Sustainable Architecture Principles

- **A world-wide commitment.**
- US Green Building Council initiative.
- The LEED certification process.
- Sustainable architecture design strategies.
- Building deconstruction and recycling.

Sustainable Architecture

World-Wide Commitment (1993)

Manifesto of the Chicago World Congress of Architects jointly sponsored by UIA and AIA in 1993.

"We commit ourselves as members of the *world's architectural* and *building design professionals*, individually and through our professional organizations, to:

- **place *environmental* and *social sustainability* at the core of our practices and professional responsibilities;**
- **develop and continually improve practices, procedures, products, curricula, services, and standards that will enable the implementation of *sustainable design*;**
- **educate our fellow professionals, the building industry, clients, students, and the general public about the critical importance and substantial opportunities of *sustainable design*;**
- **establish policies, regulations, and practices in government and business that ensure *sustainable design* becomes normal practice; and**
- **bring all the existing and future elements of the built environment - in their design production, use, and eventual reuse - up to *sustainable design standards*."**

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LEED History in the US

The US Green Building Council (USGBC) was formed in 1993 as a professional *non-governmental organization* with the mission to promote *green high-performance building* design and construction principles in the US.

1993-7	**Development of Leadership in Energy and Environmental Design (LEED) certification standard.**
1998	**Release of LEED v1.0 (for testing in an 18-building pilot program).**
2000	**Release of LEED v2.0 (certification of first building).**
2002	**Release of LEED v2.1 (tailored by building type).**
2005	**Release of LEED v2.2 (69 maximum achievable points).**
2009	**Release of LEED v3.0 (100 maximum achievable points).**

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LEED Certification Structure

LEED v3.0 (2009) aggregates the scores achieved in several *sustainability categories* into a single score toward an overall rating of Certified, Silver, Gold, Platinum, or No Rating.

- **Rating scales *tailored to building type* (e.g., LEED-NC (new construction), LEED-schools, LEED-CS (core and shell), etc.).**
- **Some very general *minimum requirements* must be met to be eligible for LEED certification (e.g., must be a building).**
- **Most sustainability categories include *prerequisites* to be even eligible for points.**
- **No minimum score requirements in any category for certification level.**

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LEED v3.0 Sustainability Categories (1/4)

The seven LEED-NC v3.0 rating categories offer a total of *110 points*: Certified (*40*); Silver (*50*); Gold (*60*); and Platinum (*80*).

1 Sustainable Sites [*26 possible points*]

Prerequisite: **Pollution prevention measures during construction.**

Credit points: **development density and proximity to existing community services (5 points); public transportation access (6 points); fuel efficient and low emittance vehicles (3 points); and, parking provisions (2 points). The remaining 10 attributes deal with various aspects of site selection and development and carry one point each.**

2 Water Efficiency [*10 possible points*]

Prerequisites: **20% reduction in freshwater usage.**

Credit Points: **Five desirable features are weighted equally with two points each and are concerned with water usage for landscaping, wastewater treatment, and additional freshwater usage reductions by 30% and 40%.**

Sustainable Architecture

LEED v3.0 Sustainability Categories (2/4)

③ Energy and Atmosphere [*35 possible points*]

Prerequisites: **Evidence that specified requirements will be met during the commissioning process and that certain minimum standards will be adhered to in both energy performance and refrigerant management.**

Credit Points: **Enhancement and optimization of energy performance (up to 19 points), on-site renewable energy (3 to 7 points), measurement and verification of energy performance (3 points). The remaining three desirable features relating to further enhancements in commissioning, refrigerant management, and the generation of at least 35% of the electricity requirement from renewable sources, are allocated 2 points each.**

④ Materials and Resources [*14 possible points*]

Prerequisites: **Provision for the on-site or off-site collection and storage of recyclable materials and products.**

Credit Points: **Building reuse of 75% of existing walls, floors and roof (2 points). The remaining desirable features ranging from additional reuse of building materials, the diversion of construction waste from disposal to recycling, the use of regional materials, to the use of rapidly renewable materials and at least 50% of wood-based material and products that are certified by the Forrest Stewardship Council (FSC), are allocated one point each.**

