Prof. Dr. Uğur Atikol

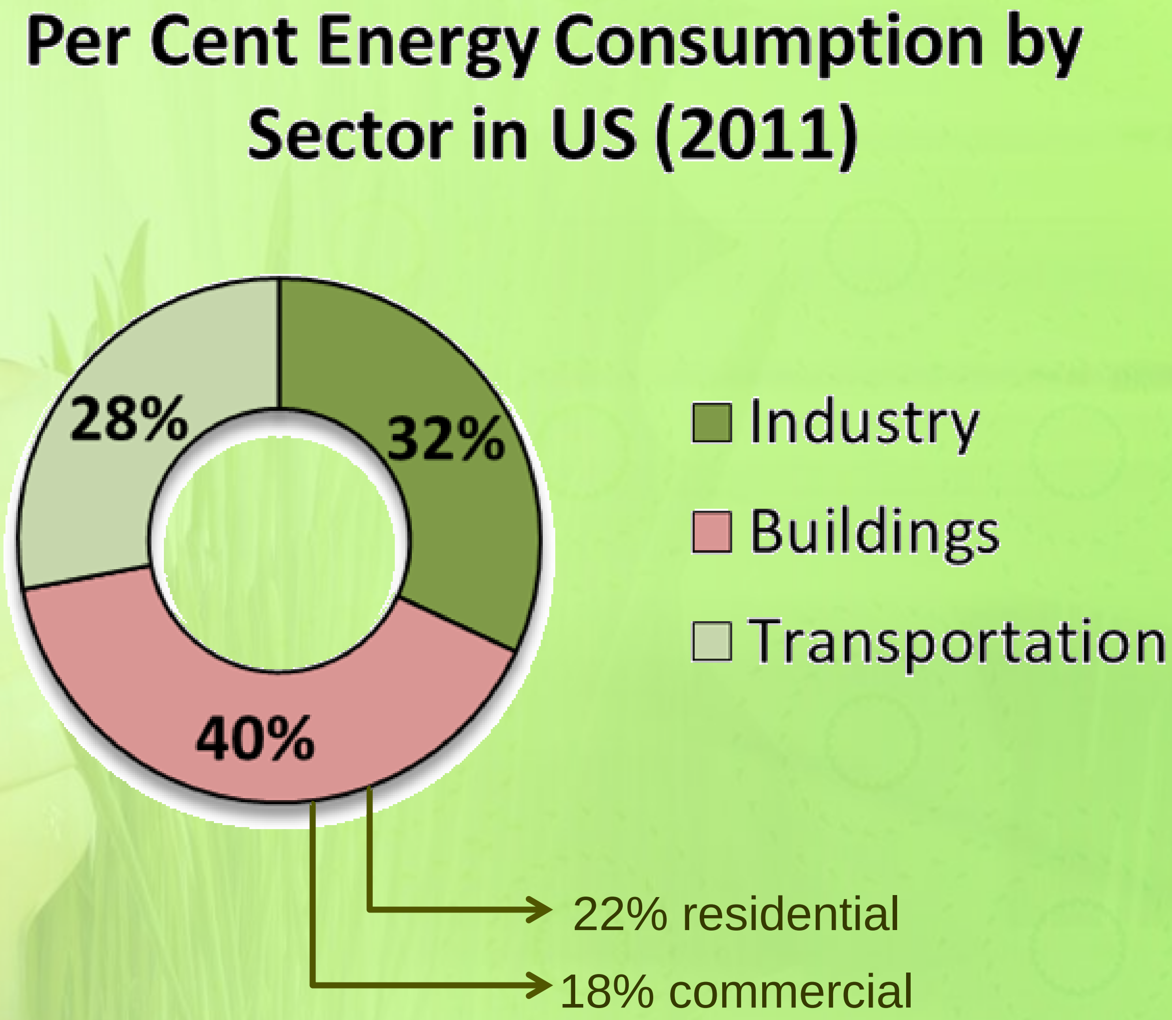
MENG449 INTRODUCTION TO ENERGY MANAGEMENT

Chapter 5 – Energy Sustainability in Buildings

Coverage:

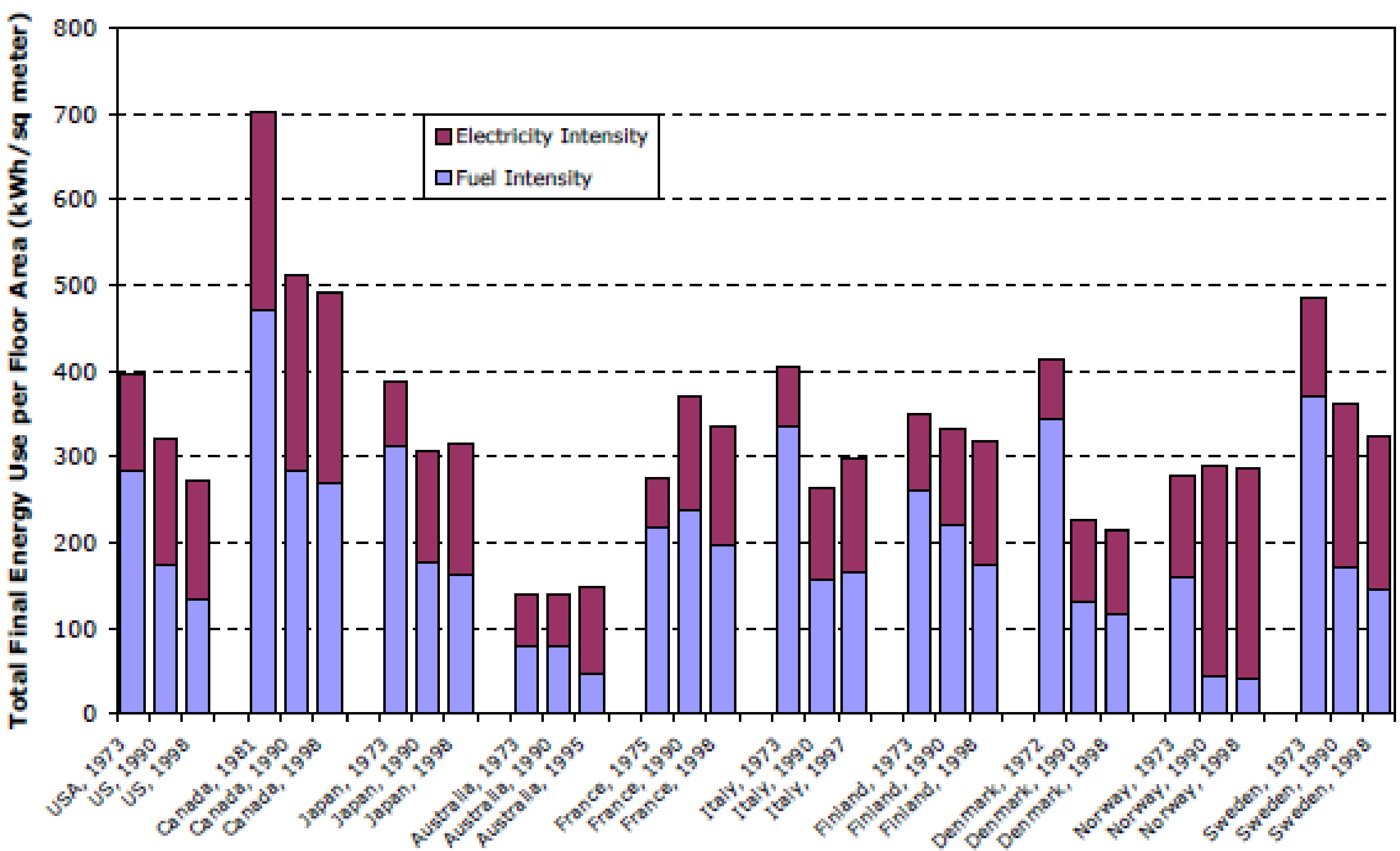
- Why buildings?
- What is energy sustainability?
- Understanding energy efficiency in buildings
- Degree days concept
- Renewable energy use in buildings

Why buildings are important?



Benchmarking: Energy use index (EUI)

- Indicates the energy performance of a building
- Energy use (in kWh) per unit area (in m^2) in a building



Source: IEA 2004

Evolution of service sector annual electricity and fuel use per unit floor area in 10 countries

Reused from: https://www.aceee.org/files/proceedings/2004/data/papers/SS04_Panel4_Paper14.pdf

Example for EUI calculation for a building

- Imagine abuilding with 10,000 m^2 of floor area
- It uses 2 million kWh electricity and 7200 GJ of natural gas in one year
- Total annual energy use,

$$E_{Total} = (2 \times 10^6 \text{kWh}) + (7200\ \text{GJ}) \times (10^6\ \text{kJ/GJ}) \times \left(\frac{1\ \text{kWh}}{3600\ \text{kJ}}\right) = 4 \times 10^6 \text{kWh}$$

- Divide the total energy use by 10,000 m^2:

$$EUI = \frac{4 \times 10^6 \text{kWh/year}}{10{,}000\ \text{m}^2} = \mathbf{400\ kWh/m^2/year}$$

Energy Cost Index (ECI)

- Another useful benchmarking criteria
- It utilizes the annual cost of energy per square meter
- Imagine in the previous example; the annual cost of electricity is 140,000 USD and the annual cost of natural gas is 60,000 USD

$$ECI = \frac{(140{,}000+60{,}000)\text{USD/year}}{10{,}000\ \text{m}^2} = \mathbf{20\ USD/m^2/year}$$

- ECI for an average building in US can be taken as 12.73 USD/m^2/year (Energy Information Adminstration, 1995)
- ECI for an average office building in US can be taken as 16.16 USD/m^2/year (Energy Information Adminstration, 1995)

