BUILDING BALANCE POINT
Level 1: Introduction to First Order Principles

The building balance point temperature is a VITAL SIGN indicator of the relationship between the various thermal forces at play within a building; the heat generated by building occupancy, the heat of the sun entering the building, and the transfer of energy across the building enclosure due to the difference in temperature between building and environment. As a measure of the dynamic interplay of several variables, the building balance point temperature is a powerful conceptual tool used to evaluate the energy flows between a given building and its surroundings. The building balance point can be estimated as a design variable, a function of building design and program variables. However, it can not be measured directly in the field. All building energy flows must be measured or estimated in the field to estimate the building balance point temperature. This section introduces the definition of the balance building point temperature, its relationship to building energy flows, and a method of estimating building energy flows from field observation.

Energy flow out of or into a building is driven by the difference between the building temperature and the outdoor ambient temperature. The rate of heat flow across the building enclosure is also proportional to the thermal quality of the building enclosure. Occupancy results in building heat gains due to both occupant metabolism and electric consumption in lights and equipment. Solar energy also adds heat to the building, primarily via glazing transmittance, but also by conduction through the building enclosure when solar energy is absorbed on the enclosure surface. The balance point temperature is a measure of the conditions required to balance heat entering the building with heat leaving the building in the absence of mechanical heating or cooling. It is defined as the ambient (or outdoor) air temperature which causes building heat transfer across the enclosure to balance building heat gains at the desired interior temperature (assumed to be the thermostat setting). This definition of the building balance point, \( T_{\text{balance}} \), is given mathematically as:

\[
T_{\text{balance}} = T_{\text{thermostat}} - \frac{Q_{\text{IHG}} + Q_{\text{SOL}}}{U_{\text{bldg}}}
\]

Where:
- \( T_{\text{thermostat}} \) is the building thermostat setting.
- \( Q_{\text{IHG}} \) is the building internal heat generation rate due to occupancy and given per unit floor area.
- \( Q_{\text{SOL}} \) is the rate of solar heat gain to the building given per unit floor area.
- \( U_{\text{bldg}} \) is the rate of heat transfer across the building enclosure per degree temperature difference, also given per unit floor area. Thus the balance point temperature is defined as the building thermostat temperature minus the ratio of total building heat gains divided by the rate of heat transfer across the building enclosure. The elements of the balance point are not constant: \( Q_{\text{IHG}} \) changes with the occupancy schedule and \( Q_{\text{SOL}} \) changes with time of day and time of year. Even \( U_{\text{bldg}} \) can vary due to variation of the building fresh air ventilation rate.

To better understand the concept of the building balance point, consider Figure 14. The top graph illustrates plots of a thermostat temperature for a building and an ambient air temperature. In this example, the ambient air temperature is always lower than the thermostat temperature indicating that heat will transfer out of the building during all hours of the day. This heat loss from the building will be proportional...
to the temperature difference between the building (or thermostat) temperature and the ambient air temperature. The thickness of the shaded area is equivalent to the temperature drop across the enclosure. The actual rate of heat transfer across the building enclosure during an hour per unit floor area is equal to the product of the temperature drop for that hour and the building enclosure heat transfer rate, $U_{bldg}$. The enclosure heat transfer rate includes heat transfer rates through the roof, walls, glazings and ground, and via ventilation. It is described in detail later.

The effect of heat gains due to occupancy, $Q_{bldg}$, is illustrated in the middle graph. When a building is occupied, heat is added to the building as a result of occupant metabolism and electric energy consumption. Many commercial and institutional buildings are occupied during the day, but not at night. When a building is unoccupied, its balance point temperature due to internal gains is usually equal to the thermostat temperature. The balance point temperature illustrated in the middle plot is equal to the thermostat temperature at night representing an unoccupied building. During the day the balance point temperature is roughly 20°F less than the thermostat temperature. This means that the ratio of $Q_{bldg}$ to $U_{bldg}$ is equal to roughly 20°F. Note that the balance point temperature has dropped below the ambient air temperature during the day, indicating that the internal heat gains will exceed the enclosure heat transfer and the building will experience net heat gains.

Finally, the lower graph illustrates the additional effect of solar heat gains. Solar gains enter primarily through the glazing. They will typically be lower at sunrise and sunset and peak at noon. In this example, the ratio of $Q_{sol}$ at noon to $U_{bldg}$ is roughly 12°F. The total area of net heat gain during the day (the light shaded area in the lower figure where the balance point is lower than the ambient temperature) is nearly the same as the total area of net heat loss at night (the darker shaded area where the balance point temperature is higher than the ambient air temperature). It is the relative magnitudes of areas of net heat gain and net heat loss that permit evaluation of building energy flows using the balance point temperature. The final graph in Figure 14 illustrates an area of net heat gain that is slightly smaller than the area of net heat loss at night. Remember, the areas actually represent temperature differences over time, not heat flow. But, due to the definition of the balance point, the net heat gain (or loss) for the day is given as a product of the shaded area and the enclosure heat transfer rate, $U_{bldg}$.

When the ambient temperature is higher than the desired indoor air temperature there is little that can be done in terms of design to bring the building into balance aside from reducing the internal and solar heat gains. However, the concept of the balance point still provides information concerning energy flows. Figure 15 illustrates the effect of higher ambient temperatures on a building’s potential heat gains and losses. The top graph illustrates $T_{thermostat}$ plotted with a warmer ambient temperature. Even before considering internal and solar heat gains, the building is subject to potential net heat gains during the day. The building balance point due to internal heat gains is plotted in the middle graph. The potential for large net heat gains is illustrated by the shaded area. Finally, the lower graph adds the solar heat gains, $Q_{sol}$, to the balance point plot.

The building balance point temperature plots provide a means of visualizing energy flows in the building. The bottom plot in Figure 14 illustrates a building with potential heat gains over the day slightly less than potential heat losses at night. Building heat storage capacity could provide a means of distributing excess day time gains to offset night time losses. The bottom plot in Figure 15 illustrates a building dominated by heat gains. Ambient conditions change over the course of a year, and the two figures could represent the same building during different seasons. The protocols developed here to estimate the building balance point temperature require four seasonal plots of the building balance point.

Variation in building design or occupancy will change the values of $U_{bldg}$, $Q_{bldg}$ and $Q_{sol}$, resulting in different balance point plots representing different potentials for building heat gain or loss. The following sections describe each variable and techniques used to estimate the variables.

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*Figure 15: Building Balance Point graphs for warm ambient temperatures.*
BUILDING HEAT TRANSFER RATE

While internal heat gains and solar heat gains represent the primary paths for heat entry into buildings, heat transfer across the enclosure represents the primary potential for building heat loss. Heat flows between the building and surrounding environment by two major paths: conduction across the building enclosure and bulk air exchange via ventilation or infiltration. The rate of heat flow via either path is proportional to the temperature difference between building and environment. When the environment is hotter than the building, heat flows into the building and the only sources of heat loss are heat flow to the ground and mechanical air-conditioning. While accurate computation of the building heat transfer rate can be complicated, the goal of a balance point evaluation is to provide a reasonable estimate with minimal effort.

Heat transfer across the building enclosure is a function of both the surface area of all enclosure components and their respective thermal conductance. Consider the two shelters at left (Figures 16 and 17). The tent has an approximate U value of .9 Btu/Hr/SF/°F which is minimal. It does have the ability to both be fully open to natural ventilation in warm weather and to be closed to unwanted infiltration in cold. The translucent fabric allows solar gains as available but there is no thermal mass to retain them. The hay bale structure has an approx. U value of 0.0125 Btu/Hr/SF/°F which is very insulating. Adequate ventilation might be a question in warm weather. Once stuccoed, infiltration rates will be extremely low. Both structures have forms that minimize the skin to volume ratio. The primary difference is the overall building heat transfer rate, $\dot{U}_{\text{bldg}}$, which is much lower for the hay bale shelter. Thus the hay bale shelter will have a lower balance point than the tent.

The authors suggest considering five separate paths for heat transfer across the building enclosure: the roof, opaque walls, glazing, ground and ventilation. The roof, walls and glazings each have exposed area and thermal qualities based on the materials of composition. Heat transfer through the ground occurs primarily along the building perimeter. Heat transfer via ventilation depends on the rate of flow between the building and the environment. Heat transfer rates vary widely from building to building due to size, exposed surface area, use and many other factors. One means of allowing comparison between buildings is to estimate all building heat transfer rates per unit floor area of the building. $\dot{U}_{\text{bldg}}$, the building heat transfer rate per unit floor area is then estimated as:

$$\dot{U}_{\text{bldg}} = \dot{U}_{\text{wall}} + \dot{U}_{\text{roof}} + \dot{U}_{\text{glzg}} + \dot{U}_{\text{grnd}} + \dot{U}_{\text{vent}}$$  \[2\]

Techniques permitting simple estimates of each of the five heat transfer paths in the building are given below. In the Level I Protocol, the range of choices for each variable is given on a scale. These scales are intended to help you visualize your choice relative to similar building constructions. The scales help convert all measurement units to a common base.

$\dot{U}_{\text{wall}}$ - Heat Transfer Rate through the Building Walls

Heat transfer rate through opaque walls is equal to the product of the wall area, $A_w$, and the wall heat transmission coefficient, $U_{\text{wall}}$. To allow comparison of different sized buildings, the heat transfer rate through the walls is divided by the floor area giving $\dot{U}_{\text{wall}}$. The heat transfer rate through opaque building walls per unit floor area, $\dot{U}_{\text{wall}}$, is expressed mathematically as

$$\dot{U}_{\text{wall}} = \frac{U_{\text{wall}} A_w}{A_f}$$  \[3\]
The wall area, $A_w$, and the floor area, $A_f$, can be estimated from field observation or from scale drawings. The wall heat transmission coefficient, $U_{WALL}$, is estimated based on visual observation in the field or from construction details. While estimation of $A_w$ or $A_f$ may be time consuming, the process is straightforward.

