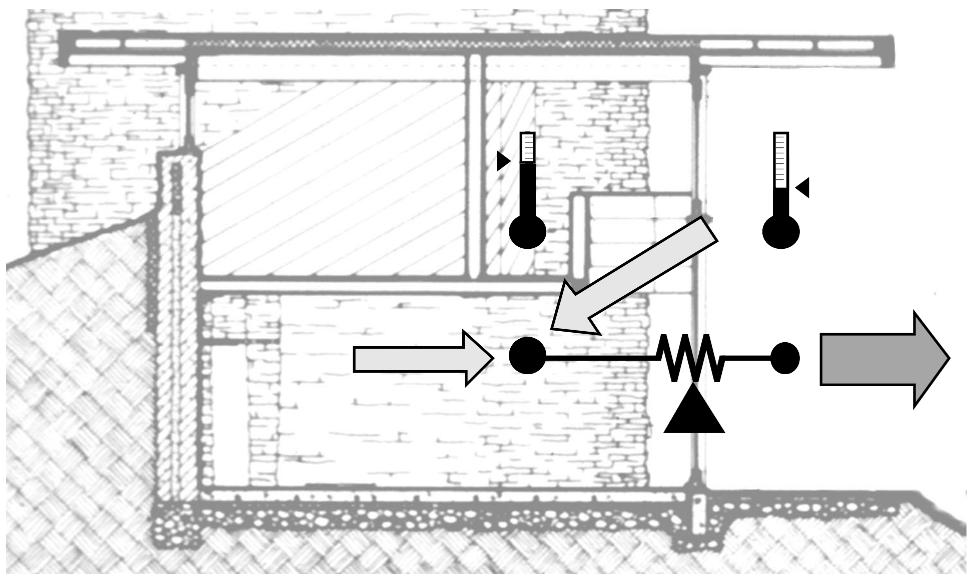
VITAL SIGNS

BUILDING BALANCE POINT



Jacobs II house (Solar Hemicycle), Middleton, Wisconsin. Frank Lloyd Wright, 1948.

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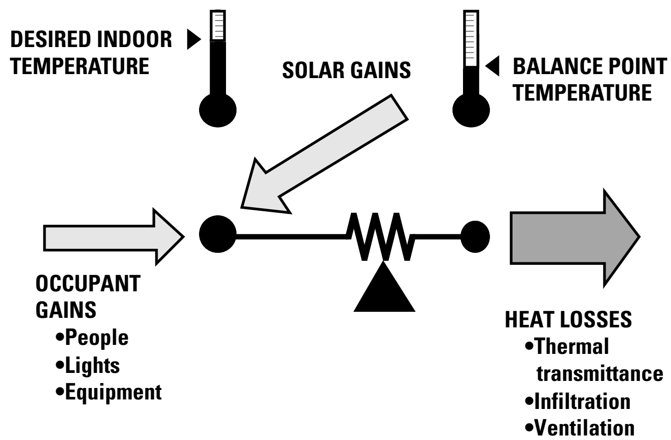
A resource package providing background information and experimental protocols for the study of thermal performance in buildings



The **Balance Point** is the outdoor air temperature causing building heat gains to be dissipated at a rate that creates a desired indoor air temperature. It is determined by design.

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Preface

Figure 1: The Bay View Public Library. Milwaukee, Wisconsin. Engberg Anderson Inc. Architects.

This library was the subject of a Level I Building Balance Point analysis by students in the authors' *Arch. 520: Illumination and Thermal Comfort* class.

It is the mark of an instructed mind to rest satisfied with the degree of precision which the nature of the subject permits and not to seek an exactness where only an approximation of the truth is possible.

-Aristotle*

This package explores the thermal life of buildings in a holistic sense; with concepts and exercises that illustrate the interrelation of internal heat production and building envelope performance, the thermal demands of the occupants and the climate outside.

We provide a provisional structure for the organizing of field studies; the 'patient search' for wisdom about the way that buildings actually work. It is our hope that one significant result of the VITAL SIGNS project as a whole will be the creation of a universally available collection of case studies of architecture from around the world.

As implied by the VITAL SIGNS title, the overriding goal of these resource packages is to document and to understand the *living* relationship between a work of architecture and its physical environment. Each package describes only a small piece of that puzzle and every piece is not only connected to but overlapping with every other piece. The Building Balance Point package specifically overlaps with the **Measurement and Display of Thermal Performance in Buildings** and the **Whole Building Energy Use (Commercial)** packages. In general terms it overlaps with any energy analysis package that requires characterization of a building's metabolism or envelope heat flows.

* Aristotle quote taken from John Harte, *Consider a Spherical Cow: A Course in Environmental Problem Solving,* Mill Valley, CA: University Science Books.1988.

ACKNOWLEDGMENTS

The work represented in this VITAL SIGNS package was produced under the auspices of the VITAL SIGNS Project at the University of California- Berkeley. Funding for the project was provided by the Energy Foundation. Additional support for equipment and staff for this project was provided by the University of Wisconsin- Milwaukee through both the School of Architecture and Urban Planning and the Johnson Controls Institute for Environmental Quality in Architecture. Students enrolled in the Fall 1996 and Spring 1997 Architecture 501 course tested the current version of the Level 1 protocol. Students enrolled in the Fall 1994 Architecture 520 course tested an early version of the Level 1 protocol.

We would like to thank the reviewers for their helpful comments and criticisms. The draft package was reviewed by G.Z Brown, University of Oregon; Victor Olgyay, University of Hawaii; and Nigel Jones, Oklahoma State University. Mark DeKay, Washington University, provided a review of a later draft. Many of these reviewers' suggestions have been included in this package.

Cris Benton, Bill Burke and Alison Kwok and Gail Brager deserve thanks for their excellent coordination of the Vital Signs project.

We thank Stephen and Margit for graciously allowing us to study their home for the Level II Protocol.

The authors don't believe our work stops with the printing of this package. We hope faculty and students using this work will tell us of their experiences and improvements. In addition to connecting with the Vital Signs project on the internet through the UC-Berkeley site, you may contact us on our Vital Signs home page at the Johnson Controls Institute for Environmental Quality in Architecture web site. Both addresses are provided below. We will maintain the Excel templates described in this package on our web page. Any questions or comments that arise in the application of these protocols may be directed to us at our web site, via e-mail or phone.

World Wide Web sites:

VITAL SIGNS Project	http://www.ced.berkeley.edu/cedr/vs/
Glazing Performance	http://www.sarup.uwm.edu/jci/vs/
e-mail:	utzinger@csd.uwm.edu
	jwasley@csd.uwm.edu
phone:	(414) 229-4045
	(414) 229-5564 (dept. of Arch. office)

Michael Utzinger and James Wasley

August 1997

VITAL SIGNS

BUILDING BALANCE POINT
Introduction

These VITAL SIGNS protocols focus on estimating a building's balance point temperature in the field, and using that knowledge to evaluate energy flows in the building under study. The resource package as a whole is designed to be iterative; returning again and again to the same concepts, each time in greater depth.

The package begins by introducing balance point temperature concepts as they relate to architectural design and to the design process, including the relationship of balance point concepts to building codes and their increasing reliance on energy modelling programs. Finally, the field protocols present methods for estimating the balance temperature in the field at two levels of sophistication. They are organized in a slightly different fashion than other VITAL SIGNS packages, in that the physical principles underlying the concept of the building balance point are divided into two separate discussions and grouped with their respective protocols. The two levels of first order principles and protocols are briefly introduced below.

1

Level I introduces a method of estimating the balance point and characterizing the dominant building energy flows from a single day field trip to the site. From simple observation of the thermostat temperature, occupancy heat generation and building heat transfer rate the balance point will be estimated. Either by computer or by hand, the resulting energy flows will be modelled through the seasons to provide a crude but telling profile of the building's climatic 'fit.' This information can then be used to develop a critique of the building's energy flows and design. The *Level I* protocol and its discussion of principles is designed to lead the student toward a conceptual understanding of building energy flows based on visual observation. It is directed toward introductory level course work.

2

Level II concludes the discussion of the theoretical relationships defining dynamic energy flow in buildings. From the principles introduced, a method of field measurement of the heating balance point is developed, requiring three temperature measurements and the heating utility bill as inputs. The use of the balance point field estimates and other temperature measurements in the estimation of related building Vital Signs is also presented and discussed. Unlike the *Level I* Protocol, the *Level II* Protocol is presented as a method by example of the application of theory to measurements in an existing building, a single family residence.

Level II is directed toward advanced graduate students with an interest in exploring the relationship between the theory underlying energy dynamics in buildings and its validation through experiment.

VITAL SIGNS

BUILDING BALANCE POINT
The Balance Point and Architectural Design: Conceptualizing Energy Flows in Buildings

To imagine the task of conceptualizing energy flows through a building, not to mention evaluating them, compare the analysis of energy flows to the analysis of structure. The analysis of a building's structure can proceed from a visual reading of the proportions of structural elements relative to their load and span. A floor deck can be 'seen' carrying its load to the floor joists, which carry their load to girders, then columns and on to the foundation. The depths of members are generally proportional to their spans and their widths proportional to the amount of load carried. In comparison, a visual assessment of a building can lead to an analysis of energy performance, but the energy flow paths are neither as simple nor as direct as the force of gravity. Intuition needs greater education to 'see' energy flows.

Figure 2: Fisherman's house, Hoonah, Alaska.

Figure 3: Office Buildings, New York City.

The balance point is the vital sign which provides insight into the relationship between climate, occupancy, architectural design and the energy flow paths in a building. The **building balance point temperature** is the outdoor air temperature required for the indoor temperature to be comfortable without the use of any mechanical heating or cooling. This is the outdoor air temperature at which the heat gains due to electric lighting and equipment, body heat and solar radiation are in balance with the heat losses through the building envelope due to temperature differences.

A typical house, for example, might receive enough heat from the sun, and its occupants generate enough heat internally, that the exterior temperature must drop below 60°F before the interior temperature drops below the 70°F set point that activates the furnace. The house has a heating balance point of 60°F under these conditions, which are taken as average condition constants but are in reality dynamic because the sources of heat gain are dynamic. In a typical office building, with its large amounts of electric lighting and equipment generating heat and its limited skin to volume ratio keeping the heat from flowing out, the exterior temperature at which mechanical heating kicks in to maintain the same 70°F inside might be as low as 20°F. This highlights the most common theme of balance point discussions; the profound differences that the measure calls attention to between the energy flow profiles of large and small buildings. This is important- many environmental mistakes are made by architects trying to apply the rules of thumb for one scale of building to another. But is the issue that easy to 'see'? The 'tale of two buildings' below introduces the architectural variables that determine the balance points of two pairs of buildings. It also is a cautionary tale about the limitations of conventional wisdom and complexity of visualizing energy flows.

The house is suspended on piers and hence exposed on all six sides. The insulation is minimal and the infiltration rate high. During the winter the sun barely touches the structure. With few available gains and little to retain them, the balance point is high and the indoor temperature is maintained not by the building but by the wood stove inside.

The office buildings, on the other hand, are dense with people, equipment, and lights that are constantly on. The balance point is driven down by this internal heat gain and the buildings require cooling year round.

Interestingly, the climates are not so different. Both Alaska's inland passage and the island of Manhattan are tempered by coastal waters. Outdoor air temperature, however, does not figure into the balance point. *The balance point is a measure of the building that can be measured against the place, not a measure of the building in place.*

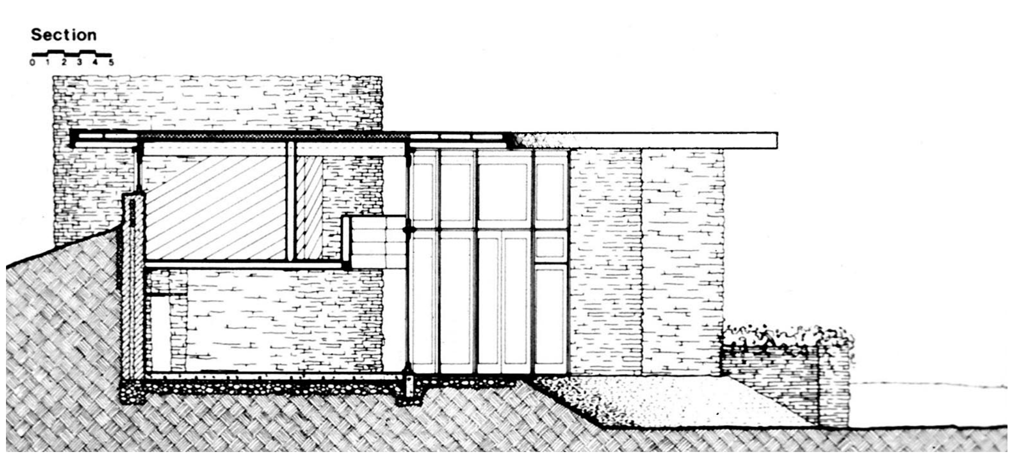


Figure 4: The Crystal Cathedral, Garden Grove, California. Philip Johnson & John Burgee, Architects, 1980.

Figure 5: Section of the Jacobs II House, Middleton, Wisconsin. Frank Lloyd Wright, Architect, 1948.

A Tale of Two Buildings

The Jacobs II house, designed by Frank Lloyd Wright in 1944, is a pioneering example of passive solar design in the cold winter climate of Middleton, Wisconsin. The Crystal Cathedral, designed by Johnson and Burgee in 1979, is an audacious post-energy crisis glass box, located in sunny southern California. A comparison of the two buildings provides an introduction into the nature of building energy flows, the difficulty of a simple visual reading of building energy performance and the meaning and usefulness of the balance point concept.

Wright designed the Jacobs II house to admit the winter sun while blocking the summer sun. Earth from the south facing sunken garden is bermed against the convex north wall, providing an airfoil directing winter winds over the house and creating a dead air space near the glazed south wall. The house is one room deep, admitting winter solar radiation into all occupied spaces. The design, referred to as the 'solar hemicycle,' is an excellent example of the use of building form to control solar admittance and air flow.

The office of Johnson and Burgee designed the Crystal Cathedral to be a visually transparent shroud bathing the church sanctuary in light year-round. To reduce solar gains, the glazing has a reflective metallic coating, giving the Crystal Cathedral its 'facets.' Many of the parishioners prefer to listen to the service from their cars and a large door next to the pulpit allows the pastor to preach to people in the parking lot as well as the sanctuary. The asphalt paving surrounding the church provides a highly absorptive surface for incoming solar radiation.

At first glance, the Jacobs II house appears to be the epitome of masterful energy conscious design while the Crystal Cathedral likely requires a massive air conditioning system. Unfortunately, while Wright considered sun and wind in his design, he ignored the issues that govern heat flow across the enclosure. The cold Wisconsin winters create a large temperature drop across the building enclosure, a drop averaging roughly 50 °F (from 70 °F inside to an average 20 °F outside) in January. In spite of this differential, the glazing is single pane. The roof, floor and much of the north masonry wall is uninsulated. Because of these details, the rate of heat loss through the building envelope is large relative to the rate of heat gain

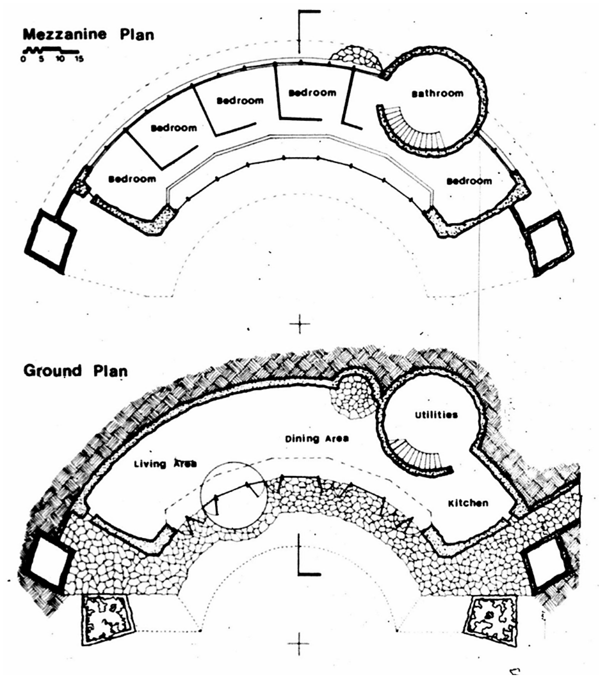


Figure 6: Floor plan of the Jacobs II House.

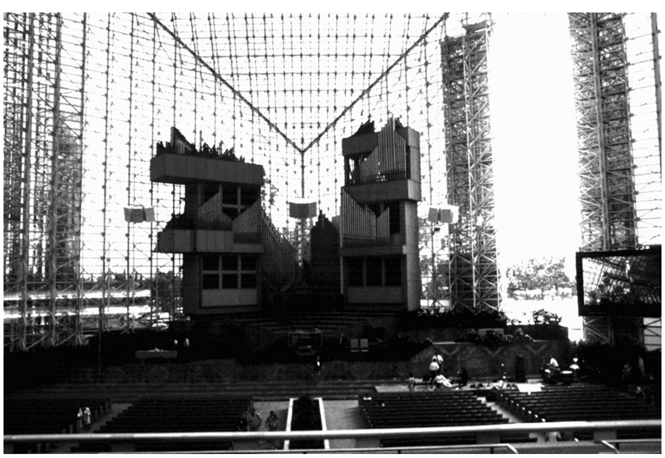


Figure 7: Crystal Cathedral. Interior view of sanctuary looking at pulpit and open door beyond.

from occupancy and solar radiation. Both heat generated by activities inside and solar energy admitted by the glazing can't equal the amount of heat flowing out of the building both day and night during the winter. The internal temperature is thus driven by this large enclosure heat transfer rate. Evidence of this situation can be seen in Herbert Jacobs' remembrances of the house in *Building with Frank Lloyd Wright: an illustrated Memoir:*

> "We had almost daily evidence of winter solar heating. Usually by nine o'clock on a sunny morning, even in below-zero weather, the heating system stopped, and did not resume until late afternoon... Of course, the windows caused heavy heat loss at night, but this was partly offset by the drapes which Katherine made..." (p.121)
>
> "In very cold weather we were apt to find ourselves dressing *en famille* in the big warm bathroom..." (p.122)
>
> "We had... the constant pleasure of a fireplace where one could build castles in the flames- and an equally satisfying joy: steaks from our own steers, broiled in the fireplace..." (p.127)

The fact is that the house is ideally sculpted for passive solar heating but without insulation the realization of that idea is incomplete. In the absence of an insulating envelope, the Jacobs' life-style in the house depended on the supplementary heat of the hearth. A study of the house in 1979-1980 showed the occupants at that time, not nearly as rustic as the Jacobs, to be consuming 3,000 gallons of fuel oil over the course of the winter.

The Crystal Cathedral was designed after the energy crisis of 1973; a glass box in sunny southern California seeming to represent the height of ignorance toward nonrenewable energy resources even after those issues should have gained universal recognition. Quite the opposite is true. The Crystal Cathedral sanctuary was constructed and occupied without air conditioning or heating systems. The glass skin is uninsulated and the consequently large envelope heat transfer rate is increased by natural ventilation through motorized operable panes scattered across the facades and through the 90 foot tall door near the pulpit. Although the occupancy density is high, there is little plug and light load in the sanctuary, meaning that little heat is generated by electrical equipment or lighting, especially since little lighting is required during a typical daytime service. Finally, the highly reflective glazing admits only 10% of the incident solar energy.

Figure 8 (left): Crystal Cathedral. Exterior view showing 90 foot tall pulpit door open for services.

Figures 9, 10 (below): Crystal Cathedral. Exterior views showing operable glazing details. Mullionless tempered glass panels are hinged outwards and controlled by motor driven openers. The ventilation rate would appear to be varied to suit the changing cooling demand by the manipulation of these openings.

The resulting rate of heat loss across the enclosure in the mild Orange County, California climate roughly equals the rate of heat gain to the building from both occupants and solar energy during Sunday morning occupancy. The sanctuary space is comfortable throughout most of the year, with occasional cold January days being the exception. Since the completion of the building, spot heating has been added to provide thermal comfort on such cool winter days, but it still operates without summer cooling.

Initial observation would hardly suggest the actual thermal conditions of either the Crystal Cathedral or Jacobs II house. In both cases, the building balance point temperature is near the desired indoor temperature or thermostat setting. In the absence of any mechanical heating or cooling, the internal temperature of each building tends to mirror the conditions outdoors. This tracking proves that neither building envelope has much ability to insulate; that the internal temperature of both buildings is determined primarily by energy transfer across their enclosures and not by their solar or internal gains. This situation is useful for a building trying to loose its solar gains to the wind in the mild year-round climate of southern California, but not for a small house in the harsh winters of Wisconsin.

Buildings such as these two examples, with high rates of heat transfer through their enclosures and balance point temperatures near the thermostat setting, are often termed **skin load dominated** buildings. In contrast, when solar gains or internal gains from lighting, equipment and human metabolism are predominant, the balance point temperature is lowered, meaning that a low outdoor temperature is required for the losses and the gains to balance at an acceptable indoor temperature. Such buildings are termed **internal load dominated** buildings.

Internally dominated buildings can be further characterized as having two generic thermal zones; a **core condition** and a **perimeter condition** (**figure 11**). When the temperature outside is cold enough, the perimeter of a building will be uncomfortable and will require heat, even as the core is overheating. The depth of this zone will vary depending on the variables that the balance point is responding to such as the solar orientation and the U value of the enclosure. The mechanics of redistributing heat evenly in large buildings has historically been more complicated than simply providing energy inputs to both heat and cool simultaneously, an extreme inefficiency from an environmental point of view.

Figure 11: Interior and perimeter thermal zones, typical large plate office plan.

The depth of the perimeter zone may change daily and seasonally depending on interior loads, envelope design, solar orientation and weather conditions.

These terms of 'skin load dominated' and 'internal load dominated' were coined to capture the differences in energy flow patterns that the balance point concept highlights between large commercial buildings and small residential buildings. Large, thick structures like modern office buildings tend to have high internal gains and low skin losses; they consequently have low balance points and require cooling constantly. They are 'internal load dominated', even as their perimeter zones may be cold due to the outside temperature. Small, thin, poorly insulated structures such as typical postwar houses tend to have low internal gains and high skin losses; they have high balance points and require both heating and cooling, depending on the season. They are 'skin load dominated' buildings.

There is some ambiguity in this terminology because it downplays solar gain, which does not intuitively fit into these neat divisions because it plays different roles in different situations. Solar gains add to the internal gains of an already overheated office building while further accentuating the dependence on external conditions of a small house. Solar gain is a wild card that also happens to be a variable that the architect has control over through design. In the protocol that follows, this is why solar gains are treated separately as an additional load layered on top of the building's performance without the sun.

The underlying logic is this: some buildings are dominated by heat gains, either solar or occupant; they have low balance points and require either passive or mechanical cooling. Other buildings are dominated by the temperature of the ambient environment, either through ventilation or heat transfer through the envelope; they have high balance points and likely have heating as their main concern. The Jacobs II house illustrates the fact that while the daytime temperatures might be driven by the sun in a poorly insulated space, the average temperature still depends on the envelope. If the house were well insulated its balance point would drop and it would act more like an office building. This would provide a neat inverse to the Crystal Cathedral, which looks like an office building but acts like a house.

Figure 12: 'Skin Load Dominated'

This lizard sunning itself is 'skin load dominated.' Cold-blooded, it depends on the warmth of the environment (via solar gains etc..) to raise its body temperature to a point where it can function actively.

Figure 13: 'Internal Laod Dominated'

The skier is generating metabolic heat by exercising. Even though the air is cold, he is warm; his body temperature is 'internally dominated.' If too warm, he will take the jacket off, increasing his rate of heat loss.

VITAL SIGNS 1

BUILDING BALANCE POINT
Level 1: Introduction to First Order Principles

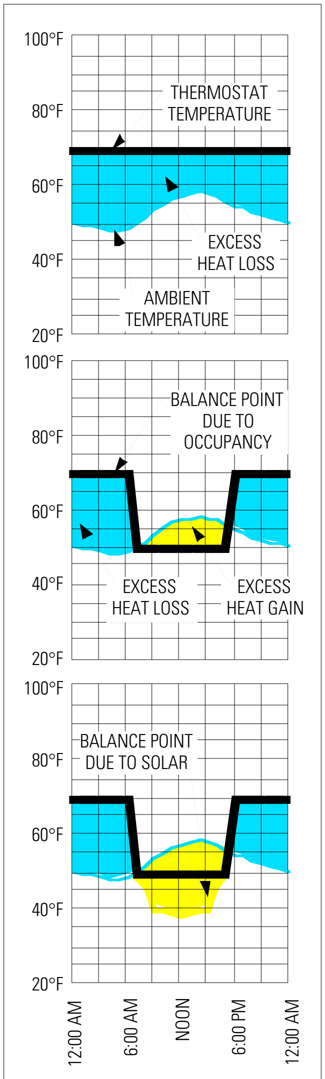


Figure 14: Structure of the Building Balance Point graphs.

BALANCING BUILDING ENERGY FLOWS: THE DEFINITION OF THE BUILDING BALANCE POINT TEMPERATURE

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 builfing balance point, **T_balance**, is given mathematically as:

$$\mathbf{T\_balance} = \mathbf{T\_thermostat} - \frac{\mathbf{Q}_{\mathbf{IHG}} + \mathbf{Q}_{\mathbf{SOL}}}{\hat{\mathbf{U}}_{\mathbf{bldg}}} \qquad [1]$$

T_thermostat is the building thermostat setting. $\mathbf{Q}_{\mathbf{IHG}}$ is the building internal heat generation rate due to occupancy and given per unit floor area. $\mathbf{Q}_{\mathbf{SOL}}$ is the rate of solar heat gain to the building given per unit floor area. $\hat{\mathbf{U}}_{\mathbf{bldg}}$ 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: $\mathbf{Q}_{\mathbf{IHG}}$ changes with the occupancy schedule and $\mathbf{Q}_{\mathbf{SOL}}$ changes with time of day and time of year. Even $\hat{\mathbf{U}}_{\mathbf{bldg}}$ can vary due to variation of the building fresh air ventilation rate.

To better understand tthe 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

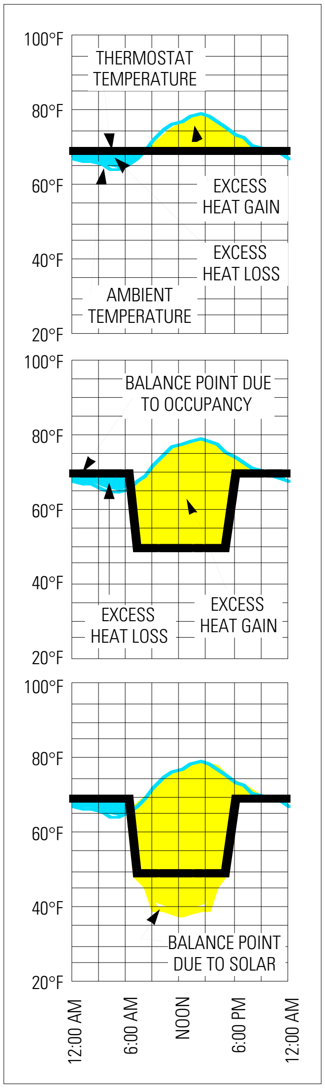


Figure 15: Building Balance Point graphs for warm ambient temperatures.

to the temperature difference between the building (or thermostat) temperature and the ambient air temperature. The thickness of the shaded area is equivelent 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, $\hat{\mathbf{U}}_{bldg}$. 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, $\mathbf{Q}_{IHG}$, 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 $\mathbf{Q}_{IHG}$ to $\hat{\mathbf{U}}_{bldg}$ 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 typicall be lower at sunrise and sunset and peak at noon. In this example, the ratio of $\mathbf{Q}_{SOL}$ at noon to $\hat{\mathbf{U}}_{bldg}$ 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, $\hat{\mathbf{U}}_{bldg}$.

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 ploted 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, $\mathbf{Q}_{SOL}$, 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 $\hat{\mathbf{U}}_{bldg}$, $\mathbf{Q}_{IHG}$ and $\mathbf{Q}_{SOL}$, 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.

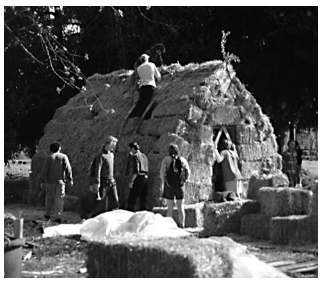


Figure 16: Moss tent. Nevada desert, 1996.

Figure 17: Hay bale construction demonstration structure, H.O.P.E.S. conference, University of Oregon. 1996.

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 approxate 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, $\hat{\mathbf{U}}_{\mathbf{bldg}}$, 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. $\hat{\mathbf{U}}_{\mathbf{bldg}}$, the building heat transfer rate per unit floor area is then estimated as:

$$\hat{\mathbf{U}}_{\mathbf{bldg}} = \hat{\mathbf{U}}_{\mathbf{wall}} + \hat{\mathbf{U}}_{\mathbf{roof}} + \hat{\mathbf{U}}_{\mathbf{glzg}} + \hat{\mathbf{U}}_{\mathbf{grnd}} + \hat{\mathbf{U}}_{\mathbf{vent}} \qquad [2]$$

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.

