The Marshall Plan Foundation Scholarship

Passive House Strategies:

The Retrofit of A School Building in New Orleans, Louisiana

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The University of New Orleans Commons Building:

- Constructed in 1969
- Located on the University of New Orleans Campus
- Approximately 1579 m^2 of Treated Floor Area
- 1 Story High – Approximately 4.5 m
- Average Summer Temperature of 32º C with a Humidity of 78%
- Building was damaged during Hurricane Katrina
- Building will be renovated to be new International Studies Center at UNO

*** Photo of Existing Building**

The Renovation of the Old Commons Building:

The old building was initially a cafeteria that serviced an adjacent dormitory as well as the near-by school buildings. Eventually the building's use as a cafeteria was phased out, and ever since a portion of the building has been used as offices for students and another portion of the building has been used for storage.

The new building will be the International Studies Building for the University of New Orleans. All International Studies Departments will be located in the building as well as some of the classrooms for the program.

Therefore, the interior of the building will be architecturally redesigned in order to fit the needs of the new building. Also, the building will be renovated to improve the building's energy usage.

Energy Renovation for the New International Studies Center:

The focus of this report is strictly on the energy renovations for the new International Studies Center. During the late 60s there was very little consideration in building design for energy consumption. As a result, this building wastes a lot of energy needlessly.

There are many areas in terms of energy usage that this building could improve. This report includes a step by step analysis of the different components that contribute to the building's energy demand (primarily the energy needed to cool the building) and the recommendations to improve each component. The analysis will include all calculations and all formulas used during the research. Also, included in the report will be explanations of the program, **the Passive House Planning Package 2007,** and explanations of each individual section of the program that was used to calculate the energy demand caused by different elements of the building.

1. The report starts with an overview of the building's architectural layout and the building's local climate.

2. Followed by an analysis of each component of the building's exterior and interior that affects the building's use of energy. This includes:

    a. Explanations of the 3 different methods of heat transfer. It is important to understand the principles of heat transfer to understand how each building component transfers heat.

    b. Explanation of the different means of heat entering the building or being created within the building.

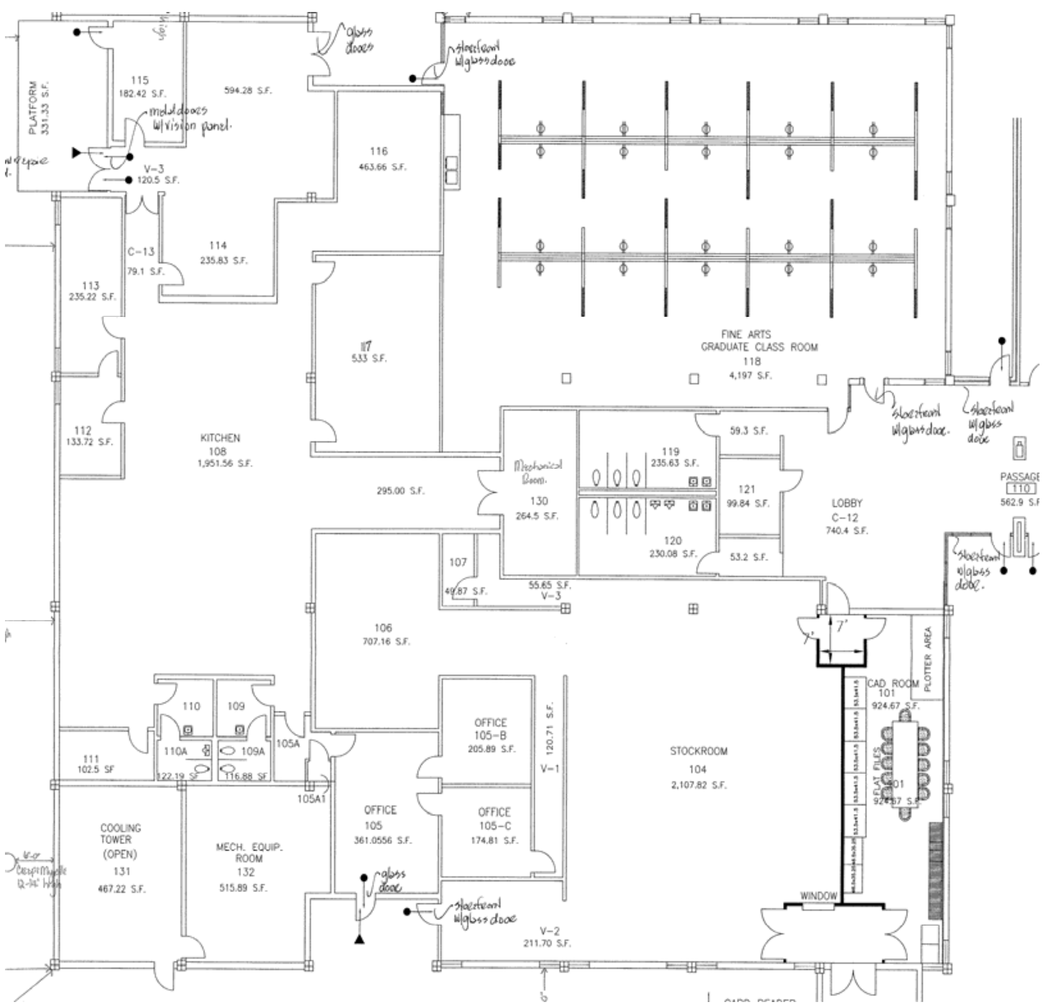
c. The method of calculating heat transfer through exterior components (walls, roofs, windows, and doors) or heat production in the interior components (people, lighting, equipment, etc.).

3. Finally, recommendations are offered for each individual problem, and detailed analysis is offered to support the need or the benefit of each individual renovation. This includes:

    a. As will be shown individual hand calculations with energy formulas would take an exorbitant amount of time, so all calculations were done with the PHPP program, which is a very helpful tool that expedites energy calculations.

    b. Then, analysis using the PHPP will show the extent to which all of these components can be improved.

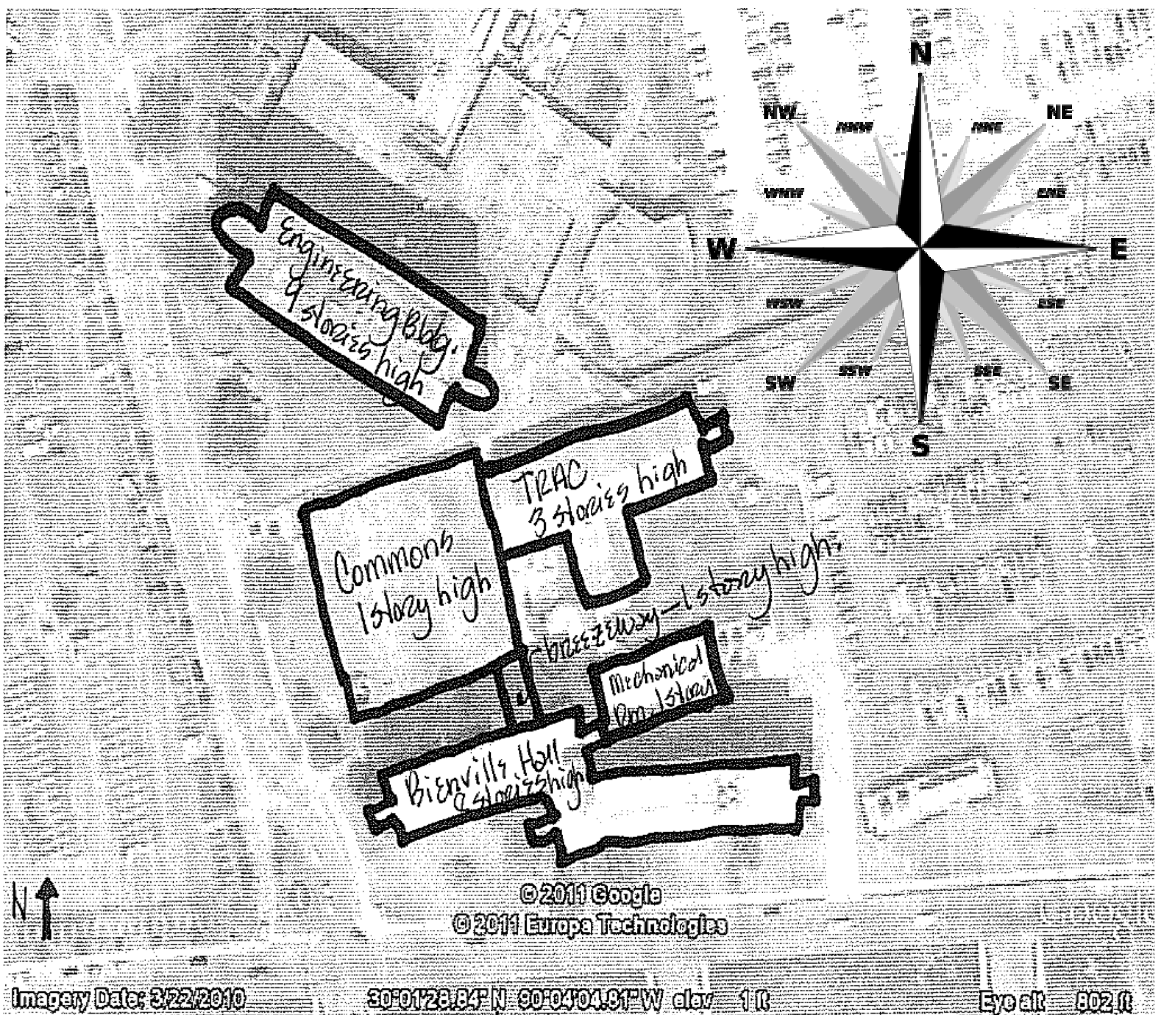
The Architectural Layout of the Commons Building:



Description of layout:

Direction of Each Wall Face:

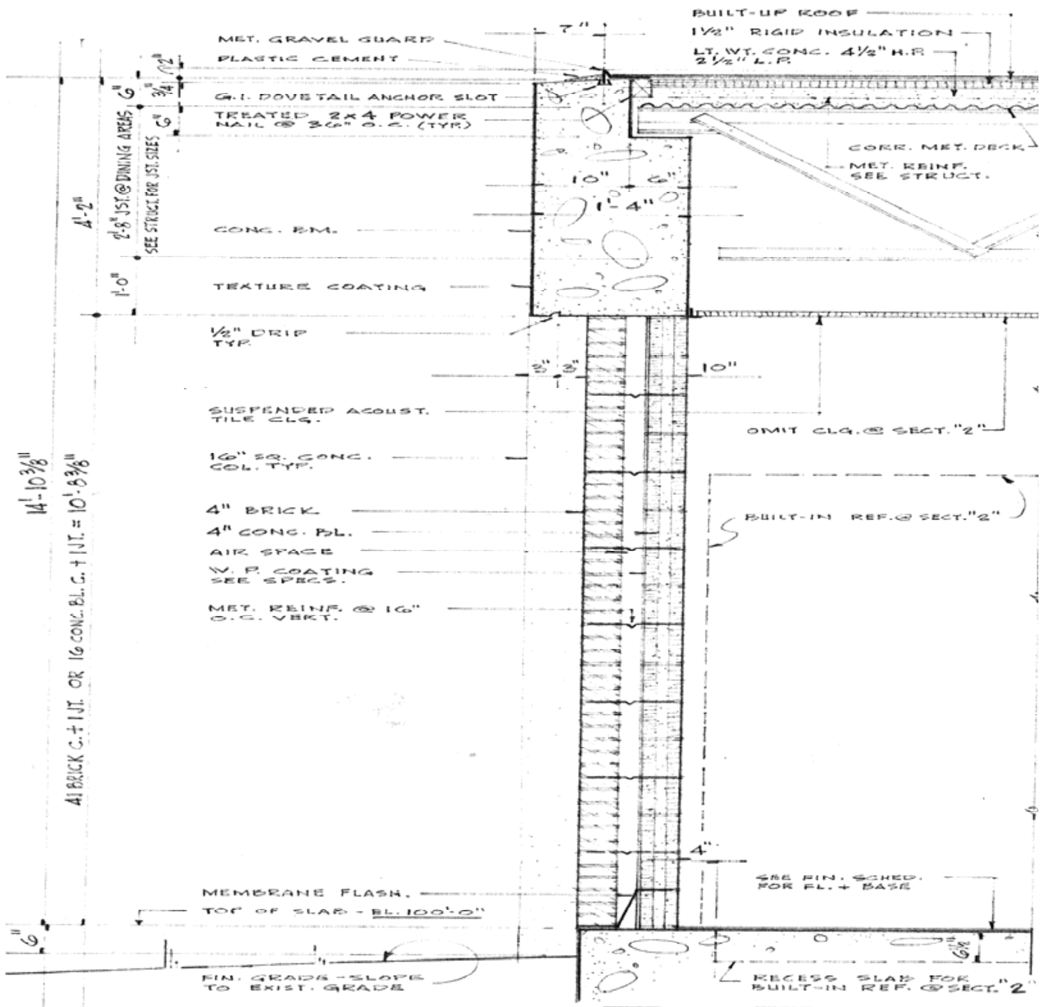
1. North Wall - Deviated 342º Clockwise from North (Faces North-West)
2. East Wall - Deviated 72º Clockwise from North (Faces East-North)
3. South Wall – Deviated 162º Clockwise from North (Faces South-East)
4. West Wall – Deviated 252º Clockwise from North (Faces West-South)



* Google Image of Building on University Campus (Commons)

Description of Exterior Wall Construction (from exterior to interior surface):

1. Brick – 102 mm thick
2. Airspace – 51 mm thick
3. Concrete – 102 mm thick.
4. Concrete Block on Top of Brick – 406 mm thick.
5. Columns (square concrete blocks) – 406 mm thick.



Roof Construction (from top to bottom):

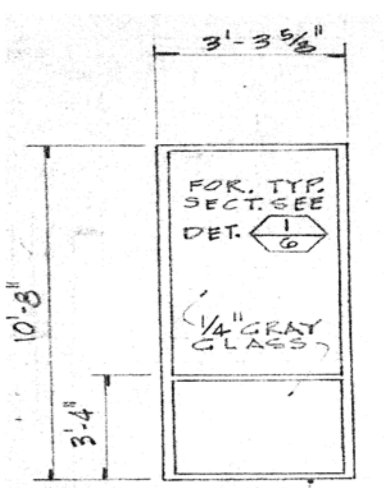
1. Gravel – 50 mm thick
2. Black Tar – 10 mm thick
3. Rigid Insulation – 34 mm thick
4. Light Weight Concrete – 114 mm thick
5. Metal Decking – 2 mm thick
6. Air Space – 1000 mm thick
7. Acoustic Tile – 25 mm thick

Floor Construction:

1. Ceramic Tile – 10mm thick
2. Concrete – 152 mm thick

Window Construction:

1. Located at the right and left of most columns. Dimensions are as shown.
2. Made of Gray Glass… energy values provided in future sections



**Exterior Walls are constructed with brick masonry 3.25 m high, and then concrete blocks 1.27m on top of the brick masonry (the walls are approximately 4.5m high).

**Structural columns are symmetrically placed around the entire building. They are spaced every 6.5 m on the North and South wall & they are spaced every 7.75 m on the east and west wall (except at the grand opening on the east wall and consequently across from it on the west wall, they are spaced 10.5m)

**Refer to building layout for dimensioning

Climate Data for New Orleans, LA:

New Orleans is located near the Gulf of Mexico, and it is located near the equator as well. Therefore, the climate of New Orleans is humid, sub-tropical with short, generally mild winters and long, hot, humid summers.

Table of All Important Climatic Data:

New Orleans Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg. Temperature	10.7	12.4	16.4	20.3	23.8	26.7	27.7	27.5	25.6	20.6	16.2	12.5	20.1
Avg. Max Temperature	16.0	17.8	22.0	25.8	29.1	31.8	32.6	32.3	30.3	26.3	21.7	17.9	25.3
Avg. Min Temperature	5.4	6.9	10.9	14.7	18.4	21.6	22.8	22.7	20.8	14.8	10.6	7.1	14.7
Days with Max Temp of 32 C or Higher	0.0	0.0	0.0	< 0.5	4.0	16.0	21.0	20.0	9.0	1.0	0.0	0.0	72.0
Days with Min Temp Below Freezing	5.0	3.0	1.0	< 0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.0	12.0

New Orleans Heating and Cooling	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Heating Degree Days	450	316	162	28.0	0.0	0.0	0.0	0.0	0.0	30.0	178	349	1513
Cooling Degree Days	25.0	17.0	56.0	133	304	450	524	512	393	157	61.0	23.0	2655

New Orleans Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation (inches)	5.0	6.0	4.9	4.5	4.6	5.8	6.1	6.2	5.5	3.0	4.4	5.8	61.9
Days with Precipitation 0.01 inch or More	10.0	9.0	9.0	7.0	8.0	11.0	14.0	13.0	10.0	6.0	7.0	10.0	115
Monthly Snowfall (inches)	0.0	0.1	< 0.05	< 0.05	< 0.05	0.0	0.0	0.0	0.0	0.0	< 0.05	0.1	0.2

Other New Orleans Weather Indicators	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Wind Speed	9.3	9.8	9.9	9.4	8.1	6.8	6.1	5.9	7.3	7.6	8.7	9.0	8.2
Clear Days	7.0	8.0	8.0	8.0	9.0	8.0	5.0	7.0	10.0	14.0	10.0	8.0	101
Partly Cloudy Days	7.0	6.0	8.0	10.0	11.0	13.0	15.0	14.0	11.0	8.0	8.0	7.0	118
Cloudy Days	17.0	14.0	15.0	12.0	11.0	9.0	12.0	10.0	10.0	9.0	12.0	16.0	146
Percent of Possible Sunshine	46.0	50.0	56.0	62.0	62.0	63.0	58.0	61.0	61.0	64.0	54.0	48.0	57.0
Avg. Relative Humidity	67.5	75.5	74.5	75.0	74.5	75.5	77.0	79.0	77.5	76.5	73.0	74.0	77.0

For the purposes of this paper, summer climate conditions will only be considered. As can be seen, hot, humid summers are the most prevailing weather condition in New Orleans, and thus the most important for design considerations.

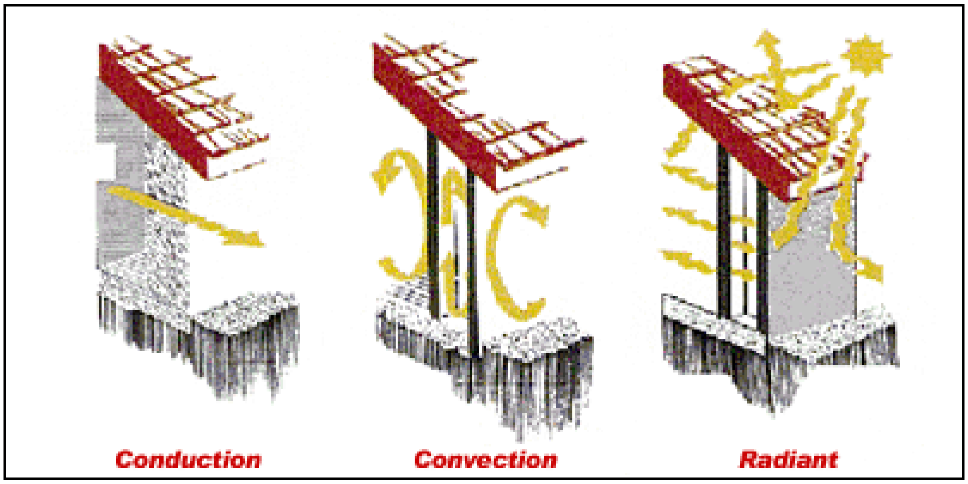
Each Component of the Common's Building that Affects the Cooling Energy Demand:

1. There is 0 insulation in the walls.
2. There is very little insulation on the roof
3. The exterior surfaces of the walls and roof have a very high solar absorption rate.
4. Due to the out-dated construction techniques, the building either leaks in a lot of hot, humid air during the summer months or leaks out cool-conditioned air.
5. Since there is not heat recovery system, all in-coming fresh air, is a direct load on the cool unit.
6. The windows have very high U & G values.
7. The building uses inefficient equipment (computers, printers, copiers, fax machines, etc…) and inefficient lighting

** In order to understand how each component affects the buildings energy usage, it is important to understand the physics behind heat transfer into a building. Thus, I will provide a summary of each method of heat transfer and how it affects the building. Then, I will go into how each component of the building relates to these different methods of heat transfer.

Heat Transfer into a Building:

There are 3 forms of heat transfer: *Solar Radiation*, *Convection*, and *Conduction*. Each mechanism of heat transfer affects the building differently, and there are different ways to combat each method.



Solar Radiation

The Sun is constantly producing energy, which gives off heat as a by-product, and thus it has a surface temperature equal to 6000º Kelvin. As a result of this heat production, radiant energy in the form of energy waves travels across space and is constantly hitting the earth's surface.

Once the solar radiation enters the earths atmosphere, the radiation hits a building's surface in three forms, by means of direct radiation, reflected radiation (radiation reflected off another body onto the building), or diffused radiation (radiation is deflected by the clouds and then hits different surfaces).

The Equation for amount of Radiation on a Surface

$$I_{tot} = I_{Dir} Cos\theta + I_{Diff} + I_{Ref}$$

I_{Dir} = Direct Radiation
I_{Diff} = Diffused Radiation
I_{Ref} = Reflected Radiation
θ = angle of incidence (the angle between the sun and the surface normal)

To Calculate the equation, $I_{tot} = I_{Dir} Cos\theta + I_{Diff} + I_{Ref}$, you need the individual equations for *direct radiation*, *diffused radiation*, *reflected radiation*, and *angle of incidence*. Once you calculate each component, you can determine the total amount of radiation incident on surface.

$$I_{Dir} = A * \exp(-\frac{B}{SinB})$$

A = solar constant

A = 1230 W/m² for winter and 1080 W/m² for summer

**The Solar Constant is the amount of incoming solar electromagnetic radiation per unit area that would be incident on a plane perpendicular to the rays.