Two complications can arise when estimating $U_{WALL}$. First, the actual wall construction is unknown and $U_{WALL}$ is difficult to estimate. Second, the wall may have more than one type of construction, with a separate heat transmission coefficient for each construction. Each of these difficulties is considered below.

In practice, $U_{WALL}$ has a possible range from near zero for well-insulated construction to 1 Btu/°F/SF for an uninsulated metal panel wall. With the exception of uninsulated single layer walls, $U_{WALL}$ will range between 0 and 0.5 Btu/°F/SF. This range is presented as a scale in Figure 18. Various residential wall constructions are described and their associated value of $U_{WALL}$ is indicated.

The Protocol contains a larger image of the $U_{WALL}$ scale with additional examples of non-residential wall construction. This scale can be taken to the field to assist in the estimation of $U_{WALL}$. While the wall construction type can generally be determined in the field, determining the type and amount of insulation in the wall can be difficult. Since $U_{WALL}$ is primarily a function of insulation, uncertainty concerning the insulation details can lead to errors in the estimate of $U_{WALL}$. To help minimize errors, the Protocol scale offers several suggestions. If the date of construction is known, the presence or absence of insulation can be estimated based on code requirements and construction standards at the time of construction. Finally, the effect of uncertainty can be evaluated by completing two estimates, one without insulation in the wall and the second with the maximum possible level of insulation in the wall. Two estimates of $U_{WALL}$ can be used in two estimates of the building balance point and the difference between the two balance point graphs evaluated. This technique is described in the next section, The Wainwright and the Portland Buildings: a case study example using the Level 1 Protocol.

While many buildings have one wall construction type, multiple wall construction types are common. $U_{WALL}$ represents the average opaque wall heat transmission coefficient for the total building wall opaque area including all construction types. The average $U_{WALL}$ can be estimated using area weighting and is given as

$$U_{WALL} = U_{WALL,1} \frac{A_{w,1}}{A_w} + U_{WALL,2} \frac{A_{w,2}}{A_w} + \ldots + U_{WALL,n} \frac{A_{w,n}}{A_w}$$  \hspace{1cm} [4]$$

Where each construction type has an associated wall area, $A_{w,i}$, and a heat transmission coefficient, $U_{WALL,i}$. The influence of each construction type on the average heat transmission coefficient is dependant on the percentage of its area to the total opaque wall area, $A_{w,i}$. When the percentage of a given wall construction’s area is low, under 5%, its effect can often be neglected providing a savings of calculation time at little loss of accuracy.

**$\hat{U}_{roof}$ - Heat Transfer Rate through the Building Roof**

Heat transfer rate through the building roof is equal to the product of the roof area, $A_f$, and the roof heat transmission coefficient, $U_{ROOF}$. As in the estimate of $\hat{U}_{wall}$, the heat transfer rate through the roof is divided by the floor area giving $\hat{U}_{roof}$. The heat transfer rate through the building roof per unit floor area, $\hat{U}_{roof}$, is expressed mathematically as

$$\hat{U}_{roof} = \frac{U_{ROOF} A_r}{A_f}$$  \hspace{1cm} [5]$$
The procedure to estimate \( U_{\text{roof}} \) is similar to the procedure used to estimate \( U_{\text{wall}} A_p \), the total roof area can be estimated in the field or from the drawings. \( U_{\text{roof}} \) is estimated from the site visit or the drawings. \( U_{\text{roof}} \) like \( U_{\text{wall}} \) will range between 0 and 1 Btu/ft²°F, although 0.5 Btu/ft²°F will be the upper limit for most constructions. A scale of \( U_{\text{roof}} \) with descriptions of roof constructions and their associated heat transmission coefficients is illustrated in Figure 19. The two difficulties potentially associated in estimating \( U_{\text{roof}} \), multiple construction types and unknown insulation levels, may also affect estimates of \( U_{\text{roof}} \). The method of accounting for multiple roof constructions with differing areas is identical to the procedure for multiple wall construction types described above. The procedure for estimating \( U_{\text{roof}} \) when the construction type and insulation level is not known is similar to procedures for unknown wall constructions, however, some additional comments might be helpful.

The roof is often the most likely location for placing or adding insulation during the course of the building's life. When a flat roof is replaced, it is often economical to add insulation to the roof deck. This change would not show up on the original drawings. When planning a site visit, contact the building engineer and arrange an interview during the site visit. Ask about insulation levels in the roof (and the wall) as well as any renovations where insulation was added or increased. If uncertainties remain, estimate possible low and high values of Uroof, plot the Building Balance Point graphs and evaluate the importance of the uncertainty.

\( U_{\text{glzg}} \) - Heat Transfer Rate through the Building Glazing

Heat transfer rate through the building glazing is equal to the product of the glazing area, \( A_g \), and the glazing heat transmission coefficient, \( U_{\text{glzg}} \). This heat transfer rate is divided by the area giving \( \dot{U}_{\text{glzg}} \). Mathematically, \( \dot{U}_{\text{glzg}} \) is given by

\[
\dot{U}_{\text{glzg}} = \frac{U_{\text{glzg}} A_g}{A_f}
\]

The procedure to estimate \( \dot{U}_{\text{glzg}} \) is similar to the procedures used to estimate \( \dot{U}_{\text{wall}} \) or \( \dot{U}_{\text{roof}} A_p \), the total glazing area can be estimated in the field or from the drawings. The glazing heat transmission coefficient, \( U_{\text{glzg}} \), depends on the glazing construction, including both glazing and frame.

A scale of glazing heat transmission coefficients is illustrated in Figure 20. The scale ranges from 0 to 1 Btu/ft²°F, This upper limit of 1 Btu/ft²°F is twice the heat transfer rate of the scales for Uwall or Uroof, indicating the generally lower insulating value of glazing compared to opaque building surfaces. Typical glazing constructions and their associated heat transmission coefficients are illustrated on the scale. While the building glazing is normally accessible for inspection, permitting a reasonable assumption of the construction, there are features of advanced glazing design that are not obvious and can change the glazing performance. For example, low emittance films, which lower the value of \( U_{\text{glzg}} \), are transparent. The Glazing Performance Vital Signs package provides a number of protocols to determine the presence of Low-E films and to estimate the value of \( U_{\text{glzg}} \).

If the building has multiple areas of differing glazing constructions, the average value of \( U_{\text{glzg}} \) for the total glazing area can be estimated in the same manner as that used to estimate \( U_{\text{wall}} \) from multiple wall construction types described above.

\( \dot{U}_{\text{ground}} \) - Heat Transfer Rate through the Ground

Buildings transfer energy with the environment through the ground. The energy transfer occurs along the building perimeter. The rate of heat transfer can be estimated per unit area of wall below grade, however,
this rate will vary with depth below grade. Thus a characterization of the heat transmission rate per unit building perimeter will be simpler to estimate. The heat transfer rate from the building through the ground to the environment is equal to the product of the building perimeter in contact with the ground, Perimeter, and the rate of heat flow through the ground per foot of perimeter for a given building construction type, $U_{GRND}$. As in the estimate of $U_{wall}$, the heat transfer rate through the ground is divided by the floor area giving $U_{grnd}$. The heat transfer rate through the ground at the building perimeter, $U_{grnd}$, is expressed mathematically as

$$U_{grnd} = \frac{U_{GRND} \cdot \text{Perimeter}}{A_f}$$  \[7\]

The procedure to estimate $U_{grnd}$ is different than the procedure used to estimate $U_{wall}$. Perimeter, the building perimeter in contact with the ground, can be estimated in the field or from the drawings. The heat transmission rate per unit length of building perimeter can be estimated from the scale of $U_{GRND}$ which is illustrated in Figure 21. Different below grade constructions and insulation levels are described and their associated value of $U_{GRND}$ noted. The below grade construction type, basement, crawl space, or slab on grade, can usually be determined from the site visit. Typically, buildings were not insulated below grade prior to the energy crisis of 1973. Thus, if a building was insulated below grade, it would be noted on the drawings, visible along the exterior wall at the ground contact, or known by the building engineer.

If the building is a slab on grade, it will typically have perimeter heating provided by circulating water and fin tubes or air ducts below grade with floor grilles. The latter system will have higher heat transfer rates. Either type is readily determined from field observation.

The representative rates of heat transfer along the building perimeter illustrated in Figure 21 (and the Level I Protocol) are derived from the ASHRAE Handbook of Fundamentals, 1993 ed. Chapter 25 Tables 13, 14 and 16. Basements and crawl spaces are assumed to be heated to the same temperature as the building. If the basement or crawl space temperature is not maintained with the rest of the building, then it will float between the building and environment. Chapter 25 of the ASHRAE Handbook of Fundamentals provides a method for estimating heat transfer rates through unheated spaces. This method is complex and should only be used if heat transfer through the ground to the environment is a major energy flow path in the building. In any case, $U_{GRND}$ will be lower if the basement or crawl space is not heated.

If the building is built over a ventilated crawl space, then the crawl space should be assumed equal to the ambient temperature, $U_{GRND}$ should be ignored, and the floor of the building above the wall space should be treated as part of the opaque wall surface area. Heat transfer to the crawl space would then be included as part of $U_{wall}$.

Finally, heat transfer through the ground will normally be significant in small buildings and negligible in large buildings. The Wainwright and Portlandia buildings explored in the next section are both multistory offices. In both cases, $U_{GRND}$ represents less than 2% of the energy flow between building and environment. Thus for large buildings $U_{GRND}$ can often be neglected.