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LEED v3.0 Sustainability Categories (3/4)

5 Indoor Environmental Quality [*15 possible points*]

Prerequisites: **Must meet specified indoor air quality requirements and prevent the occupants from being exposed to tobacco smoke.**

Credit Points: **The 15 desirable features are all rated at one point each and include: monitoring of the inlet air flow rates and carbon dioxide content with the ability to generate an alarm whenever the conditions vary by 10% or more from the set-point; increased ventilation rates; protection of the HVAC system during construction and testing of the air contamination level prior to occupancy; selection of low-emitting materials for wall, floor, and ceiling finishes; control of the entry of pollutants from the outside, as well as containment and air exhaust facilities for pollutants originating from sources inside the building (e.g., cleaning substances); a high degree of individual lighting and thermal control; a comfortable thermal environment; a monitoring system of thermal comfort conditions; and, daylight and external views for 75% and 90% of the internal spaces.**

Sustainable Architecture

LEED v3.0 Sustainability Categories (4/4)

(6) Innovation and Design Process [*6 possible points*]

Prerequisites: **None.**

Credit Points: **Up to 5 credit points may be obtained by a submission that substantially exceeds LEED-NC v3.0 requirements in one or more feature categories. Additional point may be earned if a LEED Accredited Professional (AP) is a principal member of the design team.**

(7) Regional Bonus Credits [*4 possible points*]

Prerequisites: **None.**

Credit Points: **USGBC Website (2009) provides six features for each US state that are sustainability priorities for that state. Compliance with up to four of the applicable priorities adds one point for each claimed agreement.**

Sustainable Architecture

Critique of the LEED Certification Approach

The market driven *non-governmental* structure of USGBC is a major strength and will ensure that the LEED standard will remain closely aligned with *AEC industry interests* and *capabilities*.

Q. 1 Will all of the *stakeholders continue to participate* in the evolution of LEED standards?

Q. 2 For how long can sustainable architecture design principles continue to be implemented *on a voluntary basis*?

Q. 3 Will the urgency of ecological action force the *government to take over*?

Q. 4 Is a *single LEED score* a sufficient measure of the quality of a green high-performance building design?

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Sustainable Architecture

Energy Conserving Strategies

In the US energy consumed by *buildings* is about *40%* of the total national energy consumption (i.e., approx. *100,000 BTU/sq.ft. per year*).

- **Passive Building Design**
- **Building Envelope Improvements**
- **Hot Water Systems**
- **Daylight and Artificial Lighting**
- **Active Heating, Cooling, and Ventilation**

Sustainable Architecture

Passive Building Design Strategies

The underlying concept of a *passive solar solution* is to design the building so that it can function intrinsically as a *collector*, *distributor*, and *store* of solar heat.

This requires a balance of design parameters related to:

- Building *orientation* and *shape*.
- *Layout* of internal spaces.
- Location and use of *windows*.
- Sunpath angles and *shading devices*.
- Thermal properties of building *materials*.

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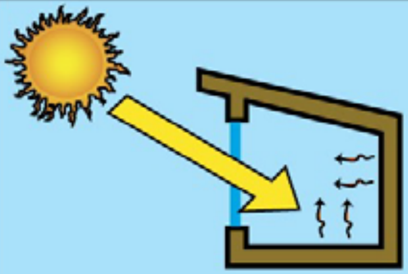
Solar Energy

Passive Solar System Types

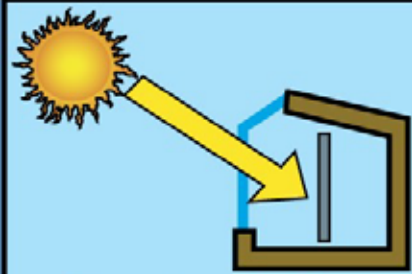
In passive solar systems the building itself is designed to be a solar collector.

Direct Gain



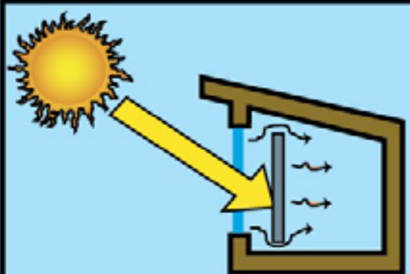
Sun penetrates directly through south facing windows or skylights into building space and is absorbed by internal surfaces, which serve as heat stores.