Energy efficiency opportunities in buildings

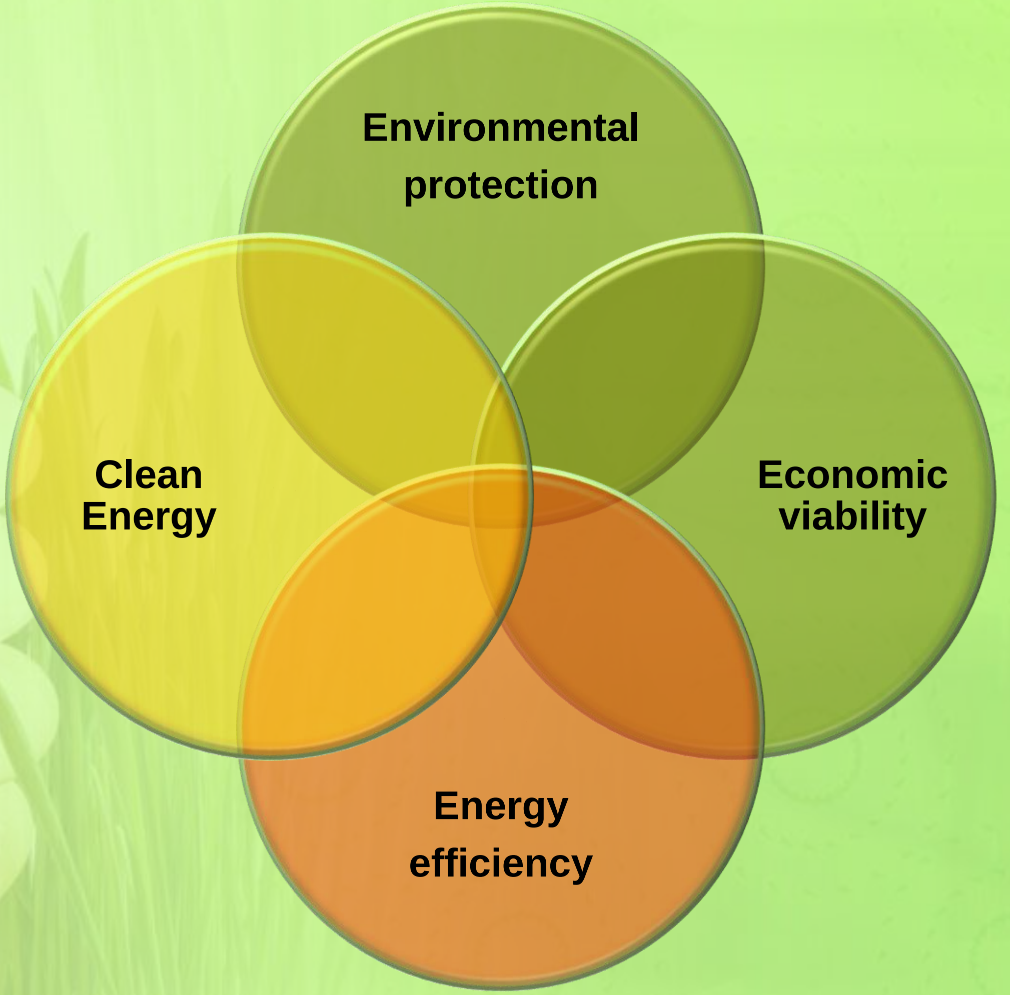
- Building Operation
- Building Envelope
- HVAC Equipment and Systems
- HVAC Distribution Systems
- Water Heating Systems
- Lighting Systems
- Power Systems
- Energy Management Control Systems
- Heat Recovery Systems

Chillers

Roof Top Units

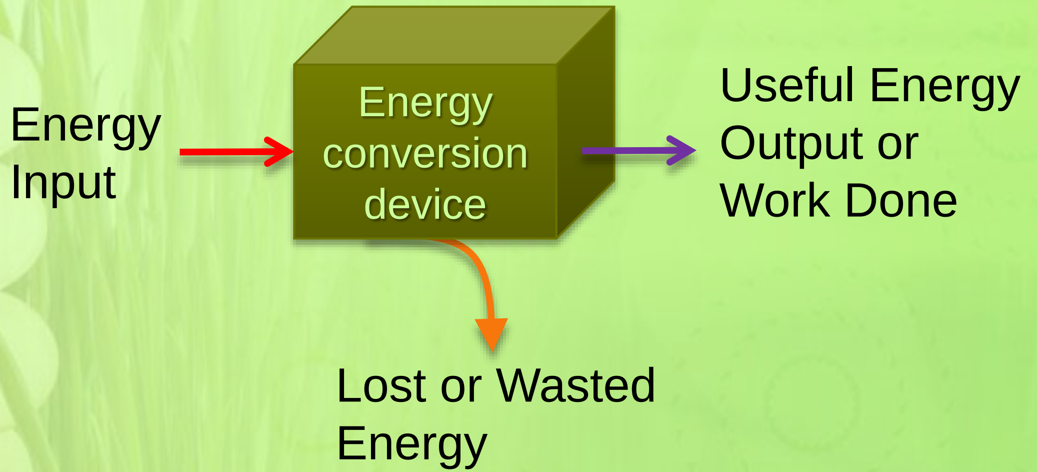
Fan Coil Units

What is meant by energy sustainability



Energy efficiency in buildings

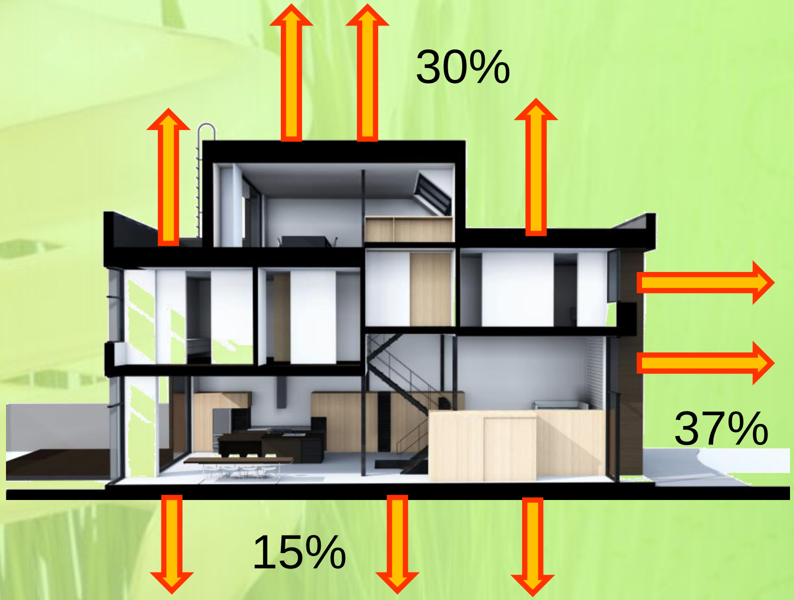
- Making more use of the available energy or doing the same amount of work with less energy
- Example: Washing the same laundry with less electricity in a washing machine



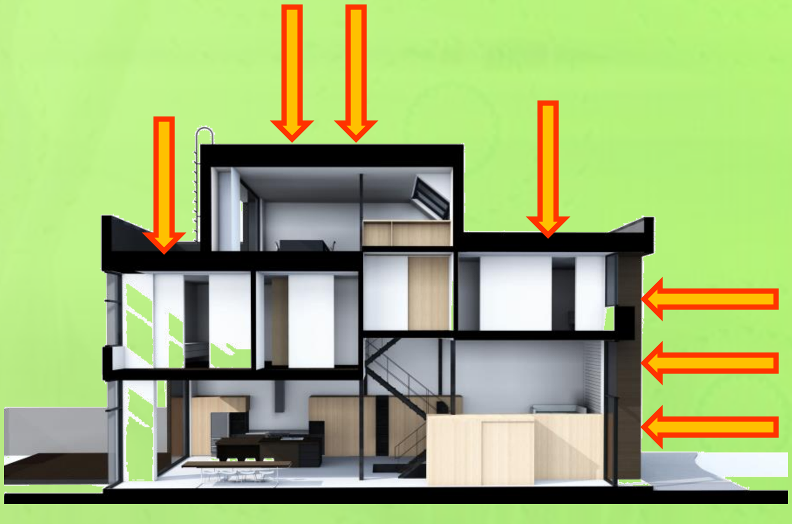
$$Efficiency = \frac{Useful\ Energy\ Output}{Energy\ Input}$$

Building envelope

Selection of materials and the level of thermal insulation on the building envelope are important in the control of heat gains and losses from the buildings.