$\dot{U}_{vent}$ - Heat Transfer Rate via Ventilation or Infiltration

Ventilation and infiltration transfer energy between building and environment through the exchange of air. Infiltration is uncontrolled transfer of air between building and environment while ventilation is the controlled transfer of air between building and environment. Infiltration can have a large impact on the total heat transfer rate of a small building such as a house, but has little impact on large structures. Ventilation can have a large impact on the total heat transfer rate on buildings of any size, and becomes
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A significant portion of the total building heat transfer rate in large commercial, educational and institutional structures. A building with an economizer cycle uses variable ventilation rates to balance building heat loss to the environment with internal and solar heat gains when the ambient air temperatures are mild. The building-ambient air exchange rates due to ventilation and/or infiltration are variable and difficult to determine from either a site visit or the drawings. For non-residential buildings, the best source of ventilation information is the building engineer.

Buildings are ventilated with fresh air to maintain indoor air quality. Building codes provide minimum fresh air ventilation rates as a function of occupancy. Ventilation rates per unit floor area of the building based on ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality are illustrated in Figure 22. The range of the scale is from 0 to 2.25 cfm/SF or 0 to 2.5 Btu/Hr°F/SF. For a space with a 9 foot floor to ceiling height, 2.25 cfm vented per square foot of floor is equivalent to 15 air changes per hour. Various occupancies are noted on the scale with their associated ventilation rate and equivalent heat transfer rate. \( \dot{U}_{\text{vent}} \), the ventilation heat transfer rate, can be taken from the scale.

Ventilation rates have changed over the past 100 years. After the energy crisis of 1973, minimum ventilation rates in buildings were reduced to save energy. As health complaints due to poor indoor air quality increased, the ventilation rates were increased to values published in ASHRAE Standard 62-1989. Thus buildings built to different code requirements will probably have different ventilation rates than those illustrated in Figure 22.

Infiltration rates for a given building are generally not known. The complete ventilation heat transfer scale presented in the Level I Protocol does provide sample infiltration rates derived from the ASHRAE Handbook of Fundamentals, 1993 ed. Infiltration becomes more significant as building volumes become smaller. This is due to the dependence of infiltration on the total opening or crack length around doors and windows, which is a property of the building surface. As buildings increase in size, the surface increases with the square of the nominal building width while the volume increases with the cube of the nominal building width.

As a rule of thumb for the Level I Building Balance Point Protocol, ventilation should be considered the primary means of building heat transfer by air exchange in non-residential buildings and residences with fresh air ventilation systems (eg. air-to-air heat exchangers in well insulated new homes). For most residences, infiltration will be the source of heat transfer by air exchange. Infiltration rates for residences based on construction type (loose, median or tight energy efficient) are given in the ventilation heat transfer scale provided in the Level I Protocol. The values are based on field measurements with blower door tests and presented in ASHRAE Handbook of Fundamentals, 1993 ed.

For large commercial or institutional buildings, fresh air ventilation is potentially the largest heat transfer path between building and environment. For this reason, many buildings, especially those located in very cold or very hot climates, have heat recovery systems included in the total mechanical system. A heat recovery system will transfer heat between the fresh air supply and the building exhaust resulting in lower ventilation heat transfer rates between building and environment. The presence of a heat recovery system for ventilation can be determined from the current HVAC system drawings or from an interview with the building engineer. As noted on a side bar to the Level I Protocol ventilation scale, the ventilation heat transfer rate should be corrected when a heat recovery system is present. The corrected ventilation rate is given as

\[
\dot{U}_{\text{vent, corrected}} = \dot{U}_{\text{vent}} (1 - \eta_{\text{HR}})
\]
Where $\dot{U}_{\text{vent}}$ is the ventilation heat transfer rate without heat recovery and $\eta_{HR}$ is the heat recovery system efficiency, typically between 60% and 80%.

The ventilation heat transfer rate is often the least known path of heat transfer in the building with the largest margin of error in the estimate. To account for this uncertainty, performing two balance point analyses with expected minimum and maximum ranges of $\dot{U}_{\text{vent}}$ is often the most appropriate means of evaluating the effects of ventilation. The case study comparison of the Wainwright and Portlandia buildings presented in the next section illustrates this technique.

**BUILDING INTERNAL HEAT GAINS**

The two flow paths for building heat gains are internal heat generation due to occupancy, $Q_{\text{IHG}}$, and solar heat gains, $Q_{\text{SOL}}$. Internal heat gains are considered in this subsection while solar heat gains will be considered in the following subsection.

Occupancy of buildings generates heat within the building. People give off the heat of metabolism to maintain a constant body temperature. Electric lights used during occupancy give off heat to the building equal to the electrical energy consumed in the luminaire. Equipment, computers, copiers, printers, coffee pots, etc. also give off heat to the building equal to the electrical energy they consume. Each of these energy flow paths is illustrated in Figure 23. The total internal heat gain rate per unit floor area, $Q_{\text{IHG}}$, can be estimated by

$$Q_{\text{IHG}} = Q_{\text{people}} + Q_{\text{light}} + Q_{\text{equip}}$$  \[9\]

Where $Q_{\text{people}}$ is the heat gain from people occupying the building; $Q_{\text{light}}$ is the heat gain from lights used in the building and $Q_{\text{equip}}$ is the heat gain from electrical equipment used by the building occupants. All three paths for internal heat gains are given in Btu of heat added to the building per hour per square foot of floor area.

The means of estimating the rate each internal heat gain is similar to the procedure used to estimate each component of the building enclosure heat transfer rate. A series of scales for each form of internal heat gain are developed and described below.

**$Q_{\text{people}}$ - Building Heat Gain Rate from the Building Occupants**

The building heat gain rate due to people is a function of both the heat generation rate per person and the density of people in the building. People generate heat at different rates based on their activity. An office worker is metabolizing energy at a slower rate than a ballet dancer during practice. The range of heat gains per person runs from roughly 300 Btu per hour for a person seated in a theater to roughly 1800 Btu per hour.
for strenuous athletics. A scale of occupant heat gain rates as a function of activity is given in Figure 24. The heat gain rates indicated were taken from the ASHRAE Handbook of Fundamentals, 1993 ed. During a visit to the building, the observed activity of the occupants can be plotted on the scale relative to the activities indicated.

In addition to the rate of heat gain per person, the effect of the number of people in the building must be estimated. The density of people in buildings is a function of building use and can be represented by the number of square feet of floor provided per person. Various building occupancies and their associated occupant densities are indicated. The information was drawn from the ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality. The occupant density for a building under evaluation can be estimated in the field from observation of the number of occupants and the floor area and then plotted on the scale.

Occupant metabolism and densities can vary in the building as the space functions vary within the building. If a balance point analysis is performed on the entire building, the occupant density can be estimated by dividing the floor area, $A_f$, by the total number of building occupants.

The building heat gain rate per unit floor area due to people, $Q_{people}$, is given by dividing the average heat generation rate per person by the area provided per person.

$$ Q_{people} = \frac{M_{people}}{D_{people}} \quad [10] $$

Where $M_{people}$ is the metabolic heat gain per person and $D_{people}$ is the occupant density in the building given in square feet of floor per person.

### $Q_{light}$ - Building Heat Gain Rate from Lights

All of the power consumed by lights is eventually dissipated as heat. The amount of heat gain from lights will depend on the type of lamp, its power rating and the number of lamps in the building. Building lighting levels are typically measured in watts per square foot of floor, the power rating. The light level can also be measured in Btu per hour per square foot of floor, the heat gain rate. A scale of heat gains due to lights is presented in Figure 26. The scale ranges from 0 to 5 watts per SF (0 to 16 Btu/HR/SF), $Q_{light}$ can be estimated directly from the scale.

Typical lighting levels for various building occupancies are plotted on the scale. These are recommended lighting power densities for energy conserving design. They are drawn from ASHRAE/IES Standard 90.1-89. Older buildings may have significantly higher installed lighting power densities. For greater accuracy, the student may wish to examine the actual lighting of the building in question for a quick comparison to the values assumed on the scale. The installed power of a luminaire (watts per luminaire) can be divided by the square feet per luminaire to estimate the lighting power density. Often, the lighting layout is repetitive and an overall estimate can be derived by inventorying a small portion of the building.

Unless the lights are turned off during a portion of the day, either manually or via daylighting controls, the lighting heat gain during occupancy will equal the installed lighting power density. When daylighting controls are employed, its effect on the building energy flows and the balance point should be estimated. As the Level I Balance Point analysis is a rough, order of magnitude estimate of building energy flows, a rough estimate of the daylight effect will suffice. For sidelighting, assume the daylight penetration is equal.
to twice the head height of the window. For a skylight, assume that daylight illuminates the area under the skylight and a distance into the space equal to the floor to ceiling height of the space. Using these two assumptions, determine the percentage of the total floor area that is daylit, \( f_{\text{daylight}} \). The corrected heat gain from lights, \( Q_{\text{light\_cor}} \), is then estimated by

\[
Q_{\text{light\_cor}} = Q_{\text{light}} \left( 1 - \frac{f_{\text{daylight}}}{2} \right) \tag{11}
\]

This method is rough and assumes that all daylit areas require only half the lighting power of non-daylit areas. An evaluation of the effect of daylighting can be developed by

**Q\_\text{equip} - Building Heat Gain Rate from Equipment used by Occupants**

Heat gain rates due to equipment are also a function of occupancy type. However, the magnitude of equipment heat gain rates can vary substantially as equipment usage varies over time. The personal computer is a case in point. The 1977 edition of the ASHRAE Handbook of Fundamentals does not include any information for typical office heat gains due to personal computers. Over the past decade, the personal computer has become a major source of equipment heat gain in buildings. More recently, advances in energy conserving features of laptop computers have found their way to desktop machines, permitting a reduction of heat gain rates during idle time that partially offsets their increasing numbers. A scale of heat gains due to equipment is illustrated by Figure 26. The scale gives power densities in both watts per square foot of floor area and Btu per hour per square foot of floor area and the range is the same as the lighting heat gain scale.

Sample power densities for different building occupancies are noted on the scale to provide a reference for site visits. The samples represent ASHRAE recommended power densities for energy conserving equipment. These values represent averaged use over occupancy, and are lower than some other sources (see, for example, page 41 of Sun, Wind and Light by G. Z. Brown). To put these ASHRAE recommended levels into perspective, the power density of a cramped office space with computers is given off the scale at the bottom of the chart.

