measure future improvements in water efficiency. The methodology for developing the water baseline follows the same steps outlined for the energy baseline, including determining the billing period, normalizing monthly consumption, calculating average tariffs, and visualizing consumption trends.

3.2 Overall Building Performance Assessment

After conducting the energy analysis, it's beneficial to compare the building's performance with benchmarks from similar buildings considering location, climate, and function. This helps to assess the high-level potential for energy savings. Common benchmarking metrics include:

- **Energy Use Index (EUI):** KWh/m^2
- **Energy Cost Index (ECI):** OMR/m^2
- **Cooling Degree Days (CDD) Regression Model**: Used to correlate consumption with climate loads in a hot or warm climate.
- **Heating Degree Days (HDD) Regression Model:** Used to correlate consumption with climate loads in cold or temperate climate.
- **Water Use intensity (WUI):** m^3/m^2

The following subsections provide guidance on how to perform consumption benchmarking using the above metrics.

3.2.1 Cooling Degree Days (CDD)

Creating a robust linear model using Cooling Degree Days (CDD) is a key step, particularly in climates with significant cooling loads such as Oman. CDDs represent how much (and for how long) the outside temperature was above a certain threshold (typically 18°C) indicating a need for cooling.
In Oman's hot-arid climate, cooling can account for over 50% of annual electricity consumption. CDD provides a simple and accessible metric to quantify cooling demand over time. To develop CDD regression model as shown in Figure 3, follow the steps using the collected at least 12 months of energy bills from the energy bill analysis:

1. **Download monthly CDD data** from degree-days for 12 months, select:
   Weather station: OOSH: Sohar Majis, OM (56.63E,24.47N),
   Data type: Cooling.
   Breakdown: Monthly
2. **Plot energy consumption Vs CDD data in Excel:** insert a Scatter plot with only markers.
   Develop regression model: add trendline in the data and (linear) and display the equation and R-squared value on the chart.

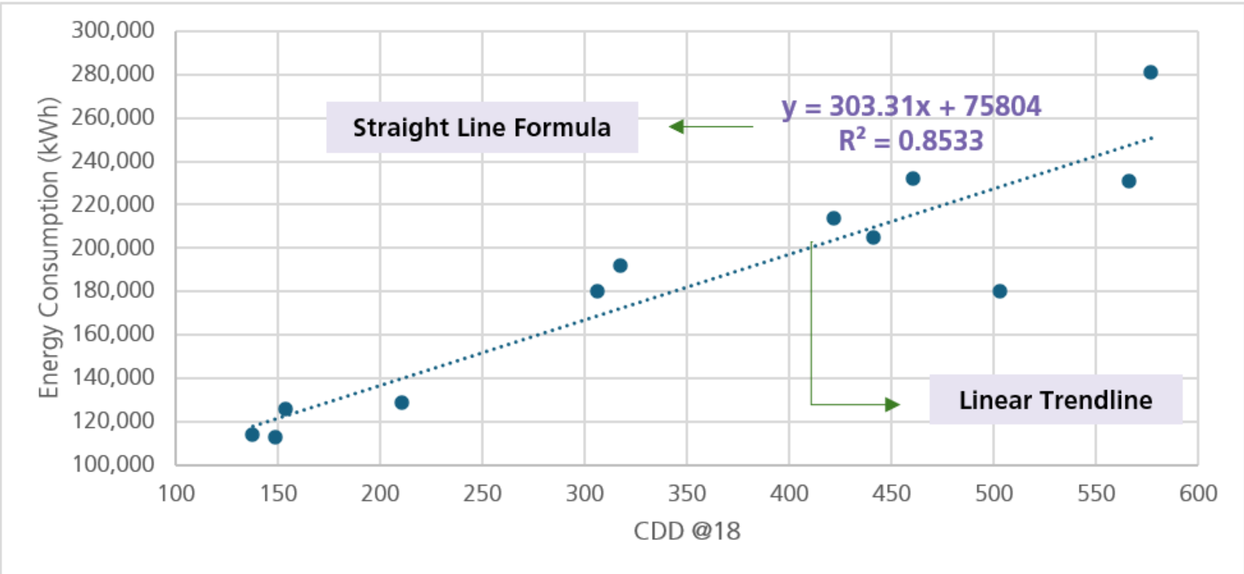


Figure 3: Scatter plot energy consumption Vs CDD

Parameter	Unit	Description & Interpretation	High Value May Indicates
Slop	kWh/CCD.month	Indicates the increase in energy consumption per unit increase in CDD. Reflects cooling load sensitivity	• Poor building envelope or HVAC efficiency • Larger cooling loads
Intercept	kWh/month	Represents base load—the energy use when CDD = 0. Independent of weather effects.	• Large floor area • Higher occupancy • Energy intensive equipment • Less efficient baseline system
R^2 (Coefficient of Determination)	NA	Measures how well variations in energy use are explained by CDD. Ranges from 0 to 1.	• Strong correlation between weather and energy use

Interpreting the Regression Model:

In General:

- A high slope suggests increased sensitivity to outdoor temperature, which could be due to inefficient cooling systems, poor envelope performance or high internal heat gains.
- A high intercept points to significant non-weather-dependent energy consumption potentially due to continuous operations or energy-intensive activities.
- According to the International Performance Measurement and Verification Protocol (IPMVP), an R^2 value ≥ 0.75 is considered acceptable for baseline models. In this case, the R^2 value of 0.8533 indicates a strong relationship between weather conditions and energy consumption, and an acceptable baseline fit.

3.2.2 Energy Use Intensity OR Energy Utilization Index (EUI)

The Energy Utilization Index (EUI) is a key metric used to evaluate a building's energy performance. It represents the annual energy consumption per unit of gross floor area and allows for comparison between buildings of similar types and operational characteristics.

The EUI is calculated using the following formula:

$$EUI = \frac{Total\ Annual\ Energy\ Consumption\ (kWh)}{Gross\ Floor\ Area\ (m^2)}$$

After calculating your building's EUI, compare against benchmark values such as those provided by Energy Star Portfolio Manager. This allows you to:

- Understand how your building performs relative to others in the same climate zone and category.
- Estimate potential energy savings if your building's EUI is higher than the benchmark.

Table 2 below helps to estimate potential savings based on Energy Star EUI ranges for :

Table 2: EUI thresholds for various facility types

Facility type	EUI (kWh/m²)		
	Minor Saving Potential (<)	**Moderate Saving Potential (>)**	**Significant Saving Potential (>)**
Data Center	223.9	255.5	268.1
Medical Office	217.6	293.3	309.1
Office	208.2	252.3	277.6
Retail Store	135.6	135.6	186.1
Supermarket/Grocery Store	205	233.4	258.6

** These thresholds help classify whether your building falls within a minor, moderate, or significant energy-saving opportunity.*

The calculated EUI provides an indication of the building's energy-saving potential:

- If the EUI is close to or lower than the minor saving threshold, the building performance is considered good. In this case, the focus should be on fine-tuning systems and implementing low-cost or no-cost Energy Conservation Measures (ECMs).
- If the EUI falls between the minor and significant saving thresholds, the building shows moderate saving potential and should consider targeted ECMs addressing key energy-consuming systems.
- If the EUI is above the significant saving threshold, the building has high saving potential. A detailed energy audit is recommended, followed by staged or comprehensive retrofit measures.