Sunspace



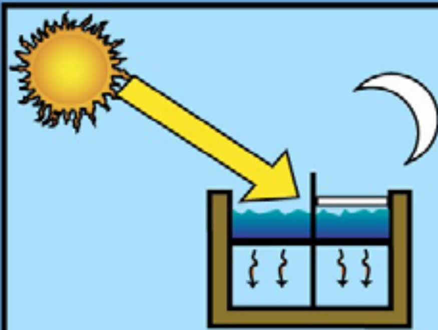
Similar to Trombe Wall with Sunspace in front of wall (often serving as a planted (green-house) area). Sunspace can be insulated from adjoining interior building space.

Trombe Wall



Sun penetrates through south facing windows or skylights, but is blocked by a heat storage wall (Trombe Wall). Heat storage and utilization can be controlled by sliding insulation panels on the internal and external sides of the Trombe Wall.

Roof Pond



Water pool on roof is exposed to sun during day and covered with insulation panels at night during Winter. Strategy is reversed for Summer cooling.

Sustainable Architecture

Building Envelope Improvements

Traditionally the functions of the building envelope have been to reduce the heat flow out of the building (*thermal insulation*) and to control the solar radiation into the building (*sunshading devices*).

Additional strategies could include:

- Thermal *insulation on demand* technologies.
- Continuous *monitoring* of internal and external conditions.
- Accurate control of *movable* sunshading devices.
- Sun tracking and *dynamic reconfiguration* of the building envelope.
- *Movable* building modules.

Sustainable Architecture

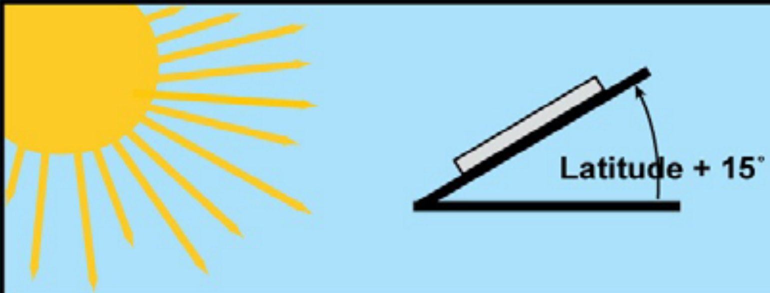
Hot Water Systems

Traditionally the most energy efficient hot water solutions have been *solar* and *tankless* hot water systems.

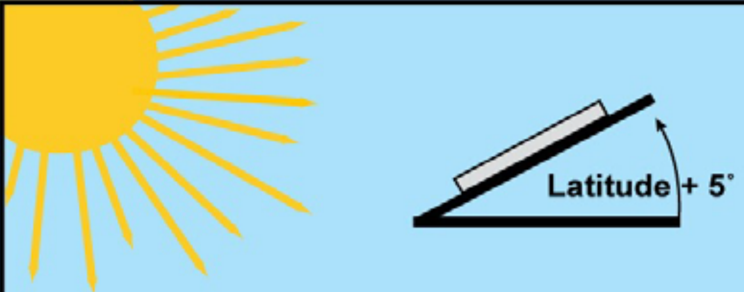
- ***Tankless*** **hot water systems require an** ***intense heat source*** **as close to the point of delivery as possible.**
- ***Solar*** **hot water systems typically require** ***two tanks*** **due to the lack of heat stratification in water.**
- **Both systems suffer from significant** ***water wastage*** **until the hot water arrives at the point of delivery.**

Solar Energy

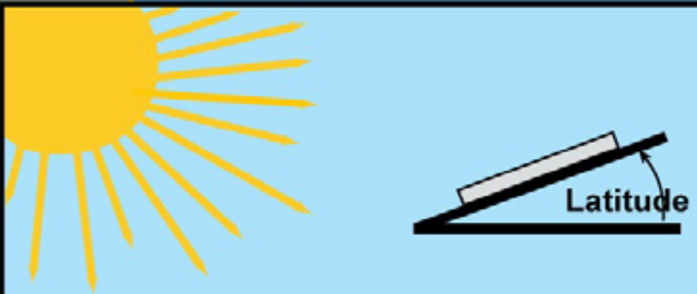
Active: Optimum Collector Tilts



For **winter heating** optimum collector tilt is approx. **latitude + 15°**.