**BUILDING SOLAR HEAT GAINS**

Solar energy enters the building through two paths. Solar gains are transmitted directly through glazings into buildings and absorbed by room surfaces and furnishings. Indirect solar gains result from solar radiation absorbed on exterior surfaces and conducted through the enclosure into the building. The sum of both entry paths for solar radiation is defined to be the building’s solar heat gain. For Level I Protocols, only solar heat gains via glazing, as illustrated in Figure 26, are considered. As we shall see, variation in daily and seasonal solar radiation makes consideration of direct gains through the glazing alone quite complex.

Solar gains are the primary heat gain source which the architect can control through design. Internal gains, such as caused by equipment loads, are primarily a function of occupancy uses. Lighting loads can be lowered with the appropriate use of new lighting technologies, but more importantly it is through the use of daylighting that electrical lighting loads can be minimized, and daylighting is directly tied to the issue of solar control.

Estimation of building solar heat gains is more complex than estimation of building internal heat gains. While internal heat gains are roughly constant during hours of occupancy, solar radiation varies over both the day and the season. In this Level I protocol, the solar heat gains are estimated three times per day for three seasons: winter, summer and the equinoxes. These nine estimates allow evaluation of the effects of the morning/afternoon and summer/winter variations in incoming solar radiation. In addition, different
building orientations receive different rates of solar energy during the same hour and each major glazing surface must be accounted for individually. Typically this means examining the solar apertures on four building orientations and possibly a roof skylight or atrium, though if the building (or room) under investigation doesn't have apertures on all of its elevations, the blank surfaces can be ignored.

Solar radiation levels vary not only with solar geometry, but also with clouds. Furthermore, the amount of incident solar radiation transmitted by a window will depend on both the glazing’s optical characteristics and the external shading strategy. At this level of study, the goal is to get a rough estimate of the scale of building solar heat gains relative to other paths of heat flow in the building.

To reduce this complexity to manageable proportions, average solar gains admitted by standard glass are provided for three times of day for three seasons and five orientations (45 solar gain values for each climate). This solar data is provided in tabular for 14 United States sites in Appendix 4. In addition, the Excel spreadsheet BPgraph.xla contains the 45 solar gain values for 72 cities scattered throughout the world. A table of the 32 US and 39 global cities included with BPgraph.xla is given in Appendix 4. A description of BPgraph.xla is given in Appendix 3.

For a given date, time and orientation, the average solar gain admitted by standard glass per square foot must be modified for both the actual glazing in the building and the area and orientation of that glazing. Standard glass, as defined in the ASHRAE Handbook of Fundamentals, 1993 ed., is 1/8 inch thick double strength glass. Solar gains admitted by standard glass are modified by the Shading Coefficient to estimate the solar gains admitted by the actual glazing. The Shading Coefficient is defined as the solar gains admitted by the actual glazing system divided by the solar gains that would be admitted if the glazing system was unshaded standard glass. Thus the Shading Coefficient \( SC_i \) is the percentage of solar energy admitted standard glass which is actually admitted by the glazing system. Figure 29 gives the scale of Shading Coefficients for a number of different glazing systems. The scale ranges from 0 to 1. The standard glass is also noted on the scale with its value of 1. The Scale provided in the Level I Protocol also includes shading coefficients for external shading and blinds.

Using the building drawings and/or site visit, the shading coefficient and area for each orientation of each glazing system is estimated. For an hour and season, the glazing solar gain per unit floor area, \( Q_{SOL} \) is given as

\[
Q_{SOL} = \sum_{i=1}^{n} I_{SOL,i} SC_i \frac{A_{g,i}}{A_f}
\]

\[10\]

\( i \) is an orientation and the summation covers each orientation on the building with glazing. There are \( n \) orientations with glazing systems. \( SC_i \) is the shading coefficient for the glazing system of orientation \( i \). \( I_{SOL,i} \) is the average solar gain for standard glass for the given climate, season, hour and orientation. \( A_{g,i} \) is the area of glazing at orientation \( i \), and \( A_f \) is the building floor area. Estimation of \( Q_{SOL} \) using equation 10 is repeated nine times (morning, noon and afternoon for three seasons). If one orientation has two different glazing systems, each of significant area, then an area weighted estimate of \( SC_i \) can be made using the same technique employed to determine an average \( U_{WALL} \) (see page 10).

The Level I Protocol is structured to permit either hand calculation or computer calculation of the Building Balance Point Temperature and associated graphs. While the computational effort required to estimate \( \dot{U}_{Bldg} \) and \( Q_{Bldg} \) is not great, the effort required to estimate \( Q_{SOL} \) nine times is. The authors strongly recommend that the Excel spreadsheet BPgraph.xla be used to calculate the Building Balance Point Temperature and graphs. The student will find computational effort is reduced and more time can be usefully spent.
explore the different building variables influencing energy flow in buildings. (See the case study of the Wainwright and Portlandia buildings in the next section.)

**BUILDING BALANCE POINT TEMPERATURE**

The Building Balance Point Temperature is a Vital Sign that, when estimated, permits analysis of energy flows in buildings. Each major path - heat transfer across the enclosure; internal heat gains and solar heat gains - can be estimated from a visual analysis of the actual building or drawing. However, as described above, that analysis can quickly become complex and time consuming. The goal of the Level I Balance Point analysis is to provide a quick, order of magnitude estimate of the building balance point and building energy flows. Simplifying assumptions are often required to achieve this goal. Fortunately, the effect of simplifying assumptions can be evaluated, as shown in the next section.

The relationship between building balance point, internal heat generation rate and building enclosure heat transfer rate is illustrated in Figure 30. When internal heat gain rate, \( Q_{\text{IHG}} \), is low, the enclosure heat transfer rate, \( U_{\text{bldg}} \), must be very small to drive the building balance point down. A residence typically has a low value of \( Q_{\text{IHG}} \) (from 1 to 3 Btu/hr/sf). Under these conditions the balance point temperature is not very sensitive to variation of enclosure heat transfer rates and highly insulated construction is required if the climate has cold winters.

When internal heat gain rate, \( Q_{\text{IHG}} \), is high, the balance point temperature is very sensitive to variation of enclosure heat transfer. Office occupancies average internal heat gain rates from 8 to 12 Btu/hr/sf. In this range, small changes in the enclosure heat transfer rate, \( U_{\text{bldg}} \), will have a significant effect on the balance point temperature. Errors in estimates of \( Q_{\text{IHG}} \) or \( U_{\text{bldg}} \) are more critical in this range. The next section provides an example of the balance point analysis with study of uncertain variables controlling \( U_{\text{bldg}} \), \( Q_{\text{IHG}} \), or \( Q_{\text{SOL}} \).

The balance point temperature provides clues for appropriate energy conscious building design strategies. Unfortunately, the balance point temperature is not a constant and cannot simply be measured directly on a field visit. Heat generated by occupancy varies over daily, weekly and seasonal cycles, as does available solar radiation and the external air temperature (as well as wind speed and humidity, which are secondary influences on the rate of heat transfer across the envelope). Thermal lag within the building and vagaries of mechanical controls strategies further complicate direct observation. These issues are considered in the Level II analysis.

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**Figure 30:** The Building Balance Point as a function of the internal heat generation rate and building enclosure heat transfer rate. The thermostat is set at 72°F. The internal heat generation rate \( Q_{\text{IHG}} \) is given in Btu per hour per square foot of floor area. The building enclosure heat transfer rate \( U_{\text{bldg}} \) is given in Btu per hour per °F per square foot of floor area.

Notice that an extremely low balance point temperatures can be reached with a combination of high internal heat generation rates and low enclosure heat transfer rates.
BUILDING BALANCE POINT

The Wainwright and the Portland Buildings: a case study example using the Level 1 Protocol

The Portland Building, designed by Michael Graves Associates, is an unambiguous example of an internal load dominated building. As is typical of deep plan office buildings, the lights and equipment generate more heat than can be dissipated at the skin. This is both because the deep plan necessitates the use of electric lights rather than daylight, and because its surface to volume ratio is much lower than in a smaller or more articulated building. In this specific case, heat loss through the skin is further restricted due to the unusually small amount of glazing punctuating the facades.

The Wainwright Building, designed by Adler and Sullivan in 1890-91, is also famous for the striking simplicity of its massive form. As an office building with significant internal gains, one might assume that like the Portland Building it is dominated by internal loads. This judgement is not as clear cut as in the case of the Portland, however, because as Adler and Sullivan designed it, behind the unifying facade lies a typical pre-modern plan approximately forty feet thick, wrapping three sides of a deep court. The court brings light and natural ventilation into the plan; a necessity in the days before fluorescent lighting and mechanical ventilation.

The question is whether or not the Wainwright’s section is thin enough that its perimeter zones challenge the dominance of the internal loads and classify the building as skin dominated. The thin plan not only has more exterior surface to lose or gain heat through but it is more adequately lit by daylight, which reduces the heat load added by electric lighting.

The Level I Balance Point Protocol provides a tool to answer this question. Even without having access to either building, we can work with the information available in books and magazines to create contrasting profiles of the blocky Portland building and the thin plan Wainwright. What follows is a comparison of the two buildings done to illustrate the use of the protocol.

Figure 31: The Portland Building, Portland, Oregon. Michael Graves Assoc., Architects. 1980.

Figure 32: Exterior view, the Wainwright Building, Saint Louis, Missouri. Adler and Sullivan, Architects. 1890-91.

Figure 33: Light court as renovated into an atrium, the Wainwright Building. (Now the Wainwright State Office Complex. Renovation and addition by Mitchell/ Giurgola, Architects in association with Hastings & Chivetta Architects, 1981.)
THE WAINWRIGHT BUILDING
Saint Louis Missouri
Adler and Sullivan, Architects, 1890-91

DETERMINED BY INSTRUCTOR
share similar climates.