B = Atmospheric Extinction Coefficient

B = .14 winter & .21 summer

$$I_{Diff} = C * I_{Dir} * Fws$$

C = .058 winter & .135 summer

Fws = view factor = $\frac{1 + Cos\xi}{2}$, where ξ = angle of inclination

ξ Ranges between 0º for horizontal and 90º for vertical.

$$I_{Ref} = (I_{Dir} + I_{Diff}) * \rho_g * FWG$$

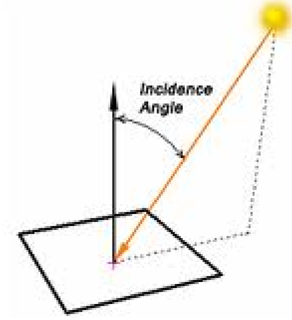
ρ = reflectivity of surface

Fwg = $\frac{1 - Cos\xi}{2}$

Once you calculate each individual component of Radiation, you need to determine the angle of incidence, which is a factor of a couple of different variables.

** Direct Radiation hits the building at a different angle depending upon the location of the sun relative to the building, and depending on that angle, the intensity of the radiation will vary.

** In order to obtain the angle of incidence, you need to be able obtain the angle for which the sun rays hit your building surface (whether it is a vertical surface like your walls, or horizontal surface like your roof). Important solar angles are ***Latitude***, ***Hour Angle***, ***Declination Angle***, and then important derived solar angles are ***Altitude Angle***, ***Azimuth Angle***, ***Wall Solar Azimuth Angle***, and ***Wall Surface Azimuth Angle***.



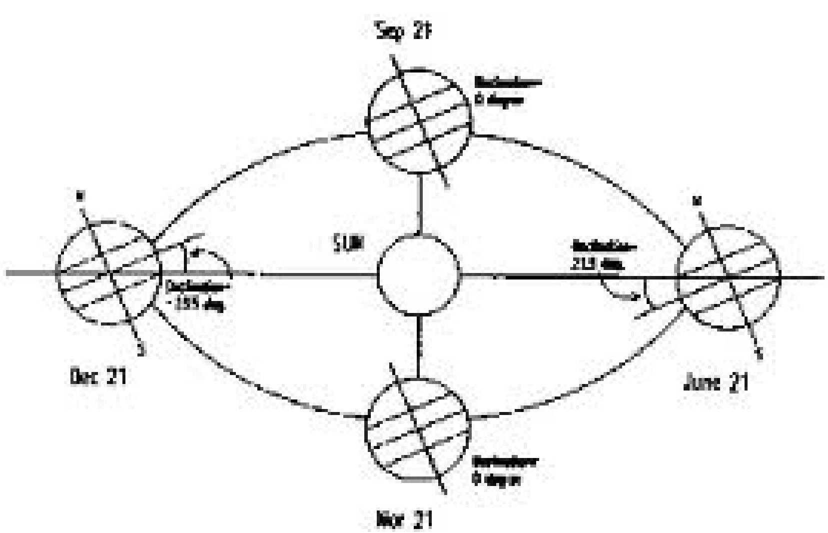
Important Solar Angles:

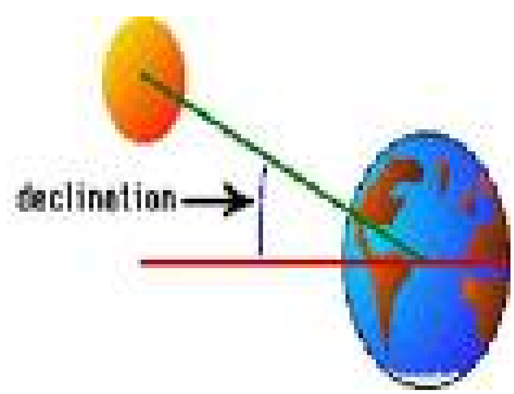
Latitude – the actual latitude of the building's location. It ranges between 0º & 90º from equator (0º) to North or South Pole (90º).

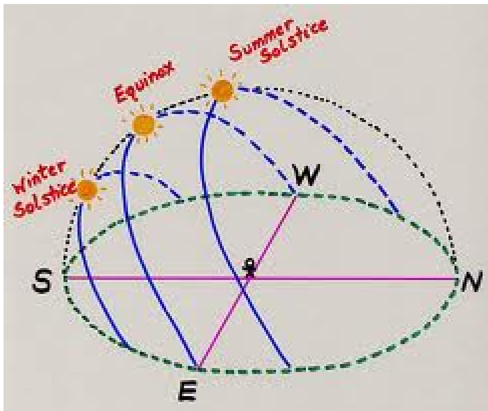
Hour Angle – the earth completes a full revolution every 24 hours. So, at each hour the building's location is somewhere relative to the sun depending on the hour of day. The angle ranges between 0º & 360º from the time the sun is directly in front of the building (Solar Noon = 0º) to the time the sun is directly behind the building (Solar Midnight = 180º)

Declination Angle – Due to the Earth's tilt and its revolution around the sun, the sun varies from +23.5º above the equator and – 23.5º below the equator. So, the Declination angle is the angle between the line joining the center of the earth & sun and its projection on the Equatorial Plane, and the angle varies depending on what day of the year it is.

$$\text{Declination Angle} = 23.47 \text{ Sin } \frac{360*(284+N)}{365}\text{; N= \# of Day (Jan.1=1)}$$

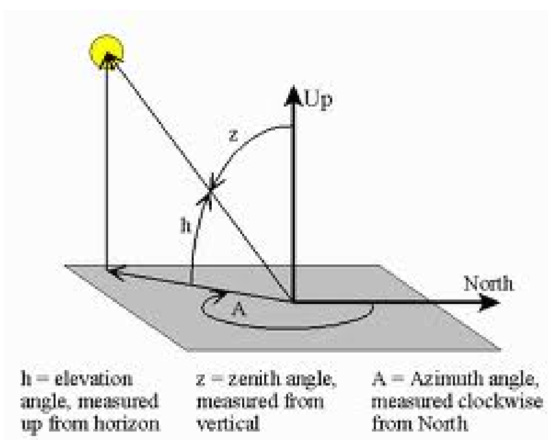






* This image shows how the hour angle & declination angle work for particular latitude. It shows how at different hours, at different times of the year for a certain location on earth, the sun follows a distinct path, and thus you are able to get your incident angle.

Important Derived Solar Angles:



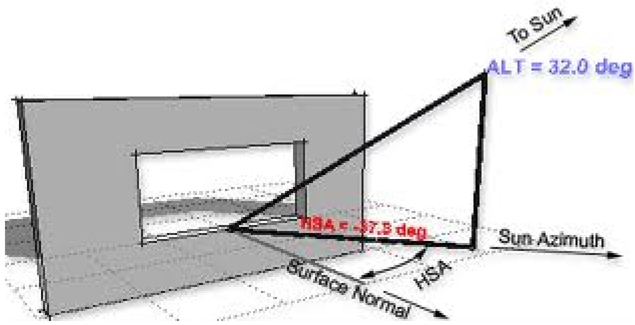
Altitude Angle – (ß) Angle between sun's rays & horizontal. (h on diagram)

β = Sin^{-1}(CosL*CosH*CosD+SinL*SinD); L=latitude; H=Hour; D=Declination

Zenith Angle – (Ψ) Angle between sun's rays & surface normal. (z on diagram)

$\Psi = 90^{o} - \beta$ ** for horizontal surfaces (like rooftops), it is the angle of incidence

Azimuth Angle – (γ) Angle between North & the projection of the sun's rays on the horizontal plane. (A on diagram)
For Vertical Surfaces (like walls) you need supplemental angles:



Wall Solar Azimuth Angle – (α) angle between normal to the wall & horizontal projection of sun's rays. (Angle HSA on diagram)

Wall Surface Azimuth Angle – (ε) angle between the normal to the wall and South.

Then: Wall Solar Azimuth $\alpha = 180^{o} - (\gamma + \varepsilon)$

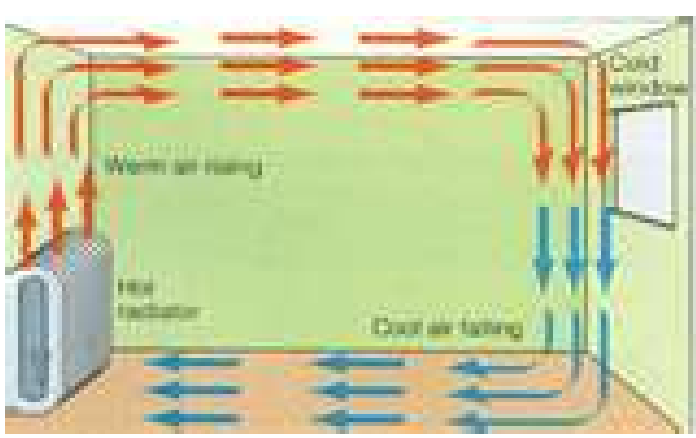
Angle of incidence on a vertical surface = $\theta_{vert} = \cos^{-1}(\cos\beta\cos\alpha)$

So, with the angle of incidence for each surface (East, West, South, & North Wall as well as Roof), you are able to calculate the amount of radiation incident on that surface, and thus the amount of solar heat on each surface.

$$I_{tot} = I_{Dir} Cos\theta + I_{Diff} + I_{Ref}$$

<u>Convection</u>

The transfer of heat due to the bulk motion (observable movement) of fluids, such as wind & water.



There are two types of convective heat transfer:

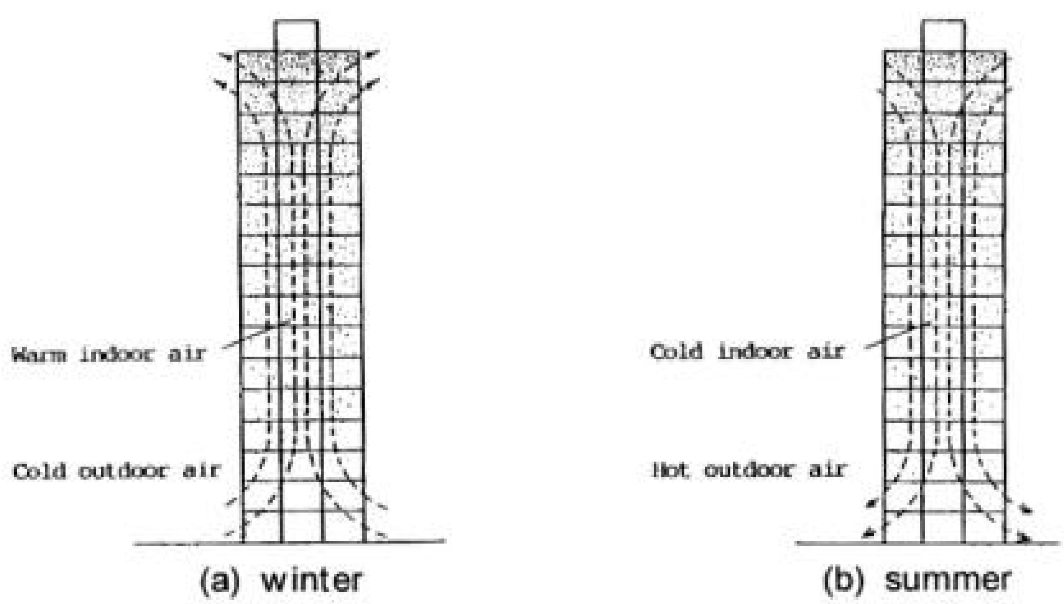
Free or Natural Convection—caused by buoyancy forces that result from the density variations due to variations of temperature in the fluid. When the mass of the fluid is in contact with a hot surface, its molecules separate and scatter, causing the mass of fluid to become less dense, and due to this process, the heated fluid is displaced vertically or horizontally and the cooler fluid gets denser and thus sinks.