After calculating the building's EUI, you can estimate the potential energy savings using the following equation:

$$Potential\ Annual\ Energy\ Saving\ (kWh) = \frac{Current\ EUI - Target\ EUI}{Floor\ Area\ (m^2)}$$

Target EUI is a performance goal that represents the desired or achievable energy use intensity for a specific facility. It serves as a benchmark to guide energy efficiency improvements and is typically derived from:

- Energy Star benchmarks (e.g., minor savings threshold)
- Best practices or peer comparisons
- Internal sustainability or cost-saving targets

By setting a Target EUI below your current EUI, you can quantify how much energy you can save annually if your building operates at a more efficient level.

3.2.3 Water Use Intensity

Water Use Intensity (WUI) is a key performance metric that indicates the efficiency of water usage in a building or facility. It is typically expressed as:

$$WUI = \frac{Total\ Annual\ Water\ Consumption\ (m^3)}{Gross\ Floor\ Area\ (m^2)}$$

The Portfolio Manager provides benchmarking data for WUI, offering insight into how a facility compares to similar buildings. This data helps assess whether a facility is performing efficiently or if there is significant potential for improvement.
Table 3 below shows typical WUI benchmarks and saving thresholds for selected facility types:

Table 3: WUI thresholds for various facility types

Facility type	WUI (m^3/m^2)		
	Minor Saving Potential (<)	Moderate Saving Potential (>)	Significant Saving Potential (>)
Data Center	0.053	0.130	0.180
Laboratory	0.285	0.680	1.291
Library	0.175	0.325	0.570
Medical Office	1.006	1.723	2.844
Office	0.517	0.782	1.185
Refrigerated Warehouse	0.155	0.399	0.981
Retail Store	0.120	0.550	1.446
Supermarket/Grocery Store	0.639	0.9127	1.051

Similar to EUI, after calculating the building's WUI, you can estimate the potential water savings using the following equation:

$$Potential\ Water\ Saving = \frac{Current\ WUI - Target\ WUI}{Floor\ Area\ (m^2)}$$

This calculation helps quantify how much water could be saved annually if the building's performance is improved to meet the target WUI. Identifying and acting on such opportunities contributes directly to cost savings and resource conservation efforts.

3.3 Building System Performance Assessment

3.3.1 Lighting System

Lighting systems typically consume around 20% of a base building's energy usage. Lighting energy use may not be the largest electrical load in every facility, but depending on operating hours and lighting density, it can still have a significant impact on overall consumption. The amount of light that reaches a specific surface is measured in Lux (Lumens/m^2) using a light meter. The performance of the lighting system is influenced by several factors, including the **type of lamp** (e.g., LED, fluorescent, halogen), the **fixture design** (reflectors, diffusers), **mounting height**, and **room characteristics** such as reflectance and layout.

Energy savings can be identified by assessing the performance of the lighting system through the following aspects:

1. **Lighting design**: Lighting systems are often designed to provide more light than needed to account for lamp lumen depreciation and other losses over time. Over-illumination can lead to unnecessary energy consumption. Each country sets its own standards for minimum light levels. In Oman, Ministerial Decree No. 286/2008 provides the following minimum lighting levels for different work environments, as presented in Table 4**.**

Table 4: Minimum lighting levels for different work environments

Work environment	Minimum limit of lighting (Lux)
Areas which are entered for short periods such as transitional storing and loading and unloading areas	50
Areas where visual tasks which rely on lighting in short periods are performed such as the staircase area.	100
Areas where visual works of high degree of variety are performed such as the paste mixing at a bakery, spray and wood works.	200
Work in areas where visual works of moderate variety are performed such as barber shops, restaurants, auto repair and machine workshops	500
Work in areas where visual tasks of little variety are performed such as textile works	1000
Work in areas where visual tasks of little variety tasks which continue for longer periods are performed such as tailoring.	2000
Work in areas where accurate visual tasks are performed during longer periods such as accurate manual welding tasks	5000
Work in areas where small size visual and low variety visual tasks are performed such as clothes manufacturing.	10000

To identify saving opportunities, measure the lux levels in each area and compare them with the required minimum levels above. If actual lux levels significantly exceed these standards, you may reduce lamp wattage or the number of fixtures without affecting task performance. Lux can be measured using a light meter (illuminance meter). Where a light meter is not available, lux levels may be estimated using the detailed methodology illustrated in Figure 5.

2. **Lighting efficiency:** Reflects how effectively a lighting system converts electrical energy into visible light, typically measured in **lumens per watt**. Higher efficiency means more light output for the same power consumption. Regular cleaning and replacing old or low-efficiency fixtures can further improve performance and reduce energy use. [1]

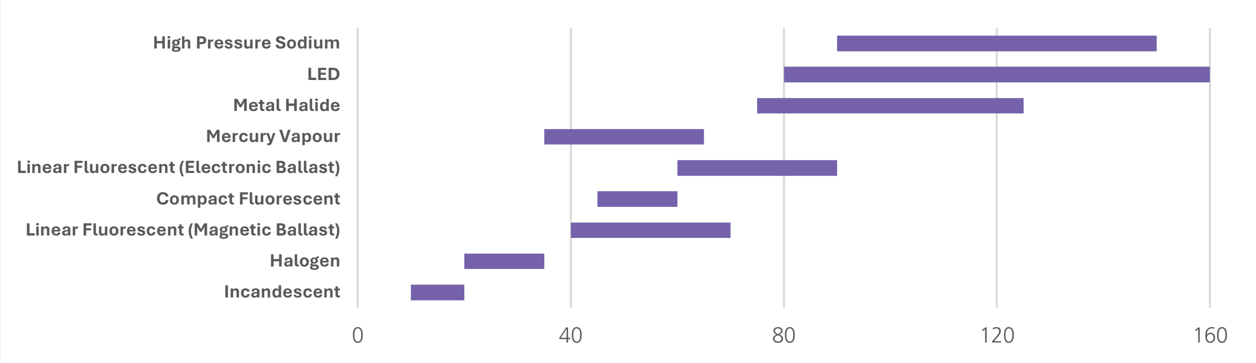


Figure 4: Lighting technology efficiency (Lumens per Watt)

3. **Operating hours:** The duration that lighting systems remain switched on directly affects total energy consumption. Lights that operate continuously (such as in corridors, parking areas, or 24-hour facilities) consume substantial energy even when illumination may not be needed. Energy savings can be achieved by analyzing actual occupancy patterns and adjusting lighting schedules accordingly. Implementing automatic timers or zoning controls allows lights to operate only when required.