The total floor area and the typical floor area of each building was obtained from the reference material, along with the diagrammatic plans. By scaling the plans against these square footage numbers we have arrived at approximate plan dimensions. By scaling photographs of the elevations and working with bits of information such as the fact that the Portland Building’s windows are 48” square, we have arrived at building heights and glazing proportions. Based on the evidence, we are assuming that both building’s floor to floor heights are 14’-0”. We are assuming that the Wainwright’s elevations are approximately 25% glass while the Portland Building’s are 10%. Since

ESTABLISHING THE BASIC BUILDING DATA AND AREA TAKE-OFFS

The thermostat settings and operating schedules are assumed to be the same for both buildings.

The climate selected for the Portland building is actually Seattle, Washington, since Portland, Oregon was not in the data base and the two cities share similar climates.

Figure 17: Typical floor plan as originally designed, the Wainwright Building. Adapted from Moore, Fuller. Environmental Control Systems: Heating Cooling Lighting. New York; McGraw-Hill, Inc. 1993. p.305.

Figure 16: Typical floor plan, the Portland Building. Shown at same approximate scale as the Wainwright building. Adapted from Architectural Record, November 1982. p. 95.

THE PORTLAND BUILDING
Portland, Oregon
Michael Graves Associates, Architects, 1980

DETERMINED BY INSTRUCTOR

The thermostat settings and operating schedules are assumed to be the same for both buildings.

The climate selected for the Portland building is actually Seattle, Washington, since Portland, Oregon was not in the data base and the two cities share similar climates. The total floor area and the typical floor area of each building was obtained from the reference material, along with the diagrammatic plans. By scaling the plans against these square footage numbers we have arrived at approximate plan dimensions. By scaling photographs of the elevations and working with bits of information such as the fact that the Portland Building’s windows are 48” square, we have arrived at building heights and glazing proportions. Based on the evidence, we are assuming that both building’s floor to floor heights are 14’-0”. We are assuming that the Wainwright’s elevations are approximately 25% glass while the Portland Building’s are 10%. Since

differences relating to daylight are important to our conclusions, we can run the calculations several times with different values if we are unsure of these percentages.
characterizing the enclosure heat flows

Each of the grey rectangles represents a variable that has been estimated using the individual scales worksheets or building area take-offs.

- $U_{wall} = 0.18$ (Btu/hr/s.f.).
- $U_{rew} = 0.14$ (Btu/hr/s.f.).
- $U_{glzg} = 1.10$ (Btu/hr/s.f.).
- $U_{grnd} = 1.75$ (Btu/hr/s.f.).
- $U_{vent} = 0.15$ (Btu/hr/s.f.).

The summary scales have been marked by hand for visual reference.

The enclosure heat transfer variables have been kept the same for both buildings so that the differences we see will be based solely on their respective massing. These values are derived from the protocol scales. They represent traditional uninsulated masonry construction and single pane glazing. This description fits what we know of the Wainwright and is not too far off for the Portland Building. Later we will look at how the Portland Building’s more insulated construction actually makes it perform worse than these variables suggest.

The variables that do jump out as different are the gross floor areas of the two buildings ($A_j$) and the resulting thermal heat transfer rates per unit of floor area ($U_{wall}$ etc.). The Wainwright is 117,700 s.f. The Portland Building is 406,000 s.f. or three and one half times as large. Also implicit in the heat transfer/s.f. differences is the fact that the Portland building has much less surface area for its volume than the Wainwright. If we go back to our initial gross wall area take-offs, we can see that the Wainwright has 76,720 s.f. gross wall area and 117,800 s.f. floor area. This equals 0.85 square feet of surface area for every square foot of floor area. The Portland building has 109,200 s.f. gross wall area and 408,000 s.f. of floor or only 0.27 square feet of wall for every square foot of floor. That’s less than half as much skin for its size.

The effects of this are evident in the various $U$ values. Overall, the $U_{wall}$ for Wainwright is 0.44 Btu/°F/s.f. while the Portland Building’s is only 0.25. The Portland Building retains heat far more effectively than the Wainwright, for better or worse.
**Characterizing Internal Heat Gains**

The Occupant Heat Gain Rate ($Q_{\text{people}}$), Equipment Heat Gain Rate ($Q_{\text{equip}}$), and Thermistat & Schedule, the Thermostat and the Schedule have been set the same for both buildings. These values are selected from the protocol scales as representative of a typical office.

The lighting Heat Gain Rate ($Q_{\text{light}}$) is where we see obvious differences between the two buildings. Consulting the Lighting Density Scale, current energy conserving ASHRAE standards for office design suggest a heat gain rate of 6.0 Btu/hr/sf... We could stop here but since the big difference between the Wainwright and the Portland Building is in their attitudes towards daylighting we have used the daylighting rule of thumb from the worksheet to adjust their lighting loads.

Working off of each plan, we will assume that the Wainwright has useful daylight penetration for 80% of its floor area and so reduce its Lighting Heat Gain Rate by half of that amount or 40%, from 6.0 to 3.6 Btu/hr/sf. On the scale this appears very efficient but less so than the levels achieved at Audubon House. Our daylighting assumption seems believable.

To be fair, we assume that the Portland Building has useful daylight penetration over 20% of its floor area and reduce its Lighting Heat Gain Rate to 5.4 Btu/hr/sf., though in reality this is unlikely. Daylighting is only effective if the building is designed to take advantage of it, both by distributing it effectively and by shutting down the electric lights when the daylight is available, which is how the heat gain rate is reduced. The Portland building actually appears to do neither.

Comparing the results several differences are apparent. The Internal Heat Gain Rate ($Q_{\text{people}}$) is different because of the different lighting loads. The Wainwright gains 8.8 Btu/hr/sf. overall while the Portland Building gains 10.6 Btu/hr/sf.

The real insight is that the temperature difference due to occupancy ($\Delta T_{\text{occ}}$) and the resulting Balance Point Temperature ($T_{\text{balance}}$) are dramatically different. For the Wainwright, an outdoor temperature of 50.0°F will balance these internal gains to produce a comfortable 70°F temperature inside. For the Portland Building the outside temperature must fall to 27.2°F for it to be comfortable inside without mechanical cooling. This is not only because the area of the Portland building is so much larger, but because its low skin/volume ratio retains heat more effectively, as we saw previously.

Finally, looking at the Sources of Internal Heat Generation, we see that people, lights and equipment all contribute roughly equally to the Wainwright’s gains, while in the Portland Building, lights account for over half of the internal heat gain. This information is useful as we look for ways to improve the design.
The courtyard of the Wainwright complicates the choice of shading coefficients. Because of its narrow shape and orientation we expect it to be quite dark, and we assume a very low SC=0.20. We estimate that the east and west courtyard walls represent 40% of the total east and west exposures. We further assume that the original glass was 1/8" clear glass with a SC=1.0 (see scale) but reason that the deep piers provide some external shading of the glass and so assign a SC=0.9 to the outer windows.

The average shading coefficient for east and west walls is then calculated to be SC=(.60x.9)+(.40x.2)=0.62 for the north wall, the courtyard elevation represents 30% of the total and the resulting average SC=0.69.

The Portland Building is known to have 1/4" clear glass SC=0.95 (see scale). Since the glass is close to the surface of the wall we wont assume any additional shading. The solar gains charts present a complex profile that resists quick observations. The aggregate result of all of these solar gains is reflected in the bar charts that show solar gains per s.f. of floor. Again, Excel adjusts the scales of each chart so that they fit on the page. Looking at the units on each scale we can see that the Wainwright’s solar gains are much higher than Portland’s.
EVALUATING THE BALANCE POINT GRAPHS

These Balance Point Graphs are the culmination of the Level I Protocol. First, compare the two climates. Saint Louis ranges between averages of 30°F - 40°F in December and 67°F - 85°F in June. Portland is much less extreme, ranging between 40°F - 45°F in December and 55°F - 70°F in June.

Now compare the effect of the internal gains and envelope performance. The Wainwright Building’s 20°F Occupancy Temperature Difference depresses its balance point from 70°F to 50°F when the building is occupied. The Portland Building’s 42.8°F difference depresses it much further to 27.2°F. Think of the area of that dip as heat captured inside the building—the graph illustrates how much more heat the Portland Building generates and/or retains than the Wainwright.

Finally, compare the gray balance point lines that include solar gains. Solar gain can be seen to be both a larger amount and a larger percentage of the total gains in the Wainwright. In the Winter, these solar gains warm it enough to bring its balance point down to the ambient outdoor temperature for a portion of the typical day. Considering the shortfall of heat at night, the Wainwright never the less has a heating problem in the Winter. In the Summer, on the other hand, solar gains add significantly to the Wainwright’s overheating.

The Portland building gains relatively little heat from the sun. Regardless, the building is always too hot during operating hours, though daytime overheating in Winter and Spring is roughly balanced by the lack of heat at night. Due to the cool summer temperatures, there even appears to be potential heat loss at night offsetting a small portion of the daily gain.

SUMMARY

This initial run of the protocol has simplified the variables to compare the massing, size and resulting climate fit of the two buildings. The profiles reflect these differences. The Wainwright’s graphs are dominated by losses to the environment for December and March and by internal and solar gains in June and September, with a large lump of unwanted ambient air temperature gain thrown in in June. The Portland Building shows a rough balance between thermal losses and internal gains in December and March, increasingly dominated by internal gains as the ambient temperature rises in June and September.

The Wainwright clearly has less internal and more solar gain than the Portland Building. Still, even given the maximum credit for daylighting, the Wainwright’s internal loads are its dominant source of heat gain.