Forced Convection—when the fluid is forced to flow over the surface by external source such as fans, stirrers, and pumps, creating an artificially induced convection current

Two Main affects of Natural Convection on Building Heat Transfer:

The **Stack effect** is the movement of air into and out of buildings, chimneys, flue gas stacks, or other containers due to buoyancy. Buoyancy occurs due to a difference in indoor-to-outdoor air density resulting from temperature and moisture differences. The greater the thermal difference and the height of the structure, the greater the buoyancy force, and thus the stack effect. The stack effect helps drive natural ventilation and infiltration.

Since buildings are not totally sealed, the stack effect will cause air infiltration. During the heating season, the warmer indoor air rises up through the building and escapes at the top either through open windows, ventilation openings, or other forms of leakage. The rising warm air reduces the pressure in the base of the building, drawing cold air in through either open doors, windows, or other openings and leakage. During the cooling season, the stack effect is reversed.

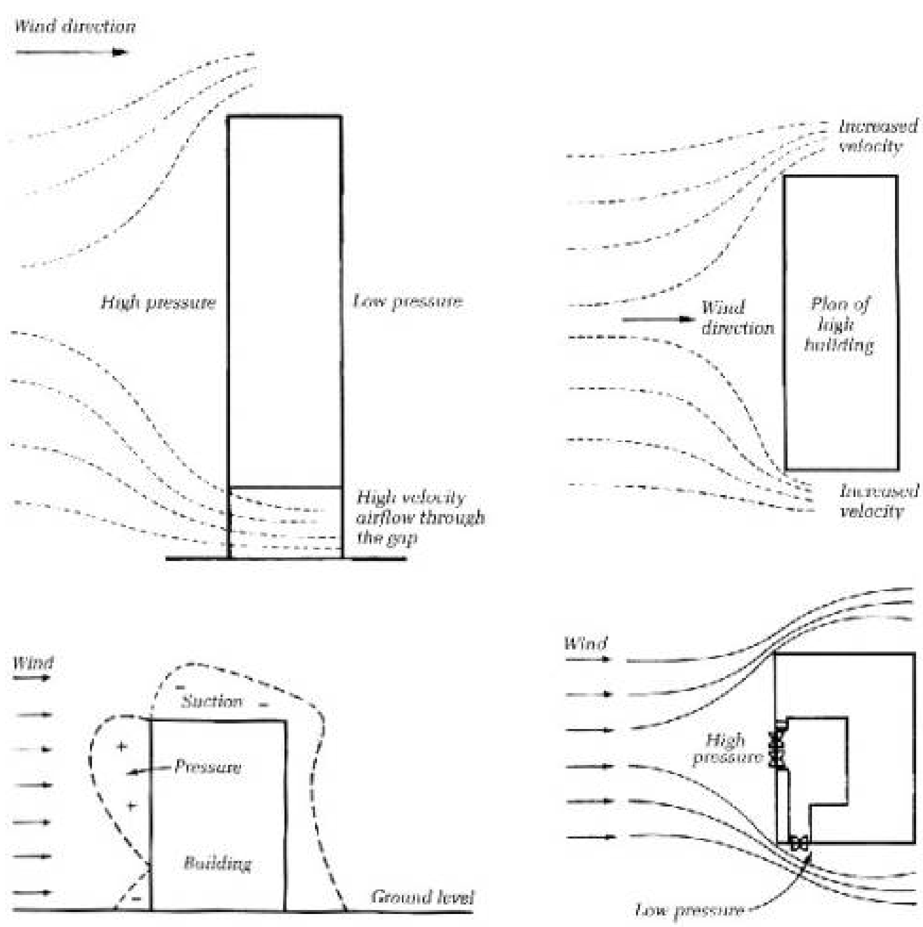


The **Wind effect** is when air flow is due to wind, air enters through openings in the windward walls, and leaves through openings in the lee-ward walls.

Wind pressures are generally high/positive on the windward side of a building and low/negative on the leeward side. The occurrence and change of wind pressures on building surfaces depend on:

- wind speed and wind direction relative to the building;
- difference in air density, due to temperature difference
- combination of both wind and stack effects

Thus, if there are any leaks, open windows or doors, etc.. in the building frame and wind is flowing on that building surface, air will enter in the building which allows outdoor, untreated air to enter the building and cause a load on the HVAC system.



ELEVATION PLAN

Conduction

The transfer of thermal energy between regions of matter due to a temperature gradient. Heat spontaneously flows from a region of higher temperature to a region of lower temperature, temperature differences over time, approaching thermal equilibrium.

On a microscopic scale, conduction occurs as rapidly moving or vibrating atoms and molecules interact with neighboring particles, transferring some of their kinetic energy. Heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal conduct. Conduction is greater in solids because the network of relatively fixed spatial relationships between atoms helps to transfer energy between them by vibration.

Conduction Can Be Either Steady State or Unsteady State:

> Steady State Conduction – Steady state conduction is the form of conduction that happens when the temperature difference between the two bodies is constant, so that after a certain period of time, the spatial distribution of temperatures in the conducting object does not change..
>
> Unsteady State Conduction – Unsteady Conduction takes places because the temperatures differences are not constant. Thus, at different times, different amounts of heat are traveling between the two bodies.

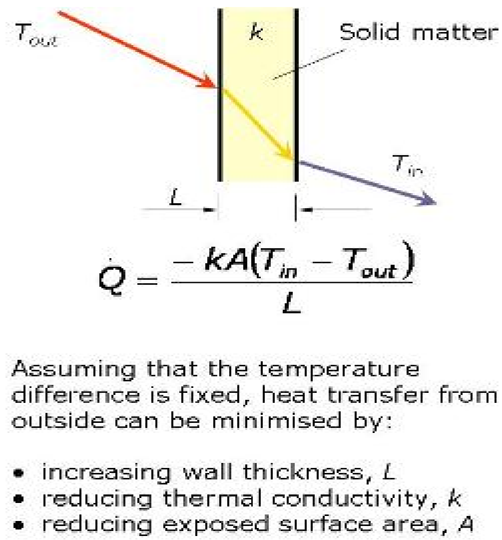
To calculate how much heat is transferred through a body by means of steady-state conduction, one uses the formula:

$$Q' = k*A*\Delta T$$

> K = thermal conductivity of the material
>
> > Thermal Conductivity is defined as the quantity of heat, ΔQ, transmitted during time Δt through a thickness x, in a direction normal to a surface of area A, per unit area of A, due to a temperature difference ΔT, under steady state conditions and when the heat transfer is dependent only on the temperature gradient.
> >
> > In other words, Thermal conductivity is a property of a material’s ability to conduct heat, and in essence heat-transfer across materials of high thermal conductivity occurs at a faster rate than across materials of low thermal conductivity

A = Area

ΔT = Difference in Temperature between two surfaces



*** This is the equation for heat transfer by conduction during steady state conditions… i.e. in a laboratory where all variables are held constant. However, due to variations in solar radiation and outdoor temperature and also due to thermal storage of the wall material, a building is subject to unsteady state conductive heat transfer. The formula for this type of conductive heat transfer is quite complicated, and I will break it down when I show how to calculate heat transfer through walls and roofs.

The Different Components of a Building, Exterior and Interior, which are Affected by Heat Transfer:

In order to determine how much heat needs to be removed from the building, one needs to calculate all the heat transferred into the building and all the heat that is produced within the building during a time of the year that is near 3% ± 2% of the peak outdoor heating conditions (what the means is, one doesn't take the hottest day of the year, because that only happens rarely, however one takes a value near the hottest day of the year when computing all the heat gain calculations so that when he/she designs the HVAC equipment, the equipment is able to handle the loads near the maximum load on the building).

Once all of these individual sources of heat are calculated, then one can know the amount of heat that the building generates and absorbs and thus determine how much energy it is going to cost to combat that heat.

In other words, different parts of the building contribute to heat gain for the building in different ways, and one needs to separate these heat sources into different areas in order to both calculate them and also to determine how much each area contributes to the overall heat gain of the building. Once each area is calculated, then one can determine if that particular area can be improved and by how much.

The Individual Areas that Affect Heat Gain:

External Loads (1-4)

Internal Loads (5-7)

1. The Transfer of Heat into a Building Through Walls, Roof, & Ground
2. The Transfer of Heat into a Building Through Windows and Doors
3. The Infiltration of Air into the Building
4. The Ventilation of Outdoor Air into the Building
5. Interior Lighting
6. Interior Equipment
7. Heat Produced by People

<u>External Loads on the Building:</u>

1. Heat Transfer Through the Walls, Roof, & Ground:

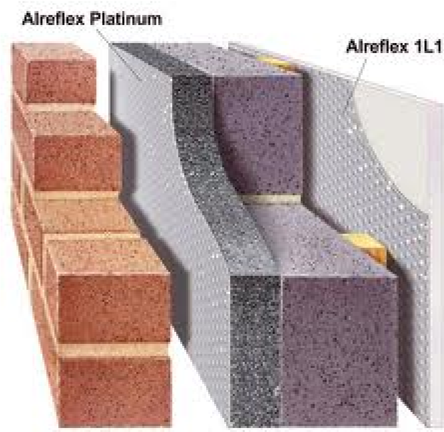
> Heat Transfer through opaque surfaces, such as walls, roofs, or ground, are done by a conductive heat transfer process. The indoor air temperature is kept at a desirable, cool temperature, and it is thus cooler than the outdoor temperature. Thus, the exterior surface of the wall/roof/ground is usually hotter than the interior surface of that element. Moreover, the exterior surface of the wall is heated because both the outdoor air temperature is higher and also because solar radiation is striking the surface. So, due to this imbalance between exterior and interior surface temperature, a conductive heat transfer is constantly taking place between the two surfaces.

However, due to variable outdoor temperatures, which are caused by changes in wind, changes in the amount of solar radiation surface striking a surface (because of cloud cover or the sun hitting the building at different incident angles due to solar path, etc…), one can't simply use the equation, Q' = k*A*ΔT, to determine the conductive heat transfer through the wall or roof into the building. While the value of k, A, and the interior temperature (usually held fixed at some desirable indoor temperature) are held constant, the exterior temperature of the wall is constantly changing.

Thus, the factor ΔT is constantly changing, so a new equation needs to be used to calculate heat transfer:

$$Q = U*A*(T_{solair,m} - T_i) + U*A*\lambda*(T_{solair,\theta-\phi} - T_{solair,m})$$

$$U = \frac{1}{\sum R}$$



The **U-Value** is the combination of all the thermal resistances for each element in the wall. In essence, each material in the wall has a particular resistance to thermal flow, and as heat travels through the wall, each element acts in series. So, the U-Value is simply one over the net of all those thermal resistances, or in other words, it is the thermal conductance of the entire wall.