$\hat{\mathbf{U}}_{\mathbf{wall}}$ - Heat Transfer Rate through the Building Walls

Heat transfer rate through opaque walls is equal to the product of the wall area, $\mathbf{A}_{\mathbf{w}}$, and the wall heat transmission coefficient, $\mathbf{U}_{\mathbf{WALL}}$. To allow comparison of different sized buildings, the heat transfer rate through the walls is divided by the floor area giving $\hat{\mathbf{U}}_{\mathbf{wall}}$. The heat transfer rate through opaque building walls per unit floor area, $\hat{\mathbf{U}}_{\mathbf{wall}}$, is expressed mathamatically as

$$\hat{\mathbf{U}}_{\mathbf{wall}} = \frac{\mathbf{U}_{\mathbf{WALL}}\mathbf{A}_{\mathbf{w}}}{\mathbf{A}_{\mathbf{f}}} \qquad [3]$$

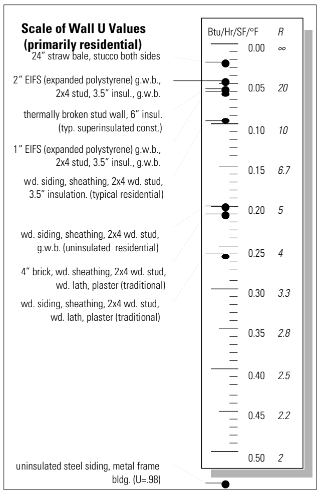


Figure 18: Scale for $\mathbf{U_{WALL}}$, the heat transmission coefficient for opaque walls. The values are given per unit area of wall.

The wall area, $\mathbf{A_w}$, and the floor area, $\mathbf{A_f}$, can be estimated from field observation or from scale drawings. The wall heat transmission coefficient, $\mathbf{U_{WALL}}$, is estimated based on visual observation in the field or from construction details. While estimation of $\mathbf{A_w}$ or $\mathbf{A_f}$ may be time consuming, the process is straight forward. Two complications can arise when estimating $\mathbf{\hat{U}_{wall}}$. First, the actual wall construction is unknown and $\mathbf{U_{WALL}}$ is difficult 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 are considered below.

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

The Protocol contains a larger image of the $\mathbf{U_{WALL}}$ scale with additional examples of non-residential wall construction. This scale can be taken to the field to assist the estimation of $\mathbf{U_{WALL}}$. 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 $\mathbf{U_{WALL}}$ is primarily a function of insulation, uncertainty concerning the insulation details can lead to errors in the estimate of $\mathbf{\hat{U}_{wall}}$. 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 $\mathbf{U_{WALL}}$ 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. $\mathbf{U_{WALL}}$ represents the average opaque wall heat transmission coefficient for the total building wall opaque area including all construction types. The average $\mathbf{U_{WALL}}$ can be estimated using area weighting and is given as

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

Where each construction type has an associated wall area, $\mathbf{A_{w,i}}$, and heat transmission coefficient coefficient, $\mathbf{U_{WALL,i}}$. 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, $\mathbf{A_w}$. 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.

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

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

$$\mathbf{\hat{U}_{roof}} = \frac{\mathbf{U_{ROOF} A_r}}{\mathbf{A_f}} \qquad [5]$$

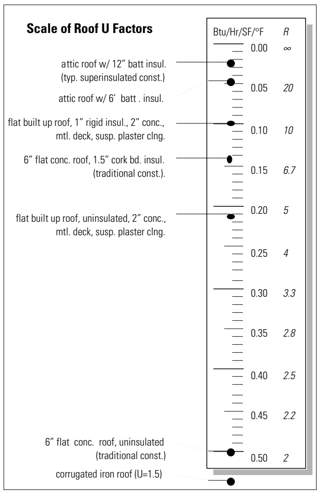


Figure 19: Scale for $\mathbf{U_{ROOF}}$, the heat transmission coefficient for the building roof. The values are given per unit area of roof.

The procedure to estimate $\hat{\mathbf{U}}_{\mathbf{roof}}$ is similar to the procedure used to estimate $\hat{\mathbf{U}}_{\mathbf{wall}}$. $\mathbf{A_r}$, the total roof area can be estimated in the field or from the drawings. $\mathbf{U_{ROOF}}$ is estimated from the site visit or the drawings. $\mathbf{U_{ROOF}}$ like $\mathbf{U_{WALL}}$ will range between 0 and 1 Btu/Hr/°F/SF, although 0.5 Btu/Hr/°F/SF will be the upper limit for most constructions. A scale of $\mathbf{U_{ROOF}}$ with descriptions of roof constructions and their associated heat transmission coefficients is illustrated in **Figure 19**. The two difficulties potentially associated in estimating $\hat{\mathbf{U}}_{\mathbf{wall}}$, multiple construction types and unknown insulation levels, may also affect estimates of $\hat{\mathbf{U}}_{\mathbf{roof}}$. 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 $\mathbf{U_{ROOF}}$ 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.

$\hat{\mathbf{U}}_{\mathbf{glzg}}$ - Heat Transfer Rate through the Building Glazing

Heat transfer rate through the building glazing is equal to the product of the glazing area, $\mathbf{A_g}$, and the glazing heat transmission coefficient, $\mathbf{U_{GLZG}}$. This heat transfer rate is divided by the floor area giving $\hat{\mathbf{U}}_{\mathbf{glzg}}$. Mathematically, $\hat{\mathbf{U}}_{\mathbf{glzg}}$, is given by

$$\hat{\mathbf{U}}_{\mathbf{glzg}} = \frac{\mathbf{U_{GLZG}A_g}}{\mathbf{A_f}} \qquad [6]$$

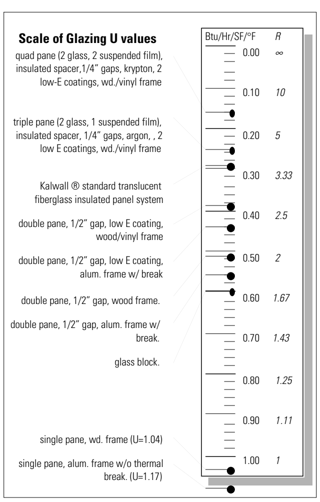


Figure 20: Scale for $\mathbf{U_{GLZG}}$, the heat transmission coefficient for glazing systems. The values are given per unit area of glazing.

The procedure to estimate $\hat{\mathbf{U}}_{\mathbf{glzg}}$ is similar to the procedures used to estimate $\hat{\mathbf{U}}_{\mathbf{wall}}$ or $\hat{\mathbf{U}}_{\mathbf{roof}}$. $\mathbf{A_g}$, the total glazing area can be estimated in the field or from the drawings. The glazing heat transmission coefficient, $\mathbf{U_{GLZG}}$, 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/Hr/°F/SF. This upper limit of 1 Btu/Hr/°F/SF 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 $\mathbf{U_{GLZG}}$, 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 $\mathbf{U_{GLZG}}$.

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

$\hat{\mathbf{U}}_{\mathbf{grnd}}$ - 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,

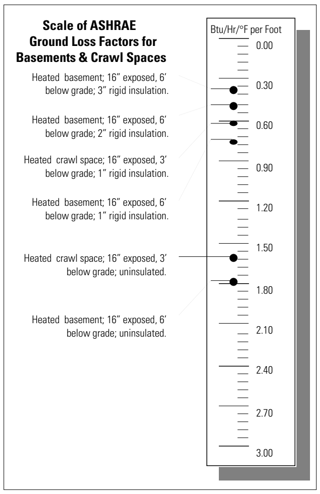


Figure 21: Scale for $\mathbf{U_{GRND}}$, the heat transmission coefficient for ground heat transfer along the building perimeter. Note that this heat transfer rate is given per foot of building perimeter length.

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, $\mathbf{U_{GRND}}$. As in the estimate of $\mathbf{\hat{U}_{wall}}$, the heat transfer rate through the ground is divided by the floor area giving $\mathbf{\hat{U}_{grnd}}$. The heat transfer rate through the ground at the building perimeter, $\mathbf{\hat{U}_{grnd}}$, is expressed mathamatically as

$$\hat{U}_{grnd} = \frac{U_{GRND}\text{Perimeter}}{A_f} \qquad [7]$$

The procedure to estimate $\mathbf{\hat{U}_{grnd}}$ is different than the procedure used to estimate $\mathbf{\hat{U}_{wall}}$. **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 $\mathbf{U_{GRND}}$, which is illustrated in **Figure 21**. Different below grade constructions and insulation levels are described and their associated value of $\mathbf{U_{GRND}}$ 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, $\mathbf{U_{GRND}}$ 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, $\mathbf{\hat{U}_{grnd}}$ 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 $\mathbf{\hat{U}_{wall}}$.

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, $\mathbf{\hat{U}_{grnd}}$ represents less than 2% of the energy flow between building and environment. Thus for large buildings $\mathbf{\hat{U}_{grnd}}$ can often be neglected.

$\hat{U}_{vent}$ - 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 a large impact on the total heat transfer rate on buildings of any size, and becomes

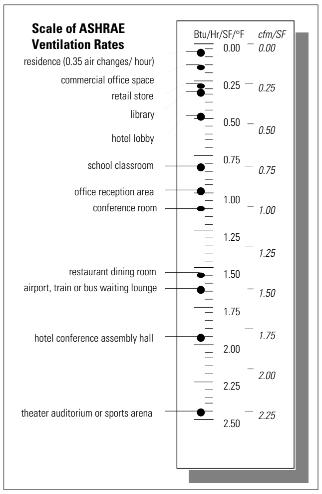


Figure 22: Scale for $\hat{\mathbf{U}}_{\mathbf{vent}}$, the heat transmission rate for ventilation between building and environment. Note that the heat transmission rate is given per unit floor area of the building.

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 equivelent to 15 air changes per hour. Various occupancies are noted on the scale with their associated ventilation rate and equivelant heat transfer rate. $\hat{\mathbf{U}}_{\mathbf{vent}}$, 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**.

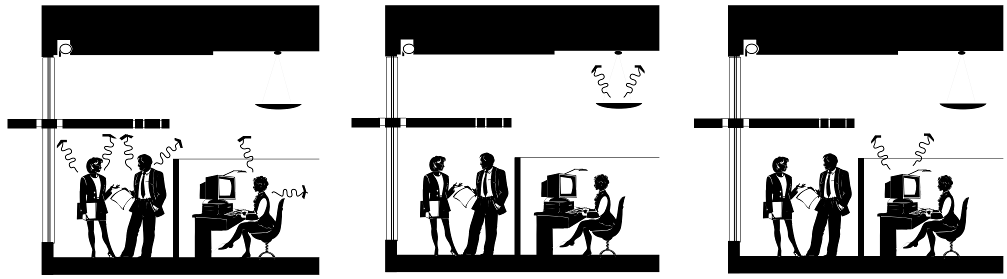
Infiltration rates for a given building are generally not known. The complete ventilation heat transfer scale presented in the Level I Protocol does provide sample infiltration rates derieved from the *ASHRAE Handbook of Fundamentals*, 1993 ed. Infiltration becomes more significant as building volumes become smaller. This is due to the dependance 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 comercial 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

$$\hat{\mathbf{U}}_{\mathbf{vent,\,corrected}} = \hat{\mathbf{U}}_{\mathbf{vent}}\left(1-\eta_{\mathbf{HR}}\right) \qquad [8]$$

Figure 23: The three major sources of internal (or occupancy) heat gains. Each source can be estimated separately and then summed to provide an estimate of the total occupancy heat gain.



A: Occupant heat gains

B: Lighting heat gains

C: Equipment heat gains (or plug loads)

Where $\hat{\mathbf{U}}_{\mathbf{vent}}$ is the ventilation heat transfer rate without heat recovery and η_{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 $\hat{\mathbf{U}}_{\mathbf{vent}}$ 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, $\mathbf{Q}_{\mathbf{IHG}}$, and solar heat gains, $\mathbf{Q}_{\mathbf{SOL}}$. Internal heat gains are considered in this subsection while solar heat gains will be considered in the following subsection.

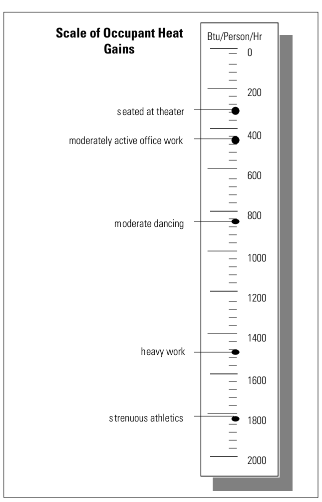


Figure 24: Scale of heat gains per person due to metabolism.

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, $\mathbf{Q}_{\mathbf{IHG}}$, can be estimated by

$$\mathbf{Q}_{\mathbf{IHG}} = \mathbf{Q}_{\mathbf{people}} + \mathbf{Q}_{\mathbf{light}} + \mathbf{Q}_{\mathbf{equip}} \qquad [9]$$

Where $\mathbf{Q}_{\mathbf{people}}$ is the heat gain from people occupying the building; $\mathbf{Q}_{\mathbf{light}}$ is the heat gain from lights used in the building and $\mathbf{Q}_{\mathbf{equip}}$ 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.

$\mathbf{Q}_{\mathbf{people}}$ - 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

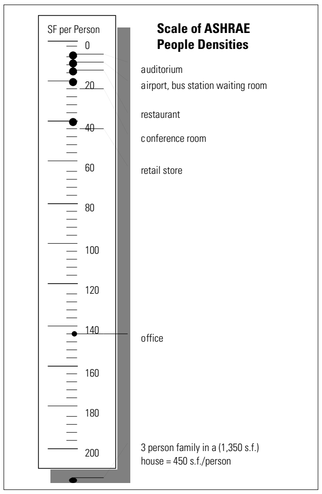


Figure 25: Scale of occupant densities in SF per person.

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 building provided per person. **Figure 25** illustrates typical occupant densities given in square feet of floor 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, $\mathbf{A_f}$, by the total number of building occupants.

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

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

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

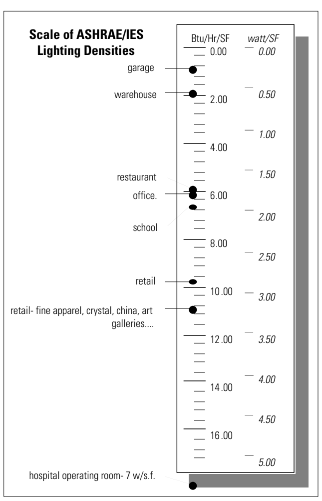


Figure 26: Scale of heat gains due to lighting.

$\mathbf{Q_{light}}$ - 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). $\mathbf{Q_{light}}$ 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

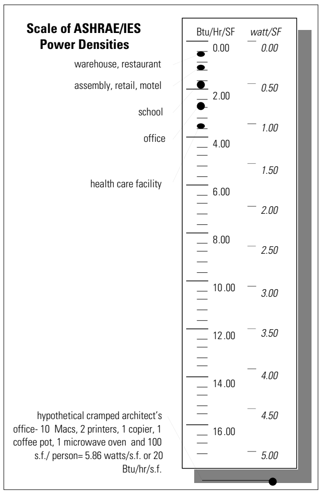


Figure 27: Scale of heat gains due to equipment.

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, $f_{daylight}$. The corrected heat gain from lights, $\mathbf{Q}_{light,cor}$, is then estimated by

$$\mathbf{Q}_{light\ ,cor} = \mathbf{Q}_{light}\left(1 - \frac{f_{daylight}}{2}\right) \qquad [11]$$

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

$\mathbf{Q}_{equip}$ - 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 there 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

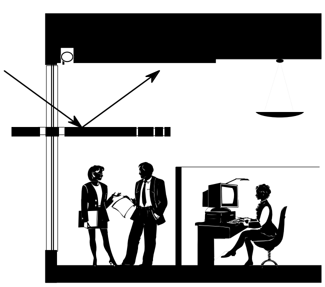


Figure 28: Solar heat gains through the building glazing.

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

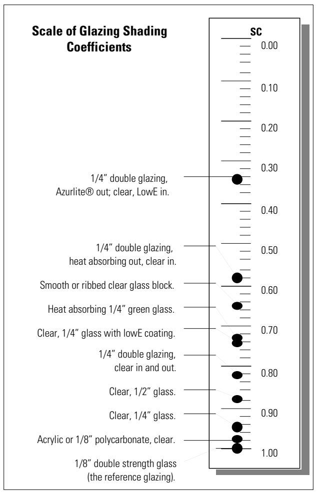


Figure 29: Scale of solar shading coefficients.

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 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**) 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, $\mathbf{Q_{SOL}}$ is given as

$$\mathbf{Q_{SOL}} = \sum_{\mathbf{i}=1}^{\mathbf{n}} \mathbf{I_{SOL,i} SC_i} \frac{\mathbf{A_{g,i}}}{\mathbf{A_f}} \qquad [10]$$

i is an orientation and the summation covers each orientation on the building with glazing. There are **n** orientations with glazing systems. $\mathbf{SC_i}$ is the shading coefficient for the glazing system of orientation **i**. $\mathbf{I_{SOL,i}}$ is the avarage solar gain for standard glass for the given climate, season, hour and orientation. $\mathbf{A_{g,i}}$ is the area of glazing at orientation **i**, and $\mathbf{A_f}$ is the building floor area. Estimation of $\mathbf{Q_{SOL}}$ 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 $\mathbf{SC_i}$ can be made using the same technique employed to determine an average $\mathbf{U_{WALL}}$ (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 $\mathbf{\hat{U}_{bldg}}$ and $\mathbf{Q_{IHG}}$ is not great, the effort required to estimate $\mathbf{Q_{SOL}}$ 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 exploring 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 estiamte 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, $\mathbf{Q_{IHG}}$, is low, the enclusure heat transfer rate, $\mathbf{\hat{U}_{bldg}}$, must be very small to drive the building balance point down. A residence typically has a low value of $\mathbf{Q_{IHG}}$ (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, $\mathbf{Q_{IHG}}$, 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, $\mathbf{\hat{U}_{bldg}}$, will have a significant effect on the balance point temperature. Errors in estimates of $\mathbf{Q_{IHG}}$ or $\mathbf{\hat{U}_{bldg}}$ are more critical in this range.The next section provides an example of the balance point analysis with study of uncertain variables controlling $\mathbf{\hat{U}_{bldg}}$, $\mathbf{Q_{IHG}}$ or $\mathbf{Q_{SOL}}$.

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.

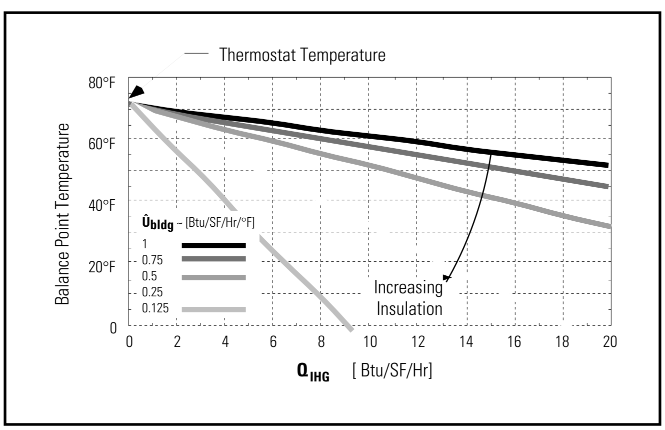


Figure 30: The Building Balance Point as a function of the internal heat generation rate and building enclosure heat transfer rate. The thermostat is set at 72°F. The internal heat generation rate ($\mathbf{Q_{IHG}}$) is given in Btu per hour per square foot of floor area. The building enclosure heat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

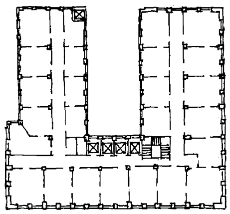


Figure 17: Typical floor plan as originally designed, the Wainwright Building. Adapted from Moore, Fuller. *Environmental Control Systems: Heating Cooling Lighting*. New York; McGraw-Hill, Inc. 1993. p.305.

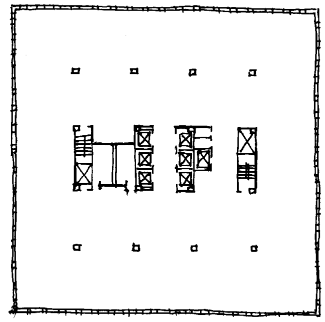


Figure 16: Typical floor plan, the Portland Building. Shown at same approximate scale as the Wainwright building. Adapted from *Architectural Record*, November 1982. p. 95.

THE WAINWRIGHT BUILDING

Saint Louis Missouri

Adler and Sullivan, Architects, 1890-91

BUILDING THERMOSTAT SETTING	Record the average setting on the thermostat. (The desired indoor air temp.) If unsure, assume 70°F.	AT	70		
BUILDING OCCUPANCY SCHEDULE	Record the period of each day through a typical week that the building is occupied. Make note of any seasonal variations in use.	ARTING TIME	7am	AVERAGE ENDING TIME	5pm
BUILDING FLOOR AREA ATION FORMAT TO BE DETERMINED BY INSTRUCTOR	Sketch the building footprint and estimate its perimeter and area. If the building has floors of different shapes and sizes, sketch and determine the area for each floor. Insert the perimeter length and total floor area in the spaces provided.	PERIMETER L_{PERIM} =	560	NUMBER OF FLOORS	11
				AREA PER FLOOR	10,700
				TOTAL FLOOR AREA A_{FLOOR}	117,700
BUILDING ROOF AND HORIZONTAL GLAZING AREA ATION FORMAT TO BE DETERMINED BY INSTRUCTOR	Sketch the building roof plan and estimate the roof area. If the building has any skylights or horizontal glazing, estimate the glazed area. Insert the glazed area and net roof area in the spaces provided.	GROSS ROOF AREA	10,700	GLAZING AREA-HORIZONTAL (S.F.) A_{GLZ},H	-0-
				NET ROOF AREA A_{ROOF}	10,700
BUILDING WALL & GLAZING AREA ATION FORMAT TO BE DETERMINED BY INSTRUCTOR	Sketch the building's elevations and their approximate dimensions. Estimate the total S.F. of wall area and the amount of that total that is glazed on each elevation. Record the information in the spaces provided.	GLAZING AREA-SOUTH (S.F.) A_{GLZ},S	3,596	GROSS WALL AREA (S.F.)	76,720
		GLAZING AREA-EAST (S.F.) A_{GLZ},E	5,994	GLAZING AREA-TOTAL (S.F.) A_{GLZ}	19,180
	Subtract the total glazing area from the total wall area to arrive at the Net Wall Area A_{WALL}.	GLAZING AREA-WEST (S.F.) A_{GLZ},W	5,994	NET WALL AREA (S.F.) A_{WALL}	57,540
		GLAZING AREA-TH (S.F.) A_{GLZ},N	3,596		

THE PORTLAND BUILDING

Portland, Oregon

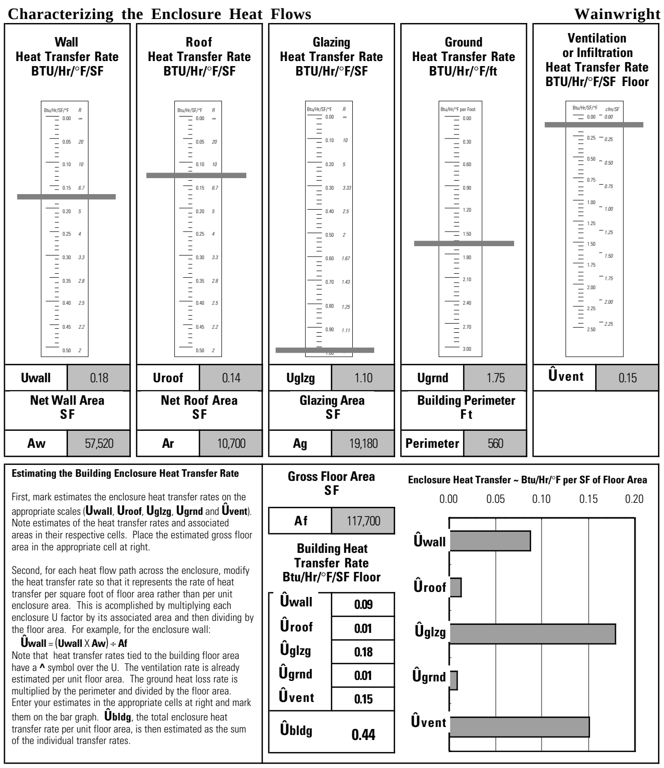
Michael Graves Associates, Architects, 1980

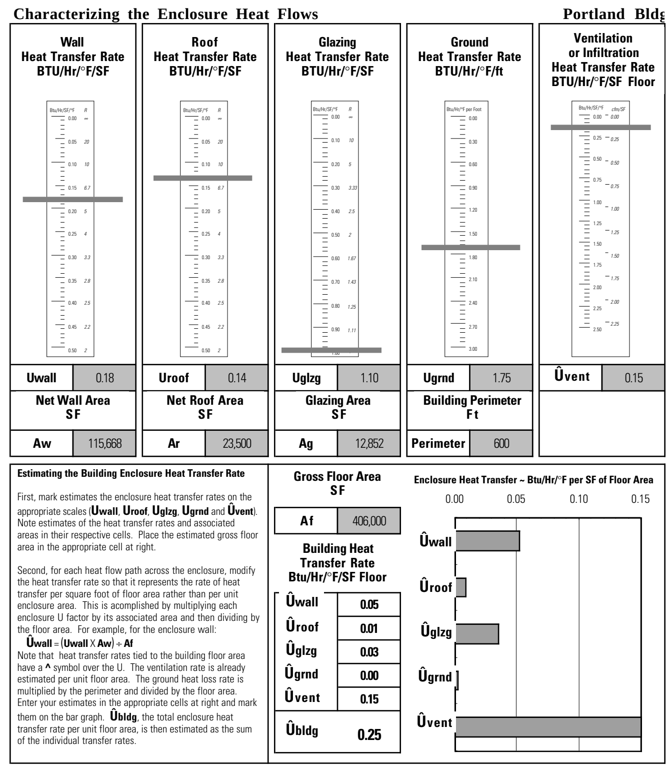
BUILDING THERMOSTAT SETTING	Record the average setting on the thermostat. (The desired indoor air temp.) If unsure, assume 70°F.	AT	70		
BUILDING OCCUPANCY SCHEDULE	Record the period of each day through a typical week that the building is occupied. Make note of any seasonal variations in use.	ARTING TIME	7am	AVERAGE ENDING TIME	5pm
BUILDING FLOOR AREA ATION FORMAT TO BE DETERMINED BY INSTRUCTOR	Sketch the building footprint and estimate its perimeter and area. If the building has floors of different shapes and sizes, sketch and determine the area for each floor. Insert the perimeter length and total floor area in the spaces provided.	PERIMETER L_{PERIM} =	600	NUMBER OF FLOORS	15
				AREA PER FLOOR	23,500
				TOTAL FLOOR AREA A_{FLOOR}	406,000
BUILDING ROOF AND HORIZONTAL GLAZING AREA ATION FORMAT TO BE DETERMINED BY INSTRUCTOR	Sketch the building roof plan and estimate the roof area. If the building has any skylights or horizontal glazing, estimate the glazed area. Insert the glazed area and net roof area in the spaces provided.	GROSS ROOF AREA	23,500	GLAZING AREA-HORIZONTAL (S.F.) A_{GLZ},H	-0-
				NET ROOF AREA A_{ROOF}	23,500
BUILDING WALL & GLAZING AREA ATION FORMAT TO BE DETERMINED BY INSTRUCTOR	Sketch the building's elevations and their approximate dimensions. Estimate the total S.F. of wall area and the amount of that total that is glazed on each elevation. Record the information in the spaces provided.	GLAZING AREA-SOUTH (S.F.) A_{GLZ},S	3,213	GROSS WALL AREA (S.F.)	128,520
		GLAZING AREA-EAST (S.F.) A_{GLZ},E	3,213	GLAZING AREA-TOTAL (S.F.) A_{GLZ}	12,852
	Subtract the total glazing area from the total wall area to arrive at the Net Wall Area A_{WALL}.	GLAZING AREA-WEST (S.F.) A_{GLZ},W	3,213	NET WALL AREA (S.F.) A_{WALL}	115,668
		GLAZING AREA-TH (S.F.) A_{GLZ},N	3,213		

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.

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 know that the floor to ceiling height in the Portland building is 9'-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 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.

$\mathbf{U}_{wall}$= 0.18 (Btu/hr/s.f.).

$\mathbf{U}_{roof}$= 0.14 (Btu/hr/s.f.).

$\mathbf{U}_{glzg}$= 1.10 (Btu/hr/s.f.).

$\mathbf{U}_{grnd}$= 1.75 (Btu/hr/s.f.).

$\mathbf{U}_{vent}$= 0.15 (Btu/hr/s.f.).

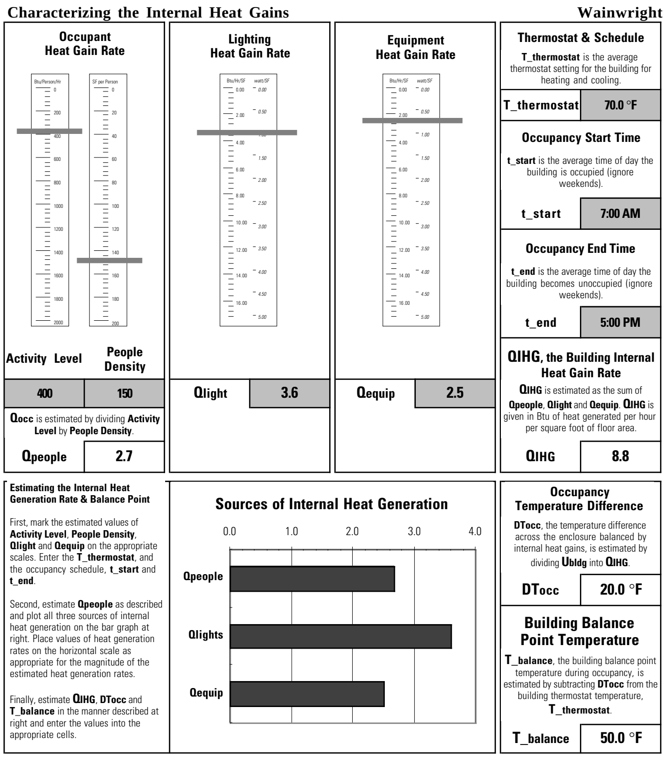
The summary scales have been marked by hand for visual reference.