The next step is to consider what sort of schematic design changes these charts suggest, which will be covered in the next section: The Balance Point as a Design Tool. First, let’s return to the Portland Building and use the protocol to reconsider our assumptions and the simplifying of the variables.
TESTING OUR ASSUMPTIONS: VARIATIONS ON THE PORTLAND BUILDING

Using the Excel workbook to generate Balance Point graphs makes it easy to change variables and to run multiple tests. By bracketing an estimate such as the % of glazing with high and low estimates, we can establish a range of possible outcomes and a sense of which variables are important. By testing the limits of good and bad performance we can see the limitations of given buildings.

Alternates A, B, and C add back performance characteristics of the Portland Building that we initially ignored to standardize the comparison of building massing between the Portland Building and the Wainwright.

Alternates D, E, and F explore various lighting and glazing parameters to first establish their importance and then to imagine the best possible redesign of the building given its massing.

**Alternate A:**
**Increased Insulation**
Add insulation to reflect actual construction: $U_{\text{wall}}=0.09$, $U_{\text{roof}}=0.07$
Portland Bldg. wall outside to in: 8" concrete, 1.5" air space, 3.5" batt insul. (R=13) between metal studs, vapor barrier, g.w.b.

Adding insulation holds in more heat, pushing the balance point down from 27.2°F to 21.3°F while the building is occupied.

**Alternate B:**
**Increased Lighting Load**
Assume energy efficient standards for late 1970's rather than the present. No daylighting.

$Q_{\text{light}}=8.25$ Btu/hr/s.f.

This change also reflects the probable construction. Increasing the lighting load has a noticeable impact on the internal gains, pushing the balance point down to 15.6°F while the building is occupied.

**Alternate C (A+B)**
**The Portland Bldg. as Built**
This combination of insulated walls, conventional lighting and no use of daylighting represents our best guess as to the actual conditions.

As built, the Portland building appears to be overheated by internal gains in all but the coldest months. The basic profile of the building hasn’t changed. These added specifications have only amplified the fact that the building profile is dominated by internal loads.
Alternate D:
Cut Glazing Est. by 50%
Decrease glazing from 10% to 5% of wall area.

Reducing the glazing area by half reduces solar gain and increases thermal resistance. Since we assumed little glazing to begin with, the effect of this reduction is not significant, only lowering the balance point 2.7°F. Uncertainty about glazing area is unimportant for this building.

Alternate E:
Match Wainwright Glazing Estimate
Increase glazing to 25% of wall area. Leave electric lighting load as is.

This increases solar load and thermal loss. Compared to the Wainwright balance point graphs, where solar loads compete for importance with internal loads, this still shows more heat generated internally than from the sun due to the building's bulk.

Alternate F:
Redesign for Best Lighting Performance
Increase glazing to match Wainwright. Increase daylighting contribution from 20% to 40%, reducing elec. lighting load by an additional 10%. Decrease SC to 0.32 by use of "cool glazing".

This scenario represents the most energy efficient lighting possible given the mass of the building. This could be achieved by the redesign of the skin, plan layout and lighting to maximize the use of daylighting.

CONCLUSION
These six tests demonstrate the power of this tool to evaluate the relative importance of the parameters that govern the thermal life of buildings. As a large box filled with heat sources set in a cool climate, the Portland Building represents an extremely simple case. To radically change the performance of the building it is clear that we would need to change its parti and not just its skin.

In the design discussion we will see a more confusing range of situations and profiles. The most important lesson that the Portland Building introduces in its simplicity is that its thermal profile represents a 'type.' Some buildings are too hot, others too cold. Some swing between being too hot and too cold daily and others seasonally. These character profiles are as real and as suggestive for design as the more familiar use types of 'house' and 'office', 'warehouse' and 'hospital.'
This comparison of the Wainwright and Portland Buildings has been done using information available in published articles on the two buildings. As is often the case, this information is incomplete. Our strategy is to make a series of educated guesses to fill in the worksheet, and then to change these variables one by one to see which of the variables that we don’t know with certainty make a difference in the final result. If one variable turns out to be important to the final outcome, that is where we then know to focus our investigation.

A further example of the complexity of interrelations of internal gains, solar gains and skin gains/losses can be seen by looking at the Wainwright building as it currently exists Figure 34. As part of a major renovation and expansion project in 1981, Mitchell/ Giurgola Architects enclosed the light court to create an atrium space. They also replaced the glazing throughout the building with tinted insulating glass, reconfigured the plan to place the circulation on the atrium, and replaced the minimal amount of incandescent lighting provided in the original design with uniform fluorescent lighting.

Note that in the original plan, the outer layer of offices is deeper than the inner layer. This difference reflects both the differing status of the two locations and the relative availability of daylight. By glazing the light court, the renovation reduces the amount of exposed surface area of the building, cutting down on heat loss but also cutting down on daylight penetration. The addition of tinted insulating glass has a similar effect, reducing heat loss and gain, as well as reducing daylight penetration. Finally, placing the circulation on the atrium cuts the office space off from the court, further reducing daylight penetration.

A DOE-2.1 computer simulation of the building before and after renovation suggests that the original design was energy efficient due to its use of daylight and that the series of trade-offs made during renovation resulted in the building becoming more thermally comfortable but not more energy efficient. The original building’s main liability was heat gain and loss through single pane windows. In the simulation, the insulating glass reduced the building’s typical heating load by 31%. These energy savings were offset by the addition of the fluorescent lighting, as well as by the addition of an air conditioning system.
The Balance Point as a Design Tool

A mechanical engineer uses balance point information to determine the magnitude of heating and cooling loads in order to size equipment. For the architect, the balance point concept and the understanding of energy flows that it involves provides a way to anticipate those demands and minimize or eliminate them through insightful design. While these VITAL SIGNS protocols are written to help you analyze existing buildings much like an engineer analyzes someone else’s design, it is also important to see the balance point concept as a design tool. The Level I Protocol in particular is intended to give you a quick sense of which issues are important to a given building’s thermal performance and which schematic design strategies might be used to improve it.

As we have seen in the analysis of the Wainwright and Portland Buildings, the balance point of a building is based on primary characteristics of the building itself; on program, parti, and details. It is useful in the design process for three fundamental reasons: First, it is a holistic measure of performance that helps a designer get the big picture. Second, the variables highlighted are all able to be manipulated by the designer. And third, because it characterizes the building independent of the climate, the building balance point allows the design to be judged against any climate.

The design variables are thermal envelope performance, occupancy loads, and the potential for integration with passive energy flows such as sun and wind or to harness those flows through the use of thermal mass. The performance of the thermal envelope is determined by the designer’s choice of building massing, materials and details. Occupancy loads may seem like a given, but in fact there are important decisions that an informed architect can influence in the programming stage of a design, especially lighting and plug loads. The integration of the building with the passive energy flows of the site involves massing, orientation and aperture design, each of which has strong aesthetic implications.

Because the balance point calls attention to the specifics of each building, it calls attention to the differences between buildings. The balance point for a large office building such as the Portland Building, with all of its internal sources of heat and low surface to volume ratio, will be very different than for a typical house with little internal gain and a high surface to volume ratio such as the Jacobs II house. On the other hand, a well insulated house which effectively conserves its limited heat gains might have the same balance point as the office, but the profile of the various heat flows will be different.

What follows is a brief overview of schematic design strategies that can be used to manipulate the balance point variables and fit a building to its climate. Extended discussions of these ideas can be found in passive design textbooks such as Sun, Wind, and Light and Inside Out by G.Z. Brown et. al. or in the more encyclopedic Mechanical and Electrical Equipment for Buildings by Benjamin Stein and John Reynolds. The Department of Energy laid out the original balance point design methodology in a document titled Predesign Energy Analysis: a new graphic approach to energy conscious design for buildings. All of these texts stress the role of the balance point concept in schematic design and the importance of good schematic design to the creation of environmentally sound architecture.
CLIMATE RESPONSIVE SCHEMATIC DESIGN

During schematics, the designer’s goal is to manipulate the sources of internal gains, the enclosure heat transfer rate and the incoming solar energy to generate a balance point appropriate to the given program and climate; to create a building that maintains the conditions of comfort passively. Table 1 reviews the possible outcomes of a level 1 analysis for a single season and on average over the year. These range from the building being constantly too cold to too hot, with a variety of distinctively different situations between. The four design objectives that come out of this analysis are to increase or decrease captured heat gains and to manage both daily and seasonal swings between periods of excess gain and loss.

Table 1: Possible Outcomes of a Balance Point Analysis by Individual Season and over a Year, with Suggested Schematic Design Responses.

<table>
<thead>
<tr>
<th>No.</th>
<th>Scenario</th>
<th>Design Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Always too cold</td>
<td>• Increase captured heat gains to minimize heating load.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Decrease the rate of heat transfer between building and environment.</td>
</tr>
<tr>
<td>2.</td>
<td>Too cold with some excess gains during the day</td>
<td>• Increase captured heat gains to balance losses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Manage daily swings, storing excess daytime gains to offset night losses.</td>
</tr>
<tr>
<td>3.</td>
<td>Potential balance between daily gains and losses</td>
<td>• Manage daily swings, storing excess daytime gains to offset night losses.</td>
</tr>
<tr>
<td>4.</td>
<td>Too hot with good potential for ambient and night cooling</td>
<td>• Decrease captured heat gain to balance. Daytime venting possible.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Manage daily swings, storing excess daytime gains to offset night losses.</td>
</tr>
<tr>
<td>5.</td>
<td>Too hot with some potential for night cooling</td>
<td>• Decrease captured heat gain to balance. Note ambient temperature too hot for daytime venting.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Manage daily swings, using night losses to offset excess daytime gains.</td>
</tr>
<tr>
<td>6.</td>
<td>Always too hot</td>
<td>• Decrease captured heat gains to minimize cooling load.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increase insulation to separate mechanically cooled building from environment.</td>
</tr>
<tr>
<td>7.</td>
<td>Building Swings Seasonally between different conditions</td>
<td>• Manage swings between months of excess gain and loss by incorporating dynamic responses to natural energy flows.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Design for the largest load first.</td>
</tr>
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**DESIGN VARIABLES CONTROLLING THE BALANCE POINT:**

- **Envelope Design**
  - Skin to Volume Ratio
  - Thermal Performance (Code Required Ventilation)
- **Occupancy load design**
  - People
  - Lights
  - Equipment
  - Occupancy Schedule
  - Thermostat Setting
- **Natural Energy Flow Design**
  - Solar Access and Solar Control
  - Ventilation for passive cooling
  - Thermal Storage
Balancing the balance point by increasing the efficiency of capturing heat gains can be achieved by capturing more energy, wasting less of it or requiring less to begin with. In cold climate buildings all three strategies are often used simultaneously.