4. **Control and sensors:** Smart controls such as occupancy, daylight, and dimming sensors, help reduce waste by adjusting lighting based on presence or natural light. Properly calibrated systems can save up to 10-90% of lighting energy without affecting comfort or safety and various based of applications as shown in Table 5. [2]

Table 5: Energy savings potential with occupancy Sensors

Application	Energy Savings
Offices (Private)	13-50%
Offices (Open Spaces)	10%
Restrooms	30-90%
Corridors	30-80%
Storage Areas	45-80%
Meeting and Conference Rooms	45%

Figure 5 presents the methodology used to assess lighting system performance and identify energy-saving opportunities

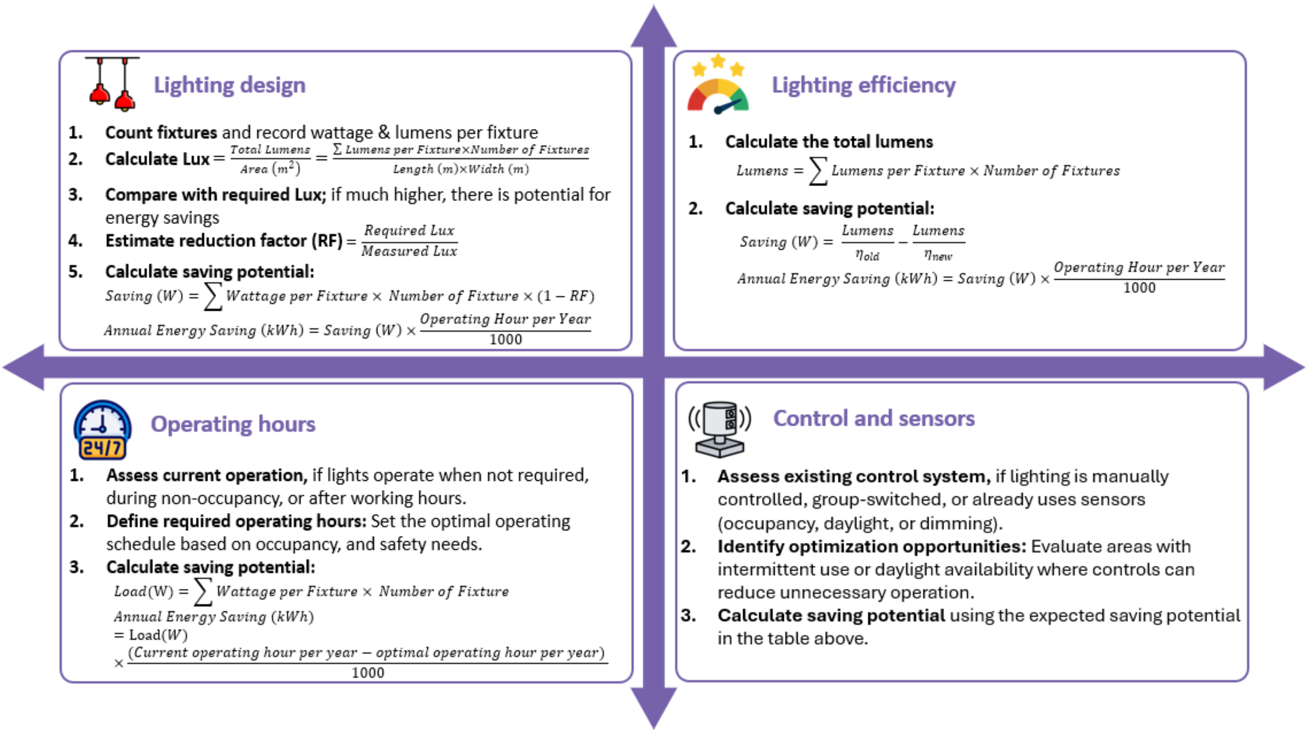


Figure 5 : Methodology for assessing lighting system performance and energy saving potential

3.3.2 Air Conditioning and Mechanical Ventilation (ACMV) System

ACMV systems typically consume around 60% of a base building's energy usage, with 25-35% of energy consumed by chillers producing air-conditioning. Therefore, the efficiency of chillers and the optimization of their performance within the ACMV systems they operate are important in achieving high performance. Energy efficiency in ACMV systems is about maximizing the performance of air conditioning units, and ventilation. It aims to optimize operations to reduce energy consumption without compromising indoor air quality, temperature, humidity, or pressure levels. This careful balance ensures that while energy usage decreases, the functionality and comfort provided by ACMV systems remain unaffected.
The energy performance of ACMV equipment depends on two main factors:

System Design: This includes the basis for selecting and sizing equipment, such as:

- Peak cooling/heating load
- Design outdoor air
- Leaving and entering air or water temperature

Operational conditions: This includes how systems are used and controlled, such as:

- Hourly and seasonal variations in load demand
- Use of energy-saving strategies like Variable Speed Drives (VSDs) and Demand-Controlled Ventilation (DCV)

3.3.2.1 Air condition

Air conditioners come in a variety of shapes and sizes, but they all operate on the same basic premises. An air conditioner provides cold air inside your home or enclosed space by actually removing heat and humidity from the indoor air. It returns the cool air to the indoor space and transfers the unwanted heat and humidity outside.

Efficiency of air condition system is measured by:

1. Coefficient of Performance (COP)

$$COP = \frac{Thermal\ output\ (kW)}{Power\ input\ (kW)}$$

$$Performance\left(\frac{kw}{Ton\ of\ Refrigeration}\right) = \frac{3.517}{COP}$$

2. Energy Efficiency Ratio (EER)

$$EER = \frac{Cooling\ Output\ \left(\frac{Btu}{hr}\right)}{Power\ input\ (kW)}$$

3. Integrated Part Load Value (IPLV) used for chiller efficiency indexes

$$IPLV\ (SI\ unit) = (1\% \times COP_{100\%PLR}) + (42\% \times COP_{75\%PLR}) + (45\% \times COP_{50\%PLR}) + (12\% \times COP_{25\%PLR})$$

$$IPLV\ (IP\ unit) = \frac{1}{\left(1\% \times \left(\frac{kW}{TR}\right)_{100\%PLR}\right) + \left(42\% \times \left(\frac{kW}{TR}\right)_{75\%PLR}\right) + \left(45\% \times \left(\frac{kW}{TR}\right)_{50\%PLR}\right) + \left(12\% \times \left(\frac{kW}{TR}\right)_{25\%PLR}\right)}$$

4. Integrated Energy Efficiency Ratio (IEEE)

$$IEER = (2\% \times EER_{100\%PLR}) + (61.7\% \times EER_{75\%PLR}) + (23.8\% \times EER_{50\%PLR}) + (12.5\% \times EER_{25\%PLR})$$

5. Cooling Seasonal Performance Factor (CSPF)

$$CSPF = \frac{Annual\ amount\ of\ heat\ removed\ (kW)}{Annual\ amount\ of\ energy\ consumed\ (kW)}$$