For combined **winter heating** and **summer cooling** optimum collector tilt is approx. **latitude + 5°**.



For year round **hot water** heating, optimum collector tilt is approx. equal to the **latitude**.

Sustainable Architecture

Daylighting

The Good News Daylight is *freely available* on most building sites and *low-E glass* can *reduce heat* transfer by more than *50%* while reducing *light* transmittance by less than *25%.*

The Bad News Daylight is only available during the *daytime* hours and varies in intensity depending on the *time of day* and *sky conditions*. In addition, it is often difficult to avoid *glare* and project daylight into *deep rooms*.

Sustainable Architecture

Artificial Lighting

The Bad News All existing artificial light sources that are suitable for buildings are singularly *inefficient* (e.g., incandescent lamps (*7%*) and fluorescent lamps (*20%*).

The Good News Advances in *electroluminescence* technology in the form of the Light Emitting Diode (*LED*) lamp promise higher efficiencies (100 lumen/watt commercially available) and a lifetime of up to *50,000 hours*.

Sustainable Architecture

HVAC: Electric Motors

Electric motors that typically drive the distribution of air in buildings consume a great deal of energy *during their operation*.

- **Internal *electrical resistance* can be reduced by using large diameter copper wire.**
- **Thinner steel laminations in the rotor will reduce *magnetization losses*.**
- **High quality bearings will reduce *mechanical friction losses*.**

However, the overall increases in efficiency may not exceed *5%*.

Sustainable Architecture

Comparative Efficiency of Electric Motors

An electric fan motor running fairly continuously will consume about *8 times its initial purchase price* in energy costs each year. Efficiencies can be achieved by designing motors with reduced electrical resistance, mechanical friction, and magnetization losses.

Motor Size (Horsepower (HP))	Operating Load		Efficiency Loss
	Full	1/4 Capacity	
100 HP	92.9%	86.5%	7%
10 HP	87%	79.9%	8%
1 HP	77.2%	54.7%	29%

Electric motors perform most efficiently at full load.

Sustainable Architecture

HVAC: Chiller Plants

The chiller plant of an air conditioning system is the largest energy user in commercial buildings, consuming more than *20%* of the *total building energy*.

To reduce energy consumption:

- *Avoid overdesign* of the chiller plant.
- Incorporate *direct digital control* and *variable frequency drives* to allow the chiller plant to operate efficiently under less than peak loads.

Chillers, like electric motors, operate most efficiently at *full power*.

Sustainable Architecture

HVAC: Air Distribution

Air distribution systems must deliver the required quantity and quality of air to all parts of the building under greatly *varying operating conditions.*

To increase energy efficiency:

- **Use *variable-air-volume* instead of constant volume systems.**
- **Use *individual* temperature control at *local* diffusers.**
- **Use a *displacement* ventilation system with floor and ceiling plenums to reduce the need for ducts.**
- **Increase duct *sizes* and avoid sharp *bends* to reduce pressure drops.**
- **Size fans based on *actual loads*.**

Sustainable Architecture

HVAC: Energy Recovery

In air conditioning systems as much as *50%* of the conditioned air is replaced by *external air*, leading to a signficant energy cost.

A *Heat Recovery Wheels* with inlaid desiccant beds to pre-heat or pre-cool the external air and remove moisture.

B *Ground-Coupling* by passing the external air through underground ducts.

The strategy is to *pre-condition* the external air.