The **R-value** is a measure of a material's thermal resistance. It is the reciprocal of thermal conductivity (Resistance to Heat Flow).

So, In essence, the **U-Value** is basically the k value from the previous conductive transfer equation, but it is the conductivity for the entire wall, not just one piece of material.

A= Area

$$T_{solair} = T_o + \frac{(\alpha * I_{tot})}{h_o} - 3.9^\circ \text{ C}$$

T_{solair} is a value that represents changes to the exterior surface temperature due to the amount of solar radiation incident on the building surface as well as changes in the surface's temperature due to convective heat transfer. The values of I_{tot} accounts for the radiation striking the surface, and the value of h_0, the outdoor heat transfer coefficient, accounts for the changes in surface temperature due to both solar radiation and convective heat transfer.

In other words, one can't simply take the difference from the outdoor air temperature and the interior temperature to determine heat flow. Due to radiation and convection, the exterior surface is actually a lot hotter than the outdoor temperature, which can easily be understood when you walk on concrete that has been exposed to the sun all day—it is a lot hotter than the air temperature.

In the equation, $T_{solair} = T_o + \frac{(\alpha * I_{tot})}{h_o} - 3.9^\circ$ C;

T_o = outdoor air temperature

α = absorptance coefficient of surface for solar radiation. (i.e. Light colors typically absorb less solar radiation than dark colors)

I_{tot} = total solar radiation incident on surface

h_0 = heat transfer coefficient, which is a value based on both convective and radiative heat transfer conditions.

*Back to Equation, Q = U*A*($T_{solair,m}$ -T_i) + U*A*λ*($T_{solair,\theta-\phi}$-$T_{solair,m}$)

T_i = interior temperature

$T_{solair,m}$ = mean sol air temperature for the day

λ = Due to the large but finite thermal capacity of the wall & roof, the heat transfer to the conditioned space is less than the heat transferred to the outer surface of the wall. This factor is taken into account by the decrement factor.

$T_{solair,\theta-\phi}$ = Due to the thermal capacity of the wall (all material has an ability to store a certain amount of heat and then the excess heat is transferred to neighboring material), the exchange of heat from the outer surface to the interior surface experiences a time lag. While the outer surface at 10 A.M might be a certain temperature, the interior surface won't feel the effect of that temperature for some time as the heat travels through the wall. Thus, the factor (□□ - □) is the time □□ minus the time lag factor □.

*** This is a very difficult and time consuming equation to do for all hours of the day and for multiple days of the week. So, if you were to do this equation by hand a simpler equation is available, which is simply Q' = U*A* ΔT_{eff}

Where you can find values of ΔT_{eff} in tables for different wall/roof orientations, different wall/roof types, different latitudes, different solar times, and different declinations.

And Thus, by either using:

$$Q = U*A*(T_{solair,m} - T_i) + U*A*\lambda*(T_{solair,\theta-\phi} - T_{solair,m})$$

$$Q' = U*A*\Delta T_{eff}$$

One can determine the amount of heat traveling through the wall or roof for all hours of the day and for every day of the week. You simply need to know the latitude, declination angle (the day of the year), the hour angle (time of day), the orientation from North that the design surface faces (or if it is horizontal or tilted such as a roof). Then, you need to calculate the U-Value for the surface, and then plug all those values into the appropriate equations, and step-by-step determine the heat traveling through each surface.

2. Heat Transfer Through Doors and Windows Due to Conduction:

The amount of heat transferred through doors and windows due to conduction is simply calculated by the steady-state equation:

Q' = U*A* ΔT

ΔT = the temperature difference between the outdoor air temperature and the indoor air temperature.

The values of U are calculated the same way as the earlier procedure, and A is simply the area of the door or window.

2. Heat Transfer Through Fenestration (Windows & Glass Doors) Due To Radiation:

Windows are transparent surfaces. Thus, radiation is able to flow through them and absorb in the indoor surfaces.

To Calculate Heat Transfer Through a Transparent Surface (windows):

$Q = A\,(T^* I_{tot} + N^* \alpha^* I_{tot})$

A = Area of Glass

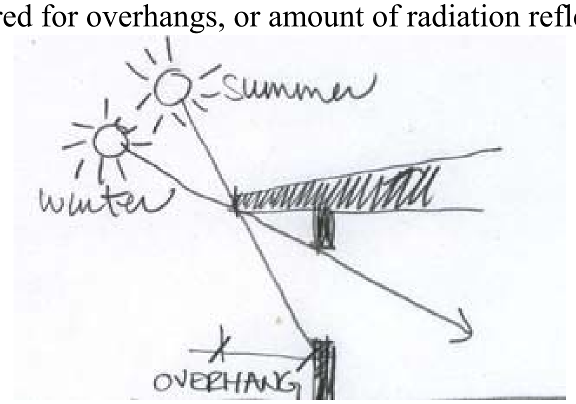
T = Transmissivity of glass

I_{tot} = total incident radiation

N = Fraction of absorbed radiation transferred through

α = abosptivity of glass

However, if the glass has external shading (overhangs…) or internal shading(blinds…) the equation also has to be multiplied by a shading coefficient **SC**, which depends on the total amount of shading and the type of shading. The value for **SC** can be found in tables depending on the different factors associated with the different shading devices. For example, as shown, overhangs are useful during the summer, when the sun has a high altitude angle, however they are not useful during the winter. So, the SC depends on these different variables, such as area covered for overhangs, or amount of radiation reflected for interior blinds.



And because the inside surface has some amount of thermal capacity; all of the radiation is not transmitted directly to the cooling load all at one time, rather the heat is released from the inside surfaces over time. Therefore, a cooling load factor is included as well, which can be found in tables depending on the interior surfaces.

Both of these factors reduce the overall amount of heat transferred into the building. The total amount is changed by:

$$Q = A\,(T^* I_{tot} + N^* \alpha^* I_{tot})^*SC^*CLF$$

3. Heat Transfer Due to Infiltration:

When hot, humid outdoor air leaks into a building, it brings two types of heat loads with it. The one due to the temperature of the air and one due to the moisture in the air.

a. Sensible Heat Gain – Temperature Driven

b. Latent Heat Gain – Moisture Driven

a. The Heat Gain Due to Temperature Differential (The Sensible Heat Gain):

$$Q = m_0 {}^* C_p {}^* (T_0 - T_i)$$

C_p = Specific Heat of Air

m_0 = mass flow rate of air into the building

$m_0 = V_o {}^* \rho_o$;

V_o = volumetric flow rate of infiltrating air

ρ_o = density of outdoor air

An exact amount of V_o can be found by doing an air leakage test, or in the absence of any detailed information about the building, a simplified procedure may be used to roughly estimate the infiltration rates arising from both wind and stack effects. The degree of shielding and the building height are the factors taken into account in this method:

$$V_o = \frac{ACH}{3600}$$

$$I = ACH = \frac{A_e}{V_r} * \frac{Q}{A_e}$$

I (Infiltration rate) = ACH (Air Changes Per Hour)

A_e = effective leakage area

V_r = volume of the room

$\frac{Q}{A_e}$ = specific infiltration

In this equation, you need two other equations to solve it. First, is the equation to determine A_e, then the equation to determine $\frac{Q}{A_e}$.

To get A_e use the equation;

$$A_e = 1000 * Q_r * \frac{\sqrt{\frac{\rho}{2 * \Delta P_r}}}{C_d}$$

Q_r = predicted air flow rate

ρ = density of air

ΔP_r = reference pressure difference

C_d = discharge coefficient

To get the Specific Infiltration, $\frac{Q}{A_e}$, use:

$$\frac{Q}{A_e} = \sqrt{A * \Delta T + B * V_w^2}$$

A = Stack Coefficient

B= Wind Coefficient

V_w = average wind speed

ΔT = average indoor-outdoor temp difference

Table 4 Stack coefficient and wind coefficient

Description	Number of Stories		
	One	Two	Three
Stack coefficient	0.00188	0.00376	0.00564
Wind coefficient			
- no obstruction or local shielding	0.00413	0.00544	0.00640
- light shielding, few obstructions	0.00319	0.00421	0.00495
- moderate local shielding	0.00226	0.00299	0.00351
- heavy shielding	0.00135	0.00178	0.00209
- very heavy shielding	0.00041	0.00054	0.00063

So, once the Infiltration Rate is determined, one can calculate the Volumetric Flow Rate, V_o, and then one can calculate the heat transfer due to infiltration Q = $m_0 * C_p * (T_0 - T_i)$.

b. Heat Gain Due To Moisture Differentials (The Latent Heat Gain)

$$Q = m_0 * C_p * (W_0 - W_i)$$

m_0 = mass flow rate (determined the same way as for the heat gain due to sensible load)

W_o = outdoor Humidity Ratio

W_i = indoor Humidity Ratio

W = the ratio of water vapor to dry air in a particular mass of air.

$$W = .622 * \frac{P_V}{P_a}$$

P_v = Pressure of Water Vapor

P_a = Pressure of Dry Air

4. Heat Transfer Due to Ventilation:

Heat transfer due to ventilation, sensible and latent heat gain due to ventilated air, is calculated the same way as infiltrated air. The only difference between the calculations is the amount of ventilated air.

Infiltrated air is un-intentional in most cases. However, ventilated air is both intentional and controllable. The purpose of ventilated air is to provide the building with adequate indoor air quality. This is accomplished by:

a. Providing fresh outdoor air that removes contaminants generated by processes or from building materials.

b. The fresh air also removes the by-products of respiration and bodily odor (including those from smoking) of human occupants.

c. Most importantly, fresh outdoor air provides sufficient supply of air/oxygen for the physiological needs of human beings (a minimum of .2 l/s/person is required for breathing purposes).

* A table of necessary ventilation rates is available that tells one how much outdoor air is required for a building depending on building type (residential, commercial, school, etc…), and different chemical contaminants present (#of computers, cleaning agents, smoking, etc…)

* Once the value of the amount of infiltrated air is determined and the value of the total amount of outdoor fresh air is required, then one will know how much ventilated air is required. Then, he/she simply needs to repeat the calculations under the infiltrated air section to determine the amount of heat generated due to ventilation.

Internal Heat Loads:

5. Heat Generation Due to Interior Lighting:

A by-product of interior lighting is heat production. Light bulbs are not 100% efficient, therefore a certain percentage of the energy used by lighting is converted into heat rather than into light. Thus, the amount of heat produced by lighting is dependent on a number of factors, such as how much it is used and the efficiency of the bulb.

To calculate heat generation:

Q = (installed wattage)*(UF)*(BF)*(CLF)

UF = Utilization Factor; $0 \leq UF \geq 1$; depending on use

BF = Ballast Factor; 1.25 for Fluorescent & 1 for Incandescent

CLF = Cooling Load Factor; * this value is obtained from a table, and it is a factor of # of fittings, # of hours of use, etc..

6. Heat Gain Due to Interior Equipment:

There are two types of Heat Produced by Equipment, sensible and latent heat. If the equipment solely has heat as a by-product than all the heat is sensible heat production. However, some equipment gives off moisture as part of the equipment process.