Efficiencies of the air conditioning systems vary based on the type of the system; common types of air conditioning systems include:

- **Water-Cooled Chiller**: Typically used in large buildings where central cooling is distributed via chilled water. The performance of these chillers can be evaluated based on standard benchmarks provided by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). AHRI defines recommended and best-available values for both the Full Load and the Integrated Part Load Value (IPLV), depending on the chiller's compressor type and cooling capacity. Table 6 summarizes the AHRI benchmarks [3]:

Table 6: Efficiency benchmarks (AHRI 500/550)

Compressor Type & Capacity	Part Load Optimized IPLV (kW/TR)		Full Load Optimized (kW/TR)	
	Recommended	Best Available	Recommended	Best Available
Centrifugal (150 - 299 tons)	0.52 or less	0.47	0.59 or less	0.50
Centrifugal (300 - 2,000 tons)	0.45 or less	0.38	0.56 or less	0.47
Rotary Screw greater 150 tons	0.59 or less	0.46	0.64 or less	0.58

Performance assessed as follows:

Water Chiller Performance Assessment

1. Measure Input Power

- Use a power meter or If a power meter is not available, it can be estimated using real-time current (I) and voltage (V) readings from the Chiller Control Panel/Human-Machine Interface (HMI)/Building Management System (BMS):

$$Input\ Power\ (kW) = \frac{\sqrt{3} \times V \times I \times PF}{60,000}$$

(V=415 V, PF = Power Factor = 0.85–0.9)

2. Calculate Thermal Output

- Determine cooling capacity using chilled water flow and temperature difference:

$$Thermal\ Output\ (kW) = \frac{\dot{V} \times \rho \times C_P \times (T_R - T_S)}{60000}$$

($\dot{V}$ =Volume flow ($\frac{gal}{min}$), ρ=water density =3.79 $\frac{kg}{gal}$, C_P =Specific heat =4.186 $\frac{kJ}{kg°C}$, T_R = and T_S are return and supply chilled water temperature respectively in °C)

3. Evaluate Efficiency

- Compute **COP** and **kW/TR using equations above.**
- Compare **COP** and **kW/TR** with **AHRI benchmarks** to identify performance gaps and potential **energy-saving measures** (e.g., tuning, retrofitting, or control optimization).

- **Air-Cooled Chiller:** Also suitable for large buildings but use air rather than water for heat rejection. Unlike water-cooled chillers, they use ambient air for heat rejection, making them suitable in locations where water use is limited or where cooling towers are not feasible. The methodology for evaluating the performance of air-cooled chillers is similar to that of water-cooled systems. Once the COP and kW/TR are calculated using input power and thermal output, the performance can be benchmarked against industry standards to determine whether the system is operating efficiently or if improvement measures are necessary. Table 7 presents the AHRI benchmark values for air-cooled chillers based on compressor type and capacity [3]:

Table 7: Efficiency benchmarks (AHRI 500/550)

Compressor Type & Capacity	Part Load Optimized IPLV (kW/TR)		Full Load Optimized (kW/TR)	
	Recommended	Best Available	Recommended	Best Available
Scroll (30 -60 tons)	0.86 or less	0.83	1.23 or less	1.1
Reciprocating (30 -150 tons)	0.9 or less	0.8	1.23 or less	1
Screw (70 -150 tons)	0.98 or less	0.38	1.23 or less	0.94

- **Variable Refrigerant Flow (VRF) Multi-split system:** VRF multi-split systems are ideal for medium-sized buildings that experience variable and zone-specific cooling and heating demands. These systems offer high flexibility and energy efficiency, particularly in facilities with fluctuating occupancy or diverse usage patterns.
  The methodology for evaluating the performance of VRF systems is similar to that used for air-cooled and water-cooled chillers by calculating EER based on input and output energy. However, unlike chiller systems, VRF systems typically do not have HMI to directly access real-time operating data. Instead, the required data are often recorded manually during preventive maintenance activities and can be obtained from the maintenance team or contractor logs.
  The performance of VRF systems can be assessed using ASHRAE Standard 90.1[4] and typically expressed in EER and varies according to system capacity, as shown in Table 8 below:

Table 8: Efficiency benchmark (ASHRAE Standard 90.1)

Equipment Type	Cooling Capacity	Energy Efficiency Ratio (EER)
VRF Multi-Split Air Conditioners	<65,000 Btu/h	13
	≥65,000 Btu/h and <135,000 Btu/h	11.2
	≥135,000 Btu/h and <240,000 Btu/h	11
	≥240,000 Btu/h and <760,000 Btu/h	10

- **Package Units:** Packaged air conditioning units are commonly used in small to medium-sized buildings, where all major components (compressor, condenser, evaporator, and fan) are housed in a single unit, typically installed on rooftops or external platforms. Assessing the efficiency of packaged units can be challenging without detailed measurement tools or manufacturer performance data. However, a visual inspection and operational analysis approach can provide valuable insight. This method focuses on identifying inefficiencies based on factors such as equipment age, physical condition, operating behavior, and control strategies.

The following indicators can help evaluate the efficiency of a packaged unit air conditioning system:

Indicator	Efficiency Implication
Equipment Age	If the unit is frequently operated and more than 10–12 years old, replacement should be considered. Older units tend to have lower efficiency and may fall below current performance standards.

Nameplate IEER	Compare the unit's nameplate IEER to benchmark values. If significantly below standards, assess whether replacement is cost-effective based on payback period and lifecycle cost analysis.
Noise/Vibration	Unusual operating sounds or excessive vibration may indicate mechanical inefficiency or lack of maintenance.
Outdoor Location	Units exposed to direct sunlight or restricted airflow may suffer from higher condenser temperatures, leading to reduced efficiency.
Coils and filters	Dust or debris on coils and filters impairs heat transfer and airflow, reducing system efficiency and increasing energy use. Regular cleaning is essential.

Compare the nameplate IEER of the package unit with Table 9 below. If the efficiency is significantly lower, or if the unit is nearing end-of-life, consider replacement with high-efficiency equipment, especially where it aligns with an acceptable payback period or lifecycle savings.

Table 9: Minimum IEER benchmarks (AHRI 340/360) [5]

Cooling Capacity	IEER
≥ 65,000 Btu/h and < 135,000 Btu/h	14.6
≥ 135,000 Btu/h and < 240,000 Btu/h	14
≥ 240,000 Btu/h and < 760,000 Btu/h	13

- **Split System:** Common in residential and small commercial spaces, offering localized cooling with indoor and outdoor components. They consist of two main components: an indoor unit (evaporator and fan) and an **outdoor** unit (compressor and condenser), connected by refrigerant piping. Split units are often manually operated and are not typically integrated into a central control system or BMS. The efficiency of split systems is best assessed using the Cooling Seasonal Performance Factor (CSPF) as shown in Table 10, which reflects seasonal efficiency under part-load conditions. According to ISO 16358-1, CSPF is calculated based on the annual heat removed (cooling output) and the annual energy consumed. [6]

Table 10: Cooling Seasonal Performance Factor (ISO 16358-1)

Capacity Range	CSPF (Climate 0B)
0-4.5 kW	5.9
4.5-9.5 kW	5.6
9.5-16 kW	5.3
>16 kW	4.6

However, when CSPF cannot be calculated due to lack of recorded annual energy consumption and cooling output by building managers or maintenance teams, then a visual inspection and operational assessment (similar to the approach used for packaged units) can be applied to identify inefficiencies.