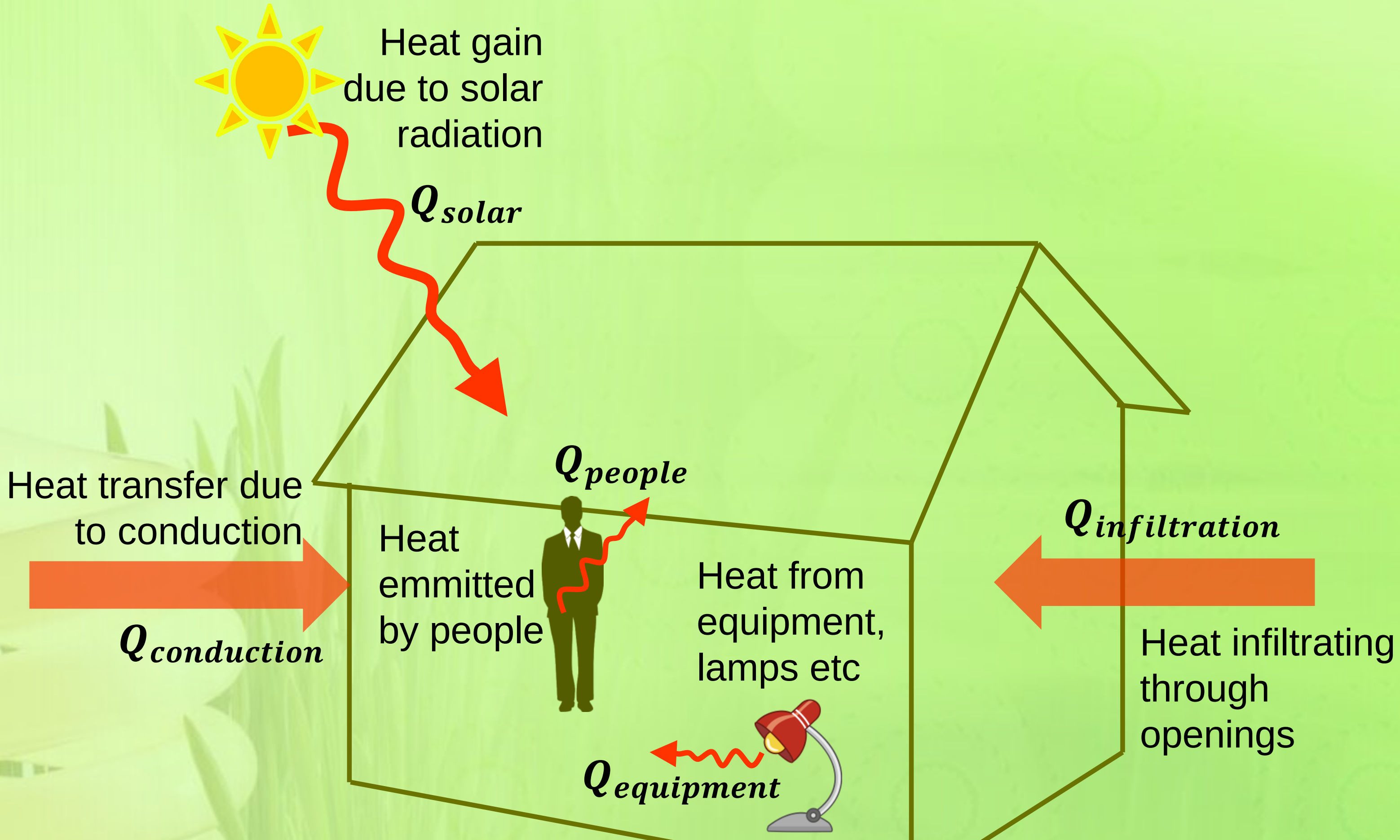


Winter heat losses



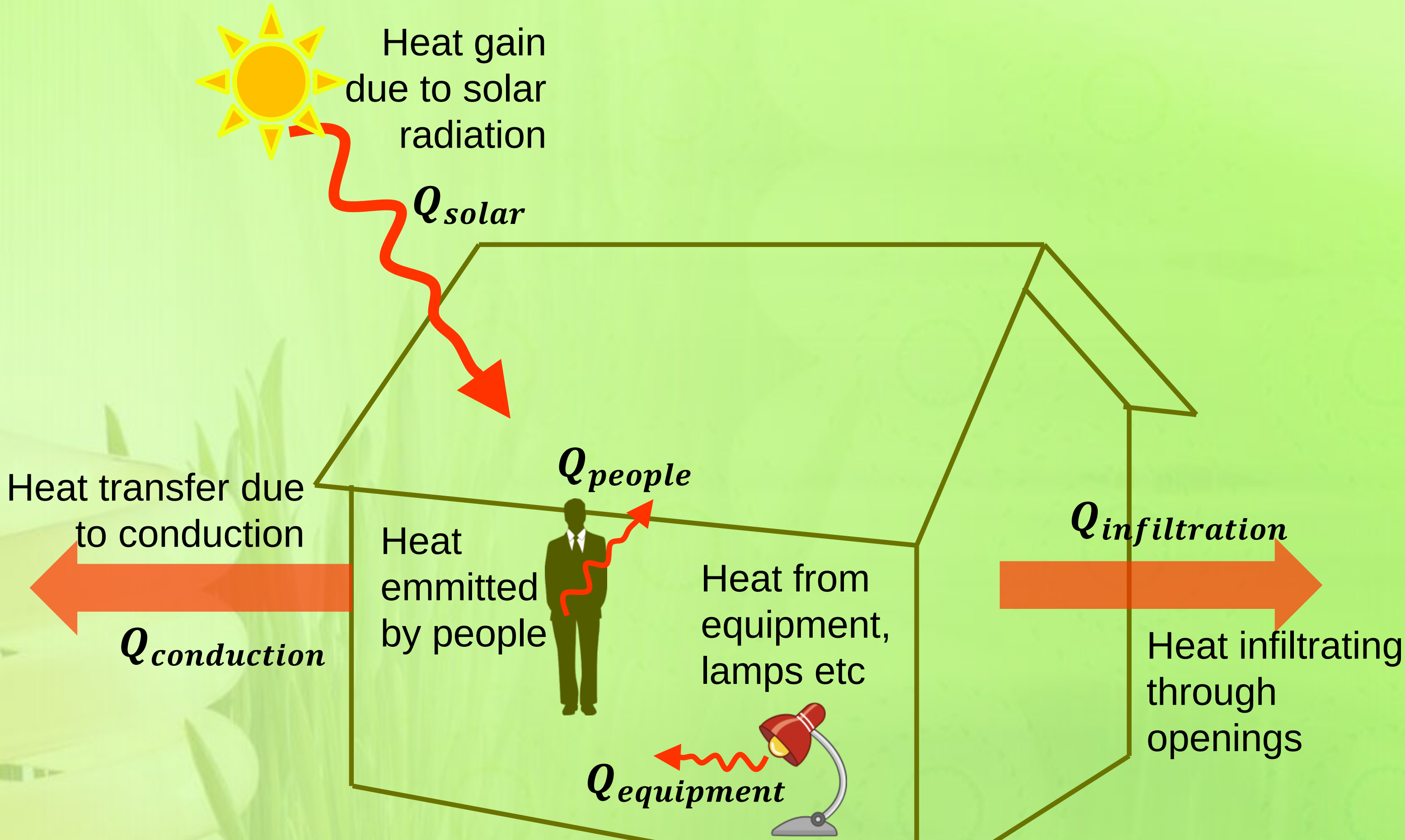
Summer heat gains

Building thermal dynamics in Summer



$$Heat\ Gain = Q_{solar} + Q_{conduction} + Q_{people} + Q_{equipment} + Q_{infiltration}$$

Building thermal dynamics in Winter



$$\textit{Heat Loss} = Q_{conduction} + Q_{infiltration} \underbrace{- Q_{people} - Q_{equipment} - Q_{solar}}_{\text{Heat gain}}$$

Useful formula for infiltration

In British units:

$$\boldsymbol{Q_{infiltration} = 1.08 \times cfm \times \Delta T}$$ (Btu/h)

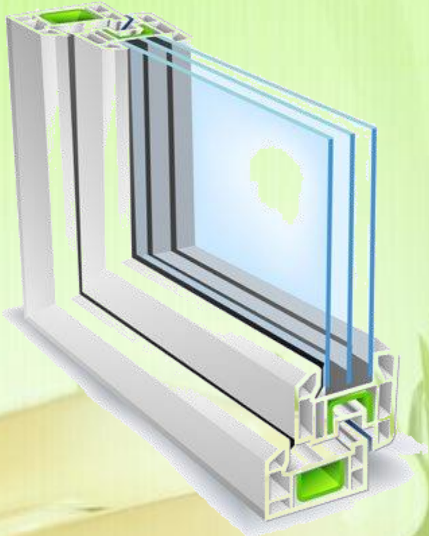
Cubic feet per minute

In SI units :

$$\boldsymbol{Q_{infiltration} = 1.21 \times L/s \times \Delta T}$$ (W)

Density x specific heat of air

Outdoor-indoor temperature difference



Building envelope measures

Energy is saved when the heat exchange between the building and the outside environment is reduced and/or solar and internal heat gains are controlled.

- Thermal insulation
- Infiltration control
- Roof color
- Solar gains
- Window shading
- Landscaping
- Window quality
- Heat bridge

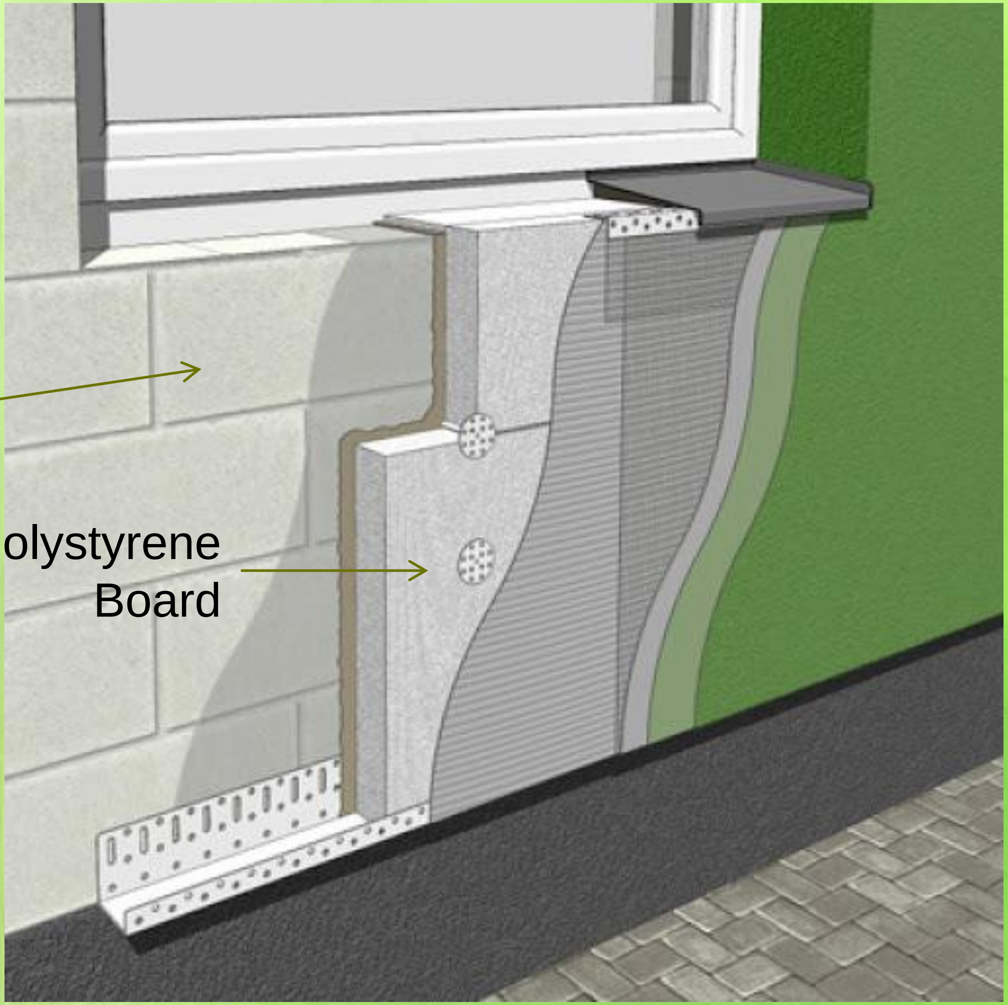
Thermal properties of some building materials at 300 K

Material	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Density (kg/m^3)
Brick	0.7	840	1600
Concrete (cast dense)	1.4	840	2100
Window glass	0.8	880	2700
Oak wood	0.16	1250	720
Granite	1.7-3.9	820	2600
Fiberglass	0.04	700	150
Expanded polystyrene	0.03	1200	50

Sources:

- Incropera, F., De Witt, D., Introduction to Heat Transfer, 2nd Edition, John Wiley and Sons, 1990.
- www.goodfellows.com
- Comfortable Low Energy Architecture website (http://www.learn.londonmet.ac.uk/packages/clear/index.html)
- www.coloradoenergy.org/procorner/stuff/r-values.htm