Q_{sen} = (Wattage)*(UF)*(CLF)

Q_{lat} = (Wattage)*(UF)*(Latent Heat Fraction)

LHF = fraction of Moisture Production

7. Heat Gain Due to Occupants

People are constantly giving off heat as a by-product of energy use. Depending on the type of activity and heart-rate of the individual, then a certain amount of heat will be produced. Moreover, to cool people off, people sweat. So, people are not only producing sensible heat, but they are producing latent heat, due to this moisture production. Therefore, for different types of buildings, standard values for the amount of sensible heat and for the amount of latent heat are provided.

For instance, there are different values for gyms, office buildings, school buildings, etc…

To calculate the heat production:

Q_{sen} = (# of people)*(Sensible Heat Gain/Person)*(CLF)

Q_{lat} = (# of people)*(Latent Heat Gain/Person)

So, after all *Internal Heat Gains* and all *External Heat Gains* are calculated, then one can total them up, and he/she can determine the amount of heat gained by a building, and then one will know the amount of energy that is going to be required to remove that heat. Also, once the percentage of the total heat gain is calculated for each area, the designer can know the biggest problem areas, and then by changing values for different variables in the calculations (such as increasing the U-Value for heat transfer through the wall), the designer can know how much each area can be improved and thus the total heat gain.

Analysis and Recommendations For Each Problem Area of the International Studies Center Building:

As was shown, these equations take a lot of time and a lot of thorough work to determine accurate values of heat gain. Therefore, the design of the International Studies Building was done using the Passive House Planning Package 2007.

The PHPP Program was developed by Dr. Wolfgang Feist to provide a tool to do all of the energy calculations for a building in a timely and an efficient manner. The program incorporates all aspects of exterior and interior heat gain that was shown earlier. The PHPP is an excel program that contains multiple worksheets that are different sheets for different types of heat transfer either through the exterior or produced in the interior. The program is broken up into these individual worksheets, and they are all linked together and work in unison to give energy demand of the building:

1. Verification Sheet

2. Area Sheet

3. U-List

4. U-Values

5. Ground

6. Windows
7. Window Type
8. Shading
9. Ventilation
10. Annual Heat Demand
11. Monthly Method
12. Heating Load
13. Summer
14. Summer Ventilation
15. Cooling
16. Cooling Units
17. Cooling Load
18. DHW + Distribution
19. Solar DHW
20. Electricity
21. Electricity Non Domestic
22. Auxiliary Electricity
23. Primary Energy Value
24. Boiler
25. District Heat
26. Climate Data
27. Internal Heat Gain
28. Utilization Non Domestic

While the program contains a large number of sheets, the individual calculations that I detailed earlier have already been inputted into the program. Therefore, on each sheet one simply needs to input the data for the building, and then the results are produced. Each sheet contains a particular portion of the building details.

Moreover, for the energy calculation of the common's building not all of the sheets were used or needed, and since there are so many sheets, I will discuss some of the more important sheets that were used, and then I will go into the findings produced by the program.

Afterwards, I will go into the findings produced when some of the variables were changed (i.e. like no wall insulation compared to wall insulation, high surface solar absorption compared to low surface insulation).

1. Verification Sheet is mainly the title sheet, but it also contains the information that is important for some of the calculations such as number of building occupants, enclosed volume of the building, and interior temperature.

2. Area Sheet is where the user puts in the data for the exterior envelope, such as the roof, ground, and walls. All data like the U-Values for each wall (north, south, east, and west), roof, and ground are put in, as well as the height and length of each wall. Also put in is the deduction of area from the windows, and the solar absorption of each surface and the deviation from north (the direction) of each surface.

3. U-Values Sheet the user defines each element of the wall construction, such as the thickness of each element and the thermal conductivity of each element, and then the sheet calculates total u-values for each individual wall construction. So, if you have a different type of wall construction on the east wall as to the west wall, one is able to calculate the different u-values and then plug in the appropriate u-value into the areas sheet.

4. Windows Sheet is where the user defines the size and location of all the windows and plugs in all appropriate information concerning the window.

5. Window Type is the same type of sheet as the U-Values sheet. Just like in the U-Values sheet the user plugs in the information about the different types of wall construction and then that information is transferred into the Areas sheet, the user plugs in the type of window construction and then that information is transferred into the windows sheet.

6. Shading is where the user types in the location and size of all objects that provide shading on the building and its windows.

7. Ventilation is where the user types in the infiltration rate and the type of ventilation that is used. The user defines whether the infiltration is accomplished by natural or mechanical means and the extent of that ventilation.

8. Cooling Units is the sheet where you determine the type of mechanical equipment that is used for cooling and ventilation purposes and all the important data associated with those processes.

9. Climate Data is the sheet where you input all the data for the building's local climate, such as year round temperature and humidity.

** Each and every sheet plays a particular function for the overall calculation of the program, but I am just offering a brief synopsis of a few of the sheets' function. For a thorough description of the program, The Passive House Planning Package 2007 Technical Information Booklet details how to input data into each sheet and also the function of each sheet.

After plugging in all the existing data for the common's building into the PHPP, the program returned the following specific cooling energy demand:

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area:	1579.0	m^2		
	Applied:	Monthly Method		PH Certificate:
Specific Space Heat Demand:	**39**	**$kWh/(m^2a)$**	**15**	**$kWh/(m^2a)$**
Pressurization Test Result:	**6.0**	**h^{-1}**	0.6	h^{-1}
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):		**$kWh/(m^2a)$**	120	$kWh/(m^2a)$
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):		**$kWh/(m^2a)$**		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		**$kWh/(m^2a)$**		
Heating Load:		**W/m^2**		
Frequency of Overheating:		**%**	over 23	°C
Specific Useful Cooling Energy Demand:	**66**	**$kWh/(m^2a)$**	15	$kWh/(m^2a)$

The Specific Useful Cooling Energy Demand is the important value for the building design. In essence, if one were to go through all the cooling load design calculations that I detailed earlier, this is the value that would be totaled up. In Passive House Buildings, they require a maximum 15 kWh/m²/a. The common's building is over 4 times as much energy at 66 kWh/ m²/a just for cooling. This large energy demand is caused by a few distinct problems, which can all be corrected.

And from the Cooling Units Sheet, one can see a breakdown of the total Sensible and Latent heat loads. These values represent the sensible and latent heat load when no renovations or changes to the structure have been made. The sensible load is 65.8 kWh/m²a and the latent load is 47.3 kWh/m²a

	Sensible	Latent	
Useful Cooling Demand	65.8	47.3	
of which			
Supply Air Cooling	25.7	25.9	kWh/(m²a)
Recirculation Cooling	40.1	21.3	kWh/(m²a)
Dehumidification		0.0	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	**65.8**	**47.3**	kWh/(m²a)

Each Component of the Common's Building that Affects Energy Usage (Both Latent and Sensible Heat Gain):

1. There is 0 insulation in the walls.
2. There is very little insulation on the roof
3. The exterior surfaces of the walls and roof have a very high solar absorption rate.
4. Due to the out-dated construction techniques, the building leaks in a lot of hot, humid air during the summer months or leaks out cool conditioned air depending on the weather and pressure conditions mentioned earlier.
5. Since there is not heat recovery system, all in-coming fresh air, is a direct load on the cool unit.
6. The windows have very high U & G values.

7. There is no radiant barrier for the roof, and as a result, radiant energy absorbed by the roof is able to permeate throughout the building (Currently, there are no calculations to prove the extent to which a radiant barrier rejects heat and thus reduces the load, however, the benefits can easily be explained).

8. Inefficient Lighting

Analyzing Each Problem Area:

1. 0 insulation in the walls.

Insulation is a material with a very low thermal conductivity, and thus it retards the flow of heat through the wall. The more insulation that is present, the longer it takes a particular amount of heat to travel through the wall medium, and thus the lower the U-Value becomes, which means the result from the equation, Q' = $U*A*\Delta T_{eff}$, is reduced the more insulation is added. In other words, Increasing the thickness of an insulating layer increases the thermal resistance. For example, doubling the thickness of fiberglass batting will double its R-value, perhaps from 2.0 m^2K/W for 110 mm of thickness, up to 4.0 m^2K/W for 220 mm of thickness

So, for the Common's Building, this is the U-Value of the main type of wall construction in its present condition:

Assembly No.	Building Assembly Description						
1	Brick Construction (All Walls N,E,S & W + All Inlet Construction)						
		Heat Transfer Resistance [m^2K/W] interior R_{si} :	0.13				
		exterior R_{se} :	0.04				Total Width
	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Brick	1.000					102
2	airspace	.275					51
3	concrete	2.100					102
4	Gypsum board	.250					13
5	Wall insulation	0.000					0
			Percentage of Sec. 2			Percentage of Sec. 3	Total
							26.7 cm
					U-Value:	1.800	W/(m^2K)

This is a fairly high value for the U-Value for the wall construction because if you apply this u-value to the total equation of heat transfer through the walls (the surface area around the entire building envelope), a lot of heat will be transferred through the building.

However, when insulation is added to the wall construction, a serious reduction in the U-Value can be achieved, and as a result the amount of heat that is permitted to travel through the walls can be reduced.

For instance, when 50 mm of insulation, with a thermal conductivity of .035, is added to the wall, the U-Value is decreased from 1.80 W/(m²K) to .504 W/(m²K).

Assembly No.	Building Assembly Description
1	Brick Construction (All Walls N,E,S & W + All Inlet Construction)

Heat Transfer Resistance [m²K/W]	
interior R_{si} :	0.13
exterior R_{se} :	0.04

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Total Width Thickness [mm]
1.	brick	1.000					102
2.	airspace	0.275					51
3.	concrete	2.100					102
4.	gypsum board	0.250					13
5.	wall insulation	0.035					50

Percentage of Sec. 2	Percentage of Sec. 3	Total
		31.7

U-Value: 0.504 W/(m²K)

By changing the U-Value of the wall to .504, a significant reduction in the sensible and latent heat loads is accomplished.

From the calculations in the Cooling Units Sheet, there was a large reduction in both the sensible and latent heat loads. The sensible load was reduced from 65.8

to 48.4 (a 26.6% reduction), and the latent load was reduced from 47.3 to 36.6 (a 22.2 % reduction).

	sensible	latent	
Useful Cooling Demand	48.4	36.6	
of which			
Supply Air Cooling	23.7	24.9	kWh/(m²a)
Recirculation Cooling	24.7	11.2	kWh/(m²a)
Dehumidification		0.5	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	**48.4**	**36.6**	kWh/(m²a)
Unsatisfied Demand	0.0	0.0	kWh/(m²a)

2. Adding Insulation to the Roof

The U-Value of the Current Roof Structure:

Assembly No.	Building Assembly Description
5	Roof

Heat Transfer Resistance [m²K/W]	
interior R_{si} :	0.17
exterior R_{se} :	0.04

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Built-Up Tar	0.170					10
2.	Rigid Insulation	0.060					34
3.	Lt. Wt Concrete	2.100					114
4.	Metal Decking	60.000					2
5.	Air Space	4.791					1118
6.	Acoustic Tile	0.300					25

Percentage of Sec. 2	Percentage of Sec. 3	Total
		130.4

U-Value: **0.828**

By adding 100 mm of insulation to the current insulation, the U-Value is greatly reduced.