Indicator	Efficiency Implication
Equipment Age	Split units older than 8–10 years, especially non-inverter types, tend to be significantly less efficient and should be considered for replacement.
Cooling Performance	Inconsistent room temperature or failure to meet setpoint may indicate undersized capacity, refrigerant loss, or system wear.
Filter & Coil Condition	Dirty filters and evaporator coils reduce air flow and cooling capacity, increasing energy use and wear on components.

3.3.2.2 Ventilation system

The ventilation system supplies conditioned air to occupied spaces within a building. Its primary function is to regulate and distribute air to maintain acceptable indoor air quality (IAQ) and ensure thermal comfort, including control of temperature and humidity. Different systems can be installed in buildings to provide ventilation, such as:

Air Handling Unit (AHU) is a centralized system that supplies conditioned air to large areas or entire buildings. It includes components such as dampers, filters, heating and cooling coils, fans, motors, and noise attenuators.

To assess the efficiency of an AHU, both individual components and the overall system should be evaluated as follows:

- **Inspect Components:** Check (1) **dampers** for leakage, (2) **filters** for dust buildup and pressure drop, it should be within acceptable limits as defined by standards, and as low as possible without compromising air quality.
- **Evaluate Fan Efficiency:** Check the operating hours of the fans to determine whether they align with occupancy schedules and calculate Specific Fan Power (SFP) to assess performance, lower SFP values indicate more efficient fan performance.

$$\mathrm{SFP(kW/(m^3/s))} = \frac{\text{All fan powers (kW)}}{\text{Gross amount of air circulated }(\frac{m^3}{s})}$$

- **Assess Control Strategy:** Confirm that Variable Frequency Drives (VFDs) and demand-based controls (occupancy or CO_2 sensors) are in place and functioning to match ventilation rates with actual building demand.

Fan Coil Units (FCUs) are localized air-conditioning systems serving individual rooms or small zones. Each unit includes a fan, coil, and filter that provide heating or cooling using recirculated air. FCUs do not supply fresh air unless connected to a Dedicated Outdoor Air System (DOAS).

To assess the efficiency of an FCU, the following aspects should be reviewed:

- **Inspect Filters:** Check for dust accumulation and monitor the pressure drop across the filter. Dirty filters restrict airflow, forcing the fan to work harder, which reduces overall efficiency. Filters should be cleaned or replaced as part of regular maintenance.
- **Assess Fan and Motor Efficiency:** Evaluate fan performance similarly to AHUs. Old or inefficient motors may lead to higher energy consumption and should be considered for replacement.
- **Assess Control Strategy:** Confirm that the FCU is properly controlled through local thermostats or room sensors. The unit should respond effectively to temperature changes and avoid unnecessary cycling or continuous operation when the space is unoccupied.

3.3.3 Domestic Hot Water (DHW) System

In our climate zone, space heating is not required, and only domestic hot water (DHW) systems are installed to provide heated water for sanitary use in washrooms, kitchens, and service areas. In hot climates such as Oman, DHW systems are typically decentralized, meaning water is heated near the point of use using compact, stand-alone heaters. The most used types include:

Electric Storage (tank) Water Heaters: These units store a fixed volume of water and maintain it at the desired temperature. They are widely used due to their affordability and ease of installation, though they are prone to standby heat losses if not properly insulated.

Tankless (instantaneous) Water Heaters: These are also common, especially where space is limited or hot water demand is intermittent. They heat water on demand, eliminating storage losses and offering higher energy efficiency, though their flow capacity may be limited.

Point-of-Use (POU) Water Heaters: Typically used for small, isolated applications such as handwashing stations or kitchen sinks. These compact units provide hot water directly at the fixture, reducing pipe losses and improving responsiveness.

Heat Pump Water Heaters (Hybrid Water Heaters): These systems are gaining attention for their high efficiency. They use ambient heat to warm water and are well-suited to hot climates like Oman. However, they require adequate installation space and involve higher upfront costs.

Solar Water Heaters: These systems use solar collectors to harness sunlight for heating water.

To ensure optimal performance and energy efficiency, the following parameters should be evaluated:

Identify the **type and age of the water** heater. Units older than 15 years should be assessed for replacement, especially if they operate for extended periods annually. Check the **efficiency rating** from the nameplate and compare it with industry benchmarks.

Typical performance factors include:

- **Electric Storage Water Heaters:** Energy factor (EF) > 0.9
- **Tankless Electric Water Heaters:** EF > 0.96
- **Heat Pump Water Heaters:** EF> 2
- **Solar Water Heaters:** Solar Fraction > 0.5, EF> 1.8

Thermostat Setting:

Check the thermostat setting and maintain the temperature below 55°C, unless higher temperatures are required for hygiene reasons. Lower settings reduce energy consumption and minimize the risk of scalding, especially in residential or public facilities.

3.3.4 Building Envelope

The building envelope represents the interface between indoor and outdoor environments, serving as the primary thermal barrier of a facility. It comprises an integrated, multi-layered system of materials and assemblies designed to control heat, air, and moisture transfer.

The envelope's thermal performance directly influences the building's cooling and heating loads by determining how much heat is gained or lost through these components. Inefficiencies such as poor insulation, uncontrolled air leakage, or excessive glazing can substant ially increase energy consumption and compromise occupant comfort. A well-designed and maintained envelope is therefore critical to achieving optimal energy efficiency and indoor environmental quality.

Building Envelop Performance Assessment

Inspect & Collect Data

1. Identify **thermal bridges, air leaks, and heat losses** using **thermal imaging cameras.**
2. Check the **condition of insulation,** window seals, and door gaskets for damage or deterioration.
3. Review **orientation, shading devices, glazing type** (single, double, or low-E), and record **materials and thickness** for walls, roofs, and windows.

Calculate Thermal Performance

1. Obtain **U-values** (W/m²·K) from drawings and **Solar Heat Gain Coefficients (SHGC)** from manufacturer data.
2. If unavailable, estimate U-value using the thermal resistance method:

$$U = \frac{1}{R_T} \text{ where } R_T = R_o + \frac{t_1}{k_1} + \cdots + \frac{t_n}{k_n} + R_i$$

where t_n is thickness of each material layer (m), k_n thermal conductivity of material (W/m·K), which varies by type, R_o and R_i are outside and inside surface resistances, which depend on air movement direction and speed

Evaluate Efficiency & Benchmark

1. Compare calculated **U-values and SHGC** with recommended standards by **NFRC** and ASHRAE:

Walls:
- **U-values** ≤ 0.483 W/m²·K

Roofs:
- **U-values** ≤ 0.3 W/m²·K

Windows:
- **U-values** ≤ 2.5 W/m²·K
- **SHGC**≤ 0.32

Outside and inside air surface resistances according to ISO 6946 are in Appendix A.