Sustainable Architecture

HVAC: Radiant Cooling

Air **is not a very efficient cooling medium because it has a very *low heat capacity* and is highly *compressible*, therefore requiring a large volume of air to cool a space.**

Water **has a *high heat capacity*, is *incompressible*, and can be pumped with the expenditure of little energy.**

Strategy: ***Circulate water through tubes embedded in floor, wall, and ceiling elements.***

Sustainable Architecture

Need for Water Conservation

Water is critical for *human survival* and although 4/5th of the Earth's surface is covered by water, less than *3%* of that enormous amount is freshwater and less than *0.3%* is not locked up in glaciers and snow cover.

- ***Severe water shortage*** **experienced by 90% of the population in West Asia.**
- **Some *80%* of water consumption is for *agricultural* purposes and much of that is wasted (up to 50%).**
- **Water-borne *diseases* (e.g., typhoid, cholera, dysentery) are responsible for over *2 million deaths each year*.**

Sustainable Architecture

Water: Definition of Terms

Water conservation must start with the differentiation of the common term *water* into its *multiple forms*.

Potable Water	Water suitable for drinking.
Freshwater	Water containing less than 500 ppm of salt, normallly found in rivers, lakes, and acquifers.
Graywater	Water from showers, bathtubs, sinks, etc.
Blackwater	Water containing human excreta such as wastewater from toilets.
Rainwater	Water collected during rainfall.

Buildings account for about *12%* of total water consumption.

Sustainable Architecture

Water Consumption Goals

The long-term sustainability goal is to *reduce* the *freshwater* draw of buildings by *90%*.

- **The World Health Organization has defined the daily water requirements for *bare survival* to be *2 gal/day* (1 gal for drinking and 1 gal for cooking).**
- **The US Agency for International Development suggests *26 gal/day* for *reasonable quality of life*.**
- **The current US water consumption is about *100 gal/day* per person.**
- **The US water consumption including *agriculture* is around *1,800 gal/day* per capita.**

Sustainable Architecture

US Energy Policy Act of 1992

Plumbing Fixture	Maximum Flush and Flow Rates
WC (toilets)	1.6 gal per flush
urinals	1.0 gal per flush
showerheads	2.5 gal/min at 80 psi pressure 2.2 gal/min at 60 psi pressure
faucets	2.5 gal/min at 80 psi pressure 2.0 gal/min at 60 psi pressure
metering faucets	0.25 gal/cycle

Sustainable Architecture

Water: The Human Element

Human Strategy

Create awareness and save freshwater by carefully *monitoring* and *communicating* water usage to the user.

- Display water usage immediately after each use.
- Display monthly and annual water usage by consumer and across consumers on request.

Mechanical Strategy

Capture (rainwater), separate, treat, and *recycle graywater* for appropriate purposes.

Sustainable Architecture

Hydrologic Strategy for Buildings

Step 1 Select the appropriate water source for each purpose (i.e., *potable water for human consumption only*.)

Step 2 For each water usage select the technology that will minimize consumption (e.g., *low-flow fixtures and sensors for control*).

Step 3 Implement a *dual wastewater system* to separate graywater from blackwater, as a prerequisite for *water treatment*.

Step 4 *Recycle graywater* and consider a constructed wetland.

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Rainwater Harvesting

Rainwater harvesting systems have been used extensively in Australia for many years.

Principal components include:

1. A large *catchment area* such as a *roof*.
2. A *roof-wash system* that allows the initial run-off from rain to clean the roof.
3. *Protective screens* for open inlets and gutters (ideally).
4. A large water *storage tank*.
5. A *booster pump* and smaller presure tank at 60 psi to 80 psi.
6. A graywater quality water *treatment facility*.

Sustainable Architecture

Closed-Loop Building Materials

The concept of *closed-loop-materials* requires the selection of *low embodied energy* materials that can be easily *salvaged* and *recycled* in some form well beyond the lifespan of a building.

This requires architects to:

- consider the *embodied energy* of any candidate material;
- favor the selection of *recycled materials*;
- consider the *recyclability* of all selected materials at the end of the lifespan of the building;
- design the building to be easily *disassembled* at the end of its lifespan.

Sustainable Architecture

Definition: Embodied Energy

The *embodied energy* of a material or product includes the entire energy consumed during *extraction*, *transportation*, and *manufacture*.