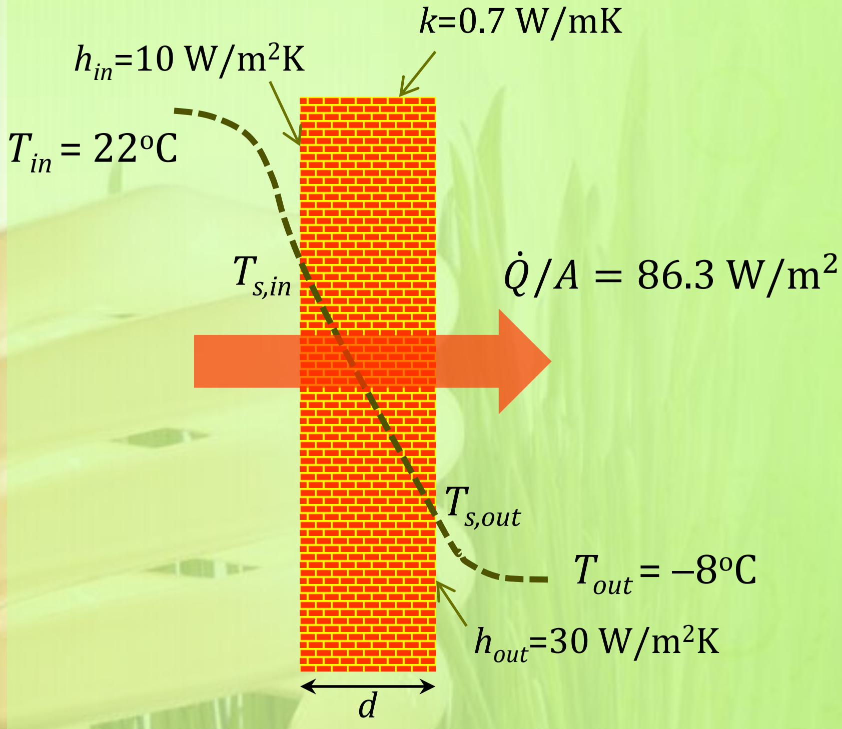
Thermal insulation of a wall with expanded polystyrene boards



Source: http://www.paints-polytex.eu/thermal-insulation-system-based-on-expanded-polystyrene

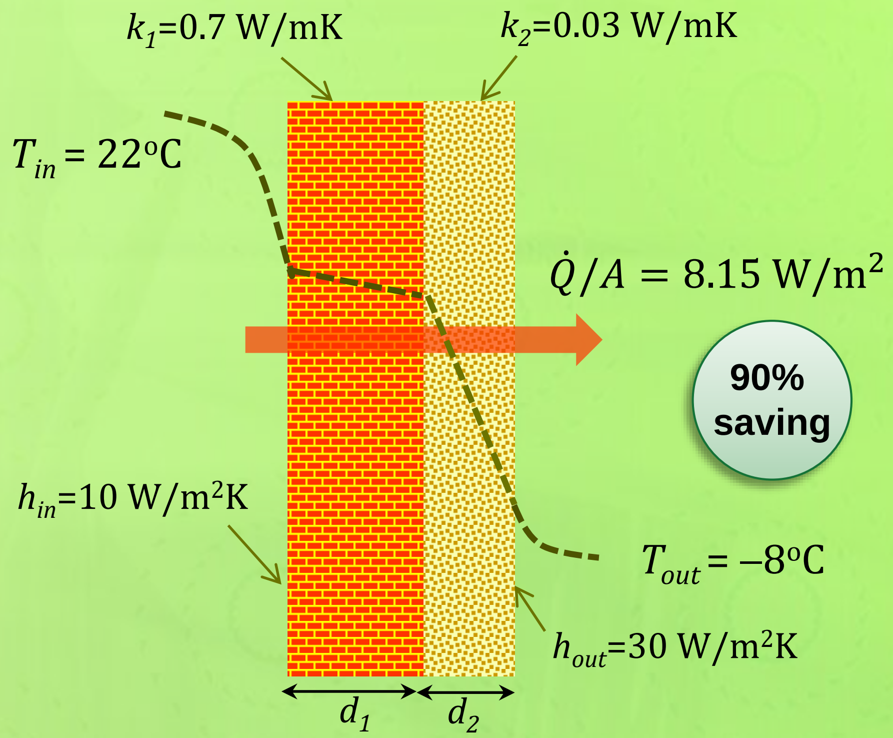
Benefit of using expanded polystyrene on a brick wall

A typical non-insulated 15-cm brick wall



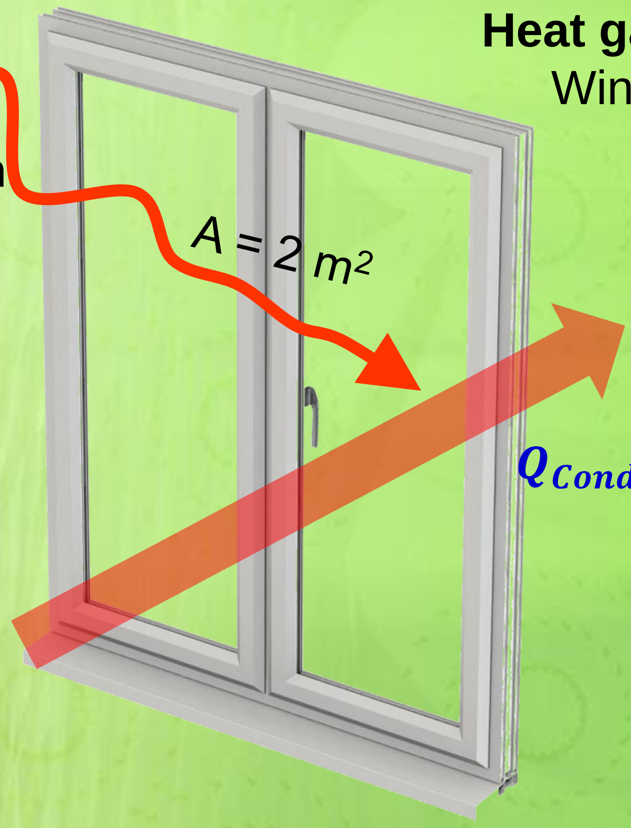
$$\frac{\dot{Q}}{A} = U\Delta T = \frac{(T_{in} - T_{out})}{\frac{1}{h_{in}} + \frac{d}{k} + \frac{1}{h_{out}}}$$

A typical brick wall thermally insulated with 10-cm expanded polystyrene



$$\frac{\dot{Q}}{A} = U\Delta T = \frac{(T_{in} - T_{out})}{\frac{1}{h_{in}} + \frac{d_1}{k_1} + \frac{d_2}{k_2} + \frac{1}{h_{out}}}$$

Example of heat gain through a window in summer



Heat gain through radiation
Solar radiation = 500 W/m^2
SHGC=0.8
Solar heat gain through the window:

$$Q_{Sol} = 500\,\frac{\mathbf{W}}{\mathbf{m^2}} \times 2\mathbf{m^2} \times 0.8$$

$$= 800\ \mathbf{W}$$

Heat gain through conduction
Window U-value = 6 W/m^2^{o}C
Outdoor temp. = 32^{o}C
Indoor temp. = 22^{o}C

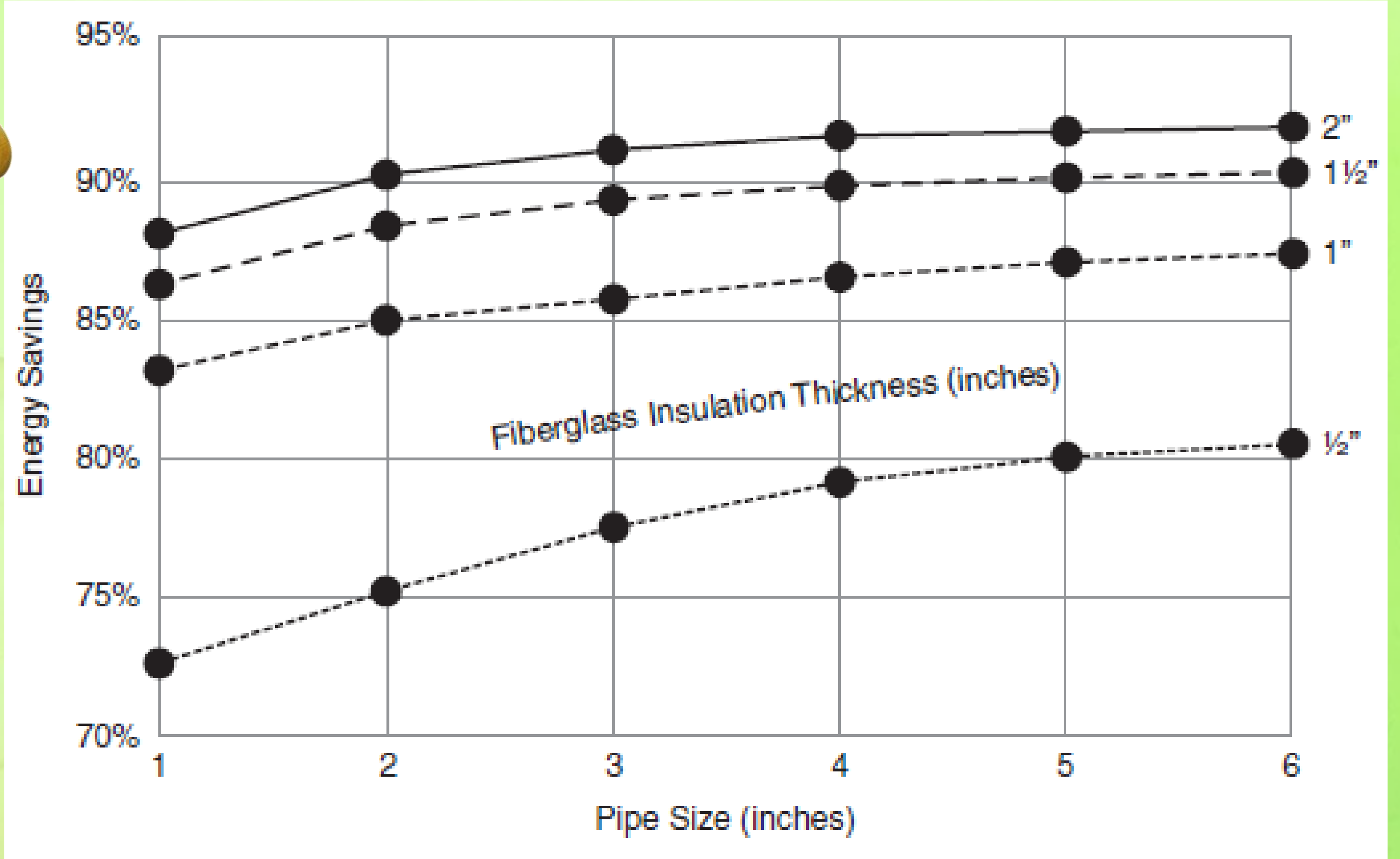
$$Q_{Cond} = 6\,\frac{\mathbf{W}}{\mathbf{m^2}{}^\circ\mathrm{C}} \times 2\ \mathbf{m^2} \times 10{}^\circ\mathrm{C}$$

$$= 120\ \mathbf{W}$$

Total heat gain would be 920 W

Pipe insulation savings on hot water pipe at 66^{o}C, losing heat to 27^{o}C ambient air.