3.3.5 Building Automation and Control Systems

The building control system includes sensors, controllers, actuators, and automation software, plays a vital role in optimizing energy use and maintaining occupant comfort. A well-tuned control system ensures HVAC, lighting, and other equipment operate only when and where required, while maintaining setpoints efficiently. So first to understand how the equipment should be operated and controlled. Poorly calibrated or overridden controls can cause significant energy waste, simultaneous heating and cooling, or continuous equipment operation outside occupancy hours.

Regular assessment of control strategies and sensor accuracy is therefore essential to sustain energy performance and operational reliability.

Inspect & Collect Data

- **Identify control system type:** Determine whether the building uses a centralized Building Management System (BMS), stand-alone controllers, or manual control.
- **Map system configuration:** List all connected or locally managed subsystems (lighting, ACMV, metering, VFDs, etc.) and communication status.
- **Document sensors and devices:** Record the type, quantity, and location of temperature, CO_2, and occupancy sensors, including calibration dates if available.
- **Collect operational data:** Export or note schedules, setpoints, and sequences from the control interface.

Assess Performance

- **Check configuration:** Confirm all controllers, sensors, and feedback loops are active and communicating properly.
- **Evaluate control logic:** Verify that setpoints and schedules match occupancy and operational needs, e.g.:
  - Maintained colling set point to be (22-24°C)
- **Assess sensor accuracy:** ompare readings with handheld instruments, e.g.:
  - CO_2 deviation $\leq \pm 75$ ppm
  - Temperature deviation $\leq \pm 1$ °C
- **Review operation:** Observe how the system responds to load or occupancy changes and identify manual overrides or disabled controls that reduce efficiency.

3.3.6 Renewable Energy

Various renewable energy technologies can be integrated into buildings, such as solar photovoltaic (PV) systems installed on rooftops or carparks, small wind turbines, and biomass systems used for power generation or water heating. However, in Oman, the most practical and widely adopted renewable energy option is solar PV, owing to the country's high solar irradiance and favorable climatic conditions.

Therefore, this section focuses on assessing the performance of existing Solar PV systems in buildings to evaluate their operational performance and energy contribution.

The performance assessment approach is excerpted from IEC 61724 – Photovoltaic System Performance Standard developed by the International Electrotechnical Commission. While the standard provides detailed parameters and monitoring requirements, the practical field assessment can be simplified into three key steps, summarized as follows:

Visual Inspection

- **Check the physical condition** of the PV system:
  - Ensure panels are clean, undamaged, and free from shading.
  - Confirm secure mounting and proper electrical connections.
  - Verify inverter operation and safety signage.

Data Collection

- **Record system details:**
  - Capacity (kWp)
  - inverter specifications, module make and model
- **Collect electricity generation** data from the inverter or monitoring system for a certain period (day, month, or year).
- **Obtain the Global Tilted Irradiation** at Optimum Angle (GTI opta) for the site from Global Solar Atlas.

Performance Evaluation

- **Calculate Performance Ratio:**

$$RP = \frac{Total\ Energy\ Production\ (kWh)}{System\ Capacity\ (kW_P) \times GTI\ opta(kWh/m^2)}$$

Note: The GTI opta period (day, month, or year) should correspond to the same duration used for total energy production.

- Typical range for well-performing systems >75%. Lower values indicate potential issues such as shading, soiling, or inverter malfunction.

3.3.7 Water fixture

Water in buildings is consumed across several key applications; through domestic uses such as restrooms, kitchens, and cleaning areas, within cooling systems including water-cooled chillers and cooling towers, and across landscaping and irrigation activities.

The Water Use Index (WUI) calculated in the previous section provides a high-level overview of the building's total water efficiency compared to benchmarks. While this index helps indicate whether overall consumption is within or beyond the efficient range, it does not show where inefficiencies occur.

To accurately identify potential areas for reduction, a detailed assessment of individual sub-systems is required. This process helps determine which systems contribute most to overall water use and where targeted improvement measures can deliver the highest savings.

The following sub-systems should therefore be examined in detail:

Indoor Fixtures

1. Inspect all fixtures including lavatories, sinks, showers, toilets, and urinals.
2. Identify visible **leaks**, **faulty valves**, or **loose plumbing joints** that may cause unnecessary water loss.
3. Collect water for a specific time interval (e.g., 10 seconds or 1 minute).
4. Calculate flow rate in L/min for each application and compare with maximum flow rate values from the **Oman Plumbing Code,** as shown in Table 11. [7] If the measured flow rate is **higher than the maximum allowable value**, this indicates potential for reduction through fixture replacement

Table 11: Maximum flow rate of water

Fixture Type	Maximum Flow Rate / Quantity
Lavatory, private	6 L/min @415 kPa
Lavatory, public (metering)	1 L per metering cycle
Lavatory, public (other than metering)	2 L/min @415 kPa
Shower head	9.5 L/min @550 kPa
Sink faucet	6 L/min @415 kPa
Urinal	1 L per flushing cycle
Water closet	6 L per flushing cycle

Cooling Systems

1. Inspect cooling towers and condensers for water losses caused by overflow, drift, or excessive blowdown.
2. Review cycles of concentration to ensure optimal performance and minimal make-up water demand.
3. Evaluate the potential to reuse condensate water or recycle treated effluent for cooling tower make-up.
4. Inspect piping and valves for leaks, corrosion, or scale buildup that may lead to inefficient water use and reduced system reliability.

Landscaping & Irrigation

1. Inspect irrigation systems for leakages, overwatering, and inefficient sprinkler coverage.
2. Recommend upgrading to drip irrigation systems, installing automatic sprinkler controls, and utilizing sub-potable or treated water for irrigation where feasible.

4. Energy Conservative Measures (ECMs) & Water Reduction Measures (WRMs)

This section presents a structured list of Energy Conservation Measures (ECMs) and Water Reduction Measures (WRMs) categorized by subsystem and implementation type: Maintenance, Controls and Equipment Upgrade.