Assembly No.	Building Assembly Description
5	Roof

Heat Transfer Resistance [m²K/W] interior R_{si} : 0.17

exterior R_{se} : 0.04

	Area Section 1	λ [W/(mK)]	Area Section 2 (optional)	λ [W/(mK)]	Area Section 3 (optional)	λ [W/(mK)]	Thickness [mm]
1.	Built-Up Tar	0.170					10
2.	Rigid Insulation	0.040					134
3.	Lt. Wt Concrete	2.100					114
4.	Metal Decking	60.000					2
5.	Air Space	4.791					1118
	Acoustic Tile	0.300					25

Percentage of Sec. 2	Percentage of Sec. 3	Total
		140.4

U-Value: 0.251

And as a result, the sensible and latent heat demands are reduced. The sensible load is reduced from 65.8 to 61.8 (a 6.1% reduction), and the latent load is reduced from 47.3 to 44.4 (a 7% reduction).

	sensible	latent	
Useful Cooling Demand	61.8	44.4	
of which			
Supply Air Cooling	27.1	27.0	kWh/(m²a)
Recirculation Cooling	34.7	17.4	kWh/(m²a)
Dehumidification		0.0	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	61.8	44.4	kWh/(m²a)
Unsatisfied Demand	0.0	0.0	kWh/(m²a)

3. Improving the Solar Absorptance of the Walls and Roof.

Currently the exterior surfaces of the walls are made of red brick, and the roof has top layer of black tar. Thus, the walls have a solar absorptions coefficient of .65, and the roof has a solar absorption coefficient of 0.8. These values represent the fraction of absorbed radiation of the total amount of incident solar radiation striking that surface. Therefore, for the walls, 65% of all solar radiation that strikes the wall is absorbed by the wall, and the same goes for the roof.

There are new paint materials on the market that can be applied to exterior surfaces that are subject to irradiation. The paint is a white color that reflects majority of all incident radiation. So, if this paint were applied to the roof and exterior wall surfaces, a large amount of radiation that is currently absorbed could be reflected off into the atmosphere.

Additional Inputs for Radiation Balance				
Exterior Absorptivity	**Exterior Emissivity**	**Deviation from North**	**Angle of Inclination from the Horizontal**	**Reduction Factor Shading**
These columns serve for considering the radiation balance of exterior, opaque surfaces. Inputs only for those surfaces which are adjacent to ambient air! For consideration of heating in Central European climates no input is required.				
0.65	0.93	342	90	1.00
0.65	0.93	342	90	1.00
0.65	0.93	342	90	1.00
0.65	0.93	342	90	0.40
0.65	0.93	342	90	0.40
0.65	0.93	72	90	1.00
0.65	0.93	72	90	1.00
0.65	0.93	72	90	1.00
0.65	0.93	72	90	0.40
0.65	0.93	72	90	0.40
0.65	0.93	162	90	1.00

Above is the portion of the sheet in the Areas Worksheet that shows the additional inputs for the walls for radiation considerations. To the left of this sheet in the PHPP program, which is shown below in order to be able to picture the input process, is the inputs for all the different walls (directional as well as different types of construction for each direction). Then, once that is entered, one enters in the additional radiation inputs for the different surfaces.

Assigned to Group	Quantity	x (	a [m]	x	b [m]	+	User-Determined [m²]	-	Subtraction Window Areas [m²]	) =	Area [m²]	Nr.	U-Value [W/(m²K)]
Treated Floor Area	1	x (		x		+	1579.00	-		) =	1579.0		
North Windows											26.2		5.427
East Windows											43.0		5.442
South Windows											32.7		5.427
West Windows											24.8		5.693
Horizontal Windows											0.0		0.000
Exterior Door		x (		x		+		-		=			
Exterior Wall - Ambient	1	x (	31.29	x	3.26	+		-	26.2	=	75.9	1	1.800
Exterior Wall - Ambient	7	x (	0.41	x	3.26	+		-	0.0	=	9.3	2	2.751
Exterior Wall - Ambient	1	x (	34.14	x	1.27	+		-	0.0	=	43.4	2	2.751
Exterior Wall - Ambient	1	x (	5.69	x	4.53	+		-	0.0	=	25.8	1	1.800
Exterior Wall - Ambient	1	x (	2.84	x	3.26	+		-	0.0	=	9.3	1	1.800
Exterior Wall - Ambient	1	x (	29.26	x	3.26	+		-	26.2	=	69.2	1	1.800
Exterior Wall - Ambient	6	x (	0.41	x	3.26	+		-	0.0	=	8.0	2	2.751
Exterior Wall - Ambient	1	x (	30.89	x	1.27	+		-	0.0	=	39.2	2	2.751

* This table is actually larger in the PHPP Program. I reduced it by cutting out particular columns so that it would fit on the page.

So, when values of 0.2 are entered into the columns for the solar absorption coefficients of the different surfaces a large reduction in sensible and latent heat gain is achieved. The sensible load is reduced to 56.8 (a 14% reduction), and the latent load is reduced to 42.4 (a 10 % reduction).

	sensible	latent	
Useful Cooling Demand	56.8	42.4	
of which			
Supply Air Cooling	23.4	24.8	kWh/(m²a)
Recirculation Cooling	33.4	17.4	kWh/(m²a)
Dehumidification		0.2	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	**56.8**	**42.4**	kWh/(m²a)
Unsatisfied Demand	0.0	0.0	kWh/(m²a)

4. Improving the Air-tightness of the Building:

The building currently leaks in hot, humid outdoor air at a rate of 6 air changes per hour. If this value were reduced to 1 air change per hour, a large reduction in the heat loads could be achieved.

					Net Air Volume for Press. Test
Wind Protection Coefficient, e			0.07	**0.18**	
Wind Protection Coefficient, f			15	**15**	
Air Change Rate at Press. Test	n_{50}	*1/h*	1.00	1.00	5000
Type of Ventilation System					
Balanced PH Ventilation	*Please Check*		for Annual Demand:	for Heat Load:	
Pure Extract Air					
Excess Extract Air		*1/h*	0.00	0.00	
Infiltration Air Change Rate	$n_{V,Res}$	*1/h*	**0.089**	**0.222**	

* This is a table from the ventilation sheet where the user enters in the air change rate and the net volume of the building. This table shows the air change rate at 1 ACH, when comparing the ACH from 6 to 1, the sensible and latent loads both drop.

The process of sealing the building is not a difficult procedure. The building leaks in air at any punctures in the exterior wall, such as electric outlets and incoming piping, as well as all areas where the exterior walls meet the roof and the foundation. So, these areas simply need to be sealed with caulk and sealant.

When the building's air change rate is reduced to 1 ACH, the sensible and latent loads are reduced to:

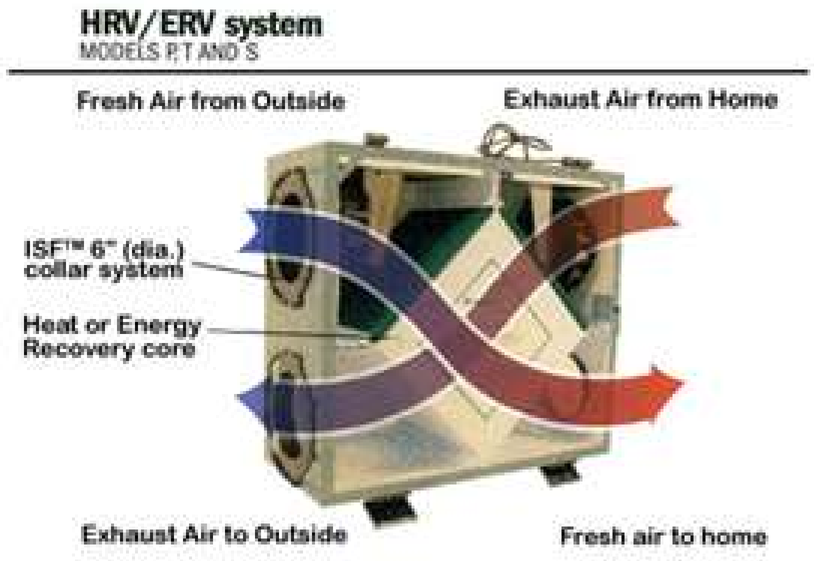
	Sensible	latent	
Useful Cooling Demand	60.5	37.5	
of which			
Supply Air Cooling	26.0	26.1	kWh/(m²a)
Recirculation Cooling	34.5	11.4	kWh/(m²a)
Dehumidification		0.0	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	**60.5**	**37.5**	kWh/(m²a)
Unsatisfied Demand	0.0	0.0	kWh/(m²a)

The sensible load is reduced by 8%, and the latent load is reduced by 21%. This is relatively easy and less costly procedure for reducing the latent and sensible loads. However, when reducing the amount of infiltrated air, it is important to make sure that appropriate amount of ventilated air is going into the building to ensure good indoor air quality.

5. Adding a Heat Recovery System:

Currently there is not heat recovery system, so all incoming air that enters through the air conditioning unit, must be cooled and dehumidified from its outdoor conditions. If a heat recovery system were used, a large portion of this heat and moisture could be transferred to the exhaust air, and thus the load on the air conditioning system could be greatly reduced.

The system works by having incoming hot, humid air flow over the outgoing cool, dehumidified air, and by natural thermodynamic processes the two air flows will try to reach a state of equilibrium. Thus, the excess heat and humidity from the incoming air will travel into the cooler, drier air until there is a balance between the two flows or for as long as the two air currents are in contact. Thus, the incoming air will be less hot and humid and therefore be less of a load on the system.



If a system is installed that has a humidity recovery of 60% and a heat recovery of 80% (and the reduction in air leakage is taken into account, these two changes work in conjunction with each other), the sensible and latent loads are reduced.

Effective Heat Recovery Efficiency of the Ventilation System with Heat Recovery

x	Central unit within the thermal envelope.
	Central unit outside of the thermal envelope.