**Envelope design-** You can increase the thermal performance of the envelope in several ways. Increase the amount of insulation in the walls, roof and foundation perimeter. Exercise greater care in detailing the envelope, especially at the structural connections, to avoid short circuiting the thermal barrier, thus increasing the effective U value of the assembly (Figure 38). Build tightly using both air and vapor barriers to minimize infiltration, while providing controlled ventilation for indoor air quality. Consider advanced glazings with higher thermal performance, which puts your design money even more directly towards making a weakness in the envelope into a strength.

In a well insulated building, the Level I Protocol demonstrates clearly that heat exchange due to code required ventilation can easily be the largest single heat loss path. This loss can be minimized by the use of heat exchangers in both residential and larger scale buildings. In residential buildings, heat exchangers often provide the controlled ventilation necessary when infiltration rates are minimized by tight construction.

In this cold climate building, the appearance of a simple concrete frame is maintained while inserting an insulating thermal break. The continuity of the break helps prevent heat loss. More importantly, it protects the structure from damage due to temperature differentials and prevents possible condensation on the inside surface.
Building Balance Point

The lighting and equipment loads could also be increased to add heat to the space. Is this a good idea? No. Using less efficient lighting in order to heat a space undermines the larger goal of reducing energy consumption overall. At a minimum, that same energy content could be utilized more effectively in a designed heating system than as undesigned waste heat. Always minimize the electric consumption of lights and equipment first, and design the building around these minimal required internal gains.

Natural energy flow design- Solar energy is the primary natural heat source. If the building is too cold, use passive solar strategies to maximize the use of solar radiation. For example, consider orienting the building on an east/west axis and placing the majority of the glazing on the southern exposure.

In a situation where there is no excess heat to store on a daily basis, the issue of thermal storage loses its importance. In reality, this situation of a constantly cold building is rare. Thermal mass may well offer performance benefits during the swing periods between heating and cooling seasons, even if there is not enough heat to store on a diurnal basis during the winter.

Figure 39: Medieval town fabric, Bremen Germany.

Party wall construction is a traditional way of minimizing the skin/volume ratio. Only the short end walls and roofs of these townhouses are losing heat to the external environment.

Figure 40: Large Hospital, Houston, TX: a 'Too Hot' Building Example

Hospitals are interesting in that they are used 24 hrs. a day. This hospital is constructed from the shell of the Portland Building, with its deep plan and compact massing. Here a high assumed ventilation rate offsets the tremendous internal loads of the building. Even so, the building’s balance point is dominated by internal gains. The ventilation will be able to dump excess heat in the winter and spring but in the summer and fall the ambient air temperature is higher than the 70°F desired indoors and this will not be possible. The model does not account for the added cooling load that this situation creates.

Figure 40: Large Hospital Balance Point Graphs

<table>
<thead>
<tr>
<th>Large Hospital</th>
<th>Houston, Texas</th>
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</thead>
<tbody>
<tr>
<td>Balance Point Graphs</td>
<td>December</td>
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**DECREASING CAPTURED HEAT GAINS/ RAISING THE BALANCE POINT**

There are two different overheating situations. In the first, internal gains plus solar gains overheat the building even though the ambient air is cooler than the desired indoor temperature. This allows for direct venting of the excess gains and suggests strategies of load shifting (below). In the second shown in the Hospital example in June and September, hot ambient temperatures only add to the building’s heat load. This calls for strategies that minimize heat gain in the first place.

Envelope design- In an overheating condition, the degree of insulation in the envelope is contingent on factors such as whether the space will be air-conditioned or not. If not, as with much industrial and vernacular architecture, the skin is often treated as a minimal or nonexistent barrier. In the unconditioned building the skin to volume ratio is also often increased to the point that the building is broken up into a series of discreet pavilions. In the conditioned building the opposite might be an advantage. If the space is to be air conditioned, insulation to keep the cooled interior isolated from the hot exterior is important and an argument can be made for a more compact plan. The use of a radiant barrier in either an insulated or uninsulated shell can improve comfort by reducing heat transfer through the walls and the radiant temperature of the interior surfaces.
The Level I Protocol does not account for heat gain through the envelope, only the potential for internal gains and solar gains through the apertures to be dissipated to the environment. This represents internally dominated buildings and buildings in cooler climates well, but understates the severity of overheating due to solar gains on the enclosure. The model provides no way to determine if added insulation might be useful.

**Occupancy load design**—In climate responsive vernacular architecture the schedule is often manipulated to reduce the impact of overheating. The tradition of afternoon siestas in countries with hot climates is a manipulation of the work schedule to avoid working in the hottest part of the day. Raising the thermostat setting by a few degrees can also produce large savings in reduced cooling demand if the design reinforces the perception of thermal comfort in other ways. The control of glare and the play of shadows, the use of cool colors, hard surfaces and water are all elements of hot climate vernaculars.

Lighting loads can be minimized in an architecturally expressive way by designing for the use of daylight, and both lighting and equipment loads can be reduced through the use of energy efficient hardware. As we have seen, the situation of the building always being too hot is common in deep plan office buildings. The extra cost of state of the art lighting is often justifiable not by the electricity that it will save directly, but by reductions in chiller capacity for air conditioning that it allows. This reduction can translate into less vertical chase space devoted to ductwork and equipment throughout a multistory building, as well as smaller mechanical rooms and less money spent on the cooling equipment itself.

**Natural energy flow design**—A large part of the effectiveness of the envelope design is control of solar radiation. If the sun can be kept off of a wall altogether, much less of its heat will drive through the wall to the interior. This applies to strategies from the scale of shade trees in the landscape down to the use of radiant barriers within the wall section (figure 41). Again, the Level I Protocol accounts for solar gains only through the glazing, not the walls and roof.

Ventilation to dump heat to the environment is unhelpful when the ambient temperature is above the desired indoor air temperature. In extreme cases such as hospitals or supermarkets in hot climates, heat recovery equipment can be used to avoid throwing away air conditioned air to meet ventilation requirements. When the ambient temperature is below the desired indoor air temperature ventilation is a primary

**Figure 41:** Larado Demonstration Blueprint Farm, Larado Texas. The Center for Maximum Potential Building Systems, Austin, Texas- Pliny Fisk III. 1991.

In a hot landscape devoid of trees, a layer of shade cloth draped over the complex reduces the solar radiation striking the buildings and extends the growing season of the planting beds.
Balancing Point and Architectural Design

Managing Daily Swings Between Excess Gains and Losses (Load Shifting)

Whenever there are both excess gains and losses present they can be used to cancel each other out and reduce the overall load on the building. The objective is to move the building from seesawing between extremes towards a stable, comfortable temperature.

Envelope design - The thermal resistance of the envelope works in conjunction with the thermal mass of the building (see below) to dampen temperature swings from day to night. While the thermal resistance of the envelope is generally fixed, the use of movable night insulation for the glazing is an example of altering the resistance of the envelope on a diurnal basis. In practice, the thermal resistance of a well insulated envelope often pushes the balance point well below a point of balance to create a surplus of captured heat that can be stored or dumped as necessary, providing protection for the worst case, rather than the averages represented in the Level I Protocol. An operable window is one such dynamic control device for dumping excess heat by increasing the ventilation rate. Mechanical ventilation systems able to vary the percentage of heat recovered or the percentage of fresh air introduced are others.

Occupancy load design - Again, in practice many examples can be found of adapting the daily schedule around the energy flows within the building. School operation schedules, for example, are often tailored to available daylight hours for the safety of the children. For a passively heated school, the challenge is to

Figure 42: The Crystal Cathedral: a ‘Daily Swing’ Building Example

The Crystal Cathedral has internal gains from people during services, which are assumed to be from 8:00 am till 11:30 am. Though the building is all glass, the SC is assumed to be 0.10, which accounts for the small amount of solar gain. Note the mild Los Angeles climate: During most of the year, early morning ambient temperatures allow for passive ventilation to offset any excess solar gain.

The building swings from cool nighttime temperatures to comfortable or overheated temperatures in the day throughout the year. The success of the building is uniquely tied to its occupancy hours. Originally, the building was only used for morning services, when it is shown to be comfortable year round. Increasing use of the building later in the day for weddings etc... has resulted in overheating becoming a problem. Actually, the building has always overheated, the hours of use now conflict with that fact.

Crystal Cathedral  Los Angeles, California

<table>
<thead>
<tr>
<th>Balance Point Graphs</th>
<th>December</th>
<th>March</th>
<th>June</th>
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MANAGING DAILY SWINGS BETWEEN EXCESS GAINS AND LOSSES (LOAD SHIFTING)

Whenever there are both excess gains and losses present they can be used to cancel each other out and reduce the overall load on the building. The objective is to move the building from seesawing between extremes towards a stable, comfortable temperature.

Envelope design - The thermal resistance of the envelope works in conjunction with the thermal mass of the building (see below) to dampen temperature swings from day to night. While the thermal resistance of the envelope is generally fixed, the use of movable night insulation for the glazing is an example of altering the resistance of the envelope on a diurnal basis. In practice, the thermal resistance of a well insulated envelope often pushes the balance point well below a point of balance to create a surplus of captured heat that can be stored or dumped as necessary, providing protection for the worst case, rather than the averages represented in the Level I Protocol. An operable window is one such dynamic control device for dumping excess heat by increasing the ventilation rate. Mechanical ventilation systems able to vary the percentage of heat recovered or the percentage of fresh air introduced are others.