Lighting System			
Category	**Cost of Implementation**	**Energy Conservative Measures (ECMs)**	**Estimated Saving Potential (%)**
Behavioral	Low	Ensure lights are switched off when spaces are unoccupied	2-5%
	Low	Maximize use of natural daylight	2-5%
Maintenance	Low	Replace damaged or discolored reflectors to maintain light efficiency	2–5%
	Low	Clean fixtures regularly	2–5%
	Low	Install motion sensors in low-occupancy areas	10–20%
Controls	Low	Use centralized lighting control panels to automate switching	5–10%
	Low	Use daylight sensors in naturally lit areas to reduce artificial lighting usage	10–20%
	Medium	Implement time-of-day and occupancy-based lighting strategies	10–15%
	Medium	Integrate with BMS for lighting schedules	10–15%
Equipment Upgrade	Medium	Replace fluorescent tubes with high-efficiency LED tubes	25–35%
	Medium	Install LED panel lights in office ceilings	25–40%
	Medium	Upgrade to high-efficiency drivers and ballasts	15–25%

Air Conditioning and Mechanical Ventilation System			
Category	**Cost of Implementation**	**Energy Conservative Measures (ECMs)**	**Estimated Saving Potential (%)**
Behavioral	Low	Set AC temp to 24°C or higher	2–4%
Maintenance	Low	Check and maintain refrigerant charge levels	2–5%
	Low	Regularly clean condenser tubes and filters to prevent fouling	up to 20%
Controls	Low	Use condenser water reset controls to optimize system efficiency	3–5%
	Low	Implement chilled water temperature reset based on outdoor air temperature	5–10%
	Low	Install smart thermostats	5–10%
	Medium	Add occupancy-based AC control	5–10%

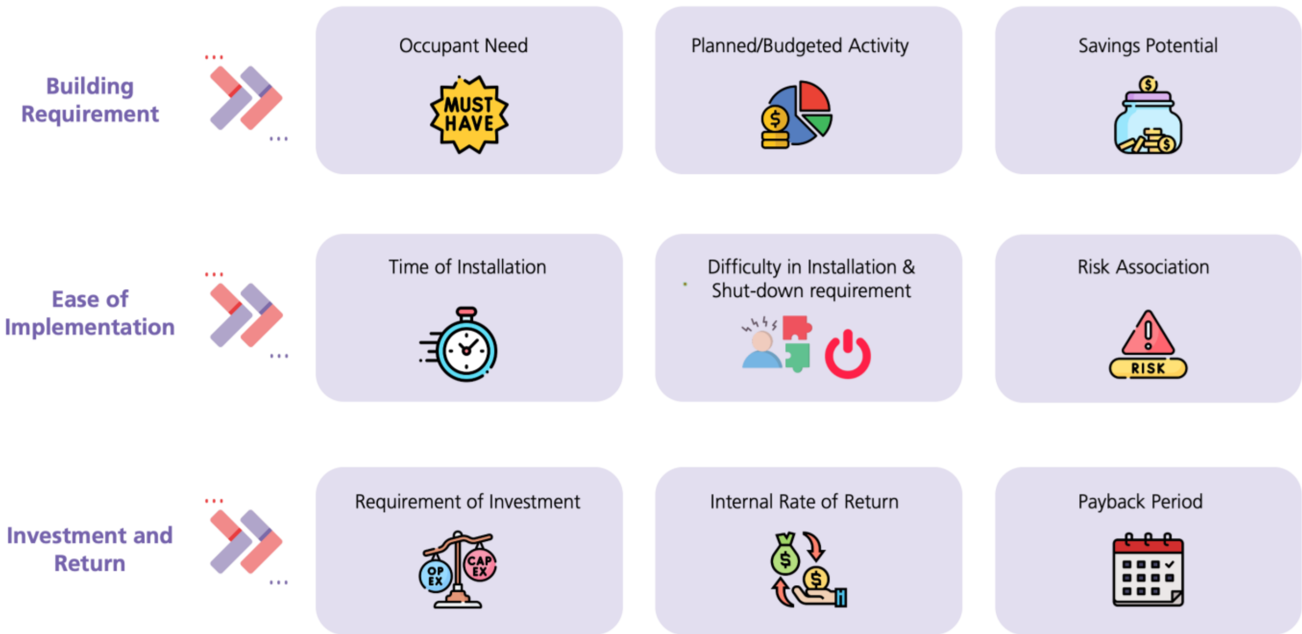
	Medium	Install Variable Speed Drives (VSDs) on chillers, pumps, and fans	10–18%
	Low	Set AC temp to 24°C or higher	2–4%
	Low	Optimize chiller plant control through evaporator temperature and condenser water temperature	5-15%
Equipment Upgrade	high	Replace old chillers with high-efficiency models (ASHRAE 90.1 compliant)	15–25%
	Medium	Replace constant-speed pumps with VFD-equipped pumps	10–15%
	High	Install inverter-based DX units	15–25%
	Medium to high	Replace single compressor with multiple different size staged compressors	5-20%
Domestic Hot Water System			
Category	**Cost of Implementation**	**Energy Conservative Measures (ECMs)**	**Estimated Saving Potential (%)**
Behavioral	Low	Avoid unnecessarily high hot water temperature settings (setpoint 50-55℃)	2-5%
Maintenance	Low	Check thermostat calibration	1–3%
	Low	Insulate hot water pipes and storage tanks	2–5%
Controls	Low	Install programmable thermostats	5–10%
	Medium	Integrate heating system with Building Management System (BMS)	5–10%
Equipment Upgrade	High	Replace old boilers with high efficiency condensing boilers	10–20%
Building Envelope			
Category	**Cost of Implementation**	**Energy Conservative Measures (ECMs)**	**Estimated Saving Potential (%)**
Behavioral	Low	Ensure external doors and windows remain closed when air-conditioning is operating	2-5%
Maintenance	Low	Seal cracks and gaps in walls, roofs, and around windows and doors	5–10%
	Low	Maintain and repair weatherstripping on doors and operable windows	2–5%
Controls	Medium	Use automated shading devices or smart blinds	5–10%
System Upgrade	High	Install insulated external wall cladding	10–20%
	Medium	Apply reflective roof coatings to reduce solar heat absorption	10–15%
	High	Replace single-glazed windows with double or triple glazing	15–25%
	High	Implement passive design features (e.g., thermal mass walls, natural ventilation)	10–20%
	High	Add green roofs to reduce heat gains and improve insulation	10–15%

Building Management System (BMS) System			
Category	**Cost of Implementation**	**Energy Conservative Measures (ECMs)**	**Estimated Saving Potential (%)**
Controls	Medium	Optimize HVAC schedules in BMS	5–10%
	High	Integrate all building systems (HVAC, lighting, metering) into a unified BMS	5–10%
System Upgrade	Medium	Deploy automated fault detection and diagnostics (FDD)	5–15%
Renewable Energy			
Category	**Cost of Implementation**	**Energy Conservative Measures (ECMs)**	**Estimated Saving Potential (%)**
Maintenance	Low	Inspect inverter operation and connections monthly	1–3%
	Low	Clean photovoltaic (PV) panels regularly to remove dust and debris	2–5%
Controls	Medium	Implement smart inverters with real-time monitoring and reactive power control	5–10%
System Upgrade	high	Install solar photovoltaic (PV) panels on rooftops or ground mounts	15–25%
	high	Install wind micro-turbines in windy locations	5–15%
	high	Add solar water heating systems	10–20%
Water Fixtures			
Category	**Cost of Implementation**	**Water Reduction Measures (WRMs)**	**Estimated Reduction Potential (%)**
Maintenance	Low	Fix leaking faucets, toilets, and pipes promptly	5–10%
	Low	Regularly check and maintain aerators and valves	5–10%
Controls	Low	Install motion-sensor faucets and flush valves in restrooms	10–20%
	Medium	Set timers for irrigation systems	5–10%
	Low	Use flow restrictors on showerheads and faucets	10–15%
System Upgrade Advanced	Low	Install Water Sense-labeled low-flow faucets, toilets, and urinals	10–20%
	High	Replace outdated plumbing systems with high-efficiency piping	10–15%
	High	Use smart irrigation controllers with weather-based automation	10–20%