Efficiency of Heat Recovery	η_{HR}		0.80	3
Transmittance Ambient Air Duct	Ψ	W/(mK)	0.000	Calculation see Secondary Calculation
Length Ambient Air Duct		M		
Transmittance Exhaust Air Duct	Ψ	W/(mK)	0.000	Calculation see Secondary Calculation
Length Exhaust Air Duct		M		
Temperature of Mechanical Services Room (Enter only if the central unit is outside of the thermal envelope.)		°C		

Effective Heat Recovery Efficiency $\eta_{HR,eff}$ **80.0%**

		1/h		Efficiency Humidity Rec.						1/h
Hygro Effective Mech. Air Change Rate Summer		0.300	* (1 -	60%	)			=		0.120
	$n_{V,nat}$	$n_{V,Res}$		$n_{Night,Windows}$		$n_{Night,mechanical}$				
	1/h	1/h		1/h		1/h				
Direct Ambient Air Change Rate Summer	0.000	+ 0.089	+	0.000	+	0.000		=		0.089
Ambient Air Change Rate Summer									Total	0.21

	sensible	latent	
Useful Cooling Demand	57.7	35.2	
of which			
Supply Air Cooling	26.1	26.2	kWh/(m²a)
Recirculation Cooling	31.5	9.0	kWh/(m²a)
Dehumidification		0.0	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	**57.7**	**35.2**	kWh/(m²a)
Unsatisfied Demand	0.0	0.0	kWh/(m²a)

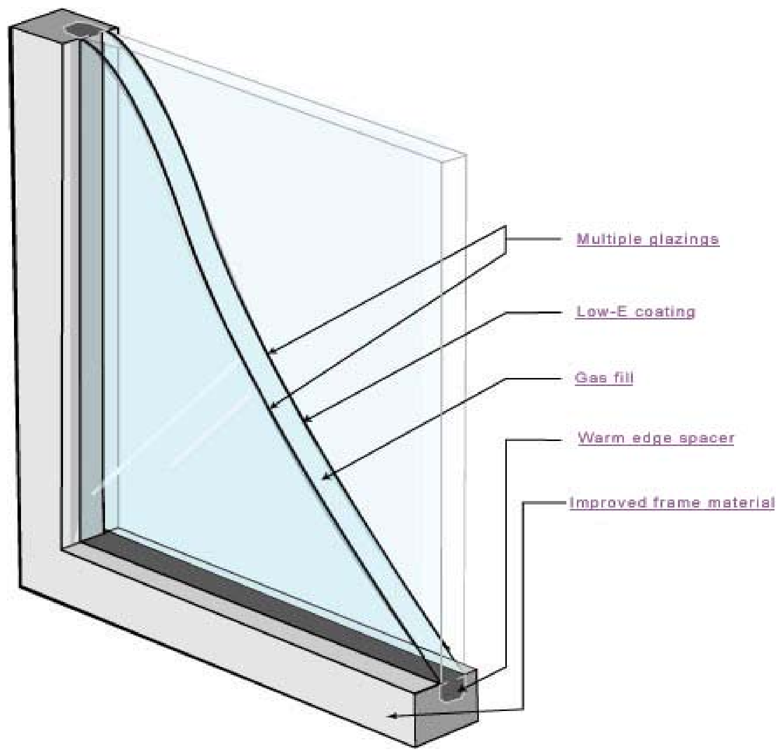
This is a 12.3% reduction in the sensible load and a 25.6 % reduction in the latent load. Both are large reductions in the cooling and dehumidification energy demand on the building.

6. Installing New Windows

The current windows are old and outdated. They are single paned units that have very little reflectivity and almost zero insulation capabilities. They let in a lot of solar radiation, and they have a very leaky construction frame. As a result, they are responsible for a lot of heat gain through the building. In total there are 70 windows (upper and lower windows) around the building envelope. There is a fair amount of shading provided by the adjacent buildings to the north, south and east, however the glass still receives some incident solar radiation, and they are also subject to a lot of wind, which causes air to leak through the window frames. Thus, these windows could be improved to double paned window units.

Double pane windows are also called dual paned or double glazed or insulating glass (IG) windows. They provide better insulation than old single pane (cutting the heat loss in half as long as the seals are intact) at a lower purchase price than triple-paned windows.

Double paned windows are made up of two facing glass panels set in a frame, separated by a small space from half an inch to three-quarters of an inch wide. The gap might be filled with air or nontoxic gasses like argon or the more expensive krypton in order to improve insulation



In warmer climates, you should select windows with spectrally selective coatings to reduce heat gain by filtering out 40% to 70% of the infrared radiation while allowing the full amount of light to enter. Windows with spectrally selective coatings on the glass reflect some of the sunlight, keeping your rooms cooler. Spectrally selective coatings are optically designed to reflect particular wavelengths but remain transparent to others. They reflect infrared portion while admitting visible light, creating a window with a low U-factor. Selective coatings can reduce the electric space cooling requirements by more than 40%. In regions in which a mixture of weather is normal, double paned windows can be designed with a combination of factors to best maximize energy-savings.

Thus, by replacing the windows with two paned windows with high reflectivity for infrared radiation and with an air-filled layer between the two panes for thermal conduction purposes, the amount of heat permitted to travel through the windows could be greatly reduced. For instance:

These are the current window unit's U & G values as well as the new window unit's U & G Values:

	Type		
Assembly No.	Glazing	g-Value	U_g-Value
			W/(m^{2}K)
1	Gray Glass	0.420	5.750
2	wire glass	0.870	5.800
3	Metal Door	0.000	5.800
4	2 pane sun-protect	0.280	1.100

When the new window units are installed for the 70 Windows in the windows sheet (which is way too large to put here):

	sensible	latent	
Useful Cooling Demand	58.8	40.1	
of which			
Supply Air Cooling	25.6	25.8	kWh/(m²a)
Recirculation Cooling	33.2	14.3	kWh/(m²a)
Dehumidification		0.0	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	**58.8**	**40.1**	kWh/(m²a)

The sensible load is thus reduced by 10.6 %, and the latent load is reduced by 15.2%.

7. Installing New Lighting

School buildings typically use one of 3 lighting fixtures; T12, T8, or T5 Lamps. The letter 'T' in the lighting industry stands for "tubular". The number directly following the letter "T" indicates the thickness or diameter of that particular tube in eighths of an inch.

- T12 = twelve eighths of an inch in diameter or one & one-half inches thick
- T8 = eight eighths of an inch in diameter or one inch thick
- T5 = five eighths of an inch in diameter or five eighths of an inch thick

There are several different factors that determine levels of efficiency. Quality of light measured in CRI (Colour Rendering Index), quantity of light measured in LPW (Lumens per Watt) and CU (Co-efficiency of utilization.) The numbers being used for CU are general for those used in the low level (12 feet and under) multi-residential environment so there can be fluctuations.

CRI levels:	LPW levels:	CU (Generally):
T12 = 62CRI	T12 = 78LPW	T12 = .46CU
T8 = 85CRI	T8 = 92LPW	T8 = .76CU
T5 = 85CRI	T5 = 103LPW	T5 = .90CU

Considering these general factors, it is obvious that T5 is the best, and currently the building uses T8 Lamps. So, the building could improve its lighting efficiency by changing over to T5 Lamps.

An overall increase in (lumens per watt) means that less heat will be produced per watt of energy usage, and it also means that the light will require less watts to produce the same amount of light. Therefore, energy reductions could be achieved by both less energy usage and less heat production.

8. Installing a Radiation Barrier

As mentioned earlier, no calculations are currently available to prove the effectiveness of a radiation a barrier. However, it is quite easy to show the usefulness of installing a radiation barrier in the roof system of a building.

A radiant barrier is made out of material that reflects over 90% of incident radiation. It also has a high emissivity on the side that receives the radiation and a low emissivity on the underside of the radiant barrier. Emissivity is the term that refers to a materials ability to emit radiation. So, if the underside of the barrier has a low emissivity, then radiant energy absorbed by the barrier will be emitted towards the roof and sky and not into the house.

In other words, solar energy is absorbed by a roof, heating the roof sheathing and causing the underside of the sheathing and the roof framing to radiate heat downward toward the attic floor. When a radiant barrier is placed directly underneath the roofing material incorporating an air gap, much of the heat radiated from the hot roof is reflected back toward the roof and the low emissivity of the underside of the radiant barrier means very little radiant heat is emitted downwards. This makes the top surface of the insulation cooler than it would have been without a radiant barrier and thus reduces the amount of heat that moves through the insulation into the rooms below the ceiling.

So, an exact amount of energy reductions caused by the installation of a radiant barrier are currently not available, however this type of renovation to a building has been shown to reduce cooling costs quite a lot in areas with a hot and humid climate.

In Conclusion:

With all of the Changes made to the building, a serious reduction in energy is achieved. Each component of the building works in conjunction with the other, so when each component is improved, the overall performance of the individual building components as well as the building itself are greatly improved.

For instance, if you added a heat recovery system without sealing the building, the majority of the fresh air required for the building would be coming through the building leaks, therefore the heat recovery system would only be working on a small percentage of the incoming air, which would make the system less useful. However, if the building were sealed, and the majority of the incoming fresh air were handled by the ventilation system, then the heat recovery system would be transferring heat out of a majority of the incoming air, which would make the system very useful. Other examples are the use of a low solar absorptance coating on the roof (a cool roof) in conjunction with a radiant barrier. By combining these two methods of reducing solar radiation into the building, the building would then have two means of reflecting solar radiation and thus cooling the building even more.

So, when all the previously mentioned improvements are made to the building exterior and interior a reduction of sensible and latent loads are made possible. The building's energy usage can be reduced by over 50%, and thus the lifetime costs of the building could be cut in half, and moreover the comfort of the building's occupants could be greatly improved.

These are the results of the building's reductions in sensible and latent heat loads when all changes are made to the building:

	Sensible	Late	
Useful Cooling Demand	30.0	24.3	
of which			
Supply Air Cooling	24.1	23.9	kWh/(m²a)
Recirculation Cooling	5.9	0.4	kWh/(m²a)
Dehumidification		0.0	kWh/(m²a)
Remaining for Panel Cooling			kWh/(m²a)
Total	**30.0**	**24.3**	kWh/(m²a)

Specific Demands with Reference to the Treated Floor Area					
Treated Floor Area:	1579.0	m^2			
	Applied:	Monthly Method		PH Certificate:	Fulfilled?
Specific Space Heat Demand:	**9**	**kWh/(m²a)**	**15**	**kWh/(m²a)**	**Yes**
Pressurization Test Result:	**1.0**	**h^{-1}**	0.6	h^{-1}	**No**
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):		**kWh/(m²a)**	120	kWh/(m²a)	
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):		**kWh/(m²a)**			
Specific Primary Energy Demand Energy Conservation by Solar Electricity:		**kWh/(m²a)**			
Heating Load:		**W/m²**			
Frequency of Overheating:		**%**	23	°C	
Specific Useful Cooling Energy Demand:	**30**	**kWh/(m²a)**	15	kWh/(m²a)	**No**
Cooling Load:		**W/m²**			

From these figures, one can see that the Specific Useful Cooling Demand was reduced from 66 Kwh/m²a to 30 kWh/m²a, which is more than half of the cooling load demand. And the sensible load was reduced 65.8 Kwh/m²a to 30 Kwh/m²a (which is a 55% reduction in sensible heat load), and the latent load was reduced from 47.3 Kwh/m²a to 24.3 Kwh/m²a (a 49% reduction in the latent heat load).

While this study did not focus on the cost of energy improvements for the building, most of these changes do not require large costs for energy usage reductions. The majority of these changes are practical, low cost, low man-power solutions for improving the building's energy demand. The goal of this project is to implement practical solutions that can be applied to similar buildings all over the region. As a result, the improvements made to the building should be simple and effective, so that this building is a model for energy efficiency to other designers.

This project will be completed under a limited budget, so it would be very difficult for this building to reach Passive House Building Standards, yet there are high ambitions for the improvements of the building. With a thorough and complete analysis of the building, and a comprehensive design plan, any building can easily achieve its goals of energy reduction. The analysis provided by this report details simple and effective means to lower the energy usage, and if the renovation follows the design outlined by this report, the building should reach its goals.

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