Occupancy load design - Again, in practice many examples can be found of adapting the daily schedule around the energy flows within the building. School operation schedules, for example, are often tailored to available daylight hours for the safety of the children. For a passively heated school, the challenge is to
have the building warm enough to use first thing in the morning, to delay operation until the building has been warmed by the sun, or to schedule daily activities such that the children are active while the building is cold. Could this explain the calisthenics that were a part of the interwar Bauhaus curriculum?

**Natural energy flow design** - When the building is swinging between being too hot and too cold on a daily basis, the issue of thermal storage becomes centrally important. The appropriate massiveness of a building allows excess heat accumulated during the day to be stored and reradiated as the building cools off at night. Concrete floors, masonry walls within the insulated envelope of the building, specialized assemblies such as water containing features are all ways of adding thermal mass to a building. They all act as flywheels, dampening the swings between hot and cold. By taking the edge off of daily extremes, thermal storage often works to bring temperature imbalances within manageable ranges for other passive strategies to be effective.

The Level I Protocol does not model the effects of thermal mass. In the protocol, when a building like the Portland Building shuts down at 5:00 PM, the temperature difference swings from over 40°F to nothing instantaneously. In actuality, the mass of the building cools slowly over the course of the evening.

In buildings without large internal heat sources, solar energy is the primary source of heat gain to offset evening losses. This solar contribution is clearly modeled in the Level I Protocol and is manipulated by increasing or decreasing the amount, orientation and shading coefficients of the glazing. For buildings that swing from being too cold to too hot daily, solar strategies are likely to emphasize early morning gain when the building is cold and to discourage late afternoon gain when the building is hot. Aperture and shading design can express this by being larger to the east and smaller to the west. Increasingly, in practice the glazing itself will be different on the two orientations, with western apertures utilizing a ‘cool glazing’ with a low shading coefficient that blocks heat gain while admitting light.

**Figure 43**: The Jacobs II House: a ‘Seasonal Swing’ Building Example

The house has been modeled to show occupancy gains in the evening. One could similarly construct a profile of the early morning gains.

Notice the strong seasonal shading effect of the overhanging roof on the south facing glazing: The summer gains are significantly reduced. Notice also the strong asymmetry in the climate: Spring is cold and fall is warm. Some form of dynamic shading would help reduce the excess gains in September.

**MANAGING SWINGS BETWEEN SEASONAL CONDITIONS OF EXCESS GAIN AND EXCESS LOSS (SEASONALLY DYNAMIC DESIGN)**

This swing condition is by far the most common situation, calling for the design response to coordinate and balance strategies of increasing and decreasing captured heat gain over the course of the seasons. Since
the climatic fit is dynamic the strategies must also be dynamic, which means that the variables already discussed must be able to be altered seasonally, such as provided for in the protocol by the variability of solar shading coefficients.

The primary means of doing this is to utilize the natural energy flows of sun and wind to heat and cool the building on demand. And while the amount of available solar radiation is symmetrical around the solstices, most local climates lag behind the sun’s rhythm due to large scale thermal mass effects. In the Jacobs II house for example (Figure 42), it is clear that March is not symmetrical with September, even though they are both equinox months. The house is too cold in March and too hot in September. Because of this lag, the very best dynamic design strategies are those that are able to track local conditions rather than the solar calendar.

Envelope design- Because the building is responding to contradictory seasonal demands, there is no one strategy that makes more sense than all others. Rather, there are a great variety of ways that the variables of skin to volume ratios and envelope performance can be balanced. Increasing the skin to volume ratio while simultaneously increasing the thermal performance of the envelope is the general strategy that allows for the most architectural expression. This suggests articulating the massing of the building to maximize the use of daylighting and natural ventilation while increasing the insulation in the walls, roof and glazing to compensate for their increased surface area. This strategy also offers the potential for the architecture to spread out and form exterior spaces with modified climates that enhance the function of the interior spaces (Figures 44 & 45). This in a nutshell describes the best of domestic architecture in temperate climates, where the mild seasonal swings inspire variety in massing and connection to the outdoors. An opposite, more economical approach might seek to keep the massing compact while insuring that strategies to reduce overheating such as daylighting and ventilation are also accommodated.

The use of storm windows is an example of a strategy that alters the thermal resistance of the envelope on a seasonal basis. This small modification has the advantage of being able to respond effectively to


The Maison La Roche responds to the freedom allowed by the temperate Parisian climate with an articulated mass and several outdoor spaces integral to the plan. Each space has a different spatial configuration creating different microclimates; alternately sunny or shady, breezy or calm.

Figure 46: The Center for Regenerative Studies, Cal Poly Pomona. Pomona, CA. Dougherty and Dougherty, Architects. 1994.

The Center’s aesthetic is in part an expression of the climate responsive integration of seasonal passive heating and passive cooling strategies, as well as year-round daylighting.
The cliff dwellings of Mesa Verde are a paragon example of the passive harnessing of natural energy flows in a climate with large daily and seasonal temperature swings. The south facing cliffs provide shade in the summer and admit sun in the winter; their mass storing the sun’s warmth and reradiating it at night. Small enclosed rooms provided the Anasazi a final retreat from the extremes of heat and cold, while daily activities presumably took place on the sheltered terraces.

Seasonal lag. The storms go up and come down depending on the temperature outside and not the position of the sun.

**Occupancy load design**—In a climate that is swinging between hot and cold, seasonal migration within the building is a commonplace response. Consider the architecture of summer porches and winter inglenooks and all of the distinctive spaces associated with seasonal use (Figure 47). Summer cooking outside, for example, not only provides for the immediate pleasure of ventilative cooling away from the hot mass of the house, it removes heat gains due to people, lights and equipment from the kitchen so that the house will stay cooler as well. Or consider migration strategies within the building, such as where family members might gather in an inner core of a house for the winter, shutting off heat to the unused rooms...this is effectively increasing the people loads by decreasing the area of the plan.

Daylighting can be designed to simultaneously provide solar gain in the winter while blocking it in the summer, providing additional heat in the winter while reducing internal heat gain from electric lighting year round. The glazing will be directed towards the sun rather than away and should be designed to prevent glare from direct beam penetration.

**Natural energy flow design**—Designing for the sun in this situation means both capturing solar radiation in the winter and blocking it in the summer. This is a central issue of most discussions of solar design, with different strategies appropriate for different building types, seasonal swing patterns, daily swing patterns etc. (Figure 48). While fixed shading is extremely useful it does not respond to seasonal lag. The implications of this can be seen in the Jacobs II house, where March and September have symmetrical solar gains and September is consequently overheated. Adjustable shading devices can respond more dynamically, as do deciduous plants that leaf out and drop their leaves in sync with the local microclimate of the building.

The same logic of alternately blocking and capturing solar energy applies to natural ventilation design. Prevailing winds often change direction seasonally, allowing for the simultaneous creation of wind sheltered structures and outdoor spaces for winter use as well as for structures and external spaces that are open to summer breezes.

Building mass does not play a role in offsetting gains and losses on a seasonal basis. Some specialized mechanical systems such as large scale ice storage for district cooling may operate with seasonal time lags but even massive buildings heat up and cool down in a matter of days at the most.
Energy Codes, Degree Days and the Balance Point

Building codes do not refer specifically to the building balance point temperature. However, the balance point is a variable used in estimating degree days, which can be used to estimate a building's annual energy requirements. Building codes which allow or require estimates of the energy consumption of building designs often refer the designer to methods based on degree day information. Understanding the concept of the balance point in this case might make the difference between making the case for a novel design and being confined to prescriptive standards.

Citing an example familiar to the authors, the Wisconsin Administrative Code Chapters ILHR 50 to 64: Building and Heating Ventilating and Air Conditioning gives a set of prescriptive criteria relative to building energy consumption, with the option of having alternative solutions accepted if they are shown to meet the state's standards using a recognized analysis procedure such as ASHRAE's degree day based method.

ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers, is the source of a number of code recognized methods for performing energy analysis. Underlining the importance of the balance point concept, the 1993 edition of the ASHRAE Handbook of Fundamentals contains the following statement before presentation of the degree day method of energy analysis:

"Even in an age when computers can easily calculate the energy consumption of a building, the concepts of degree days and balance point temperature remain valuable tools. The severity of a climate can be characterized concisely in terms of degree days. Also, the degree-day method and its generalizations can provide a simple estimate of annual loads, which can be accurate if the indoor temperature and internal gains are relatively constant and if the heating or cooling systems are to operate for a complete season." (p.28.3)

The single building design variable required to estimate a building’s heating or cooling degree days is the building balance point temperature. Thus balance point concepts are central to simple procedures used to estimate annual heating and cooling energy requirements.

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The work that this VITAL SIGNS package is based on goes further with the balance point concept than ASHRAE does at this time. Daryl Erbs, whose methods for estimating degree days to any balance point temperature are those published in the 1993 ASHRAE Handbook of Fundamentals, developed a more complete method of building energy analysis based on monthly average weather statistics in his Ph.D. thesis titled Models and applications for weather statistics related to building heating and cooling loads. This method includes temperature, degree day and solar radiation distribution over different hours of the day, the effects of building thermal capacitance, ventilation, and models for wet bulb temperature distribution. This expanded method is programmed into the COOL_HEAT Excel program included here. Since conduction, ventilation and solar heat flow in the building are estimated as functions of the building balance point, Erbs' work provides the theoretical framework underlying this set of Vital Signs protocols, though the full method is not yet recognized by a national organization, nor has it been completely published. The full theory is presented in abbreviated form in the appendix. Experimental protocols which might validate the method are discussed in the Level III protocol.

Developed in the 1980's, the range of balance point methods described above remain at the cutting edge of building energy analysis and represent areas of potentially fruitful research at the graduate level in architecture. As such, they represent building blocks of both the current and the next generation of energy performance codes.