The effect of fiberglass insulation on savings



Source: Shapiro, Energy audits and improvements for commercial buildings, 2016, Wiley

Degree day method for estimating the amount of heating or cooling in a building

- This method utilizes the outside temperature to estimate the annual heating or cooling energy required for a building
- **Baseline temperature (T_b)** (or balance point) is the value of outdoor temperature at which the heat loss from the building is equal to its heat gains (from the sun, occupants, lights etc.)

$$\underbrace{K_{tot}}(T_{in} - T_b) = \underbrace{\dot{Q}_{gain}} \quad \rightarrow T_b = \underbrace{T_{in}} - \frac{\dot{Q}_{gain}}{K_{tot}}$$

K_{tot} (W/K) is the total heat-loss coefficient

Heat gain from the sun, occupants, lights etc.

Indoor Temp

Degree day method for estimating the amount of heating or cooling in a building

- *HDD* = baseline temp – average daily (outdoor) temp

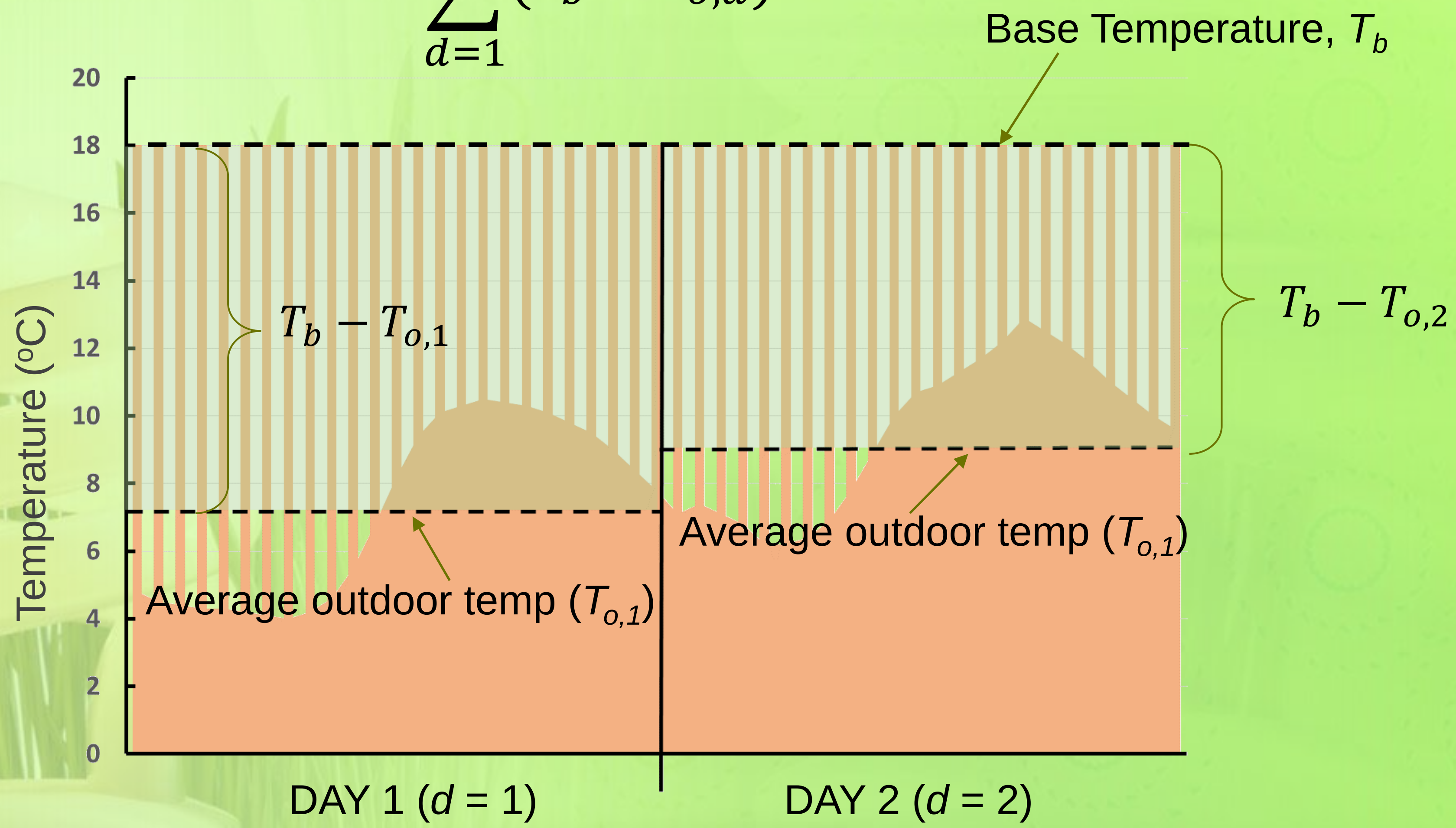
$$HDD = \sum_{d=1}^{365} \left(T_b - T_{o,d}\right)$$

- For each day the average outdoor temperature $T_{o,d}$ is subtracted from the baseline temperature then these temperature differences are added up to evaluate HDD.
- Cooling degree days (CDD) can be obtained in a similar way:

$$CDD = \sum_{d=1}^{365} \left(T_{o,d} - T_b\right)$$

Calculating heating degree days

$$HDD = \sum_{d=1}^{365} (T_b - T_{o,d})$$



How to estimate the heating requirement in a building by using HDD

- The annual heating requirement is obtained from:

$$Q_{h,yr} = \frac{K_{tot}}{\eta} \times HDD$$

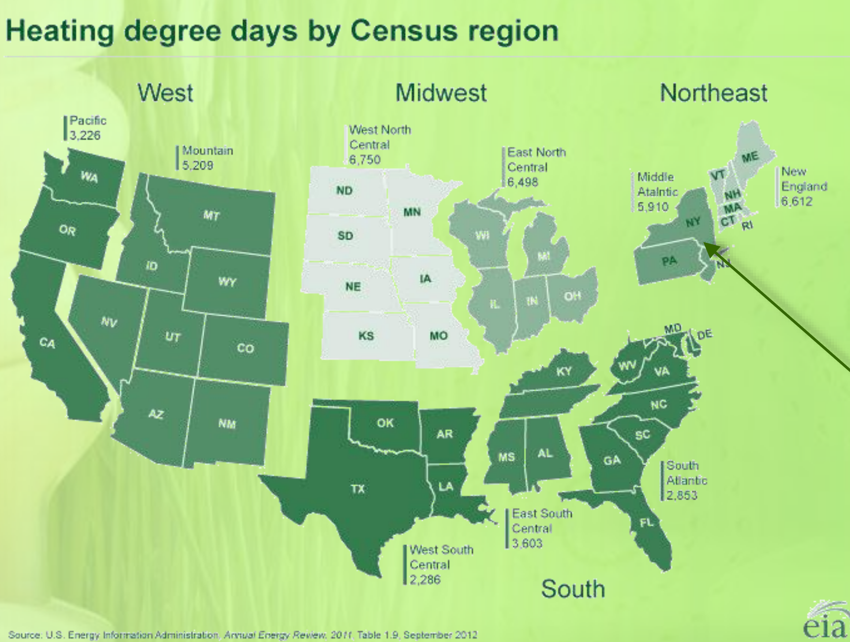
- K_{tot} (W/K) is the total heat-loss coefficient and can be obtained by adding the product of U-values and areas of each component on the building envelope, such that:

$$K_{tot} = \sum_{k} U_k A_k$$

where k is the building envelope component considered

Example: Annual heating bill for a house in New York where heating is on for 24h

- Given: $K_{tot} = 205\ \mathrm{W/K}$; $\dot{Q}_{gain} = 569\ \mathrm{W}$; $T_{in} = 21.1℃$;
- Given: Efficiency of heating system $\eta = 0.75$
- Given: Fuel price $8/GJ
- Assumption: K_{tot}, $\dot{Q}_{gain}$, T_{in} and η are constant.



Lookup for degree-days

Degree days for N. York:
5040 °F . Days
or
2800 K . days

Solution

- Evaluate the baseline temperature: $T_b = T_{in} - \frac{\dot{Q}_{gain}}{K_{tot}}$

$$T_b = 21.1\text{°C} - \frac{569\ \text{W}}{205\ \ \text{W/K}} = 18.3\ \text{°C}$$

- Annual heating energy: $Q_{heating} = \frac{K_{tot} \times HDD}{\eta}$

$$Q_{heating} = 205\,\frac{\text{W}}{\text{K}} \times 2800\ \text{K. days} \times 24\ \text{h/day} \times \frac{1}{0.75} \times \frac{3600\text{s}}{\text{h}}$$

$$Q_{heating} = 6.61 \times 10^{10}\ \text{J} \quad (\text{or } 66.1\ \text{GJ})$$