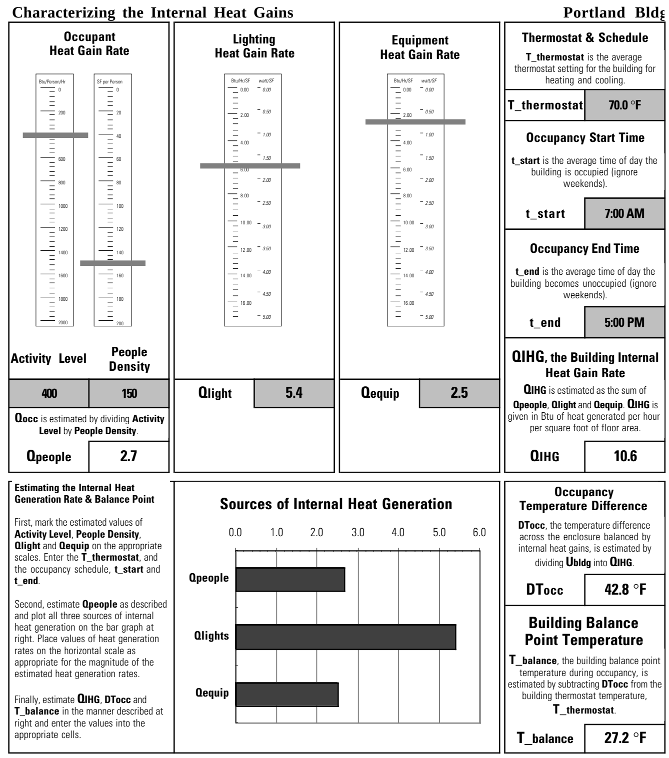
The enclosure heat transfer variables have been kept the same for both buildings so that the differences we see will be based soley on their respective massing. These values are derived from the protocol scales. They represent traditional uninsulated masonry construction and single pane glazing. This 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 ($\mathbf{A}_f$) and the resulting thermal heat transfer rates per unit of floor area ($\hat{\mathbf{U}}_{wall}$ 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 0.65 square feet of surface area for every square foot of floor area. The Portland building has 109,200 s.f. gross wall area and 406,000 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 $\hat{\mathbf{U}}$ values. Overall, the $\hat{\mathbf{U}}_{bldg}$ 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.

The bar graphs illustrate the individual Enclosure Heat Transfer rates. Looking at the Wainwright Building, losses through the walls, glazing and ventilation all stand out as important. In the case of the Portland building, the heat transfer due to code required ventilation is clearly the most important flow path. Notice that Excel has changed the scale of the graph so that it fits on the page. By comparing the units it is clear that the ventilation rate is the same 0.15 Btu/Hr/°F for both (we set this variable) and that the bar graph is really illustrating how low the wall and glazing transfer rates are in the Portland Building.





CHARACTERIZING INTERNAL HEAT GAINS

The Occupant Heat Gain Rate (Q_{people}), Equipment Heat Gain Rate (Q_{equip}), 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_{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/s.f.. 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/s.f.. On the scale this appears very efficient but less so than the levels achieved at Audubon House. Our daylighting assumption seems believable.

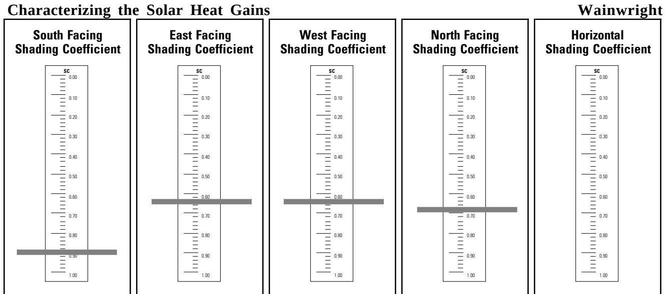
To be fair, we assume that the Portland Building has useful daylight penetration over 20% of its floor area and reduce its Lighting Heat Gain Rate to 5.4 Btu/hr/s.f., though in reality this is unlikely. Daylighting is only effective if the building is designed to take advantage of it, both by distributing 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_{IHG}) is different because of the different lighting loads. The Wainwright gains 8.8 Btu/hr/s.f. overall while the Portland Building gains 10.6 Btu/hr/s.f..

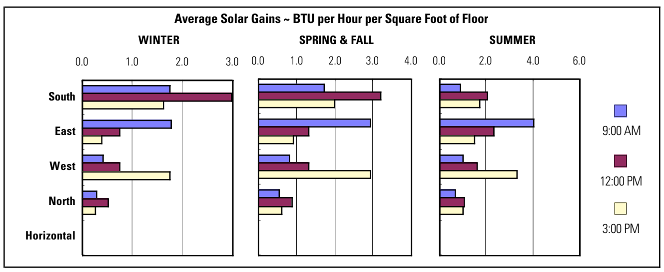
The real insight is that the temperature difference due to occupancy (DT_{occ}) and the resulting Balance Point Temperature ($T_{balance}$) are dramatically different. For the Wainwright, an outdoor temperature of 50.0°F will balance these internal gains to produce a comfortable 70°F temperature inside. 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.

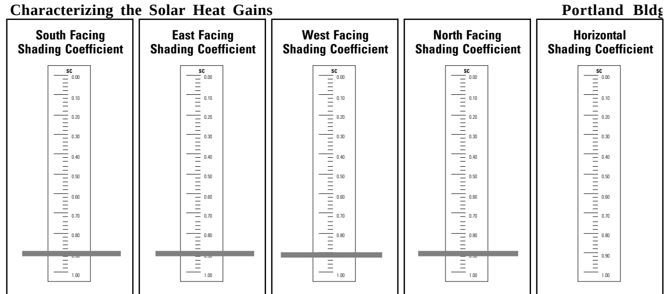
Characterizing the Solar Heat Gains — **Wainwright**



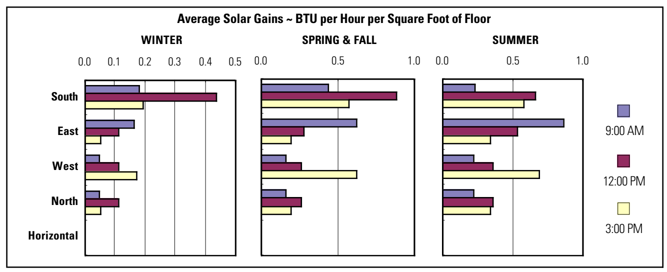
South Facing		East Facing		West Facing		North Facing		Horizontal	
Area	3,596	Area	5,994	Area	5,994	Area	3,596	Area	0
Ag,s/Af	3%	Ag,e/Af	5%	Ag,w/Af	5%	Ag,n/Af	3%	Ag,h/Af	0%
Winter SC	0.90	Winter SC	0.62	Winter SC	0.62	Winter SC	0.69	Winter SC	0.00
Fall & Spring SC	0.90	Fall & Spring SC	0.62	Fall & Spring SC	0.62	Fall & Spring SC	0.69	Fall & Spring SC	0.00
Summer SC	0.90	Summer SC	0.62	Summer SC	0.62	Summer SC	0.69	Summer SC	0.00



Characterizing the Solar Heat Gains — **Portland Bldg**



South Facing		East Facing		West Facing		North Facing		Horizontal	
Area	3,213	Area	3,213	Area	3,213	Area	3,213	Area	0
Ag,s/Af	1%	Ag,e/Af	1%	Ag,w/Af	1%	Ag,n/Af	1%	Ag,h/Af	0%
Winter SC	0.95	Winter SC	0.95	Winter SC	0.95	Winter SC	0.95	Winter SC	0.00
Fall & Spring SC	0.95	Fall & Spring SC	0.95	Fall & Spring SC	0.95	Fall & Spring SC	0.95	Fall & Spring SC	0.00
Summer SC	0.95	Summer SC	0.95	Summer SC	0.95	Summer SC	0.95	Summer SC	0.00



CHARACTERIZING THE SOLAR HEAT GAINS

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.

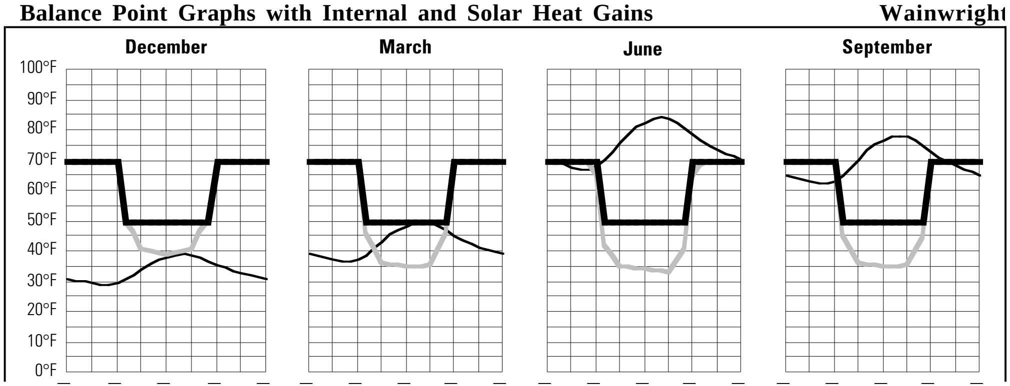
The average shading coefficient for east and west walls is then calculated to be SC=(.60x.9)+(.40x.2)=0.62

for the north wall, the courtyard elevation represents 30% of the total and the resulting average SC=0.69.

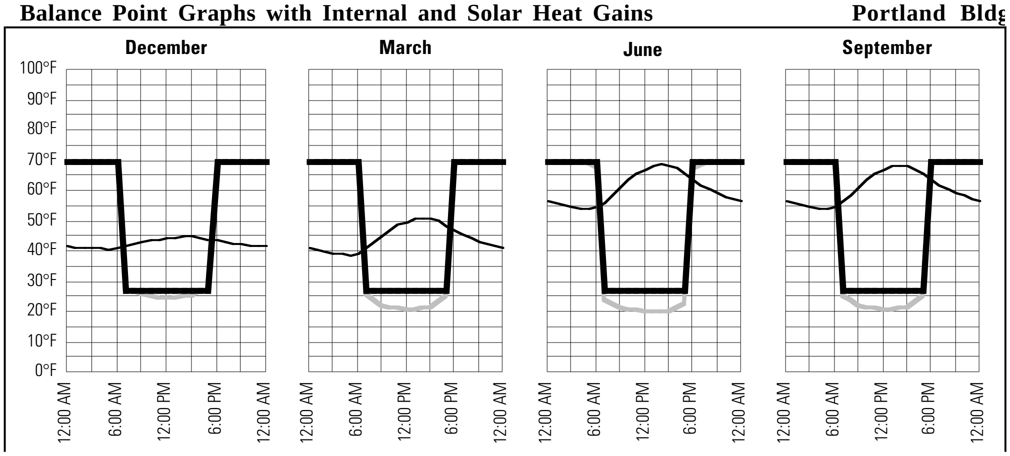
The Portland Building is known to have 1/4" clear glass SC=0.95 (see scale). Since the glass is close to the surface of the wall we wont assume any additional shading.

The solar gains charts present a complex profile that resists quick observations. The aggregate result of all of these solar gains through various orientations will be clearly visualized in the final balance point chart. For now notice that the area of glass per s.f. of floor (**A_g/A_f**) for each orientation is three to five times higher in the Wainwright than in the Portland building. This 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.

Balance Point Graphs with Internal and Solar Heat Gains **Wainwright**



Balance Point Graphs with Internal and Solar Heat Gains **Portland Bldg**



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 overheat-ing 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, lets 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.

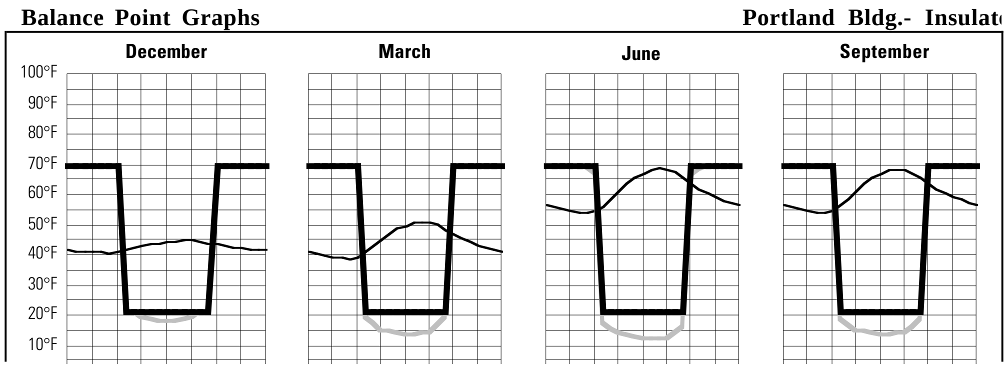
Alternates **D, E,** and **F** explore various lighting and glazing parameters to first establish their importance and then to imagine the best possible redesign of the building given its massing.

Alternate A: Increased Insulation

Add insulation to reflect actual construction: $\mathbf{U}_{wall}$=0.09, $\mathbf{U}_{roof}$=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..

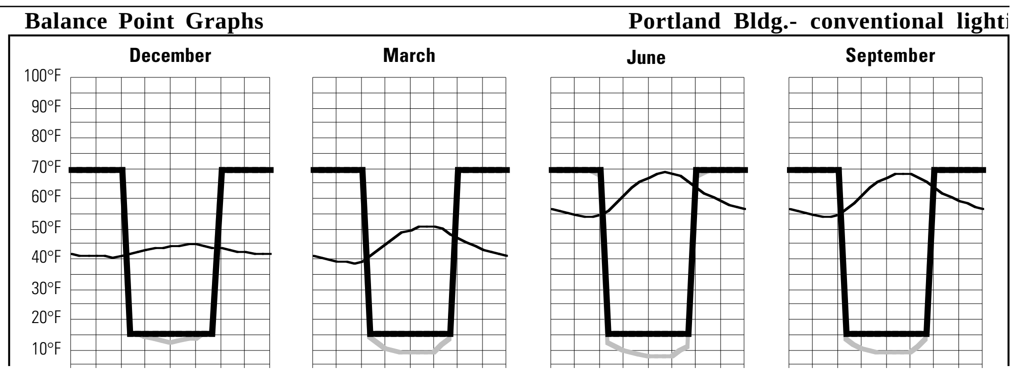
Adding insulation holds in more heat, pushing the balance point down from 27.2°F to 21.3°F while the building is occupied.



Alternate B: Increased Lighting Load

Assume energy efficient standards for late 1970's rather than the present. No daylighting. $\mathbf{Q}_{light}$=8.25 Btu/hr/s.f.

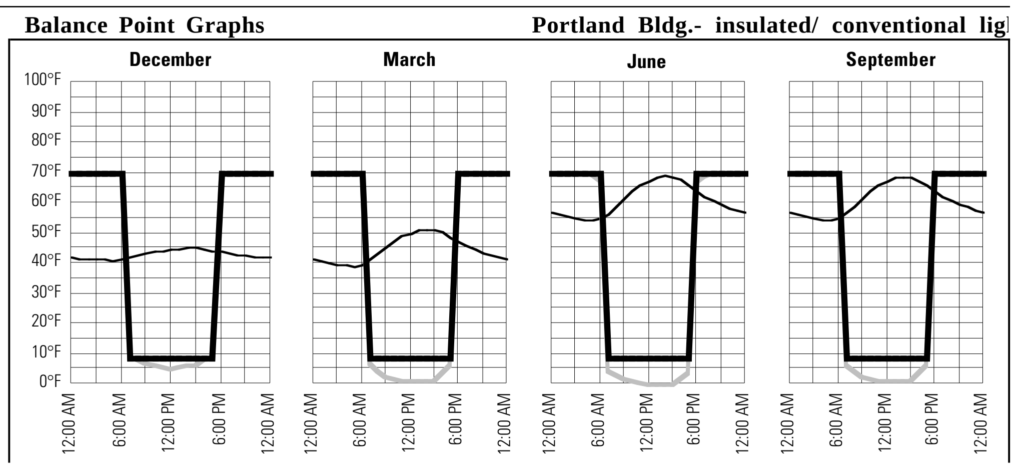
This change also reflects the probable construction. Increasing the lighting load has a noticeable impact on the internal gains, pushing the balance point down to 15.6°F while the building is occupied.



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.

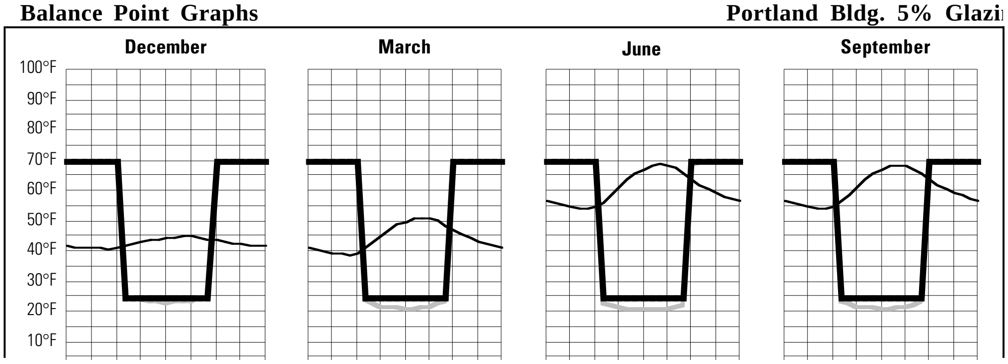
As built, the Portland building appears to be overheated by internal gains in all but the coldest months. The basic profile of the building hasn't changed. These added specifications have only amplified the fact that the building profile is dominated by internal loads.



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.

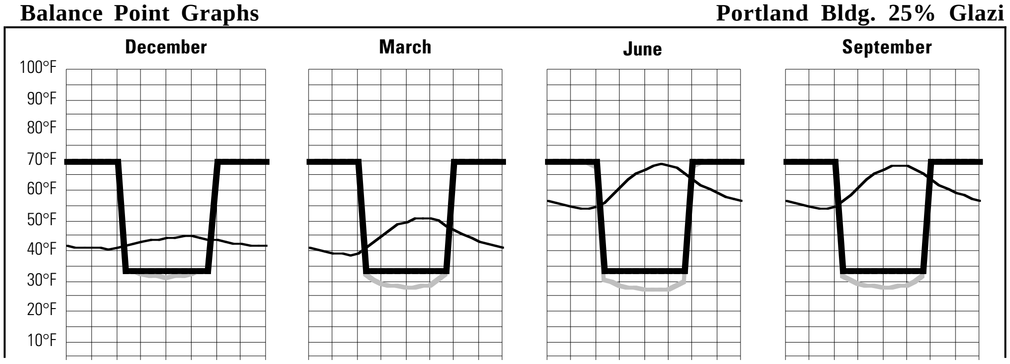
Balance Point Graphs **Portland Bldg. 5% Glazi**



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.

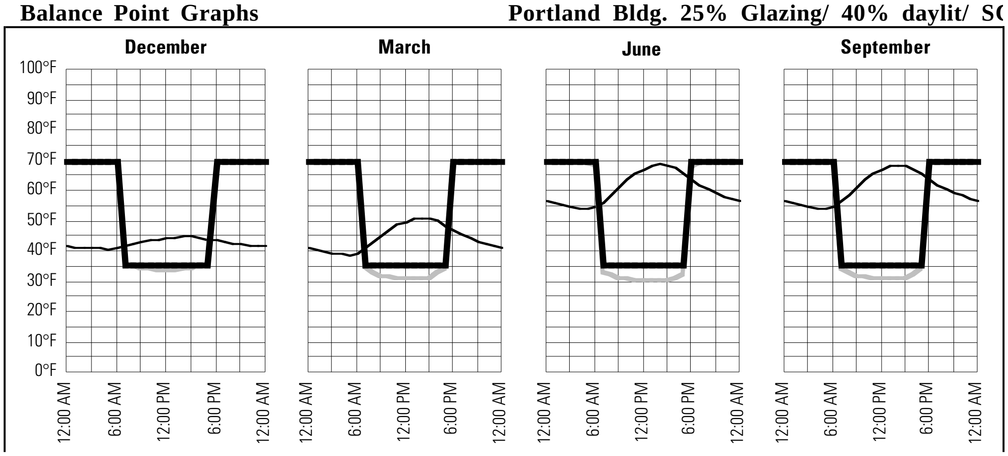
Balance Point Graphs **Portland Bldg. 25% Glazi**



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.

Balance Point Graphs **Portland Bldg. 25% Glazing/ 40% daylit/ SC**



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.'

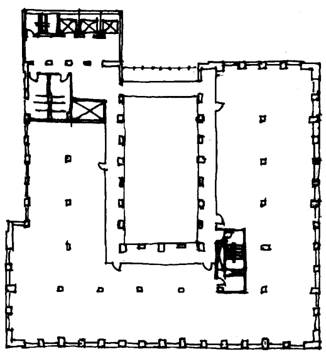


Figure 34: Typical floor plan, the Wainwright Building (now a part of the Wainwright State Office Complex) as renovated and expanded by Mitchell/ Giurgola, Architects in association with Hastings & Chivetta Architects, 1981. Adapted from *Progressive Architecture* 11:81 p.103-107.

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.

BUILDING BALANCE POINT
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.

Figure 35: Worker's housing, Manchester, New Hampshire. 19th Century

Figure 36: Habitat, Montreal, Canada. Moshe Safdie, Architect. 1967.

These two buildings stand in similar cold climates and strive to create a similar range of microclimates, but their approach to the variables of the balance point and their final fit with the climate are different. The worker's housing presents a compact mass with few openings, juxtaposed with airy summer porches. Habitat explodes mass into individually articulated units, each serving simultaneously as winter container and summer balcony for the unit above. By breaking up the compact form typical of pre-modern construction Habitat necessarily demands better envelope performance and/or higher fuel consumption.

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.

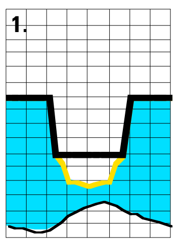
Table 1: Possible Outcomes of a Balance Point Analysis by Individual Season and over a Year, with Suggested Schematic Design Responses.

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



Always too cold
- Increase captured heat gains to minimize heating load.
- Decrease the rate of heat transfer between building and environment.

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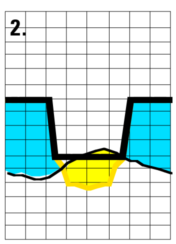
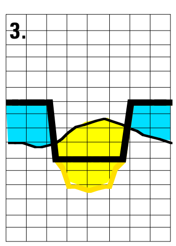
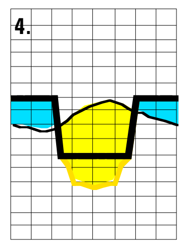


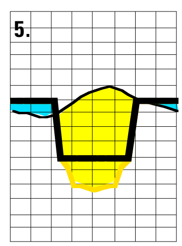
Too cold with some excess gains during the day
- Increase captured heat gains to balance losses.
- Manage daily swings, storing excess daytime gains to offset night losses.



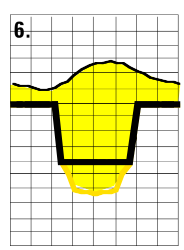
Potential balance between daily gains and losses
- Manage daily swings, storing excess daytime gains to offset night losses.



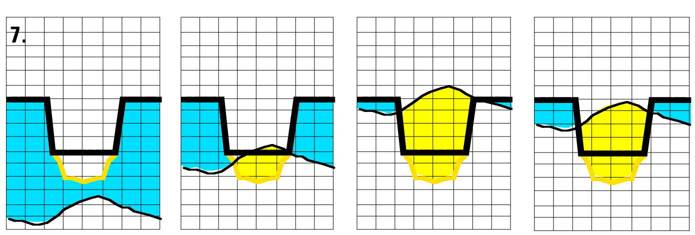
Too hot with good potential for ambient and night cooling
- Decrease captured heat gain to balance. Daytime venting possible.
- Manage daily swings, storing excess daytime gains to offset night losses.



Too hot with some potential for night cooling
- Decrease captured heat gain to balance. Note ambient temperature too hot for daytime venting.
- Manage daily swings, using night losses to offset excess daytime gains.



Always too hot
- Decrease captured heat gains to minimize cooling load.
- Increase insulation to separate mechanically cooled building from environment.



Building Swings Seasonally between different conditions
- Manage swings between months of excess gain and loss by incorporating dynamic responses to natural energy flows.
- Design for the largest load first.

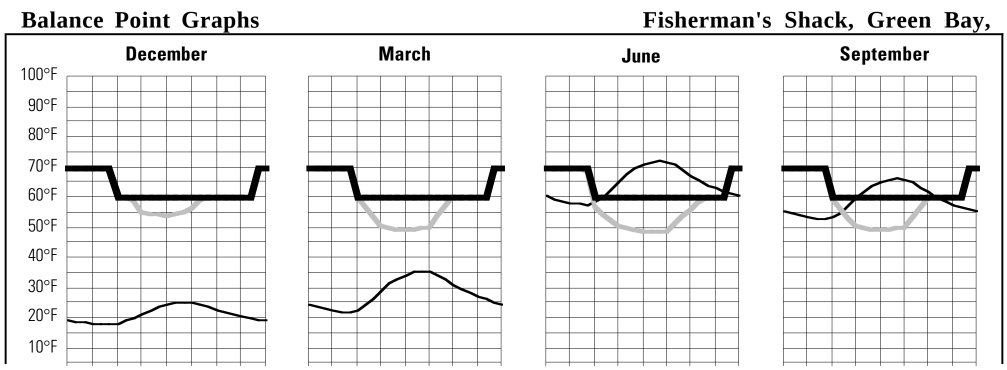


Figure 37: Alaskan Fisherman's Shack, Green Bay, WI: a 'Too Cold' Building Example (See **Figure 2**).

This small, poorly insulated house with even smaller windows is clearly too cold in December and March. Furthermore, internal gains depressing the balance point from 70°F to 60°F exaggerate the heat gain from lights, which would typically only be on in the early morning and evening.

INCREASING CAPTURED HEAT GAINS/ DRIVING DOWN THE BALANCE POINT

Lowering 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.

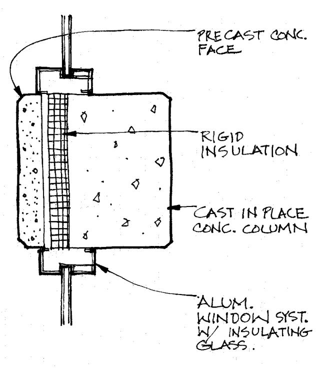


Figure 38: Column detail, School of Architecture and Urban Planning, University of Wisconsin- Milwaukee. Holabird and Root in association with Herbst Epstein Keller and Chadek Inc., Architects. 1991.

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.

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.

More fundamentally, the total rate of heat transfer across the envelope, $\hat{U}_{bldg,}$ not only considers the envelope in the abstract but as a function of the square footage of the building. If the building is cold, consider a more compact plan with a consequently lower skin/ volume ratio as a way of reducing the surface area loosing heat to the outside **(Figure 39)**.

Occupancy load design- Often, the relation between the number of people that the architect is asked to accommodate and the s.f. requirements for each seem beyond question. Is this always the case? If the building is always cold, consider grouping activities by acceptable temperature range, allowing a portion of the building to be cooler than the required core temperature. Does storage space, for example, need to be heated to the same degree as living or work space?

Figure 39: Midieval 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 loosing heat to the external environment.

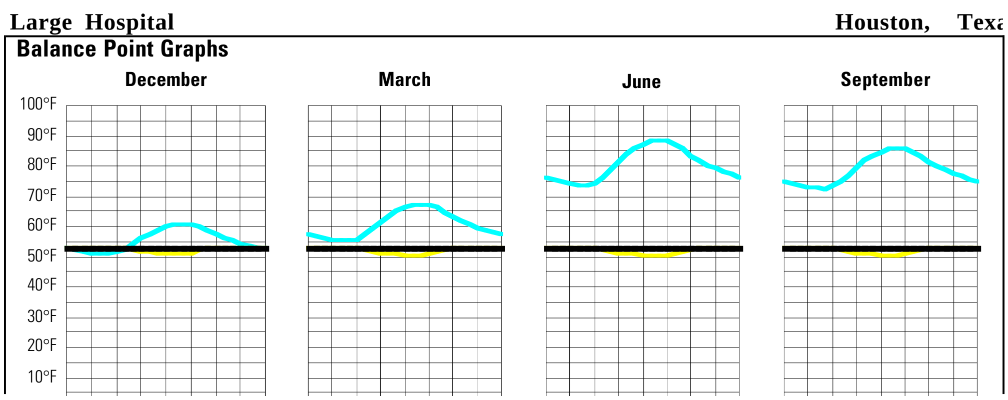
The lighting and equipment loads could also be increased to add heat to the space. Is this a good idea? No. Using less efficient lighting in order to heat a space undermines the larger goal of reducing energy consumption overall. At a minimum, that same energy content could be utilized more effectively 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 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.



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.

means for decreasing the amount of heat captured within the building. This may take the form of an open window in a small structure or an economizer cycle flushing fresh air through the ductwork of a large building.

Passive ventilation can be encouraged through design that orients the building to capture prevailing breezes and to allow them to pass freely through, for example. Mechanically assisted ventilation does require often substantial amounts of fan power and so is not as energy efficient as passive ventilation.