- About *40%* in extraction, *50%* in manufacture, *6%* transportation, and *4%* for processing machinery.
- *Specific values vary* among countries, regions, and with time, due to: climate; machinery; processes; and, advancing technology.
- No international agreement on units of measurement (i.e., *by volume* or *by weight*).

Building material selection is the *most complex aspect* of sustainable architecture.

Sustainable Architecture

Embodied Energy: Units of Measurement

Units of measurement for *embodied energy* may be by *volume* or *mass* (and sometimes by *distance* for transportation) and are normally given in metric units.

Volume (MJ/m^3)	1 MJ/m^3	=	*26.84 BTU/ft^3*
		=	*0.0079 kWh/ft^3*
		=	*6.762 Cal/ft^3*
Mass (MJ/kg)	1 MJ/kg	=	*429.9 BTU/lb*
		=	*0.126 kWh/lb*
		=	*108.5 Cal/lb*
Transportation (MJ/km)	1 MJ/km	=	*592.4 BTU/mile*
		=	*0.174 kWmile*
		=	*149.3 Cal/mile*

Sustainable Architecture

Embodied Energy of Construction Materials

Common Construction Materials	Embodied Energy					
	By Volume			By Weight		
	BTU/cu.ft.	kWh/cu.ft.	Cal/cu.ft.	BTU/lb.	kWh/lb.	Cal/lb.
concrete (4,300 psi)	85,351	*25*	21,503	559	*0.16*	141
aluminum (new)	13,841,388	*4,074*	3,487,163	97,587	*28.60*	24,630
aluminum (recycled)	586,991	*173*	147,885	3,482	*1.02*	879
steel (new)	6,742,208	*1,984*	1,698,614	13,757	*4.03*	3,472
steel (recycled)	998,716	*294*	251,614	3,826	*1.12*	966
timber	37,039	*11*	9,332	1,075	*0.32*	271
bricks	138,763	*41*	34,960	1,075	*0.32*	271
gypsum wallboard	158,088	*47*	39,828	2,622	*0.77*	662
particle board	118,096	*35*	29,753	3,439	*1.01*	868
plywood	153,525	*45*	38,679	4,471	*1.31*	1,128
fiberglass insulation	26,035	*8*	6,559	13,026	*3.82*	3,288
polystyrene insulation	101,187	*30*	25,493	50,298	*14.74*	12,695
linoleum	4,050,961	*1,192*	1,020,589	49,868	*14.62*	12,586
carpet (synthetic)	2,278,716	*671*	574,094	63,625	*18.65*	16,058

Sustainable Architecture

Embodied Energy: Methods

The *embodied energy* of a material or product is very difficult to determine. Values obtained by *different methods* can *vary widely*.

Process Analysis Method Considers both the *direct* and *indirect* energy consumed. The direct energy used in the production processes normally is fairly accurate, but the *indirect* energy used during raw material extraction and transportation can be quite *inaccurate*.

Input-Output Method Based on *national financial data* that tracks the flow of money in and out of energy producing and consuming sectors.

Hybrid Analysis Method Combines the *Process Analysis* and the *Input-Output* methods with mixed results.

Statistical Method Based on published *statistical data* of the *energy profile* of a particular industry. Lacks detail but good for order-of-magnitude estimates.

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Sustainable Architecture

Deconstruction and Disassembly

To consider the *disassembly* and *recycling* of the materials and products at the deconstruction stage adds a whole *new dimension* to the design of buildings.

- **Buildings are typically *custom designed* and with computers industry has found ways to customize mass-production.**
- **It is *difficult to recycle products* such as window units because they come in so many different sizes and configurations.**
- **Over the 50(+)-year lifespan of a building, *technological advances* will make many products and some materials obsolete.**

Sustainable Architecture

Design Guidelines for Deconstruction

1. Adopt a *modular design* approach.
2. Use a *standard structural grid* and separate the building envelope from the structure.
3. Design *joints* and *connectors* for ease of disassembly (e.g., bolts, nails and screws instead of welds and glued joints).
4. Reduce the *number of different materials* and avoid composite materials that cannot be easily separated.
5. Provide *comprehensive documentation* of building components, material types, and assembly/disassembly processes.