5. Prioritizing Building Measures

Energy Conservative Measures (ECMs) and Water Reduction Measures (WRMs) can range from low-cost operational improvements to high-investment retrofits, and their impact may vary depending on several factors such as building age, equipment condition, climate, and physical feasibility.
To ensure optimal results, measures should be carefully evaluated and prioritized before initiating any major retrofit, aligning with occupant needs, capital investment plans, and the building's overall design or asset management strategy.

A priority matrix is typically developed to guide this process, allowing decision-makers to compare and rank measures objectively. The evaluation parameters are grouped into three key categories:



Detailed financial assessments are in Appendix B.

6. Implementation of ECMs and WRMs

Once retrofit opportunities are identified and prioritized through the assessment process, the next step is implementation, turning identified savings into measurable performance improvements.
Effective implementation requires developing a strong business case and engaging the right technical and financial partners to deliver the measures efficiently and sustainably.

In many cases, building owners face financial or technical capacity constraints that limit their ability to execute retrofit projects. In such cases, Energy Service Companies (ESCOs) play a critical role in bridging the gap by providing performance-based solutions that link project repayment to achieved savings.

There are two primary Energy Performance Contracting (EPC) models commonly adopted worldwide [8]

A Guaranteed Savings Model

- **ESCO guarantees a certain level of energy savings**, thereby taking the **technical risk**
- **Client face financial risk**, being responsible to **secure financing** to pay predetermined fees to ESCO
- In case of **project fails to achieve the guaranteed savings**, the **ESCO** is responsible for **covering the difference**

B Shared Savings Model

- **ESCO provides financing** and **covers the project development** and **implementation costs**
- **ESCO** assumes both **technical & credit risk**
- **ESCO & the client** agree to **share actual savings** generated based on a predetermined percentage
- **ESCO & the client share** performance **risk & rewards**

Different Success Several projects across the GCC and internationally have demonstrated the effectiveness of performance contracting models [9,10]

Ministry of Municipal and Rural Affairs (MOMRA)

- **Location:** Riyadh, Saudi Arabia
- **Project Type:** Guaranteed Energy Savings EPC
- **Measures:**
  - Replacement of air-cooled chillers and
  - Replacement of primary chilled water pumps
- **Contract duration:** 10 years
- **ESCO:** Enova
- **Results:** Annual energy costs savings 40% (9,714 barrels of oil yearly)

RSA GLOBAL DUBAI

- **Location:** Dubai, UAE
- **Project Type:** Shared Savings EPC
- **Measures:**
  - Interior and warehouse lighting retrofit
  - Pump VFD retrofit
  - Chilled water plant optimization
  - +2 more
- **Contract duration:** 5 years
- **ESCO:** Taka Solutions
- **Results:** 24.1% electricity saving (2,328,441 kWh annually)

German University of Technology Campus

- **Location:** Muscat, Oman
- **Project Type:** Guaranteed Energy Savings EPC
- **Measures:**
  - Facility management platform
  - HVAC retrofits
- **Contract duration:** 10 years
- **ESCO:** Siemens
- **Results:** annual energy costs savings 36%, 4-year payback period

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Appendix A: Surface Air Film Resistance

Wall or roof	Direction of flow	R_{conv} $(m^3.°C/W)$
Still air (inside)		
Roof	Up (heating)	0.10
Floor	Down (cooling)	0.17
Wall	Horizontal	0.13
Moving air (outside)		
7 m/s	All	0.03
4 m/s	All	0.06
2 m/s	All	0.06

Appendix B: Detailed Financial Assessments

After prioritizing potential ECMs and WRMs, each measure must undergo a financial evaluation to determine whether it is economically viable and delivers sufficient return. This assessment compares all key financial indicators—payback period, ROI, NPV, and long-term operational costs—to ensure that only measures with strong financial performance and acceptable investment risk proceed to implementation.

By evaluating and comparing these metrics, decision-makers can confidently select the measures that pass financial screening and deliver the highest overall value and savings for the building.
The key financial indicators used in this guideline include:

Simple Pay-back Period (SPP)

The Simple Payback Period represents the time required for the cumulative savings to equal the initial investment cost:

$$SPP = \frac{\text{Initial Investment Cost}}{\text{Annual Cost Saving}}$$

Simple Return on Investment (ROI)

Return on Investment measures the project's annual profitability relative to the investment cost:

$$ROI = \frac{\text{Annual Net Saving}}{\text{Intiial Investment Cost}} \times 100$$

Net Present Value (NPV)

NPV represents the present value of future cash inflows (savings) minus the present value of all cash outflows (investment and costs), discounted over the project's lifetime:

$$NPV = \sum_{t=1}^{n} \frac{\text{Net Cash Flow}_t}{(1+r)^t} - \text{Initial Investment}$$

Where:

- $\text{Net Cash Flow}_t = \text{Savings} - \text{Operational cost in year t}$, r is discount rate , n is project life.

Interpretation:

- $NPV > 0$ → Project adds financial value and is acceptable.
- $NPV = 0$ → Project breaks even.
- $NPV < 0$ →Project is not financially viable.

Internal Rate of Return (IRR)	The IRR is the discount rate at which the NPV of all cash flows equals zero. It represents the project's effective rate of return and is obtained by solving the equation: $$0 = \sum_{t=1}^{n} \frac{\text{Net Cash Flow}_t}{(1+\text{IRR})^t} - \text{Initial Investment}$$ Interpretation: A project is considered financially viable if its IRR is higher than the organization's minimum acceptable rate of return (hurdle rate) or the cost of capital. Typical benchmark: 8–15% for energy efficiency projects.
Savings to Investment Ratio (SIR)	The SIR compares the present value of total savings over the project's life to the present value of total investment costs. $$\text{SIR} = \frac{\sum_{t=1}^{n} \frac{\text{Savings}_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{\text{Investment}_t}{(1+r)^t}}$$ Interpretation: ▪ $\text{SIR} > 1.0$ → Project is cost-effective. ▪ $\text{SIR} = 1.0$ → Break-even point. ▪ $\text{SIR} < 1.0$ → Project is not financially justified.