Thermal storage capacity is generally unhelpful in overheated situations. Often, buildings in hot climates are designed to be as thermally light as possible, so that any drop in the external temperature in the evening will be mirrored by a drop in the indoor air temperature. Once again there are strategies that would have the opposite effect, such as creating a large thermal mass insulated from the outside and meant to be chilled by less expensive off-peak electricity at night to keep the interior comfortable through the day.

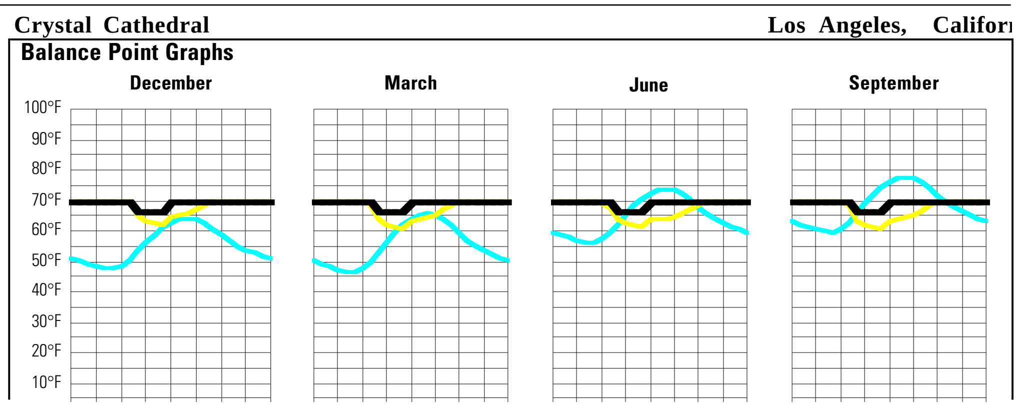


Figure 42: The Crystal Cathedral: a 'Daily Swing' Building Example

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.

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.

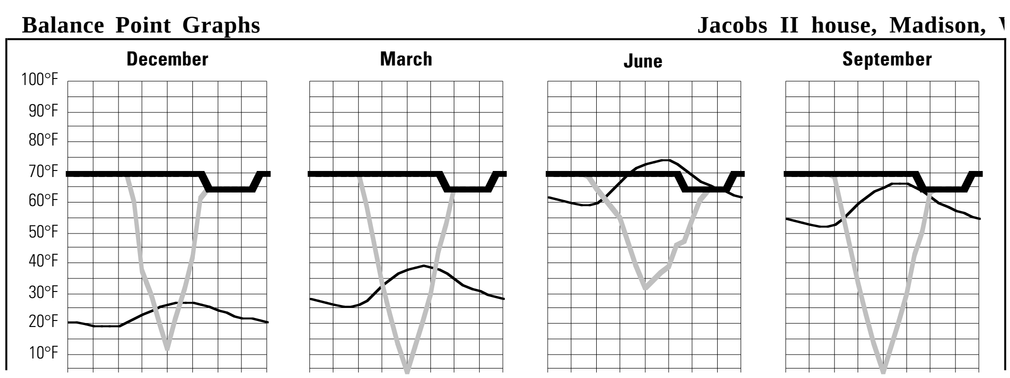


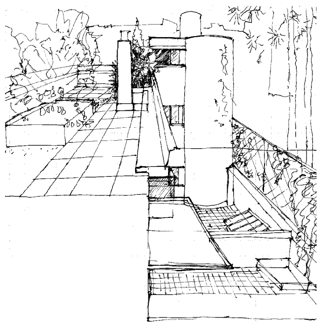
Figure 43: The Jacobs II House: a 'Seasonal Swing' Building Example

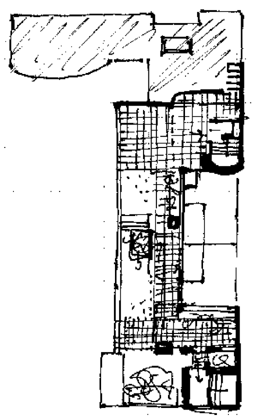
The house has been modeled to show occupancy gains in the evening. One could similarly construct a profile of the early morning gains.

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

Figures 44, 45: Roof garden and enclosed courts- perspective and roof plan sketches. Maison La Roche-Jeanneret, Auteuil, France. Le Corbusier and Pierre Jeanneret, Architects. 1923-24.

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.

Figure 47: Plantation porch, Natchitoches, Louisiana.

for much of the year, the shaded porch provided the best access to breezes and hence the most livable space in the hot and humid climate of central Lousiana.

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.

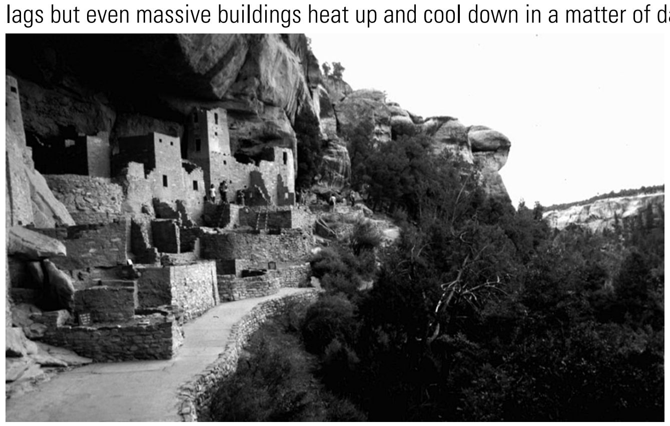


Figure 48: Anasazi cliff dwellings, Mesa Verde, Colorado.

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.

BUILDING BALANCE POINT
Energy Codes, Degree Days and the Balance Point

Table 2 Degree-Day and Monthly Average Temperatures for Various Locations

Site	Variable Base Heating Degree-Day, °F · days[a]					Monthly Average Outdoor Temperature, °F[b]											
	65	60	55	50	45	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Los Angeles, CA	1245	522	158	26	0	54.5	55.6	56.5	58.8	61.9	64.5	68.5	69.6	68.7	65.2	60.5	56.9
Denver, CO	6016	4723	3601	2653	1852	29.9	32.8	37.0	47.5	57.0	66.0	73.0	71.6	62.8	52.0	39.4	32.6
Miami, FL	206	54	8	0	0	67.2	67.8	71.3	75.0	78.0	81.0	82.3	82.9	81.7	77.8	72.2	68.3
Chicago, IL	6127	4952	3912	2998	2219	24.3	27.4	36.8	49.9	60.0	70.5	74.7	73.7	65.9	55.4	40.4	28.5
Albuquerque, NM	4292	3234	2330	1557	963	35.2	40.0	45.8	55.8	65.3	74.6	78.7	76.6	70.1	58.2	44.5	36.2
New York, NY	4909	3787	2806	1980	1311	32.2	33.4	41.1	52.1	62.3	71.6	76.6	74.9	68.4	58.7	47.4	35.5
Bismarck, ND	9044	7656	6425	5326	4374	8.2	13.5	25.1	43.0	54.4	63.8	70.8	69.2	57.5	46.8	28.9	15.6
Nashville, TN	3696	2758	1964	1338	852	38.3	41.0	48.7	60.1	68.5	76.6	79.6	78.5	72.0	60.9	48.4	40.4
Dallas/Ft. Worth, TX	2290	1544	949	526	250	45.4	49.4	55.8	66.4	73.8	81.6	85.7	85.8	78.2	68.0	55.9	48.2
Seattle, WA	4727	3269	2091	1194	602	39.7	43.5	45.5	50.4	56.5	61.3	65.7	64.9	60.6	54.2	45.7	42.0

Figure 49: "Degree Day and Monthly Average Temperatures for Various Locations" From ASHRAE (1993) p.28.6. Table 2. Reprinted with permission.

Degree day information is a common means of assessing local climate demands on a building. Note that the 'Variable Bases' of 65°F, 60°F, 55°F, etc.. are a range of typical residential balance points by another name.

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.

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.

VITAL SIGNS 1

BUILDING BALANCE POINT
Level 1 Protocol: Estimating the Balance Point from Visual Observation

OVERVIEW

This protocol allows you to evaluate net building heat gains and losses and estimate the building balance point in a "snapshot" visit to a building. Using the protocol worksheets in sequence, you will:

1. Establish the basic building data, floor area and enclosure area.
2. Estimate the building's enclosure area and thermal performance.
3. Estimate the building's internal heat generation due to occupancy.
4. Estimate the building's solar gains.
5. Estimate the building's Balance Point temperature.
6. Evaluate the net building energy gains and losses.

This Protocol relies on a series of "scales" depicting plausible ranges of internal and solar heat gains and enclosure heat transfer rates. Based on site observations, you will select appropriate values from each scale to estimate each balance point variable. These estimates provide the necessary information for a rough calculation of the building balance point and an evaluation of the building's thermal performance.

Each step of the protocol evaluates a particular flow path for energy exchange between the building and the environment. The enclosure evaluation has five scale worksheets (wall, roof, glazing, ground loss, and ventilation) and a summary page to enter your selections on. The occupancy evaluation has three scale worksheets (occupants, lighting, and equipment) and a summary page to enter your selections on. the solar gain evaluation has one scale worksheet (shading coeficients) and a two page summary. It also includes a page of instructions for doing the calculations by hand if you are not using the enclosed Excel workbook. Finally, a page of resulting Balance Point graphs chart the resulting building performance over the course of a year.

COMPUTER TOOLS

A dual platform Excel workbook consisting of an add in Macro **solar.xla** (containing functions and climate data) and worksheet **bpproto1.xla** (containing formatted entries for the balance point worksheets)

The protocol package does include an Excel workbook formatted for either Mac or PC. This workbook allows you to work through the calculations involved quickly and print out the final graphics. While these simple calculations and graphics can also be done by hand, we strongly recommend the use of the computer, even if you are unfamiliar with Excel. The strength of the balance point as a concept is in the way that it relates all of the major energy flows within a building to each other and to the overall fit of the building to its climate. These interrelationships can best be explored by quickly testing out different values for each of the variables, which the computer tools make effortless. (See the Appendix for set up instructions)

SITE VISIT PREPARATION

Bring sketching/ writing instruments and a hard surface such as a clipboard.

Bring a tape measure and calculator to assist you in doing simple area takeoffs and a camera to assist your visual memory (optional).

Fill in any information that you can before going out into the field. Roughing in the required sketches beforehand from available information is one way to make field sketching easier and more accurate. This allows you to use the site visit to verify and add detail to the information that you already have.

BASIC BUILDING DATA

YOUR NAME

DATE AND TIME OF VISIT

BUILDING NAME AND LOCATION

ARCHITECT AND YEAR BUILT

BUILTING THERMOSTAT SETTING

Record the average setting on the thermostat.(The desired indoor air temp.) If undure, assume 70°F.

THERMOSTAT (°F.)

BUILDING OCCUPANCY SCHEDULE

Record the period of each day through a typical week that the building is occupied. Make note of any seasonal variations in use.

AVERAGE STARTING TIME

AVERAGE ENDING TIME

BUILDING FLOOR AREA

PRESENTATION FORMAT TO BE DETERMINED BY INSTRUCTOR

Sketch the building footprint and estimate its perimeter and area. If the building has floors of different shapes and sizes, sketch and determine the area for each floor. Insert the perimeter length and total floor area in the spaces provided.

PERIMETER (L.F.) L_{PERIM} =

NUMBER OF FLOORS

AREA PER FLOOR

TOTAL FLOOR AREA (S.F.) A_{FLOOR}

BUILDING ROOF AND HORIZONTAL GLAZING AREA

PRESENTATION FORMAT TO BE DETERMINED BY INSTRUCTOR

Sketch the building roof plan and estimate the roof area. If the building has any skylights or horizontal glazing, estimate the glazed area. Insert the glazed area and net roof area in the spaces provided.

GROSS ROOF AREA (S.F.)

GLAZING AREA-HORIZONTAL (S.F.) A_{GLZ},H

NET ROOF AREA (S.F.) A_{ROOF}

BUILDING WALL & GLAZING AREA

PRESENTATION FORMAT TO BE DETERMINED BY INSTRUCTOR

Sketch the building's elevations and their approximate dimensions. Estimate the total S.F. of wall area and the amount of that total that is glazed on each elevation. Record the information in the spaces provided.

Subtract the total glazing area from the total wall area to arrive at the Net Wall Area A_{WALL} .

GLAZING AREA-SOUTH (S.F.) A_{GLZ},S

GLAZING AREA-EAST (S.F.) A_{GLZ},E

GLAZING AREA-WEST (S.F.) A_{GLZ},W

GLAZING AREA-NORTH (S.F.) A_{GLZ},N

GROSS WALL AREA (S.F.)

GLAZING AREA-TOTAL (S.F.) A_{GLZ}

NET WALL AREA (S.F.) A_{WALL}

A RULE OF THUMB

For an alternate method of producing a rough estimate of the R value of an assembly, use the R value of the insulation layer only. Thermal bridging in the assembly typically cancels out the added benefit of the layers of sheathing and finishes.

3.5" fiberglass: R= 11
5.5" fiberglass: R= 19
3.5" blown in mineral fiber: R=11
1" molded bead polystyrene: R= 3.8
1" extruded polystyrene: R= 5.0
1" foil-faced polyisocyanurate: R= 7.2

THE LAW OF DIMINISHING RETURNS

Doubling the R value of a wall or roof assembly cuts the heat transfer for that component by half. To cut the heat loss through an R=5 wall (U=0.20) by half, increase its insulative value to R=10 (U=0.10). Now to cut the heat loss of that R=10 wall by half, you must again double its insulating value to R=20 (U=0.05).

Each step takes twice the effort and gives back half the return. At some point, the wall or roof is no longer the weak link in the chain and money is better spent on higher performance glazing or ventilation strategies.

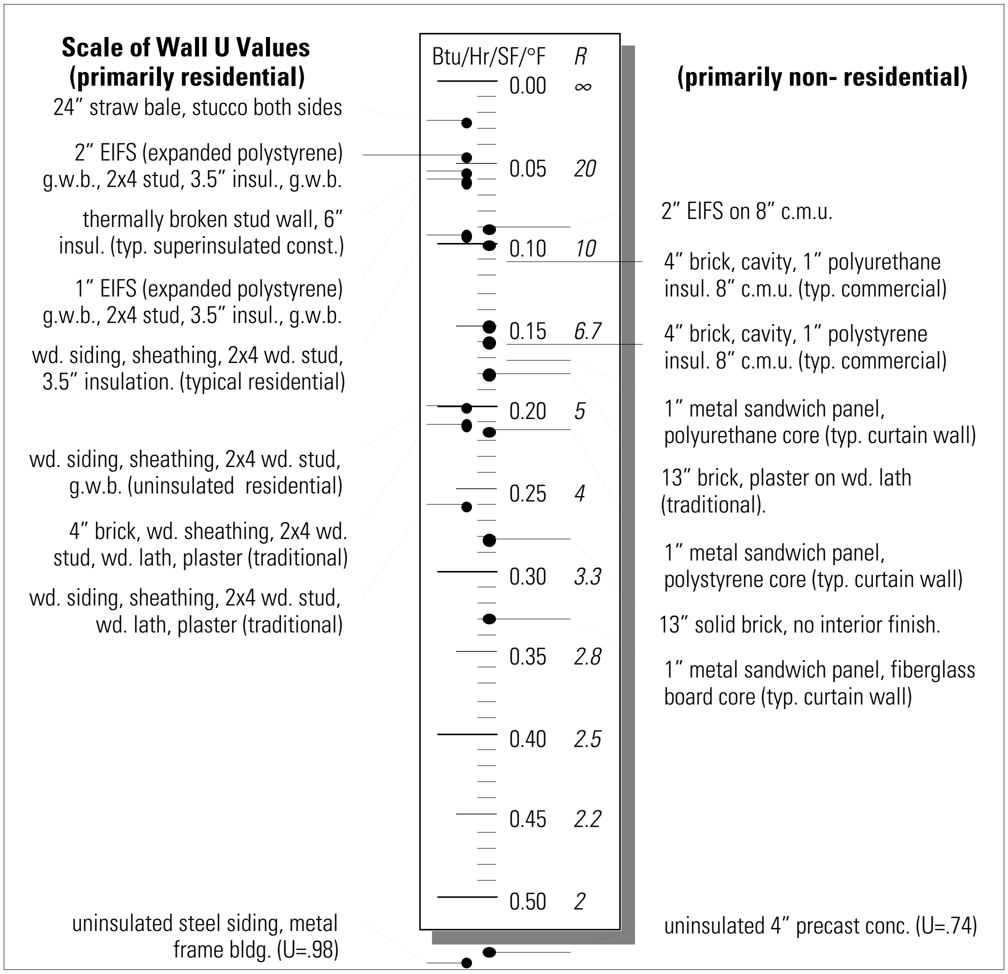
The first small increase in R value makes the biggest difference. If you are looking at a building with little or no insulation, the effect of an error in selecting a U value will be greater than for a building with a higher level of insulation. To see if this effects the outcome, test a high and low value.

PARTY WALLS

Walls shared with other conditioned structures are assumed to not transfer heat. They are not exterior walls and do not figure into the balance point calculation.

WALL HEAT TRANSFER RATE ~ U_{WALL}

The scale below gives U values for common building wall constructions. Equivalent R values are shown for your information. (U values for assemblies are determined by adding the resistances (R values) of each component and taking the inverse of the total resistance to be the total conductance. **$U=1/\sum R$**.) Sample values are drawn from the *ASHRAE Handbook of Fundamentals*, 1993 ed., Chapter 26, Table 19, and for traditional construction from Harding and Willard, *Heating , Ventilating and Air Conditioning*, N.Y.: John Wiley and Sons, 1937. Straw bale value undocumented.



NOTES:

TASK :

Describe the wall construction and estimate its U value using the ruler above as a guide. Mark the scale with your choice and fill in the U_{wall} box below. If you are unsure of the wall construction, make an educated guess of the most likely wall type. If there is more than one wall type, pick the most common.

WALL U-VALUE (BTU/HR/SF/°F) U_{WALL} | |
|---|

20TH C. INSULATION STANDARDS

While the energy crisis of the 1970's is the largest landmark in the general rise of the well insulated envelope, guessing the amount of insulation in a wall or roof based on the date of construction is more difficult than that. Practices will vary based on the climate and on the building type as well as by era.

• As early as the 1930's, engineering textbooks argued for the financial advantages of insulated construction. Still, the dominant reason for improving performance until the energy crisis of the 1970's was for improved comfort. In traditional construction, plaster or wall paper finishes offered a major comfort advantage by increasing the wall's R value and cutting down on infiltration.

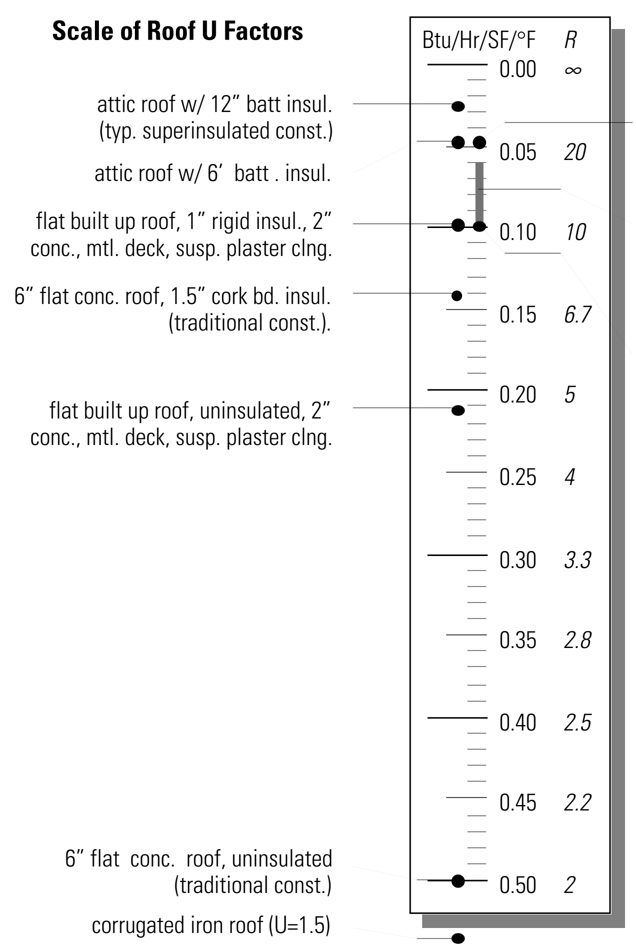
• In the 1950's the introduction of air conditioning prompted better envelope construction in hot climates. The spread of A/C also generated a large demand for electricity, and to balance their summer and winter loads, electric utilities aggressively marketed electric heating. To compete with less expensive oil heat, the utilities popularized the use of insulation to reduce utility bills in electrically heated houses.

• In response to the energy crisis, in 1974 HUD, FHA and other govt. agencies adopted construction standards promoting energy efficiency. By 1977, the first energy conservation standards were adopted in state building codes.

• Building codes continue to change, with the trends towards tighter performance standards that balance energy conservation with other issues such as indoor air quality.

ROOF HEAT TRANSFER RATE ~ U_{ROOF}

The scale below gives U values for common building roof constructions. Equivalent R values are shown for your information. The sample values are drawn from the *ASHRAE Handbook of Fundamentals*, 1993 ed., Chapter 26, Table 13, and for traditional construction from Harding and Willard, *Heating , Ventilating and Air Conditioning*, N.Y.: John Wiley and Sons, 1937.



Historical clues: notes on changing insulation standards

1961- “well insulated” roof.
1978- HUD minimum residential standard.

1978- ASHRAE 90.75 minimum standards adopted by 21 state codes. U= 0.06 to U= 0.10 depending on climate.

1961- “moderately insulated” roof.
1978- typical commercial design criteria.

NOTES:

TASK:

Describe the roof construction and estimate its U value using the ruler above as a guide. Mark the scale with your choice and fill in the U_{ROOF} box below. If you are unsure of the roof construction, make an educated guess of the most likely roof construction.

ROOF U-VALUE (BTU/HR/SF/°F) U_{ROOF}

IDENTIFYING GLAZING IN THE FIELD

Identifying the thermal properties of glazing can be difficult but there are telltale clues to look for:

• Thermal performance is generally not effected by visible tints or coatings. These will effect solar gain, as reflected in the shading coefficient scale.

• Multiple pane units can be identified by their edge spacer, a silver strip visible at the edge of the glass. Double glazing will have a single spacer. It will likely have one or more rows of perforations running along its length that allow moisture to be absorbed by the desiccant within the spacer. Triple pane glass will have two distinct spacers separated by the thickness of the glass.

• Suspended films may appear virtually invisible. The edge spacer will have a distinct seam running down its length that holds the film. Two separate seams indicate two suspended film layers.

• Low-E coatings are detectable using a small flame as a light source. The light a coated surface reflects back will be a slightly different color than the other surface reflections.

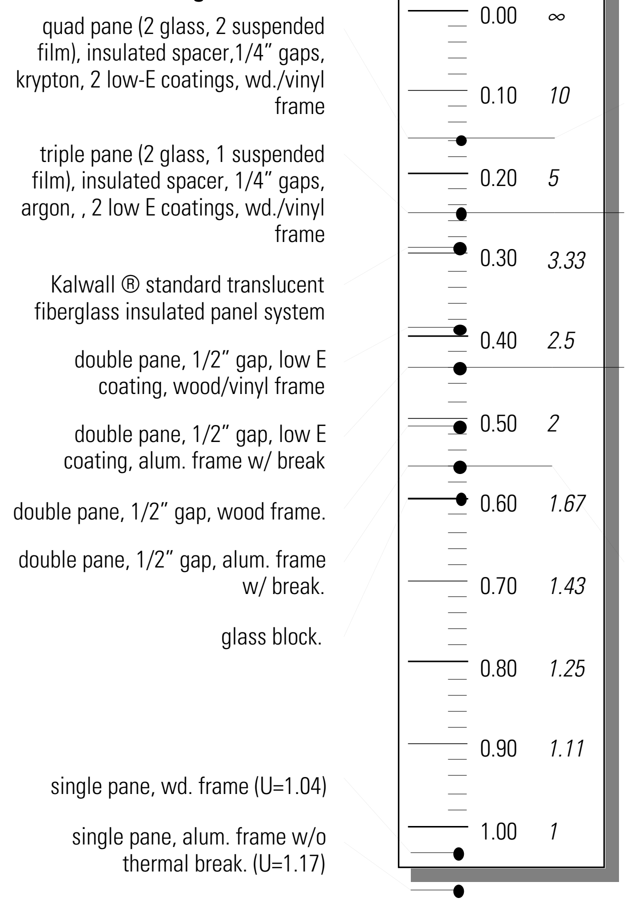
• No simple method exists to determine the fill gas of a glazing unit in the field.

For an in-depth discussion of glazing, including identification protocols, see the **Vital Signs Glazing Package**.

GLAZING HEAT TRANSFER RATE ~ U_{GLZ}

The scale below gives U values for common building glazing constructions. Equivalent R values are shown for your information. The sample values are drawn from the *ASHRAE Handbook of Fundamentals*, 1993 ed., Chapter 27, Table 5. Low-E values are for E=2.0 (an average value). All values for fixed windows. Operable windows will decrease perfromance of higher performance glazings by up to 0.05 Btu/Hr/SF/°F.

Scale of Glazing U values



Historical clues: notes on performance advances

1989- "Super Windows" first introduced by Southwall Technology

1978- Glazing units with suspended film for third, inner layer become available.

1979- Clear low-E coatings first become available. By 1993, low-E coatings control one third of residential and one fifth of commercial market.

1945- Sealed unit double glazing ("insulating glass") introduced.

NOTES:

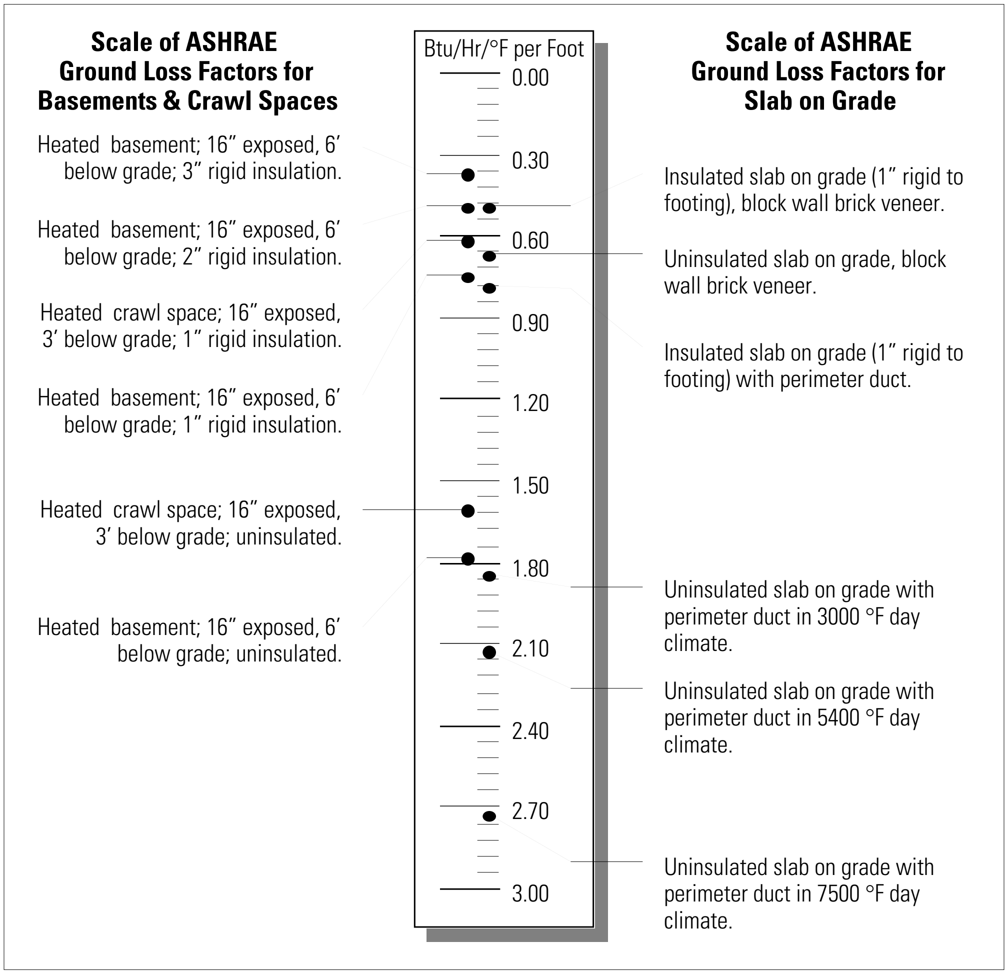
TASK:

Describe the glazing construction and estimate its U value using the ruler above as a guide. Mark the scale with your choice and fill in the U_{GLZ} box below. If you are unsure of the glazing type, make an educated guess of the most likely glazing type. If there is more than one glazing type, pick the most common.

GLAZING U-VALUE
(BTU/HR/SF/°F) U_{GLZ}

GROUND HEAT TRANSFER RATE ~ U_{GRND}

The scale below gives heat transfer values for common building base conditions. Note that the heat loss to the ground is calculated based on the perimeter length of the building in linear feet and not on the area of the footprint.



NOTES:

TASK:

Describe the way in which the building meets the ground and estimate its U value using the ruler above as a guide. Mark the scale with your choice and fill in the **U_{GRND}** box below. If you are unsure of the construction, make an educated guess of the most likely type.