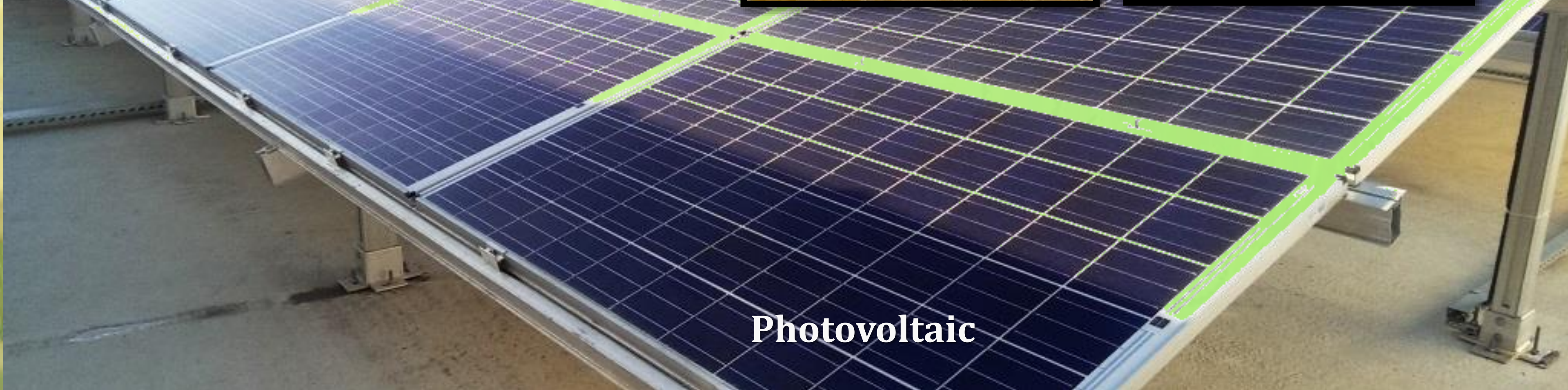
$$\text{Annual heating cost} = 66.1\ \text{GJ}\ \times \frac{\$8}{\text{GJ}} = \$\mathbf{528.8}$$

Renewable energy usage in buildings

- Solar thermal
- Photovoltaic
- Wind energy
- Geothermal hot springs
- Bio-energy

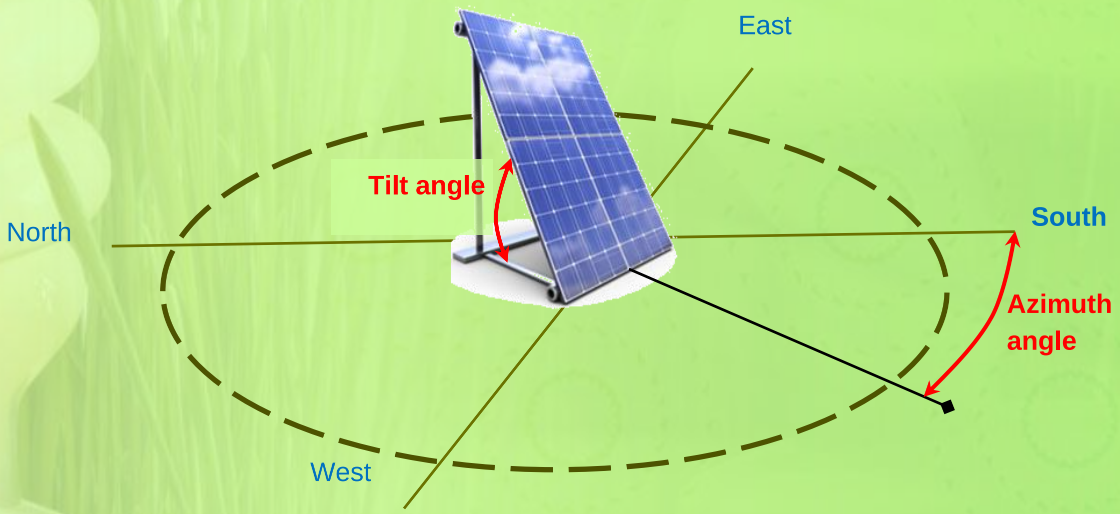

Solar water heater


Solar air heater


Photovoltaic

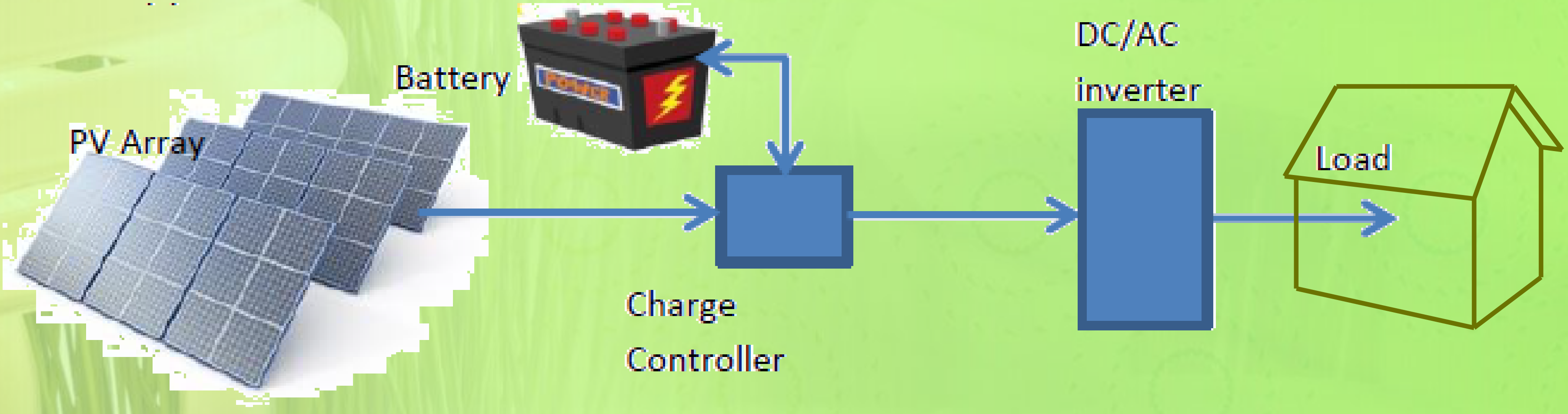
Orientation of PV panels

- PV panels should be oriented towards
  - South at sites located in the Northern hemisphere
  - North at sites located in the Northern hemisphere
- Tilt angle depends on the latitude of the site (In N. Cyprus the most optimum tilt angle is approximately 30^o.



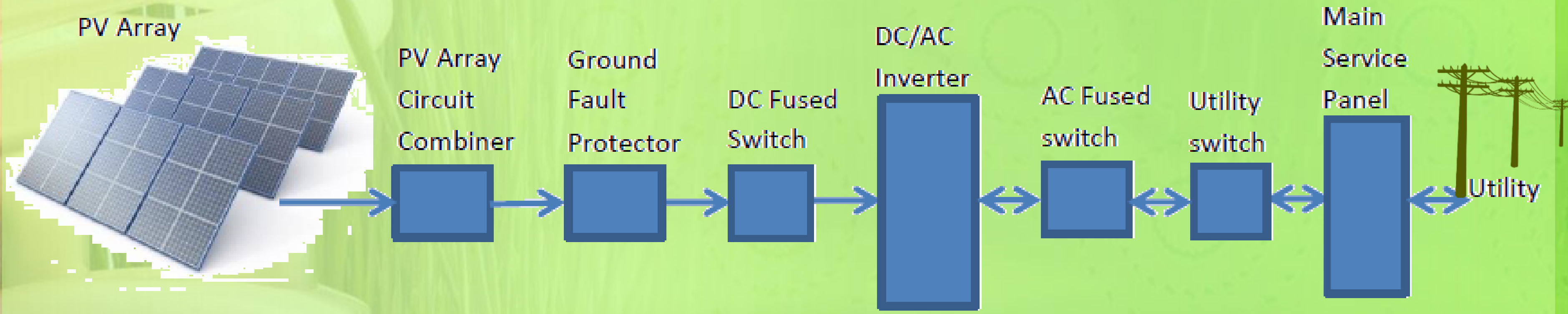
Stand-alone PV system

- The system is not connected to the grid; also known as *off-grid system*
- A battery is required for storing energy for times other than sunshine periods
- Ideal for areas which are remote from electrical network



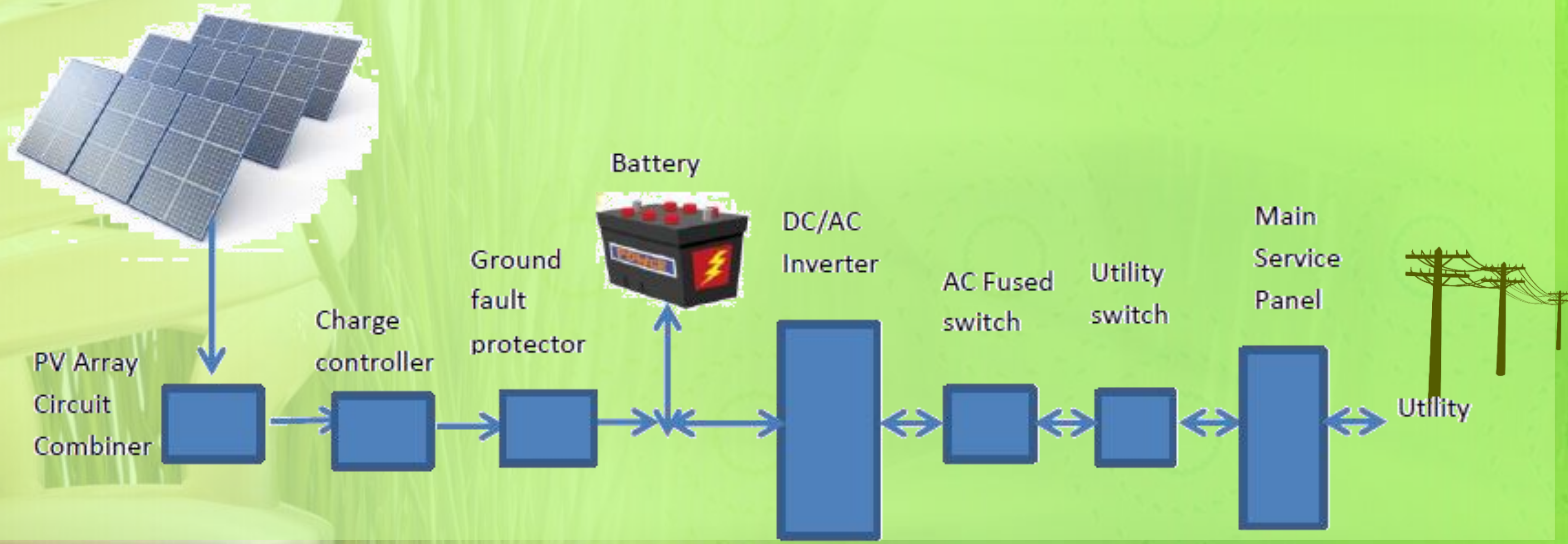
Grid-connected PV system with no battery backup

- The system is connected to the grid directly; also known as *on-grid system*
- The grid is used like a battery. Electricity is sold to the grid and whenever it is needed it is consumed from there
- This can cause several problems for the grid:
  - ✓ Voltage instability
  - ✓ Frequency instability
  - ✓ Power instability in the grid