GROUND U-VALUE
(BTU/HR/LF/°F) **U_{GRND}**

VENTILATION VS. INFILTRATION

The **ventilation rate** scale applies to tightly constructed homes and larger buildings that use mechanical systems to provide and regulate the amount of fresh air indoors. The **infiltration rate** scale applies to typical residential structures and small structures without ducted fresh air. Ventilation rates increase with greater occupancy and activity. Infiltration rates are dependent on the ratio of enclosure surface to building volume first and enclosure construction second. In a large building, heat transfer through infiltration will be unimportant overall, even if the building is poorly sealed.

VENTILATION AND INDOOR AIR QUALITY

Buildings built from the late 1970's to 1990 may have lower ventilation rates than those indicated...

VENTILATION AND HEAT RECOVERY

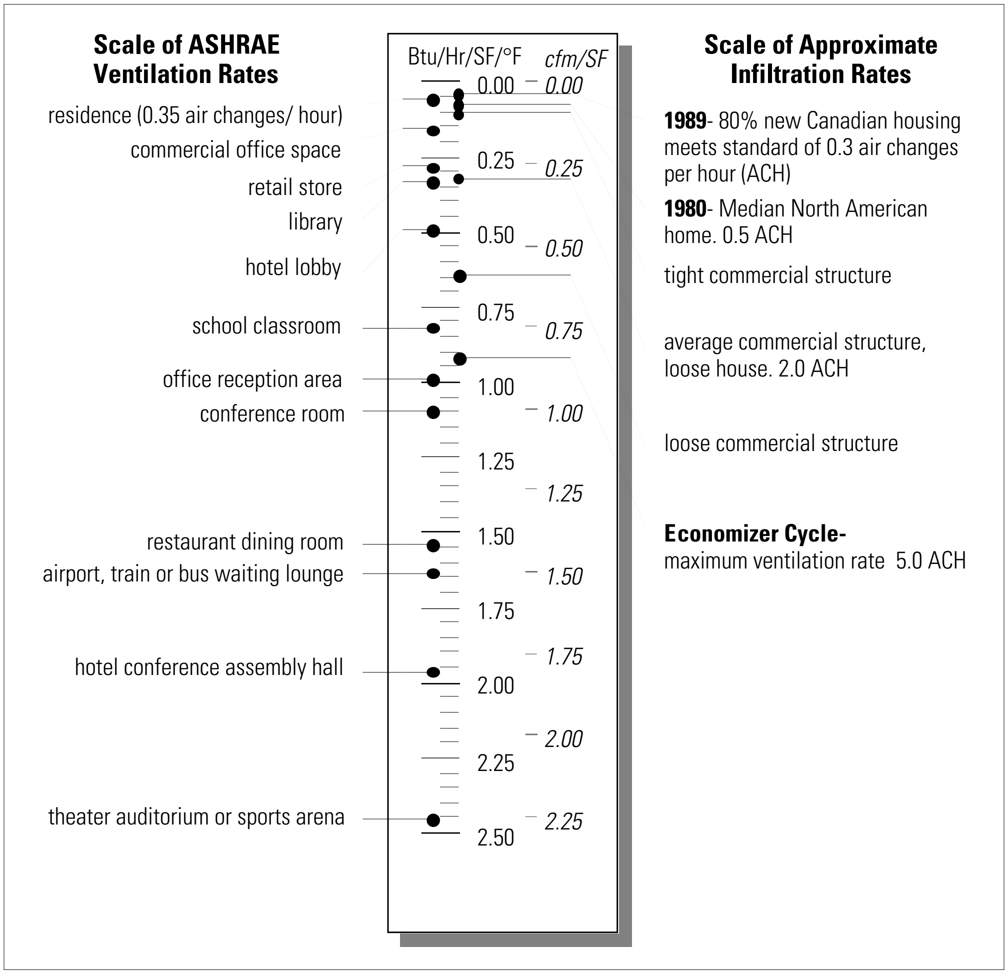
If a heat recovery system is used, the ventilation heat transfer rate can be reduced by 50% to 75%. ...

EFFICIENT MECHANICAL COOLING USING AN ECONOMIZER CYCLE

In a building with a ducted ventilation system, an economizer cycle can be used to circulate 100% ambient air through the building when the building requires cooling and the ambient air temperature is below the desired indoor air temperature. A max. rate of 5.0 ACH is given on the scale. (?) Distributing the air requires fan power, so this alternative is not 100% efficient (?)

VENTILATION HEAT TRANSFER RATE ~ $\hat{U}_{VENT}$

The scale below gives both typical building ventilation and infiltration rates per square foot of floor (cfm/SF) converted into equivalent ventilation heat transfer rates (Btu/Hr/SF/°F) for your use below. The sample ventilation values are drawn from data given in *ASHRAE Standard 62-1989*, *Ventilation for Acceptable Indoor Air Quality*, Table 2. The approximate infiltration rates are from the *1993 ASHRAE Handbook of Fundamentals, IP edition*, pp. 23.12-23.17.



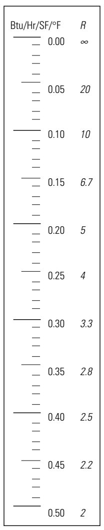
NOTES:

TASK:

Use the side of the scale that most adequately describes your building. Choose a ventilation or infiltration rate, mark the scale and record the heat transfer rate in the U_{VENT} box. For multiple occupancies assume the primary occupancy, or average the differences over the floor area.

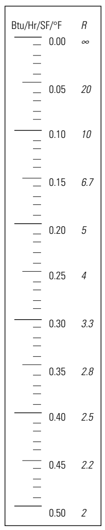
VENTILATION HEAT TRANSFER RATE (BTU/HR/SF/°F) U_{VENT}

Wall Heat Transfer Rate BTU/Hr/°F/SF



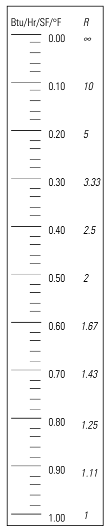
Uwall	
Net Wall Area SF	
Aw	

Roof Heat Transfer Rate BTU/Hr/°F/SF



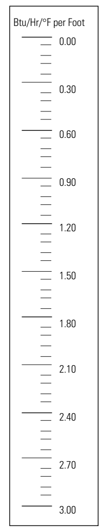
Uroof	
Net Roof Area SF	
Ar	

Glazing Heat Transfer Rate BTU/Hr/°F/SF



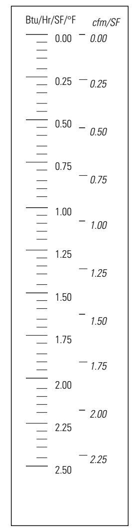
Uglzg	
Glazing Area SF	
Ag	

Ground Heat Transfer Rate BTU/Hr/°F/ft



Ugrnd	
Building Perimeter Ft	
Perimeter	

Ventilation or Infiltration Heat Transfer Rate BTU/Hr/°F/SF Floor



Ûvent	

Estimating the Building Enclosure Heat Transfer Rate

First, mark estimates the enclosure heat transfer rates on the appropriate scales (**Uwall**, **Uroof**, **Uglzg**, **Ugrnd** and **Ûvent**). Note estimates of the heat transfer rates and associated areas in their respective cells. Place the estimated gross floor area in the appropriate cell at right.

Second, for each heat flow path across the enclosure, modify the heat transfer rate so that it represents the rate of heat transfer per square foot of floor area rather than per unit enclosure area. This is acomplished by multiplying each enclosure U factor by its associated area and then dividing by the floor area. For example, for the enclosure wall:

Ûwall = (**Uwall** X **Aw**) ÷ **Af**

Note that heat transfer rates tied to the building floor area have a **^** symbol over the U. The ventilation rate is already estimated per unit floor area. The ground heat loss rate is multiplied by the perimeter and divided by the floor area. Enter your estimates in the appropriate cells at right and mark them on the bar graph. **Ûbldg**, the total enclosure heat transfer rate per unit floor area, is then estimated as the sum of the individual transfer rates.

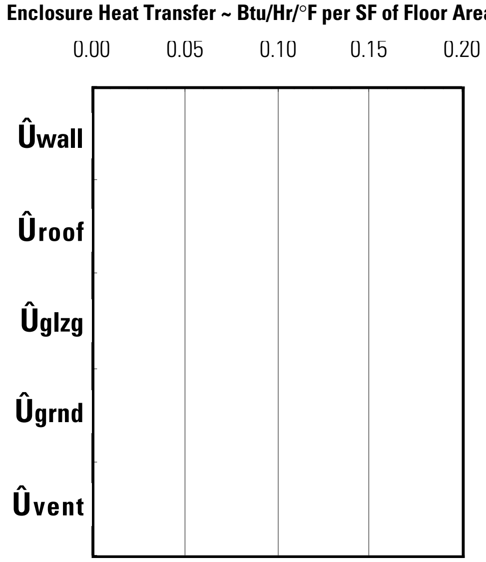
Gross Floor Area SF

Af	

Building Heat Transfer Rate Btu/Hr/°F/SF Floor

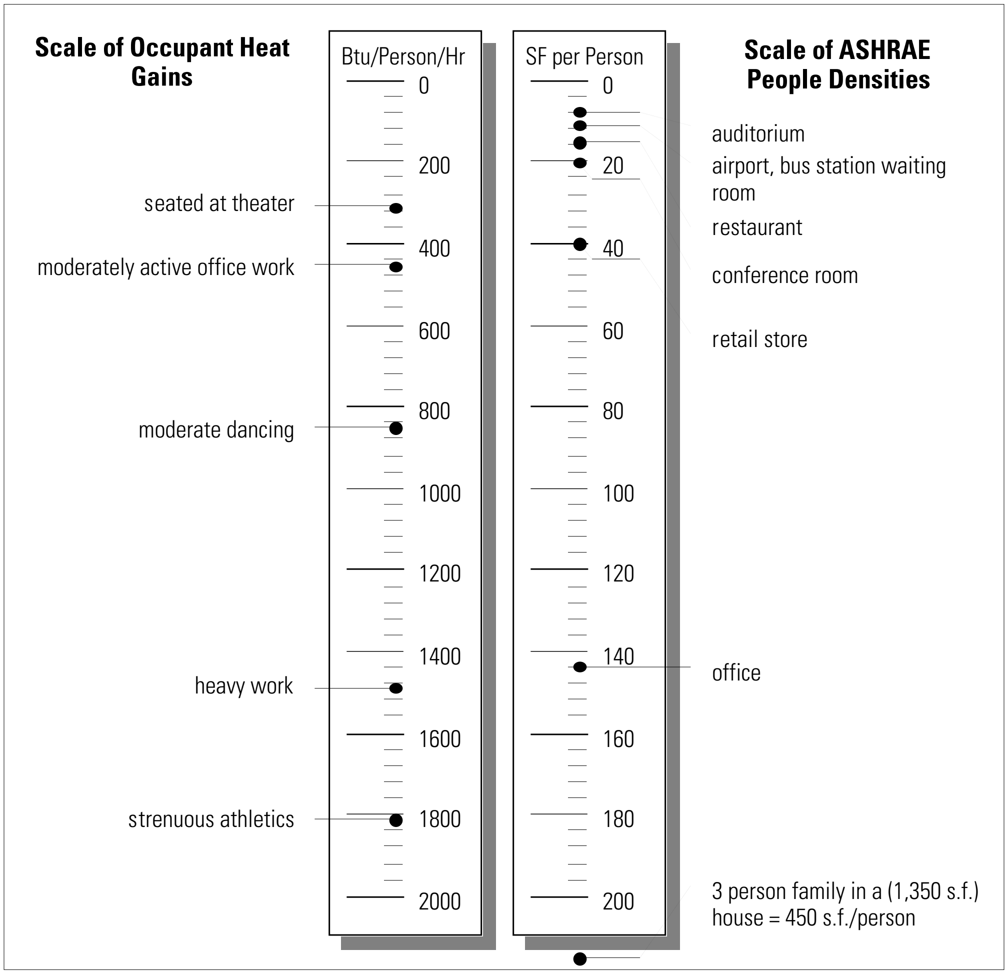
Ûwall	
Ûroof	
Ûglzg	
Ûgrnd	
Ûvent	
Ûbldg	

Enclosure Heat Transfer ~ Btu/Hr/°F per SF of Floor Area



HEAT GAIN RATE DUE TO OCCUPANCY~ Q_{PEOPLE}

The rulers below provide a range of estimates for both the heat generated and the S.F. per person assumed for various activities. The values for occupant heat gain rates as a function of activity are drawn from the ASHRAE Handbook of Fundamentals, 1993 ed., Chapter 26, Table 3. The values for occupant density are taken from *ASHRAE Standard 62-1989*, *Ventilation for Acceptable Indoor Air Quality*, Table 2. Note that the ventilation rates given on the Ventilation scale are a function of occupant density.



NOTES:

TASK:

Estimate the activity level of building occupants from observation and the scale above left. Estimate the floor area provided per occupant from the scale above right based on occupancy use or from site observations. Divide the heat gain rate per person by the occupancy density (square foot of floor provided per person).

OCCUPANT HEAT GAIN RATE (BTU/PERSON/HR) ______________

PEOPLE DENSITY (SF/PERSON) ÷______________

OCCUPANCY HEAT GAINS (BTU/HR/SF) $\boxed{}$

Q_{PEOPLE}

VERIFYING LIGHTING DENSITIES IN THE FILED

The best way to establish existing lighting densities is to make a quick count of the actual fixtures in use and the wattage of their lamps. For example: a 300 s.f. office with 24 40 watt fluorescent bulbs has a total of 960 watts of lighting. 960 watts/ 300 s.f. = 3.2 watts/s.f.. This converts to 10.9 btu/hr/s.f..

Some typical lamp wattages:
Standard 4' fluorescent - 40 watts
Compact fluorescent - 12 or 18 watts
Incandescent PAR lamps (typ. recessed spot)- 100- 500 watts
HID lamp- 250 or 400 watt.s

ACCOUNTING FOR DAYLIGHTING

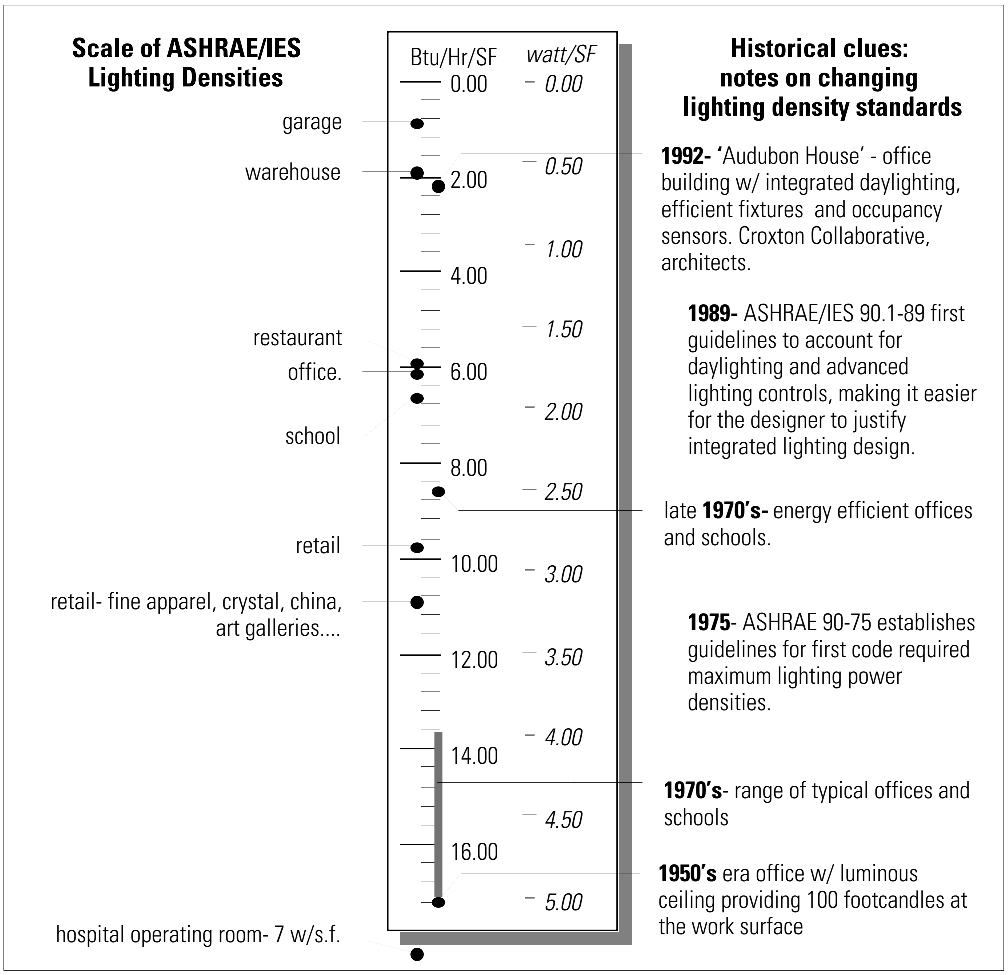
The use of daylight in place of electric light lowers the overall lighting density. Either count fixtures turned off due to daylight or assume that a useful amount of daylight penetrates x2 the height of the windows. Calculate the % of the plan that is daylit and reduce the lighting density by half of that percentage. If a school (6.5 Btu/Hr/SF) is 50% daylit, reduce the density by 25%. (6.5 x 0.75 = 4.9 Btu/Hr/SF).

LIGHTING STANDARDS BACKGROUND

Code required illumination levels have changed as electric lighting has evolved. The trend was for ever higher levels until the energy crisis and has since reversed. This can be seen in the levels of illumination required for office work: In 1918 the first code standard called for 3 fc minimum, as a supplement to daylight. By 1947 the minimum was 30 fc and daylight was ignored. By 1960 the minimum had risen to 100 fc.. The 1982 code standards reversed this trend and called for the current level of 50 fc..

HEAT GAIN RATE DUE TO LIGHTING~ Q_{LIGHT}

The scale below gives typical lighting densities for various occupancies in Btu/Hr/SF for your use below. Equivalent watts/SF are provided for reference (1 watt = 3.412 Btu/Hr.). The rates given are current recommendations for energy conserving design and older buildings may be significantly higher. The variability of actual lighting conditions make this scale a crude tool and field verification is recommended- see side-bar note.



NOTES:

TASK

Use the scale along with field observations to arrive at a lighting heat gain rate. Mark the scale and fill in the Q_{LIGHT} box below. For greater accuracy, you may choose to break the building into zones based on lighting, calculate the heat gain for each zone, and average the gain rates based on the s.f. of each zone.

LIGHTING
HEAT GAIN RATE
(BTU/HR/SF) Q_{LIGHT}

HEAT GAIN RATE DUE TO EQUIPMENT~ Q_{EQP}

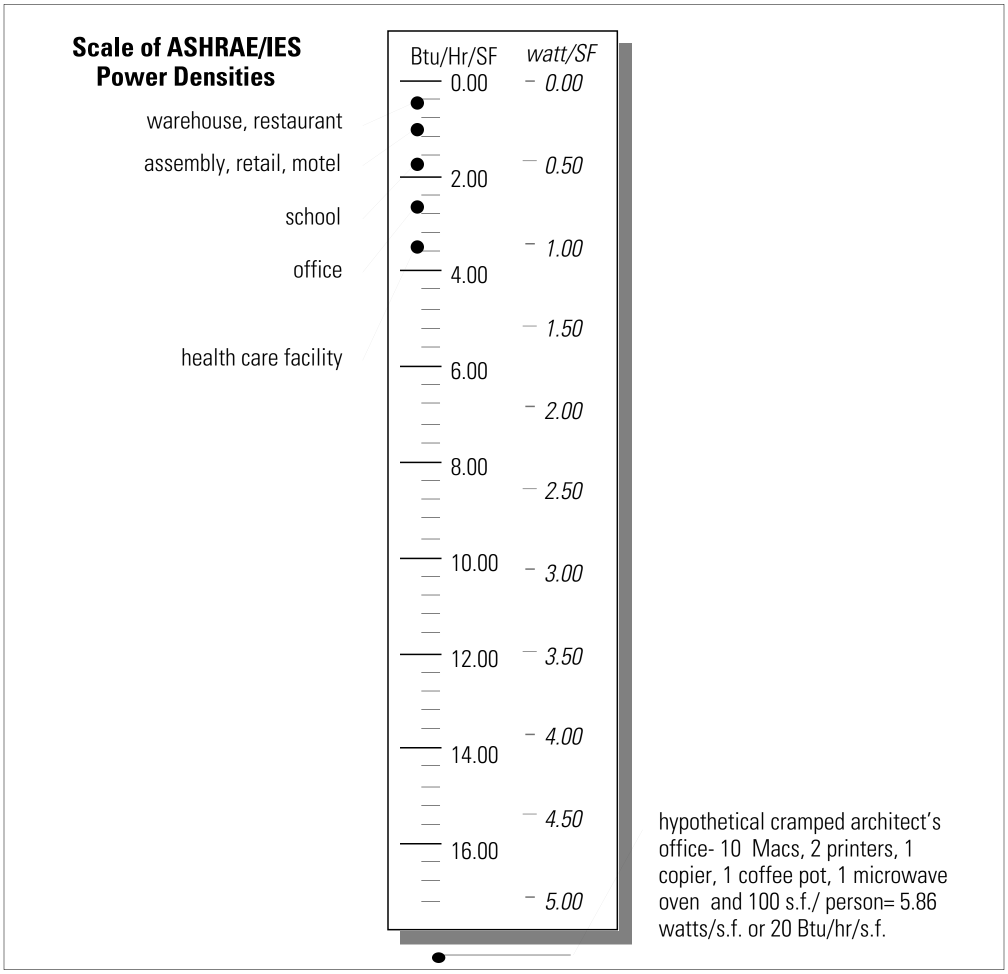
The scale below gives typical power densities (also known as plug loads) in Btu/Hr/SF for your use below. Equivalent watts/SF are provided for reference (1 watt = 3.412 Btu/Hr.). From *ASHRAE Standard 90.1-1989 Energy Efficient Design of New Buildings Except Low Rise Residential Buildings*.

VERIFYING POWER DENSITIES IN THE FIELD

The best way to establish existing plug loads is to make a quick count of the actual electrical devices in use in a space and their wattages, which are often listed on the equipment. Then simply divide the total wattage in use by the s.f. of the space to enter the scale on the watts/SF side.

Chapter 26.14 Table 9 of the *1993 ASHRAE Fundamentals Handbook* lists recommended heat gain rates for various types of office equipment in Btu/hr for sizing cooling loads. These are 1980 values and may not reflect current, more efficient electronics. Some typical values are:

Letter Quality Printer: 1,000 Btu/hr
Photocopier: 5,800 Btu/hr
Desktop computer: 300- 1,800 Btu/hr
Vending machine: 820- 940 Btu/hr
Coffee maker: 3,580 Btu/hr



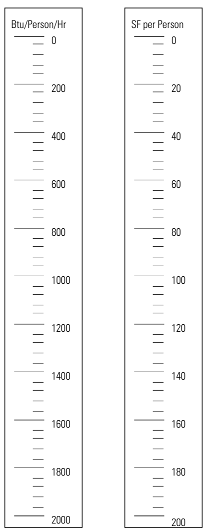
NOTES:

TASK:

Describe the equipment usage in the building due to occupancy. Estimate the equipment heat gain rate using the occupancy scale. Mark the scale and fill in the Q_{EQP} box below. Sample rates given are current recommendations for energy efficient design, observed rates may be higher or lower.

EQUIPMENT HEAT GAIN RATE (BTU/HR/SF) Q_{EQP}

Occupant Heat Gain Rate

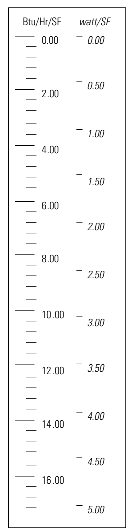


Activity Level | **People Density**

Qocc is estimated by dividing **Activity Level** by **People Density**.

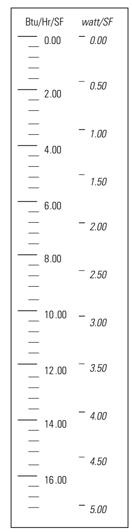
Qpeople

Lighting Heat Gain Rate



Qlight

Equipment Heat Gain Rate



Qequip

Thermostat & Schedule

T_thermostat is the average thermostat setting for the building for heating and cooling.

T_thermostat

Occupancy Start Time

t_start is the average time of day the building is occupied (ignore

t_start

Occupancy End Time

t_end is the average time of day the building becomes unoccupied (ignore weekends).

t_end

QIHG, the Building Internal Heat Gain Rate

QIHG is estimated as the sum of **Qpeople**, **Qlight** and **Qequip**. **QIHG** is given in Btu of heat generated per hour per square foot of floor area.

QIHG

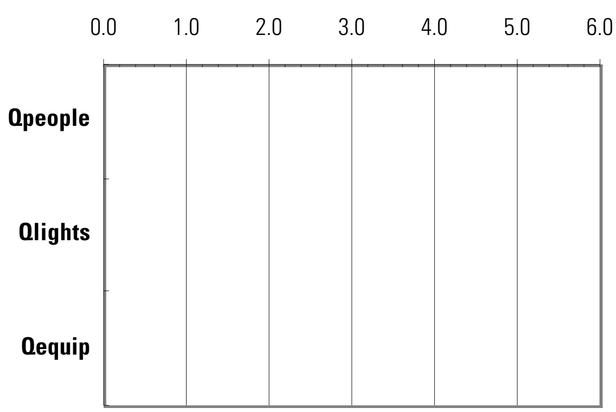
Estimating the Internal Heat Generation Rate & Balance Point

First, mark the estimated values of **Activity Level**, **People Density**, **Qlight** and **Qequip** on the appropriate scales. Enter the **T_thermostat**, and the occupancy schedule, **t_start** and **t_end**.

Second, estimate **Qpeople** as described and plot all three sources of internal heat generation on the bar graph at right. Place values of heat generation rates on the horizontal scale as appropriate for the magnitude of the estimated heat generation rates.

Finally, estimate **QIHG**, **DTocc** and **T_balance** in the manner described at right and enter the values into the appropriate cells.

Sources of Internal Heat Generation



Occupancy Temperature Difference

DTocc, the temperature difference across the enclosure balanced by internal heat gains, is estimated by dividing **Ubldg** into **QIHG**.

DTocc

Building Balance Point Temperature

T_balance, the building balance point temperature during occupancy, is estimated by subtracting **DTocc** from the building thermostat temperature, **T_thermostat**.

T_balance

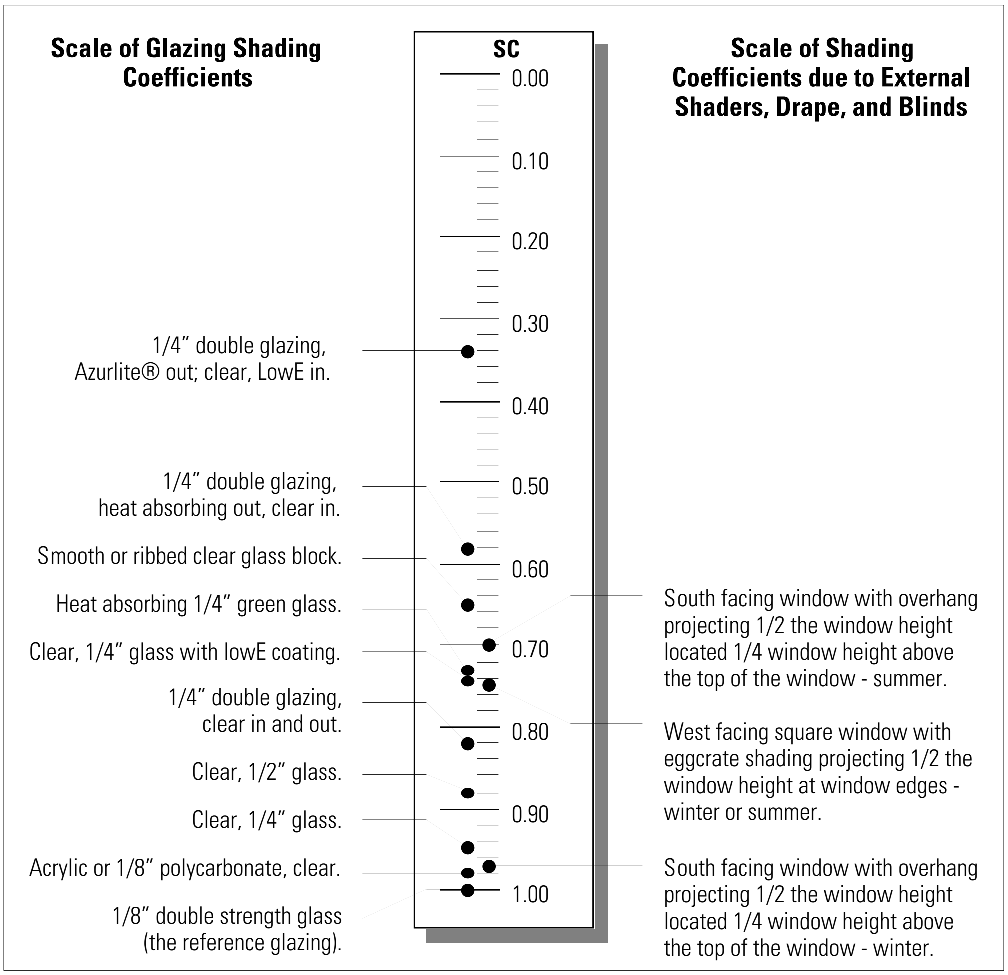
REDUCTION IN SOLAR PENETRATION DUE TO SHADING

Sample values for various types of glazing are drawn from Window 4.1 (?)

SHADING COEFFICIENT EXPLAINED

The Shading Coefficient (SC) is a reduction factor to account for various ways that the amount of solar energy passing through an aperture is reduced. The terminology is misleading. Think of them as transmission coefficients, since a SC of 0.7 means that 70% of the available energy is being transmitted. SC's are relative to a reference glazing of a standard 1/8" sheet of glass. This fact is a relic of earlier engineering practice. A SC of 0.2 means that 20% of the energy that would pass through a single pane window is passing through this window. Multiple SC's may apply to a given situation. A window with an SC of 0.7 due to external shading may also have a low-e coated glazing with an SC of 0.74. The SC for the aperture would then be 0.7 x 0.74 = 0.518.

SC's are a crude measure. At best, they should help you develop an intuitive feel for how much of the available sunlight is making it inside for each season and each window design, from none to all of it.

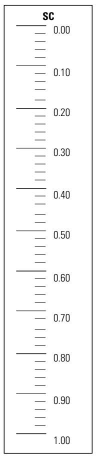


NOTES:

TASK:

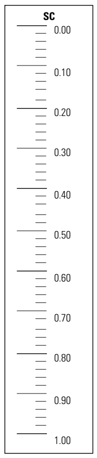
Describe the apertures and any shading strategies present. Estimate the Shading Coefficient **SC** for each orientation and season and fill these values in directly in the Excel workbook or on the hand calculation worksheet on the following page.

South Facing Shading Coefficient



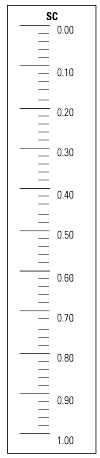
Area	
Ag,s/Af	
Winter SC	
Fall & Spring SC	
Summer SC	

East Facing Shading Coefficient



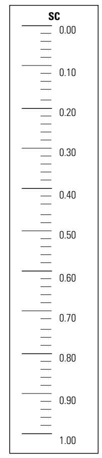
Area	
Ag,e/Af	
Winter SC	
Fall & Spring SC	
Summer SC	

West Facing Shading Coefficient



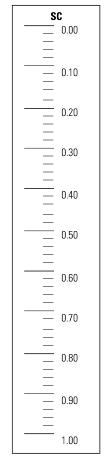
Area	
Ag,w/Af	
Winter SC	
Fall & Spring SC	
Summer SC	

North Facing Shading Coefficient



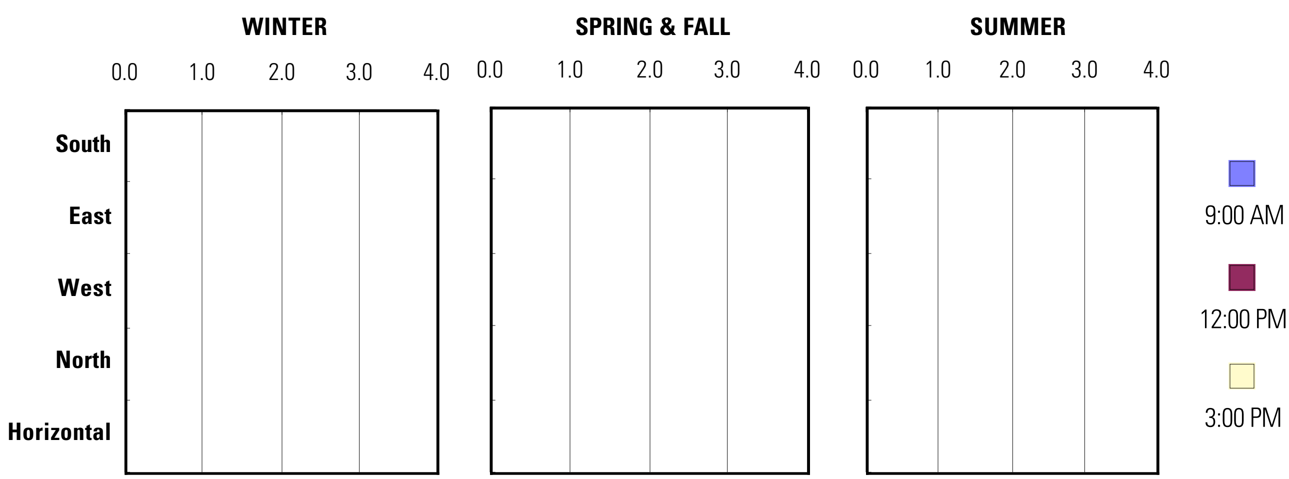
Area	
Ag,n/Af	
Winter SC	
Fall & Spring SC	
Summer SC	

Horizontal Shading Coefficient



Area	
Ag,h/Af	
Winter SC	
Fall & Spring SC	
Summer SC	

Average Solar Gains ~ BTU per Hour per Square Foot of Floor



MODELLING SOLAR GAINS

Since the amount of energy available from the sun fluctuates seasonally and with the weather, and since it can be further manipulated by design, solar gain quickly becomes a complex question. The climate data used here is based on weather data that accounts for average cloud cover for each location and month.

The designer can control how much solar gains are admitted to the building by a variety of strategies, from fixed or movable shading devices to invisible low-e coatings on the glass. Solar radiation is the primary and most dynamic natural energy flow that architecture can manipulate to alter the balance point. To help account for this design flexibility, the glazing scales allow for different SC values for each season and orientation.

While the authors recommend the use of the BPgraph.xla spreadsheet to estimate the building balance point, hand estimation is possible. The tables on this page permit entry of the scading coefficient for each glazing surface in the shaded cells. The solar gain per square foot of floor for each orientation at each hour and season is then given as a product of the shading coefficient, solar gain for standard glass for the appropriate climate from appendix 4 and area of glazing to area of floor ratios from page 51. This calculation is repeated nine times for each orientation.

GLAZING AREA & ORIENTATION AS A PERCENTAGE OF FLOOR AREA

	South	East	West	North	Horizontal
Glazing Area					

WINTER SOLAR GAINS

	South	East	West	North	Horizontal
Shading Coefficient					

Solar Gain per square foot of Floor - Btu per Hour per SF

	South	East	West	North	Horizontal	Total
9:00 AM						
12:00 PM						
3:00 PM						

SPRING & FALL SOLAR GAINS

	South	East	West	North	Horizontal
Shading Coefficient					

Solar Gain per square foot of Floor - Btu per Hour per SF

	South	East	West	North	Horizontal	Total
9:00 AM						
12:00 PM						
3:00 PM						

SUMMER SOLAR GAINS

	South	East	West	North	Horizontal
Shading Coefficient					

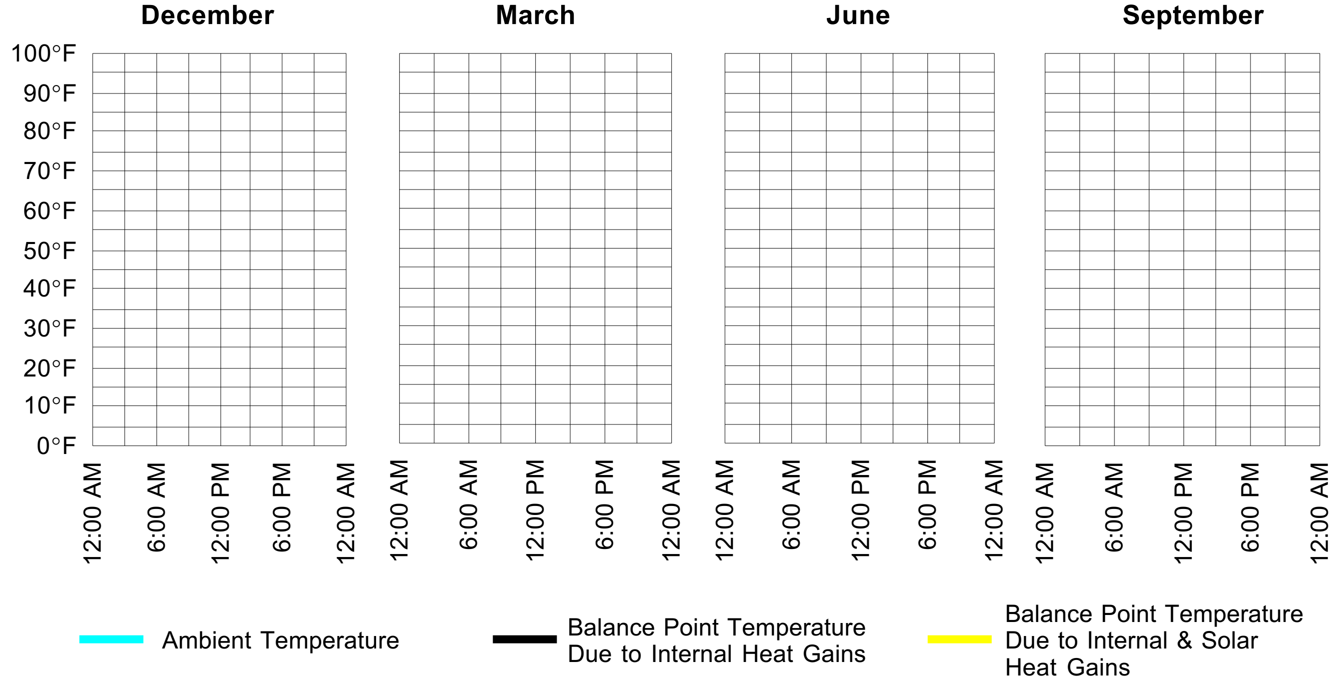
Solar Gain per square foot of Floor - Btu per Hour per SF

	South	East	West	North	Horizontal	Total
9:00 AM						
12:00 PM						
3:00 PM						

SOLAR TEMPERATURE DIFFERENCE

	Winter	**Spring**	**Summer**
9:00 AM			
12:00 PM			
3:00 PM			

Balance Point Graphs



LEVEL 2 FIRST ORDER PRINCIPLES: DEGREE DAYS AND BUILDING ENERGY CONSUMPTION

The building balance point was introduced in Level 1 as a means of evaluating the relative magnitude of energy flows into and out of buildings. A building was deemed in balance with its environment when areas of excess heat gain during the day were balanced by an equal amount of excess heat loss at night. The Balance Point serves additional purposes which aide the estimation of building heating and cooling loads. In this section the principles underlying estimation of building heating and cooling loads from the building balance point and pertinent climate variables is presented. The discussion leads to the Level 2 Protocol which can be used to measure the heating balance point temperature in buildings.

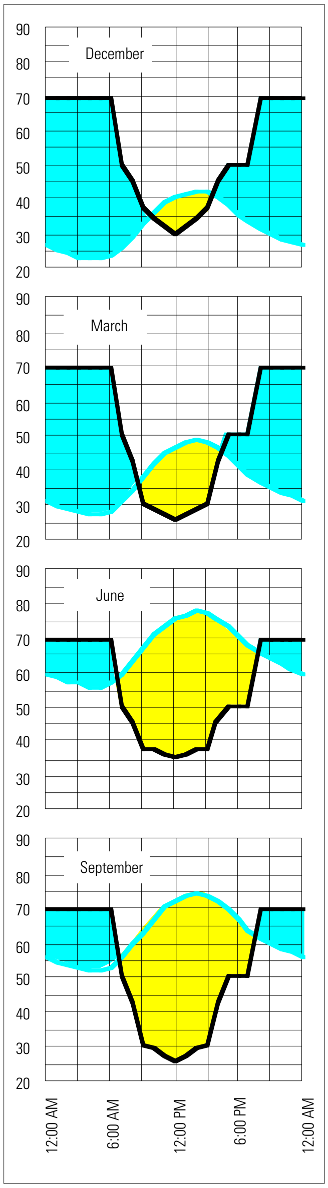


Figure 50. Building balance point temperature plots for a hypothetical commercial building located in Denver, Colorado.

THE BUILDING BALANCE POINT GRAPHS AND BUILDING HEATING AND COOLING LOADS

The results of the Level I Protocol were four graphs which related the balance point temperature to the ambient air temperature for all four seasons, winter, spring, summer and fall. A sample set of plots is illustrated in **Figure 50** at left which represents a hypothetical small commercial building located in Denver, Colorado. When the ambient air temperature is higher than the building balance point, the area bounded by the temperature curves (the light grey areas in the figure) represents a net heat gain to the building. Conversely, when the building balance point plot is higher than the ambient air temperature, the area bounded by the temperature curves (the dark grey areas in the figure) represents a net heat loss from the building. When the two areas are roughly equal, the building heat gains are in balance with the building heat losses over the day for that season. Although a building design with all energy flows in balance throughout the year is desired, it is seldom achieved. Seasonal variation of temperature and solar radiation result in heating loads during winter and cooling loads during summer. Considering the four seasons illustrated in Figure 1, the building heat losses exceed the building heat gains during winter and spring while the building heat gains exceed the losses during summer and fall.

The areas bounded by temperature curves in **Figure 50** don't represent heat gains or heat losses. They actually have units of degree hours (the product of the hour scale on the horizontal axis with the temperature scale on the vertical axis). The net heat gain or loss would be estimated as the product of the degree hours area in Figure 1 and the building heat transfer rate. The building heat transfer rate can be given per unit floor area, $\hat{U}_{bldg}$, or for the total building, $\hat{U}_{bldg}*A_f$. Methods used to estimate $\hat{U}_{bldg}$ were described in the Level I Protocol. The unit of degree hours is similar to the unit of degree day. An area of degree hours in **Figure 50** can be converted to degree days by dividing the area by 24 hours/day. A degree day is a measure of the length and severity of the heating (or cooling) season of a particular climate. The definition of degree days and the relation of degree days to estimates of building heating and cooling loads are described later in this section.

We have stated that a building which has equal amounts of daily heat gains and losses as represented by equal areas of degree hours in or out of the building is in balance over that day. In fact, the equal areas represent a potential for balance over the day. If excess heat gains during the day can be stored in the mass of the building and then dumped to the environment when excess heat loss occurs at night, then the building energy flows might be balanced over the day. Daryl Erbs developed a method of estimating heating and cooling energy savings based on excess daytime heat gains and night time heat losses computed using building balance point temperatures (Daryl's thesis is listed in the bibliography). Coupled with degree day methods used to estimate building heating and cooling loads the heat storage method gives a means of estimating the annual sensible heating and cooling loads of buildings.

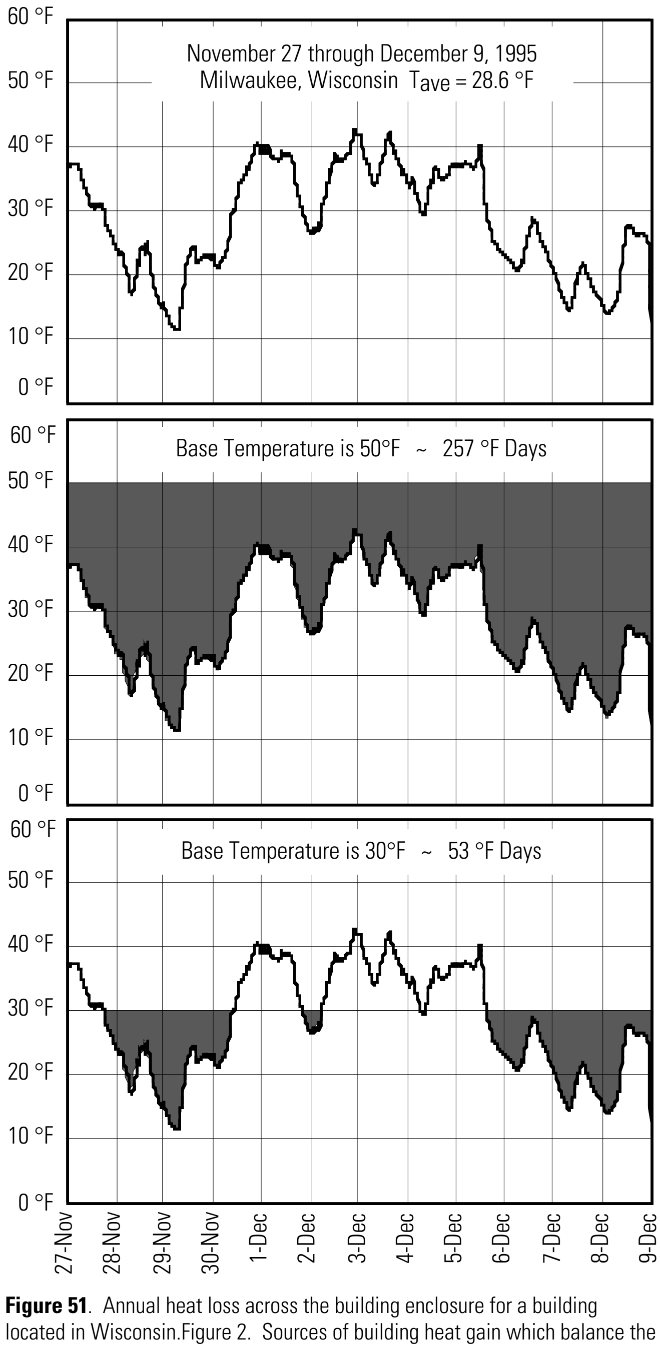


Figure 51. Annual heat loss across the building enclosure for a building located in Wisconsin.Figure 2. Sources of building heat gain which balance the heat loss across the enclosure.Monthly Building Heat Loss ~ [million Btu/ month]. Ambient temperature during 12 days of late fall in Milwaukee is illustrated in the top graph. The grey area in the second graph represents the degree days occuring between a balance point of 50 °F and the ambient temperature. The dark grey area in the lowest graph represents the degree days occuring between a balance point of 30 °F and the ambient.

DEGREE DAYS

Degree days were developed to permit the estimate of seasonal heating energy consumption. Degree days provide a means of representing the temperature difference across the building enclosure over the course of a month or year. Degree days are measured from a base line temperature. For a building the appropriate base line temperature is its balance point temperature. Weather stations and utility companies use 65°F as a base temperature for determining heating degree days. Using the 65°F base line, one day with an average temperature of 55°F would generate 10°F days (1 day times 10°F temperature difference between base and outdoor air). Ten days, each with an average temperature of 64°F would also generate 10 °F days (10 days times 1°F temperature difference).

Why is the base temperature 65°F? Researchers studying energy consumption in homes in the late 1940s determined the average thermostat setting in a home to be 72°F, with an average ratio of internal heat generation to enclosure heat transfer of 7°F resulting in a typical building balance point for post World War II homes of 65°F. If the outdoor air temperature were above 65°F, no heating would be required as internal heat generation would offset heat loss to the environment. Heating would only be needed on days when the outdoor air temperature was below the building balance point of 65°F. The annual heating energy required could be estimated as the product of the annual heating degree days for a base temperature of 65°F and the enclosure heat transfer rate (with that rate converted to Btu/day/°F). The heating energy required by a building can be estimated using building variables described in the Level I Protocol:

$$\mathbf{Q}_{\mathbf{aux,h}} = \mathbf{DD}_{\mathbf{h}}(\mathbf{T\_balance})\hat{\mathbf{U}}_{\mathbf{bldg}}\mathbf{A}_{\mathbf{f}}24 \qquad [11]$$

$\mathbf{DD_h}$**(T_balance)** is the heating degree days for a given balance point temperature and has units of °F days (or °C days). $\hat{\mathbf{U}}_{\mathbf{bldg}}$ is the building heat transmission coefficient per unit floor area and $\mathbf{A_f}$ is the building floor area. The constant 24 converts the heat transfer rate from hours to days. $\mathbf{Q}_{\mathbf{aux,h}}$ is the axillary heating required by the building and has units of BTU (or kiloJoules).

Since the 1970s, houses have been constructed with higher insulation levels, resulting in a lower enclosure heat transfer rate and lower balance point. Many nonresidential buildings will typically have a building balance point lower than the 65 °F base given on the utility bill. Thus the estimation of building heating and cooling energy requirements needs degree days based on any balance point temperature.

The relationship between balance point temperature and degree days is illustrated in **Figure 51**. The top figure gives Milwaukee's ambient air temperature for 12 days in late fall, 1995. The grey area in the

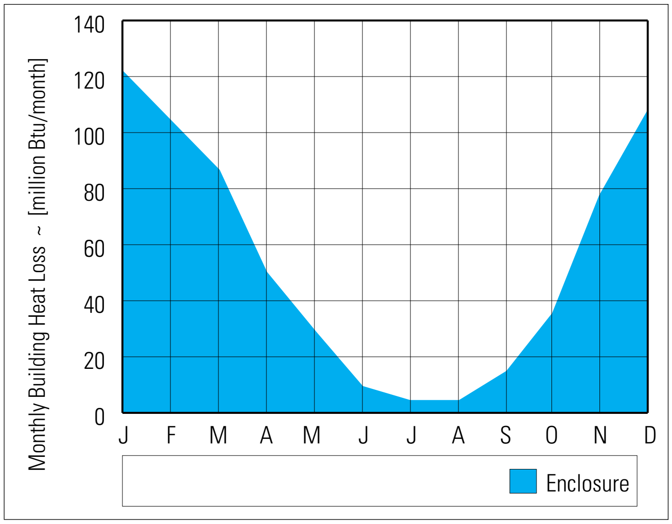


Figure 52. Annual heat loss across the building enclosure for a building located in Wisconsin.

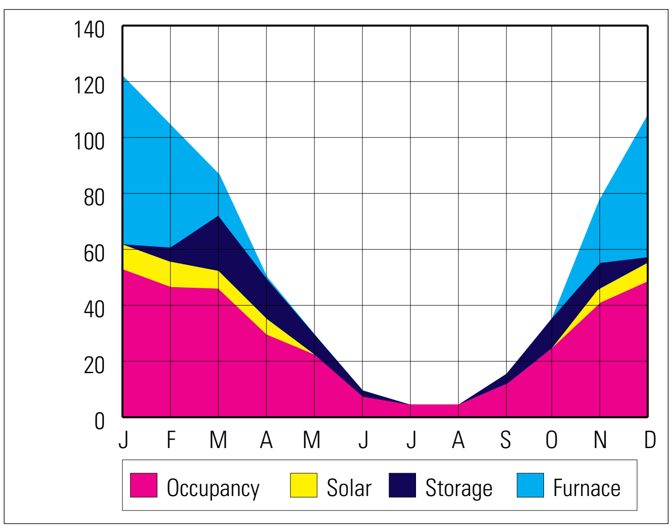


Figure 53. Sources of building heat gain which balance the heat loss across the enclosure.

second figure illustrates the degree days for a balance point temperature of 50 °F. The degree days are literally the area under the 50 °F line bounded by the ambient temperature. The lower figure gives the degree days for a balance point temperature of 30 °F. Note that only the area below the balance point and bounded on the bottom by the ambient temperature is included in the degree days.

When the ambient air temperature falls below the balance point temperature throughout the period of measurement, the condition illustrated in the middle figure, the number of degree days for the period is equal to the product of the number of days and the difference between the balance point temperature and the average ambient air temperature. For the 50 °F balance point condition in the middle figure, and the average ambient air temperature given in the top figure (28.6 °F), the 12 day period would result in 257 °F days, the same value measured from the data. However, the ambient air temperature crosses the balance point in the lower figure. Degree days cannot be determine from the average ambient temperature.

Cooling degree days are determined in an analogous manner. The difference is that cooling degree days are bounded by the balance point temperature below and the ambient temperature above. *Solar.xla*, the *Excel* add-in macro included with this package, has functions which can be used to estimate both heating and cooling degree days.

Lowering the building balance point can substantially reduce the annual heating degree days, resulting in lower annual heating energy requirements. Cutting the enclosure heat transfer rate in half will reduce the heating requirements by more than 50%. The degree days, which are based on the building balance point, are also a function of the enclosure heat transfer rate.

The equations for degree days at any building balance point published in the 1993 *ASHRAE Handbook of Fundamentals* were developed by Daryl Erbs as a part of his Ph.D. Thesis titled *Models and Applications for Weather Statistics Related to Building Heating and Cooling Loads*. In addition to models for heating and cooling degree days to any building balance point, Erbs developed models for average hourly temperatures; degree days for any fractional time of the day; ventilation degree days (to estimate the portion of the cooling load which might be met by ventilation); sol-air heating and cooling degree days (including both glazing transmittance and solar energy absorbed on surfaces); statistical distributions of wet bulb temperature; and thermal capacitance effects when buildings experience diurnal variation of net heat gain and net heat loss. Building heating and cooling loads based on Erbs models are illustrated in **Figure 52** through **Figure 55**.

The heat loss across a building enclosure for a building located in Wisconsin is illustrated in **Figure 52**. Notice that the Wisconsin

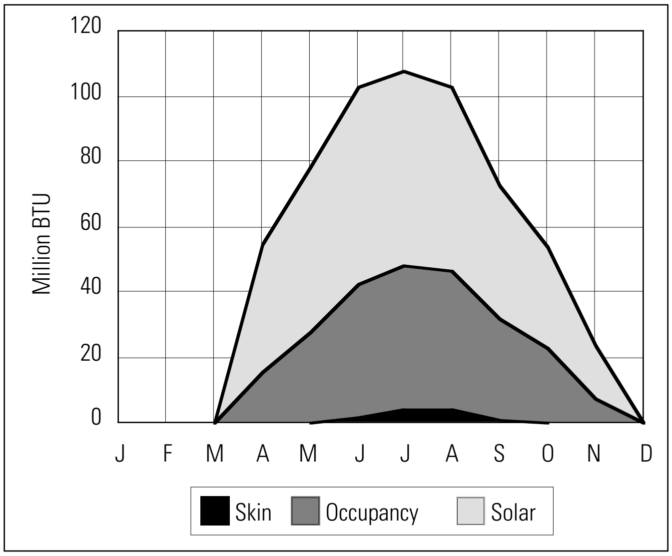


Figure 54. Annual building sensible heat gain.

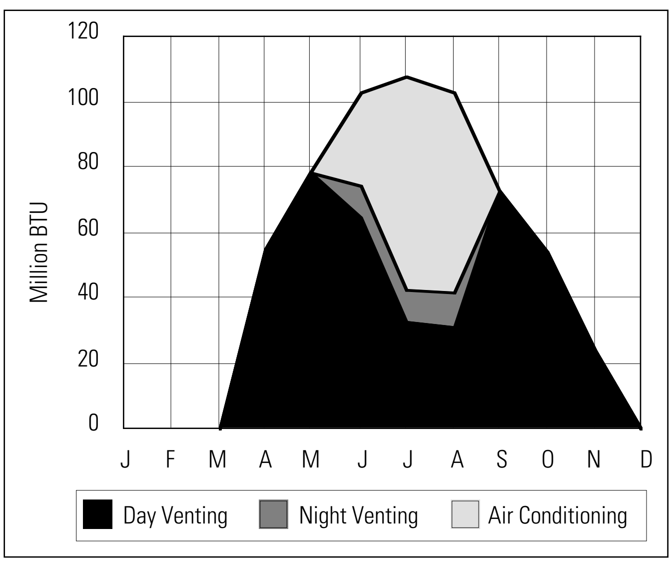


Figure 55. Sources of building cooling which balance the sensible heat gain.

climate is mild during summer and an enclosure heat loss even occurs during the months of July and August. This heat loss was estimated using equation 11. Although buildings loss heat during summer in Wisconsin, heating systems are usually shut down from April or May through September and into October. Four sources of heat gain balance the enclosure heat loss: occupancy heat gain, solar heat gain, daytime heat storage (which offsets some of the nighttime heat loss), and heat supplied by the building heating system. During the summer months, occupancy and solar heat gains, along with building heat storage, offset the enclosure heat loss. Heating supplied from the HVAC system is not required.

The annual distribution of the four heat sources which offset building heat loss through the enclosure are illustrated in **Figure 53**. Energy demand from the HVAC system, supplied through the boiler or furnace, is greatest during winter. Occupancy heat gains balance enclosure heat loss during summer. Daytime solar heat gains are most effective balancing enclosure heat losses during winter. During spring and fall, excess daytime heat gains are available for storage in the building thermal mass to offset night time enclosure heat loss.

The cooling load for the same building is modeled in **Figure 54**. The cooling load is due to three sources of heat gain: occupancy heat gains, solar heat gains and heat transfer into the building when the building temperature is lower than the ambient temperature. Note that in Wisconsin heat gain across the building enclosure is a very small portion of the total cooling load. The solar portion of the cooling load includes both glazing transmittance and solar heat absorbed on opaque enclosure surfaces which is conducted into the building. Only the sensible cooling load is modeled.

The paths that can be used to remove excess heat gains are illustrated in **Figure 55**. During spring and fall ventilation can meet all the building cooling needs. This represents the potential of an economizer cycle in the HVAC system or a well designed natural ventilation system. During summer in Wisconsin both ventilation and mechanical cooling are required. The estimate of ventilation cooling is based on cooling degree days and the building balance point as given by Erbs.

The estimate of building heating and cooling loads based on the building description and weather statistics offer a powerful tool for the architect in the design of energy conscious buildings. These models are based in part on the building balance point temperature. They are also based on other building vital signs including solar heat gains and building thermal capacitance effects. Appendix 2: Future directions provides some experimental protocols which are not covered in this package but would be useful in the overall evaluation of building energy flows.

VITAL SIGNS

BUILDING BALANCE POINT:
Level 2 Protocol: Verification of Balance Point Temperature from Temperature Data

Level 1 protocols provided estimates of the building balance point from simple observations of energy flows based on anecdotal evidence gathered during a site visit. This protocol provided a means of determining whether (and when) a building's energy flow was dominated by internal heat generation, solar heat gains or skin heat loss. The **Level 2** protocols will use field temperature measurements and the physical theory underlying building thermodynamics to provide experimental measurements of the building balance point. The **Level 2** protocols are appropriate for students in a graduate seminar studying building thermodynamics, independent study at the graduate level, or thesis work at the Masters or Ph.D. level. The protocols presented here provide techniques that can be used to test and validate the theory underlying the balance point and degree day methods used to estimate building energy consumption.