Grid-connected PV system with battery backup

- The system is connected to the grid directly like the previous system; however, there is a battery backup for electricity outages
- Specially suitable for places with frequent electricity shortages



Feasibility of a 3-kW grid-connected PV system in N. Cyprus

Assumptions:

Annual electricity generation = 1750 kWh/kWp → Electric tariff (average) = 0.15 EUR/kWh → Annual savings = 1750 x 3 x 0.15 = 787.5 EUR → O&M cost = 30 EUR every 2 years

Feasibility of a 3-kW grid-connected PV system in N. Cyprus

Life cycle investments

Year	New	Old	Net Amount
0	€ 4,250		€ 4,250
1			€ 0
2	€ 30		€ 30
3			€ 0
4	€ 30		€ 30
5			€ 0
6	€ 30		€ 30
7			€ 0
8	€ 30		€ 30
9			€ 0
10	€ 30		€ 30
11			€ 0
12	€ 30		€ 30
13			€ 0
14	€ 30		€ 30
15			€ 0
16	€ 30		€ 30
17			€ 0
18	€ 30		€ 30
19			€ 0

Annual Savings

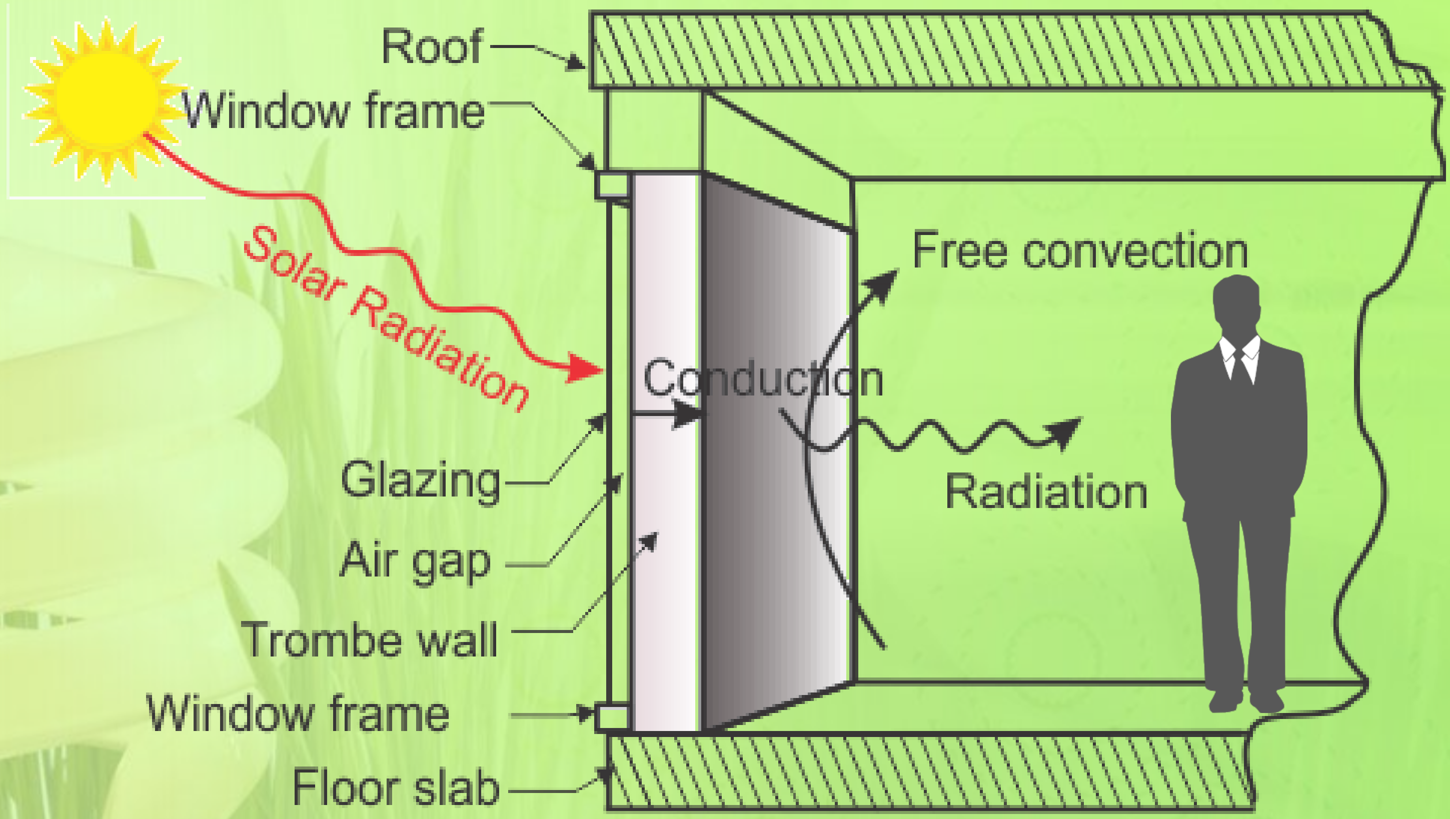
Annual Savings	€ 787
Discount Rate	3%
Analysis period (years)	20
Residual value	€ 500

Present value analysis

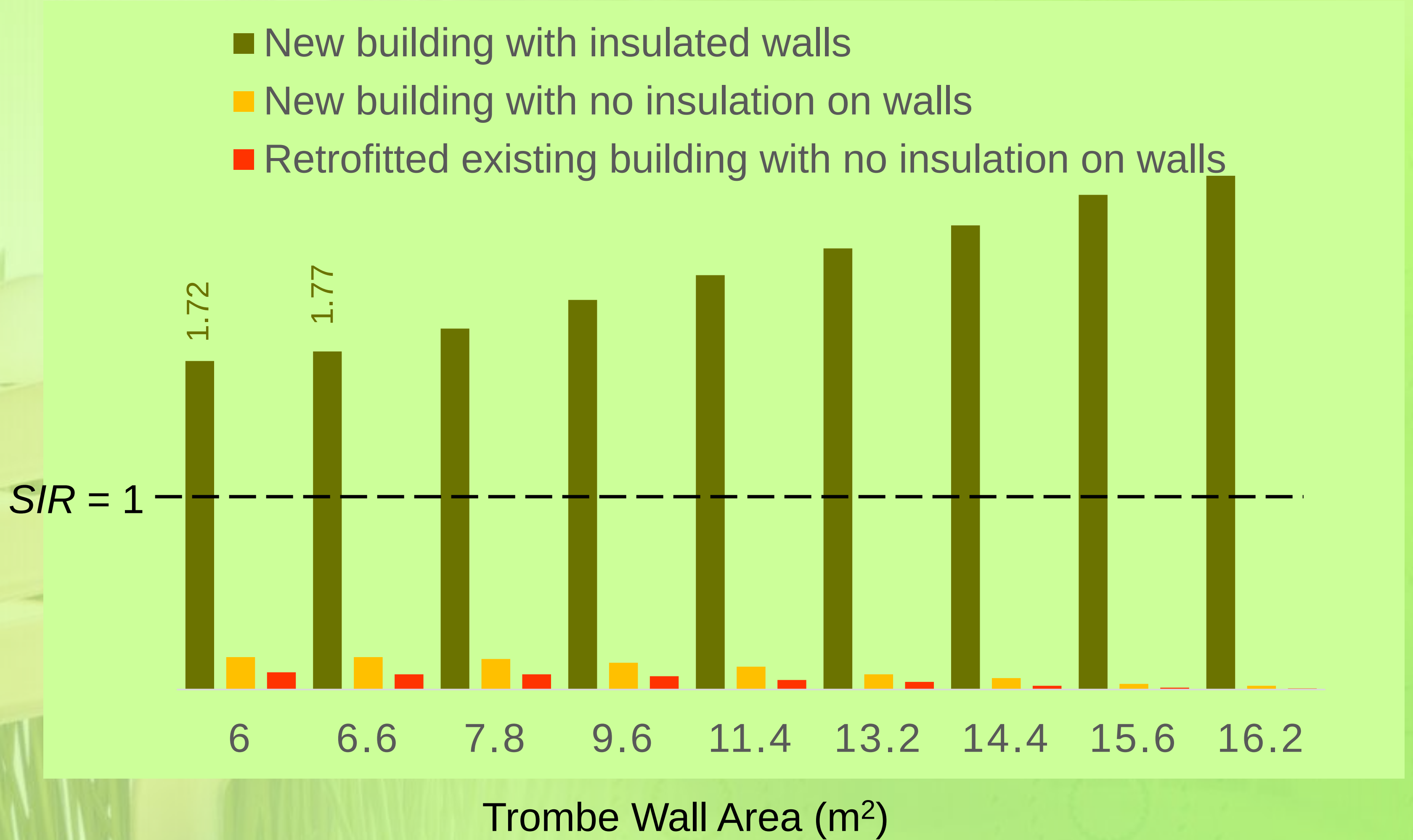
LCC Indicators

Net Present Value (NPV)	**€ 7,532**
Savings-to-Investment Ratio	**2.8**
Internal Rate of Return (IRR)	**18%**
Simple Payback (years)	**5.4**

Passive solar energy strategies:
Thermal storage wall (Trombe wall)

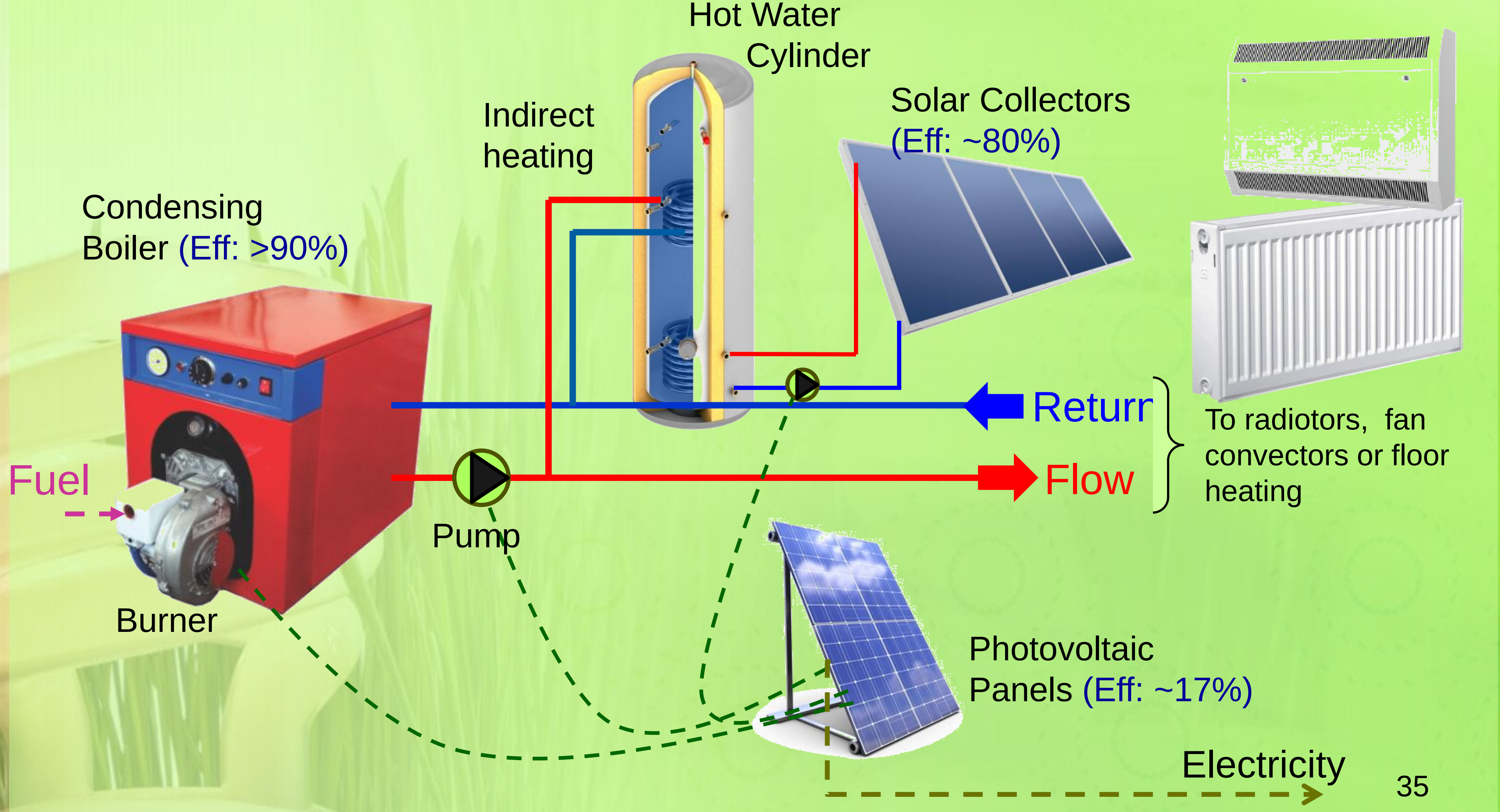


Economic feasibility of Trombe wall in North Cyprus (For a 35-m² South-oriented room)

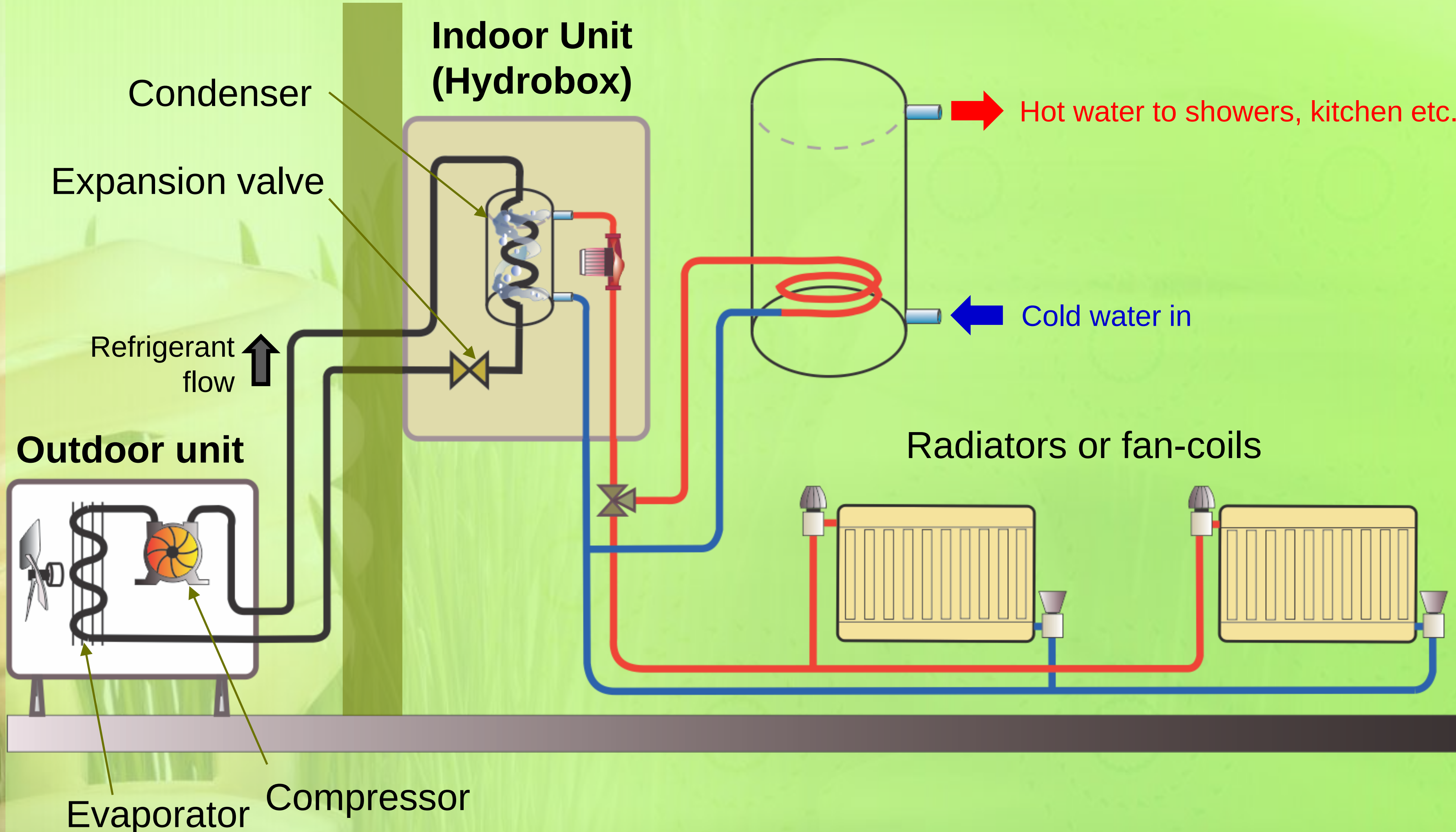


Source: Solar Energy, Vol 174 pp 359 – 372.

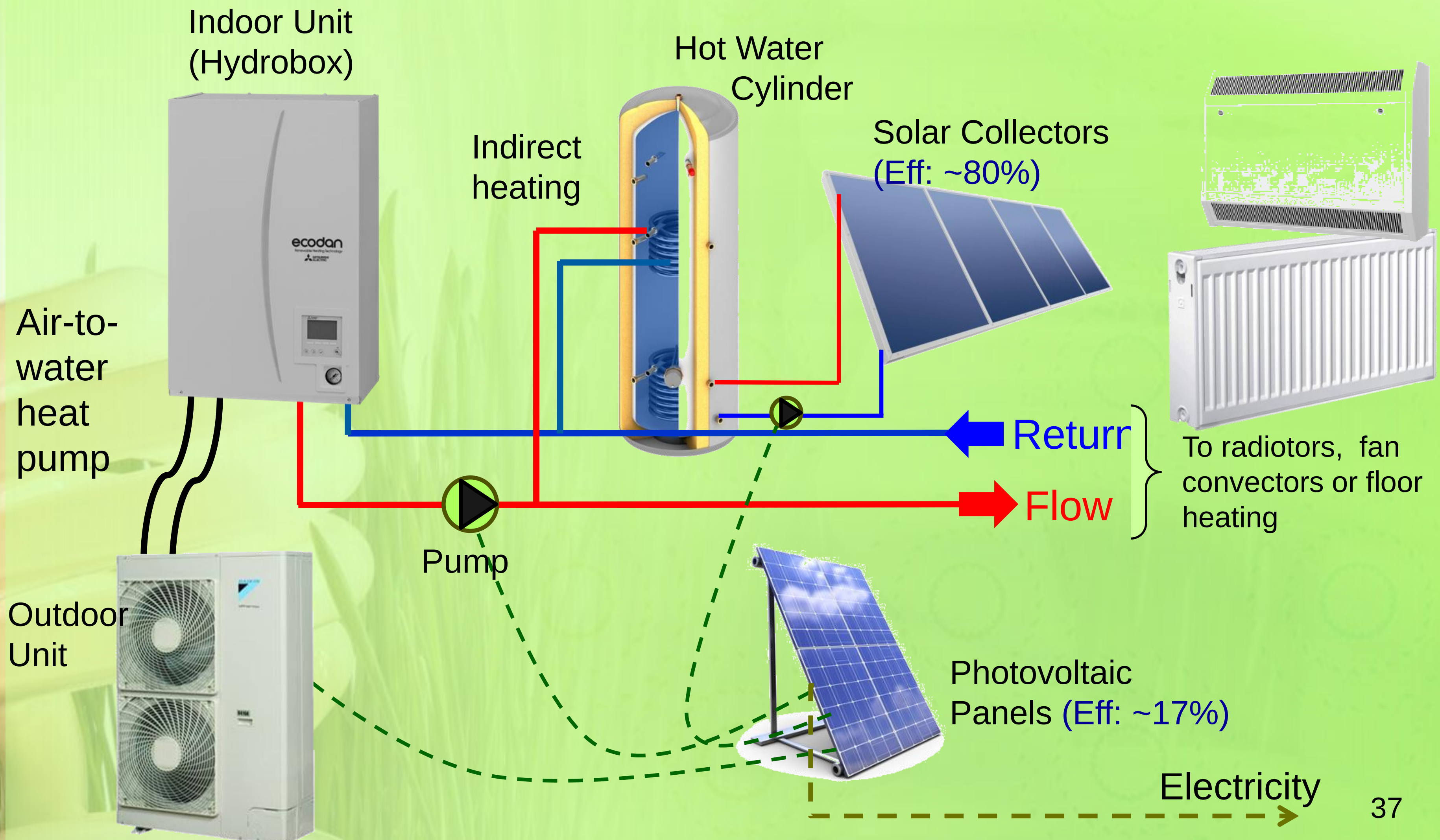
On-site energy generation: *Designing for energy efficiency and sustainability*



Heat Pump: *A More Efficient Alternative to Boiler*



On-site energy generation: *Designing for energy efficiency and sustainability*



On-site energy generation: *Designing for energy efficiency and sustainability*