In **Level 2** the discussion of physical principles is integrated with the protocols. The protocol is presented as a case study of an experiment to measure the building heating balance point temperature of a typical residence. The intent is to present the process of using measured data with physical equations, not limit the application to the heating balance point of residences. The faculty or student applying this protocol may be attempting to measure the building cooling balance point temperature, or the building balance point for a nonresidential building. Part of the nature of field experiment is being able to adjust protocols to fit a particular context. By presenting this protocol as a case study, the authors hope to present a framework that can be adjusted and modified by other faculty or students for their particular building and context.

Three field temperature measurements are required to estimate the heating balance point: the building temperature, the ambient temperature and the heat supply temperature. This protocol begins with a discussion of the house being studied and the data collection design. In particular, sensor location and collection time are discussed. Second, the collected data is presented with discussion of relevant patterns and events. Third, the data is evaluated and an estimate of the building balance point is presented. The possible sources of experimental error and the reliability of the estimate are discussed.

THE HOUSE

Figure 56. Milwaukee bungalow circa 1918 viewed from the northeast.

The bungalow is a typical house type found throughout the United States. Although constructed in 1918, the 2200 SF bungalow studied in this protocol is in very good condition. The first floor includes the living room, dining room, kitchen, bedroom, full bath and an unheated sun room. The second floor includes an unheated attic at the east end and two bedrooms, full bath and a playroom at the west end. The playroom is located over the garage (**Figure 56**). The basement has uninsulated brick walls extending 15 inches above the ground. The wood frame construction is brick clad and insulated with rock wool. The attic and second floor ceilings are insulated with fiberglass batts.

The heating system is circulating hot water. The boiler is old and has been converted from oil to gas. Gas is also used for water heating and clothes drying. However, clothes are also hung outside as the weather allows during the summer and in the basement during winter. An interview with the owner suggests that the dryer is used slightly less during the winter than the summer, since hanging the cloths to dry inside is used to add needed moisture to the winter air.

If the building balance point is the outdoor air temperature resulting in a balance between occupancy heat gains and enclosure heat losses, one would expect the heating system to turn on when the ambient air temperature falls below the building balance point, and turn off when the ambient air temperature rises

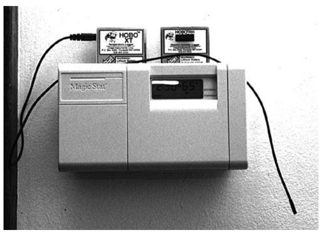


Figure 57 House programable thermostat with HOBO temperature and humidity sensors. The thermostat is located in the dining room.

Figure 58 Cast iron hot water radiators in the dining room, under north facing windows. HOBO temperature sensors were taped to the radiator supply and return piping in the basement.

above the building balance point. Thus three temperatures should be measured: the ambient air temperature, the building air temperature and the heating supply temperature. Additional data on electric and natural gas consumption was also collected.

HOBO™ datalogers were used to record temperatures. The HOBO™ records 1800 temperatures at a time step specified by the user. The choice of time step is important. Averaging readings over an hour is often desirable. If the increment of an hour is not an integer multiple of the time step, the reduction of the data to hourly averages in Excel or Lotus is extremely difficult. For this experiment a time step of 12 minutes was chosen, allowing the HOBO to store exactly 15 days of data. Data was collected every fourteen days. This margin provided flexibility in the time of day that the data was collected. A morning collection could be followed by an afternoon collection two weeks later. Other time steps can also work. A 10 minute intervals result in 12.5 days of data. For one week data collection intervals, a 7.5 minute time step gives a 9.375 day collection interval and a 6 minute time step gives a 7.5 day collection interval. The time step should be short enough to catch the cycling of the heating (or cooling) system. For this study, the 12 minute interval caught each boiler firing.

The gas and electric meters were also read every two weeks. All electric consumption was assumed to translate into occupancy heat gains. The gas used for the boiler was separated from gas used for water heating or clothes drying by estimating daily gas consumption during summer when the boiler was shut down and assuming the same daily consumption during winter for both hot water heating and clothes drying. Location of the temperature sensors is discussed below.

Since operation of the heating system is initiated by room air temperature falling below the thermostat setting, the building temperature of importance is the air temperature at the thermostat. The programmable thermostat and its associated air and relative humidity dataloggers are illustrated in **Figure 57**.

The heating supply temperature was be measured by taping a HOBO sensor to the dining room hot water supply pipe. A sensor with an extended range (-39°C to 123°C) was used. This supply pipe was chosen because the thermostat was located in the dining room. The heating system had one circulating pump and two branches: one for the dining room and living room and the other for the rest of the house. A multizone building would be treated differently, since each thermostat zone could in practice have a different associated balance point temperature. The dining room cast iron radiator is illustrated in **Figure 58**.

The ambient or outdoor air temperature should be measured at a location away from solar radiation. During winter a shaded location on the north side of the building will suffice. During summer the sun can reach the north side of a building near both sunrise and sunset and a shaded southern location might be appropriate. The sensor should well ventilated, but shaded from direct and strongly reflected sunlight. For this experiment, the sensor was located on the north side of the house during the winter as illustrated in **Figure 59**. During the summer, the sensor was located on the south side under an eave shaded by a tree.

When the sensor was located on the north side of the house, it was hanging roughly 0.5 in. from the wall. Comparison of air temperatures measured at night in the open air away from the house with measurements from this sensor indicate that the air temperature collected at the wall might be roughly 1 °F warmer than the actual air temperature. This is due to the fact that the sensor was located in the surface boundary layer of the wall. If the experiment were repeated, the sensor would have been mounted at least 12" from the wall.

Figure 59 Outdoor air temperature was measured along the north wall during winter and in shade under an eave on the south wall during summer. The HOBO dataloger was placed in a plastic bag, taped shut with duct tape. While the north side sensor location pictured at left was well shielded from solar radiation, the proximity to the wall increased the air temperature reading by roughly 1°F during winter.

The first step after completion of a field experiment is a preliminary examination of the data. Every two weeks, when the HOBO™ temperature data was collected, the utility meter readings were recorded with the time of collection. The table below gives the date and times of the site visits to collect the data. The table, generated in Excel, gives the electric and natural gas energy consumption over the data collection period and averaged per day. Every two weeks, when the HOBO™ temperature data was collected, the utility meter readings were recorded with the time of collection. Electric usage in kWhr for each two week data collection interval is the difference between previous and current meter reading. Average daily electric consumption was determined by dividing the two week usage by the difference between times of readings in days. Natural gas usage was determined in a similar manner except the two week consumption is given in hundreds of cubic feet (ccf) and the average daily consumption is in therms. The conversion used appropriate heat factor values from the gas utility bill for the same time period. The summer period (shaded in the table) was used to estimate the daily natural gas energy consumption for water heating and cloths drying. This gas usage was then subtracted from the fall, winter and spring gas consumption readings to provide an estimate of the natural gas consumed to heat the house.

As an initial observation of the thermal profile of the house, temperature plots of the ambient, house and heating delivery temperature were constructed. The HOBO™ temperature data, gathered every two weeks, was plotted in the software package, Boxcar™, provided with the HOBO™'s. The plots were copied from Boxcar™ to the graphics program ClarisDraw. The plots were scaled to 25% and are presented here.

Five two week data sets for spring are illustrated in **Figure 60**. Each plot represents two weeks of data describing either the ambient, thermostat or heating supply temperatures. The temperature ranges in each

Date & Time	Days	Electric Meter	kWhr	kWhr/day	Gas Meter	CCF	Therm/day
4/15/95 13:30		4274			5006		
4/29/95 12:50	13.97	4432	158	11.31	5058	52	3.75
5/13/95 13:30	14.03	4592	160	11.41	5098	40	2.89
5/27/95 13:00	13.98	4769	177	12.66	5120	22	1.59
6/10/95 14:05	14.05	4954	185	13.17	5135	15	1.09
6/24/95 12:05	13.92	5116	162	11.64	5146	11	0.80
7/8/95 16:10	14.17	5293	177	12.49	5156	10	0.71
7/22/95 17:15	14.05	5482	189	13.46	5165	9	0.65
8/7/95 20:45	16.15	5723	241	14.93	5176	11	0.69
8/19/95 13:10	11.68	5910	187	16.00	5185	9	0.78
9/2/95 13:50	14.03	6123	213	15.18	5194	9	0.65
10/14/95 12:00	41.92	6747	624	14.88	5237	43	1.03
10/28/95 15:50	14.16	6975	228	16.10	5271	34	2.41
11/11/95 14:45	13.95	7199	224	16.05	5336	65	4.72
11/25/95 12:15	13.90	7395	196	14.10	5421	85	6.20
12/9/95 13:30	14.05	7603	208	14.80	5511	90	6.50
12/23/95 14:35	14.05	7827	224	15.95	5623	112	8.09
		Average Daily Electric Use		**14.10**	Average Daily Gas Use		**0.71**

graph were revised to be concictant in each figure. For the spring temperatures illustrated in **Figure 60** the Ambient temperature ranges from 0°F to 90°F (measured temperatures range from 7°F to 88°F). The Thermostat temperature range is 55°F to 75°F and the Heating Supply temperature range is 50°F to 140°F. The solid horizontal line located at 65°F in each graph indicates the house thermostat setting.

The end of the heating season can be observed in early May as the rapidly decreasing number of temperature spikes seen in the heating supply graphs. The thermostat temperature is maintained at its minimum level of 65° (with night set-backs) from March 31- May 13. Once the heating system is no longer used, the thermostat temperature tracks the form of the ambient air temperature.

May 27 - June 10 Illustrates a large ambient air temperature drop towards the end of the two week period and the effect of that drop on the temperatures measured by the thermostat sensor and heating supply sensor, which is now simply measuring basement air temperature. Both show significant drops at the same time. When the building temperature is not maintained at some constant value by the heating or cooling system, the thermostat temperature profile

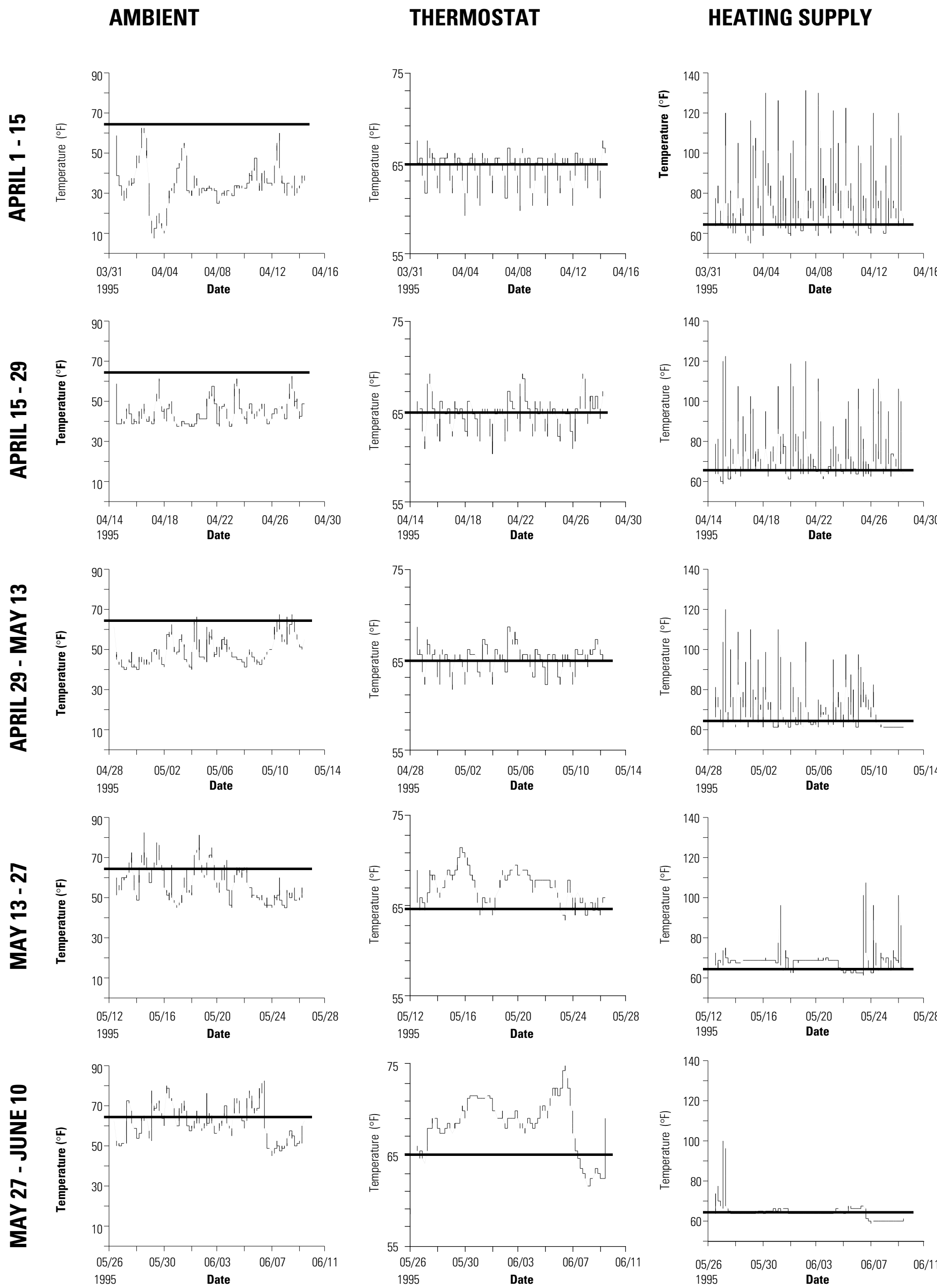


Figure 60 Two week temperature measurement sets from March 31, 1995 to June 10, 1995. Each row represents a two week data collection period. Each column represents a temperature sensor: ambient air, thermostat and heating supply.

will mirror in shape the ambient air temperature profile.

Figure 61 illustrates five two week periods during the summer. The first heat wave is shown in the top row at right (June 10-24). Although on a different scale, the form of the thermostat temperature curve follows the ambient temperature curve.

At the end of June the heating supply sensor was moved to the attic to track it as a space. The attic temperature profile follows some of the ambient temperature form, but has daily peaks caused by solar radiation absorbed through the roof. Heat gains in the attic drive heat gains into the house.

The twin spikes of the July 8-22 plots capture the two hottest days of the year, with ambient temperatures exceeding 100°F.

The balance point temperature has meaning only when the building is maintained at a constant maximum temperature during summer or a constant minimum temperature during winter. For this house the cooling balance point does not have meaning because air conditioning is not provided to maintain a maximum allowable temperature. Instead, the room temperature floats, its form similar to the ambient air temperature.

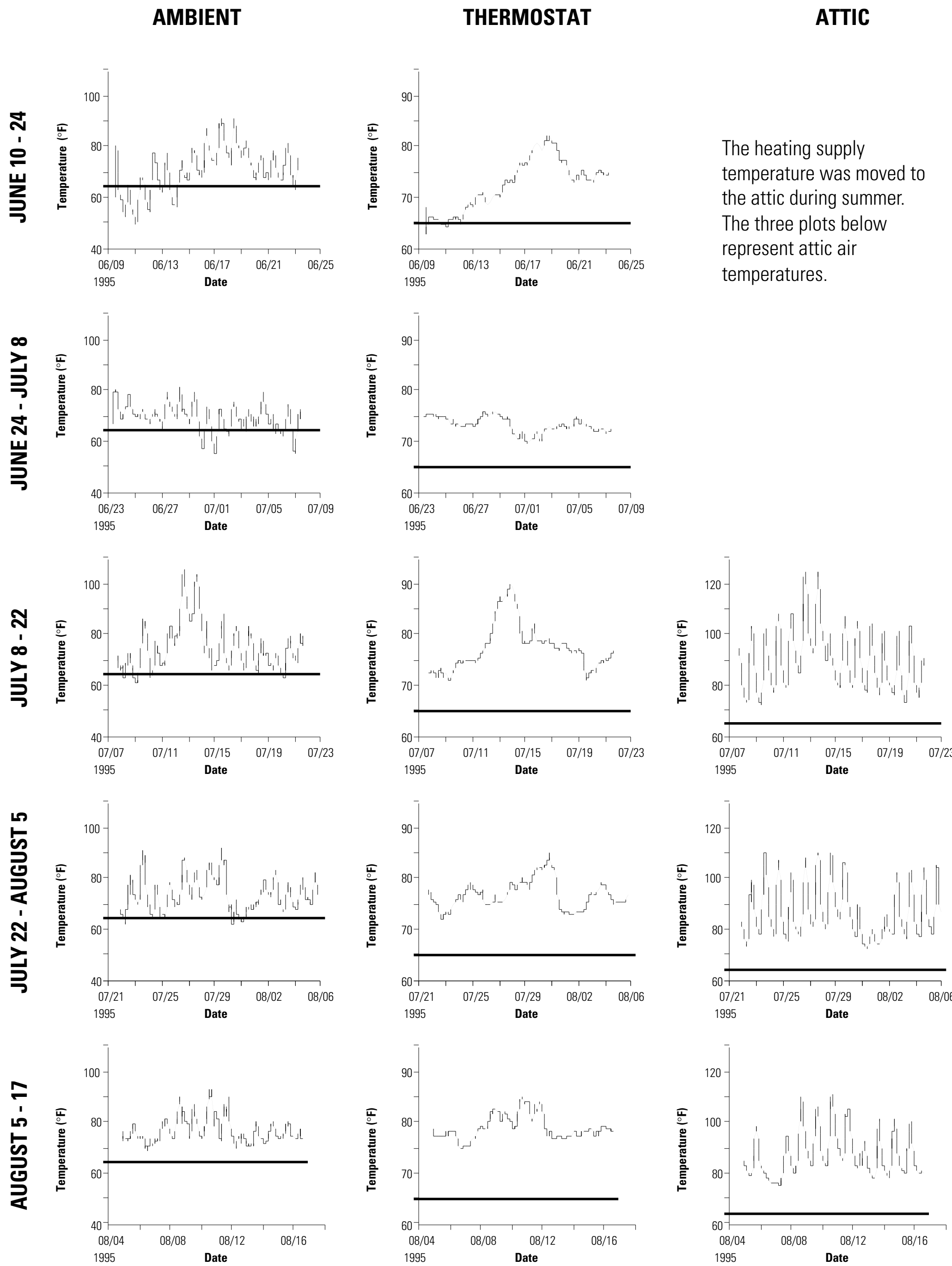


Figure 61. Two week temperature measurement sets from June 10, 1995 to August 19, 1995. Each row represents a two week data collection period. Note the shape similarity between ambient and thermostat temperatures, the building temperature tracks the ambient.

The five two week data sets of **Figure 62** illustrate the onset of the Fall 1995 heating season.

The first row, Oct. 14 - 28, shows the thermostat temperature shifting from following the ambient temperature to maintaining a minimum temperature during the day with a drop corresponding to a thermostat set back at night. The heating supply profile illustrates the temperature spikes indicating boiler operation in the early morning to bring the house temperature back up to the daytime minimum.

The constant daytime temperature with night set back can be easily read in the thermostat data from the second through the fifth row, Oct. 28 - Dec. 23. The night drops that are the result of the night set back are counteracted by the daily morning heat up spikes visible in the heating supply plots. In the resulting graph the thermostat setting is clearly expressed as a horizontal line that reads through the spikes and troughs. This shape is driven by and visually similar to the heating supply temperature rather than the ambient air temperature. This horizontal line is evidence that a constant temperature minimum (or maximum if apparent in summer data) is being maintained, which means that the balance point temperature concept will have relevance in this situation.

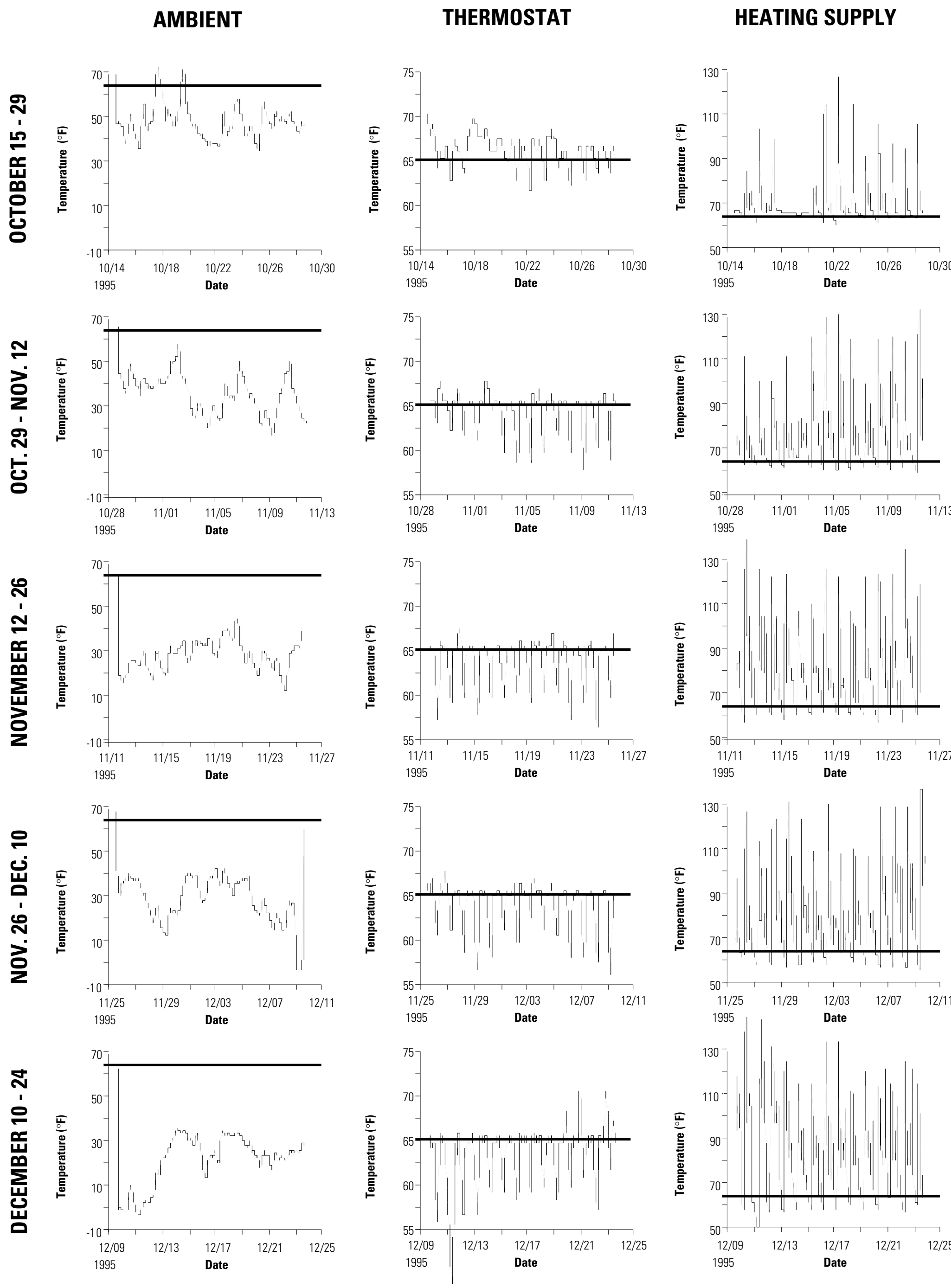


Figure 62. Two week temperature measurement sets from October 14, 1995 to December 23, 1995. With the onset of the heating season, the thermostat temperature shifts to a line of constant temperature with daily drop spikes representing the night set back. The thermostat temperature does not track the ambient temperature. The thermostat temperature spike dropping below 55F on December 11 was a day the boiler was not functioning and under repair.

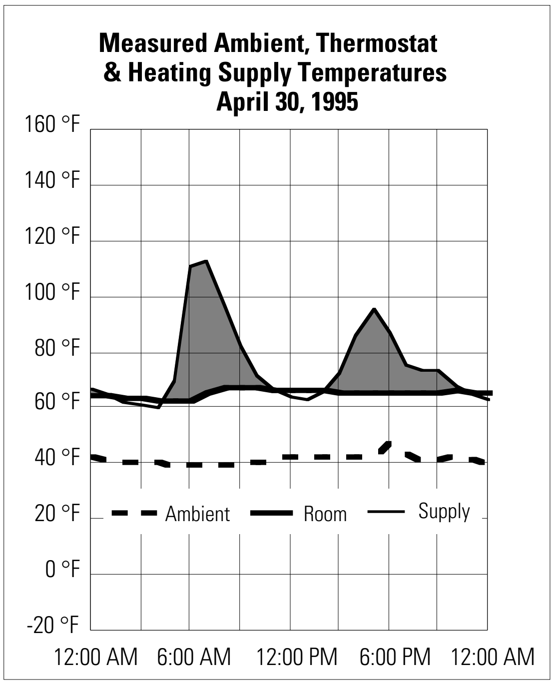


Figure 63. Heating degree hours (area in gray) supplied to the house on a cool spring day. The heating degree hours are correlated with the average ambient air temperature to provide an estimate of the heating balance point temperature of the house.

The first three rows of two week data (March 31 - May 13) representing the end of the Spring heating season and all five rows (Oct. 14 - Dec. 23) representing the onset of the winter heating season exhibit thermostat plots of a constant building temperature with night setback. These eight two week data sets will be used to develop an experimental estimate of the building heating balance point temperature.

How can the data be arranged to provide an estimate of the balance point? Determining the average ambient air temperature at the time the heating system turns on or off would seem to provide an estimate of the balance point consistent with the definition of the balance point temperature. However, this method might only be appropriate for buildings maintained at a constant temperature. As we have seen, HVAC systems for buildings with night set back on the heating system or shut down of the cooling system when the building is unoccupied are driven by the cycle of the thermostat setting, not the ambient air temperature. The spikes in the heating supply temperatures just noted are initiated by the daily thermostat set back cycle, not the ambient air temperature.

Another approach is to correlate the number of hours per day a heating system is delivering heat to the building with the average ambient air temperature for the day. As the daily average ambient air temperature falls further below the balance point, the number of heating hours should increase. This method would be appropriate when the heating supply system delivers energy at a constant rate. For a hot water heating system with a constant speed pump and a constant hot water temperature, this correlation of heating hours and average ambient air temperature might be the most appropriate method.

The case study house has a constant speed pump, but the hot water delivery temperature varies. Rather than measuring the number of hours the heating system was on, the average daily ambient air temperature was correlated with the daily degree hours of heating delivered. (The definition of heating degree hours is illustrated in **Figure 63**.) The area between the heating supply temperature and the thermostat temperature represents the heating degree hours delivered for the day. Note that heating degree hours are not counted when the heat supply temperature falls below the thermostat temperature. Compare the heating degree hours supplied (the grey area) of **Figure 63** with the heating degree hours supplied on a much colder day illustrated in **Figure 64**. As the daily average ambient air temperature approaches the balance point temperature, the degree hours of heating supplied should approach zero.

Degree hours are calculated from the data using a spread sheet program. Data from the HOBO™ sensors is exported in the appropriate text format for a spread sheet (e.g.. for Lotus or Excel). The time that ambient, thermostat and heat supply temperatures are recorded, however, is typically not in sync. In this analysis the average ambient air temperature was used as the base line data. The difference between the time that an ambient air temperature was recorded and the time that

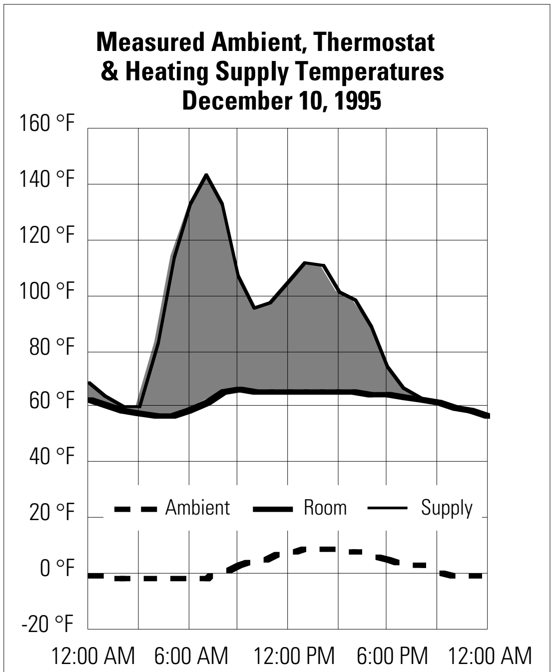


Figure 64. Heating degree hours (area in gray) supplied to the house on a cold winter day. Note the increase in heating degree hours compared with **Figure 63**. Both Figures are plotted at the same scale.

the next thermostat temperature was recorded represents the lack of synchronization of the data.

This offset was divided by the timestep and the fraction used to linearly interpolate the thermostat temperature to its value when the ambient air temperature was recorded. The heating supply temperature was also interpolated to its value at the time the ambient air temperature was recorded.

Degree hours of heating supplied for each day, $\mathbf{DHr_h}$, were computed by summing all positive values of the heating supply temperature minus the thermostat temperature multiplied by the timestep in hours, given by

$$\mathbf{DHr_h} = \sum_{\mathbf{day}} \left(\mathbf{T_{SUPPLY}} - \mathbf{T_{THERMOSTAT}}\right)^{+} \Delta\mathbf{time} \qquad [12]$$

Where $\mathbf{T_{SUPPLY}}$ is the measured value of the heating supply temperature. $\mathbf{T_{THERMOSTAT}}$ is the measured thermostat temperature and Δ**time** is the time interval between temperature measurements in hours. For this experiment, temperatures were recorded by the HOBO sensors every 12 minutes and Δ**time** equals 0.2.

The daily heating hours were correlated with the associated average daily ambient air temperature. The days on which the sensor data was collected were not included in the calculation. Each two week data set thus provided 13 pairs of average ambient air temperature and heating degree hours delivered. The eight two week data sets provided a total of 104 pairs of data. These are plotted in **Figure 65**.

Although the data exhibits a large scatter, a linear trend can be readily seen. The line crossed the temperature axis at 59.4 °F. This temperature represents the heating balance point temperature of the house. As the house was maintained at a thermostat setting of 65°F, the effect of internal and solar heat gains is a temperature drop of 5.4°F (the ratio of $\mathbf{Q_{IHG}} + \mathbf{Q_{SOL}}$ to $\mathbf{\hat{U}_{bldg}}$).This is similar to the 7°F temperature drop due to internal heat gains and solar heat gains determined by ASHRAE which lead to the 65°F base temperature for heating degree days.

The scatter in the data plotted in **Figure 65** is due to a variety of sources. The actual daily internal heat gains, $\mathbf{Q_{IHG}}$, were variable, both in terms of occupancy and electrical energy consumption. The actual daily solar heat gains, $\mathbf{Q_{SOL}}$, vary due to cloudiness. The fireplace was operated intermittantly during the heating season. An additional study could examine these sourses of variation.

This Level 2 Protocol illustrates a method leading to experimental estimate of the heating balance point temperature of a residence. But what about the heating balance point temperature of a commercial or institutional building? What about the cooling balance point? Finally, if the Building Balance Point is a conceptual

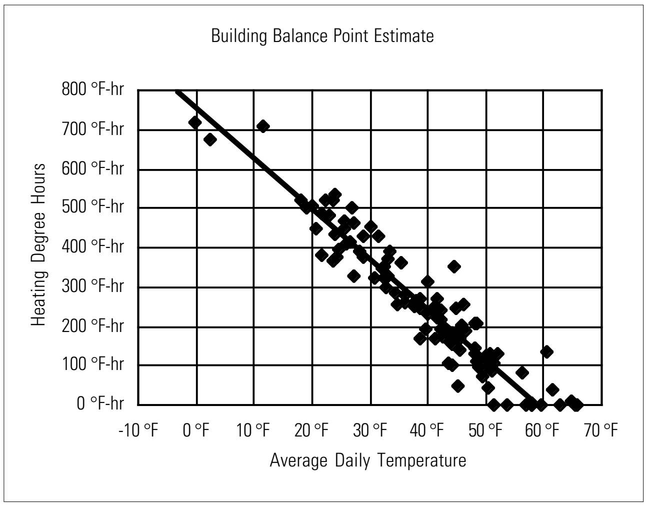


Figure 65. Plot of heating degree hours delivered vs average daily temperature for 104 days. The linear model with the best fit is also plotted. Its intersection with the temperature axis is at 59.4 °F, the experimentally determined value of the house heating balance point temperature.

idea that leads to an understanding of building energy flows, what Vital Sign Protocols might relate to the Balance Point?

Looking back at **Figures 52** through **55** (pages 56 and 57), the heating energy required by a building is that portion of heat flow out of the enclosure that is not effectively balanced by internal heat gains, solar heat gains and diurnal thermal storage. This would apply to residences, offices and any other building type. The method presented in this section for residences should work for any building with a heating system used to maintain a minimum temperature for occupancy.

The cooling balance point is a more complex problem. While only heat loss from the building drives the building heating load, the cooling load is driven by occupancy heat gains, solar heat gains, and heat transfer into the building when the outdoor temperature is higher than the building temperature. The last component is usually the smallest (see **Figure 54**). Thus the balance point concept may not be easily measured using the techniques presented here. However, the exploration of thermal dynamics of building cooling are worth studying using the basic procedure. The direction of analysis may move toward some other means of estimating the cooling balance point of the building.

A number of building Vital Signs relate to the building balance point and building energy flows including HVAC system efficiency, the building thermal storage capacity, means of separating solar and internal heat gains in measured data, and ventilation rates in buildings. **Appendix 2: Future Directions** provides a discussion and some starting points directed at the exploration of some other building Vital Signs, including the building thermal capacity and a simple method of estimating solar radiation at the building site.

We hope that the experiments presented in this session will encourage faculty and students to go beyond the **Level I Protocol** and explore the life of buildings revealed in the long term experiments described in this section.

BUILDING BALANCE POINT
Appendix 1: Bibliography

ASHRAE Centennial Committee, Stephen Comstock (Ed.), Proclaiming the Truth: Completed as a Centennial Project Commemorating the 100th Anniversary of ASHRAE's Founding. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1995.

1993 ASHRAE Handbook Fundamentals, I-P Edition. Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1993.

ASHRAE/IESNA Standard 90.1-1989: Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. and Illuminating Engineering Society of North America, 1993.

Brown, G.Z., V. Cartwright. Sun, Wind, and Light: Architectural Design Strategies. New York: John Wiley and Sons, 1985.

Brown, G.Z.Inside Out: Design Strategies for Passive Environmental Technologies. New York: John Wiley and Sons, 1992.

Department of Energy. Predesign Energy Analysis: a new graphic approach to energy conscious design for buildings. Office of Conservation and Solar Energy Federal Energy Management Program DOE/CS-0171 Dist Cate·°ry UC 95 D. September 1980.

Duffie, John and William Beckman. Solar Engineering of Thermal Processes. Second Edition. New York; John Wiley and Sons, 1991.

Erbs, Daryl Gregory. "Models and Applications for Weather Statistics Related to Building Heating and Cooling Loads." Doctor of Philosophy (Mechanical Engineering) dissertation, University of Wisconsin-Madison. 1984.

Harding and Willard, Heating , Ventilating and Air Conditioning, N.Y.: John Wiley and Sons, 1937.

Harte, John. Consider a Spherical Cow: A Course in Environmental Problem Solving. Mill Valley, CA: University Science Books. 1988.

Jacobs, Herbert with Katherine Jacobs. Building with Frank Lloyd Wright: an illustrated Memoir. San Francisco: Chronicle Books, 1978.

Stein, Benjamin and John Reynolds. Mechanical and Electrical Equipment for Buildings, 8th Edition. New York: John Wiley and Sons, Inc., 1992.

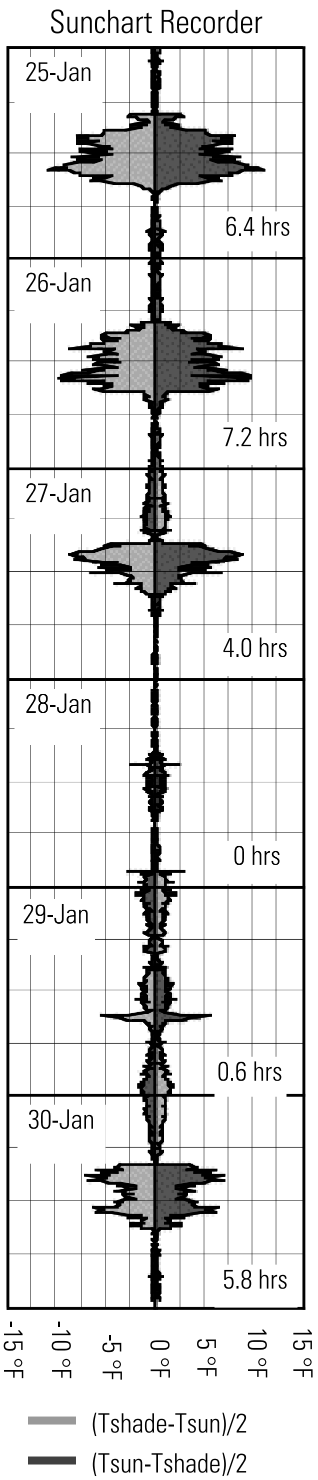
BUILDING BALANCE POINT
Appendix 2: Future Directions ~ Ideas for Further Development of the Building Balance Point Package

This Building Balance Point package is offered as a starting point in the development of a curriculum covering application of the building balance point to estimates of building energy flows. It is just that: a starting point and not the final word. In conclusion we would point to some of the directions that remain to be fleshed out and tested in the field. This list serves both as a way to put the current package into perspective and as a list of suggestions for independent student research. It is our hope that the package itself will continue to grow and develop along with the library of case studies that it aims to promote.

The accuracy of balance point and degree day techniques related to residential heating loads have been demonstrated here and elsewhere. The relationship of balance point based degree day and solar methods to estimates of cooling loads in buildings and heating loads in nonresidential buildings has not been fully verified through experiment. These methods can be very useful to architects evaluating their designs. However, the architect's faith in the theory should rest on a more thorough validation. The protocols developed in **Level 2** point toward an experimental approach aimed at providing that validation. The authors intend to continue working with the protocols in this package to explore the relationship between the actual thermal performance of buildings and the theoretical balance point models that estimate the building performance. We hope that faculty and graduate students intrigued by the ideas presented in this package will press the boundaries of the work into new territories.

One question that arose during the development of this package involves unconditioned buildings. The balance point concept assumes an HVAC system maintains the building at a constant temperature during occupancy. What building Vital Sign would give the designer an indication of the average temperature to which a building would rise (or fall) to in the absence of heating or cooling equipment? The temperature plots for the bungalow presented in **Level 2** indicate that the form of the building temperature curve follows the form of the ambient air temperature curve. Given differing designs and the climatic conditions of the building's location, the building temperature would be closer or farther from the comfort range for occupants. This would be an important Vital Sign for architects designing buildings without heating or cooling systems (most houses in Wisconsin, for example, are not air-conditioned).

The following pages suggest some simple future protocols which relate to the building balance point and building energy flows. First, a simple method for making a sunshine recorder is suggested. Second, a technique to estimate the building time constant and the building thermal capacitance is suggested. We hope these suggestions help spur the student and faculty to develop their own protocols for measuring building Vital Signs.

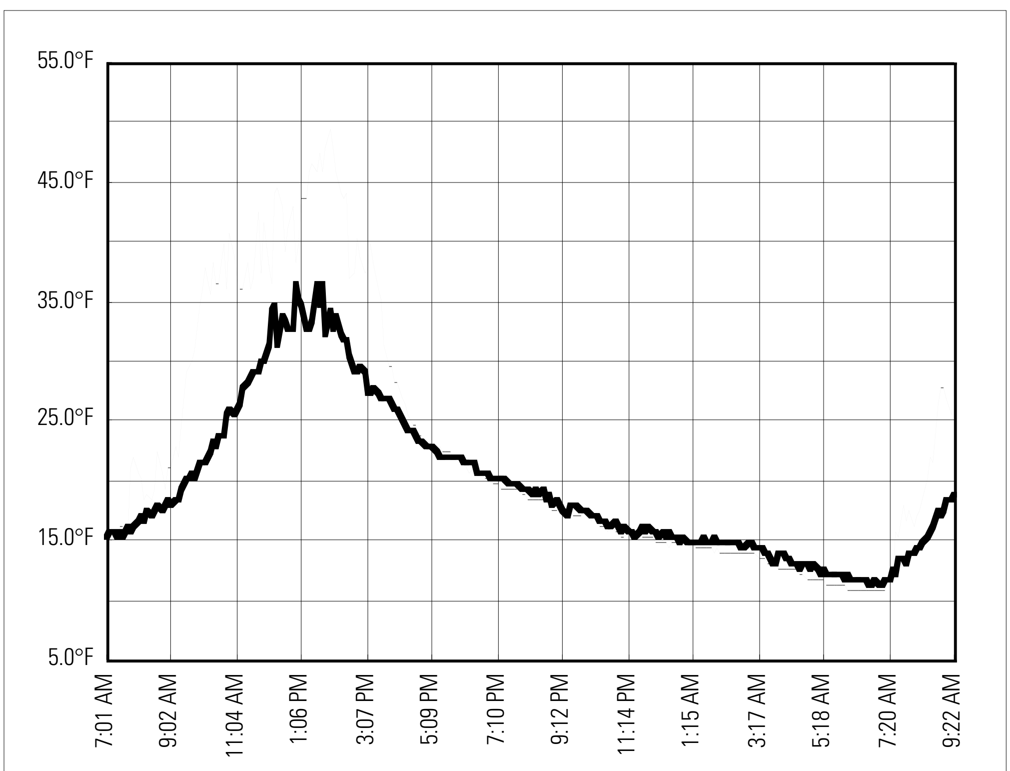


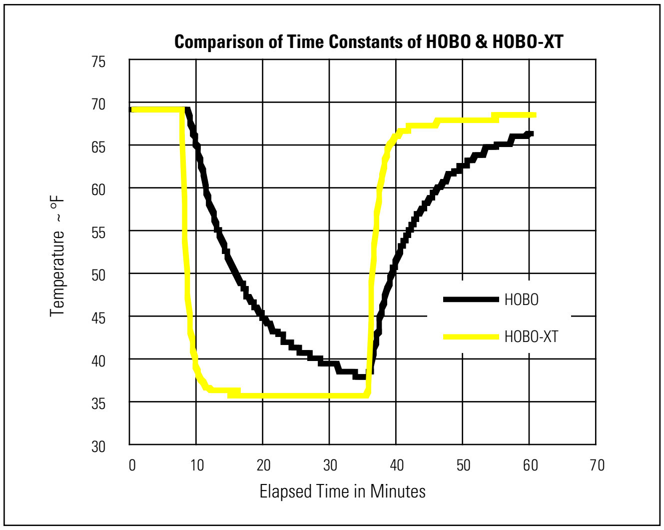
MEASURING SOLAR VARIATION WITH A SUN CHART RECORDER

The field estimates of the Building Balance Point presented in Level 2 do not separate the internal heat gains and solar heat gains. The incident solar radiation can be measured with a pyranometer and datalogger. A less expensive method uses two HOBO-XT data loggers. The measurements do not provide the accuracy of a pyranometer, but are, instead, very similar to the output of a sunchart recorder.

The Level 2 Protocol requires heating supply, indoor and outdoor temperature measurements. With one additional exterior temperature measurement, a sun chart recorder can be modeled. By placing one HOBO-XT temperature sensor away from direct and reflected solar radiation, the ambient air temperature is measured. Placing another HOBO-XT sensor in the open so that sunlight can strike it throughout the day results in elevated temperature readings for that sensor. The figure below illustrates the temperature profile of two HOBO-XT sensors during one day. One sensor is located in the shade and the other in the sun. The temperature elevation of the solar irradiated sensor is clearly seen. The sensor in sunlight also "sees" the clear sky at night and registers a lower temperature than the sensor located in the shade.

A sunchart recorder was a divice which rolled a sheet of recording paper continuously under a lens. In direct sunlight, the lens burnt a small hole in the paper. The size of the length of the burn provided an indication of the sunshine hours. The number of sunshine hours was then corelated with the daily solar energy received. The two HOBO temperature outputs are converted into a sunchart recorder by plotting both $(T_{sun} - T_{shade})/2$ and $(T_{shade} - T_{sun})/2$. An example is illustrated at right. A 5°F temperature difference was arbitrarially chosen as the threshold for sunny conditions. The number of sunshine hours are indicated for each day. For the correlations of sunshine hours, see *Solar Engineering of Thermal Processes*, 2nd ed. by J. Duffie and W. Beckman.



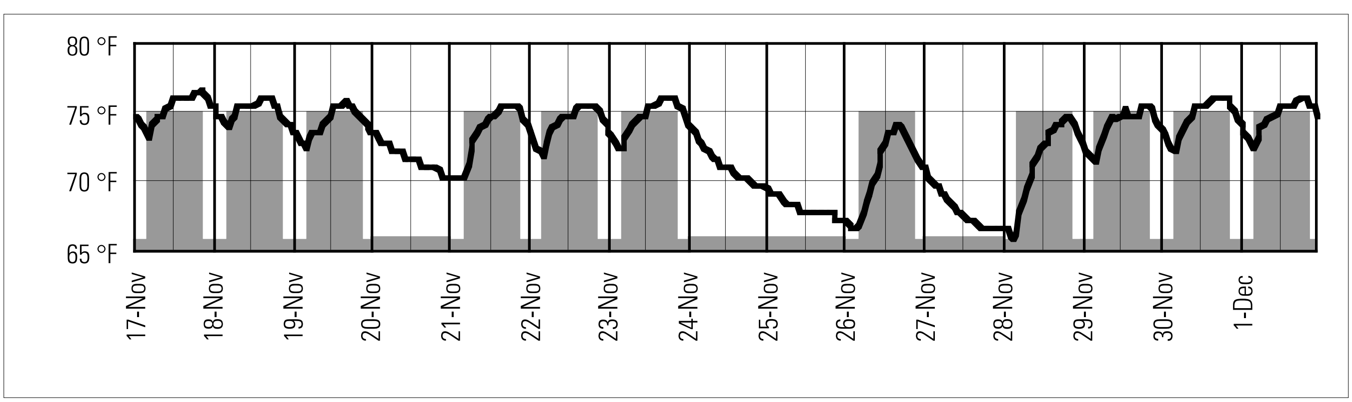


MEASURING THE BUILDING THERMAL CAPACITANCE

While the thermal capacitance is a building variable that influences dirunal energy flows, it was considered outside the scope of this set of Protocols. The methodology for estimating thermal capacitance is offered here for anyone wishing to extend the building balance point analysis or to explore the effects of thermal capacitance in buildings.

When any object at one temperature is suddenly placed in another temperature, its temperature will move toward the new environmental temperature. The rate that the object's temperature changes is a function of both the thermal capacitance of the object and its rate of heat transfer to the environment. The figure at left illustrates the rate of temperature change in a HOBO and HOBO-XT sensor. Both were moved from an indoor temperature of 69°F to an outdoor temperature of 36°F. The HOBO-XT, with an external temperature sensor, Drops to the outdoor temperature very rapidly, reaching it within 8 minutes. The HOBO, with the sensor inside the plastic case along side the microprocessor has a much lower rate of heat transfer to the environment and cools much slower. After 30 minutes it still has not reached the ambient air temperature. Each sensor type has a different time constant. The HOBO-XT has a much shorter time constant than the HOBO. The temperature drop (or rise) of an object moving towards thermal equilibrium with its environment is a simple exponential function of its time constant. Given a measured temperature drop, the time constant can be estimated. The time constant is the ratio of an object's thermal capacitance to its heat transfer coefficient to the environment. If a building's time constant and heat transmission coefficient are known, its thermal capacitance can be estimated.

The figure below illustrates a plot of the building temperature of a library overlaying a bar graph of the occupancy schedule. The weekends, when the temperature is allowed to float provide, a perfect set of data to determine the time constant (and, by extension, the building thermal capacitance).



VITAL SIGNS

BUILDING BALANCE POINT
Appendix 3: *BPgraph.xla*, a Spreadsheet for Balance Point Analysis

The Build Balance Ponit package includes three *Excel* files which assist the user in performing a simple balance point analysis. The files are *Solar.xla*, *BPgraph.xla* and *BPsGain.xla*. Each is described briefly below.

SOLAR.XLA

Solar.xla is an Excel add-in macro. It provides over fifty climate, solar and energy based functions which are added to the *Excel* function set. The add-in macro also includes a climate data file for 70 cities from around the globe. See Appendix 4 for a listing of the cities. The *Solar.xla* file is placed in the startup file for *Excel* which is located in the Preferences folder in the System folder on a macintosh and the xlstart directory in the msoffice directory on a pc running windows. This file is required by both *BPgraph.xla* and *BPsGain.xla*..

BPGRAPH.XLA

This file is the spread sheet used to automate the Level I building balance point analysis. The six pages of input and output from the spreadsheet are illustrated on the next six pages of the appendix. All input cells are color coded yellow (which prints light grey in a black ink printer). The first page provides a macro to change the city location and prints temperature and solar radiation data. The second page organizes estimate of the building heat transfer coefficient, $\hat{\mathbf{U}}_{\mathbf{bldg}}$. The third page organizes estimate of the building internal heat gain rate, $\mathbf{Q}_{\mathbf{IHG}}$. The fourth page organizes the solar radiation data for all surfaces. The fifth page provides tabular data underlying the solar admittance graphs. Finally, the building balance point graphs are plotted on the last page.

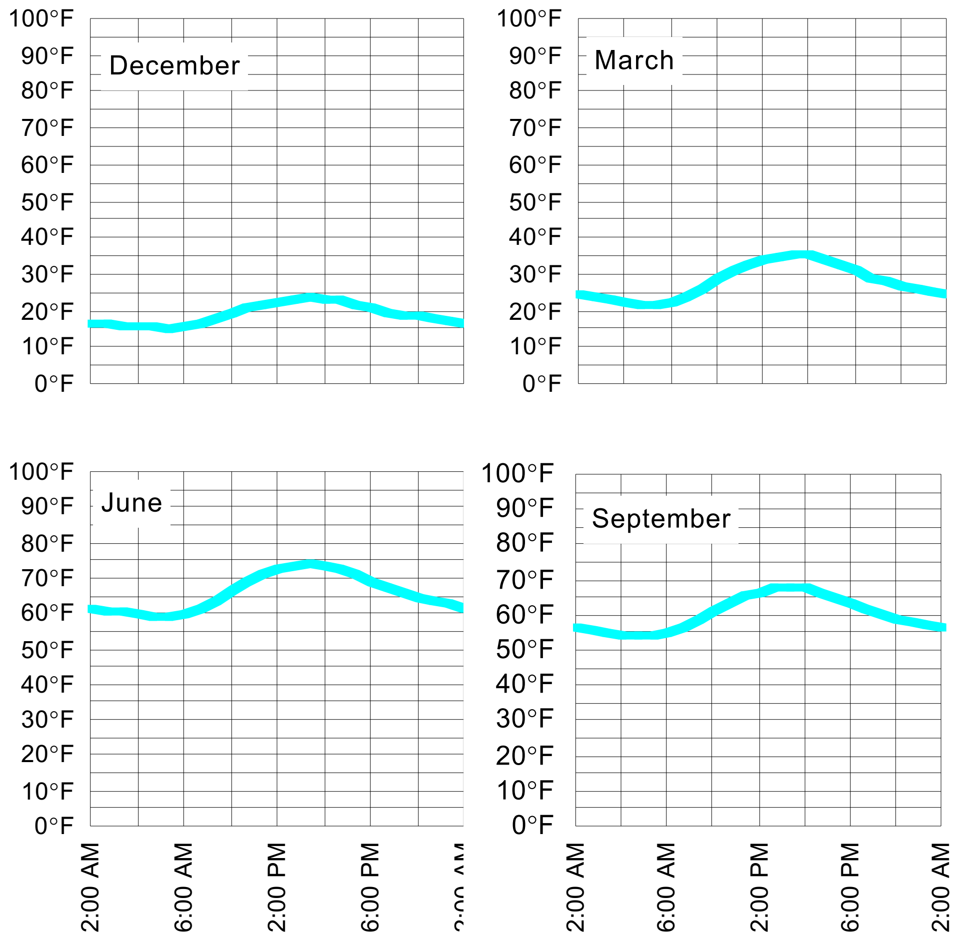
BPSGAIN.XLA

This is the template that was used to estimate solar heat gains for standard glass for each season and orientation for seventy cities. The data generated in this spreadsheet is part of the window solar gain database in *BPgraph.xla*. This spreadsheet is provided to illustrate the method for modeling solar heat gains through glazing using functions from the *Solar.xla* add-in macro. The spreadsheet can be used for different orientations, slopes and glazing systems.

Change City

City **Minneapolis - St. Paul**
Latitude **44.88°**

Building **Uninsulated Solar House**

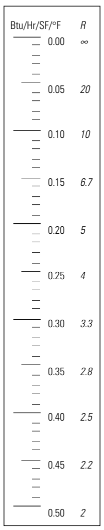


AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

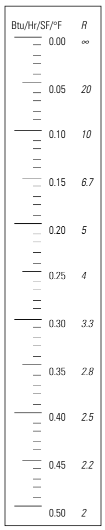
		South	East	West	North	Horizontal
WINTER	9:00 AM	45	41	8	8	16
	12:00 PM	92	18	18	18	50
	3:00 PM	49	9	42	9	19
SPRING & FALL	9:00 AM	62	92	22	22	64
	12:00 PM	125	40	37	37	129
	3:00 PM	83	27	91	27	87
SUMMER	9:00 AM	29	113	29	29	96
	12:00 PM	82	73	48	48	178
	3:00 PM	73	46	90	46	167

Estimating the Enclosure Heat Flows — Uninsulated Solar House, Minneapolis - St. Paul

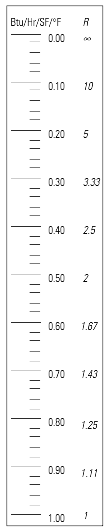
Wall Heat Transfer Rate BTU/Hr/°F/SF



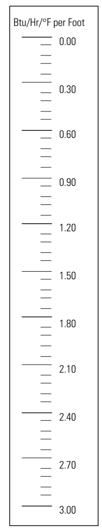
Roof Heat Transfer Rate BTU/Hr/°F/SF



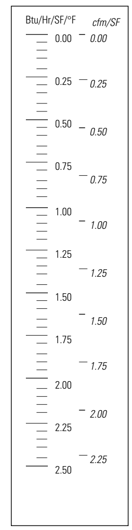
Glazing Heat Transfer Rate BTU/Hr/°F/SF



Ground Heat Transfer Rate BTU/Hr/°F/ft



Ventilation or Infiltration Heat Transfer Rate BTU/Hr/°F/SF Floor



Wall		Roof		Glazing		Ground		Ventilation	
Uwall	0.20	Uroof	0.20	Uglzg	1.10	Ugrnd	0.70	Ûvent	0.15
Net Wall Area SF		Net Roof Area SF		Glazing Area		Building Perimeter			
Aw	1,200	Ar	2,000	Ag	800	Perimeter	350		

Estimating the Building Enclosure Heat Transfer Rate

First, mark estimates the enclosure heat transfer rates on the appropriate scales (**Uwall**, **Uroof**, **Uglzg**, **Ugrnd** and **Ûvent**). Note estimates of the heat transfer rates and associated areas in their respective cells. Place the estimated gross floor area in the appropriate cell at right.

Second, for each heat flow path across the enclosure, modify the heat transfer rate so that it represents the rate of heat transfer per square foot of floor area rather than per unit enclosure area. This is acomplished by multiplying each enclosure U factor by its associated area and then dividing by the floor area. For example, for the enclosure wall:

Ûwall = (**Uwall** X **Aw**) ÷ **Af**

Note that heat transfer rates tied to the building floor area have a **^** symbol over the U. The ventilation rate is already estimated per unit floor area. The ground heat loss rate is multiplied by the perimeter and divided by the floor area. Enter your estimates in the appropriate cells at right and mark them on the bar graph. **Ûbldg**, the total enclosure heat transfer rate per unit floor area, is then estimated as the sum of the individual transfer rates.

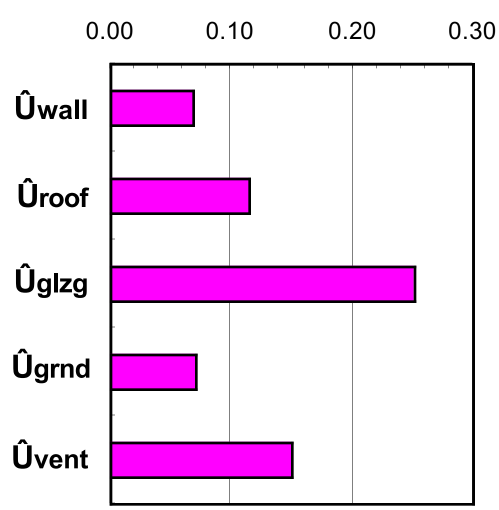
Gross Floor Area SF

Af	3,500

Building Heat Transfer Rate Btu/Hr/°F/SF Floor

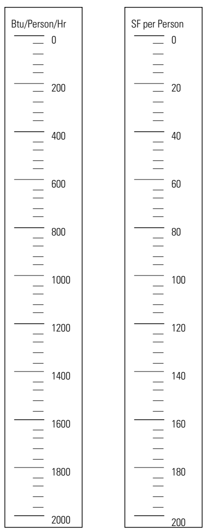
Ûwall	0.07
Ûroof	0.11
Ûglzg	0.25
Ûgrnd	0.07
Ûvent	0.15
$\hat{U}_{bldg}$	0.65

Enclosure Heat Transfer Btu/Hr/°F per SF of Floor Area



Characterizing the Internal Heat Gains — Uninsulated Solar House, Minneapolis - St. Paul

Occupant Heat Gain Rate

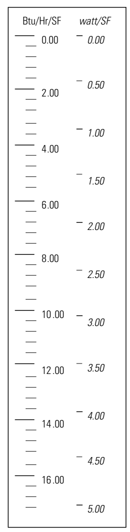


Activity Level	People Density
500	875

Q_{occ} is estimated by dividing **Activity Level** by **People Density**.

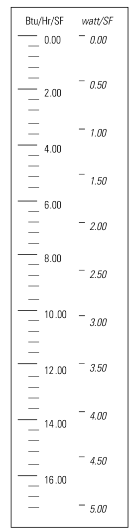
Qpeople	0.6

Lighting Heat Gain Rate



Qlight	0.7

Equipment Heat Gain Rate



Qequip	0.5

Thermostat & Schedule

T_thermostat is the average thermostat setting for the building for heating and cooling.

T_thermostat	68.0 °F

Occupancy Start Time

t_start is the average time of day the building is occupied (ignore weekends).

t_start	6:00 AM

Occupancy End Time

t_end is the average time of day the building becomes unoccupied (ignore weekends).

t_end	10:00 PM

Q_{IHG}, the Building Internal Heat Gain Rate

Q_{IHG} is estimated as the sum of Q_{people}, Q_{light} and Q_{equip}. Q_{IHG} is given in Btu of heat generated per hour per square foot of floor area.

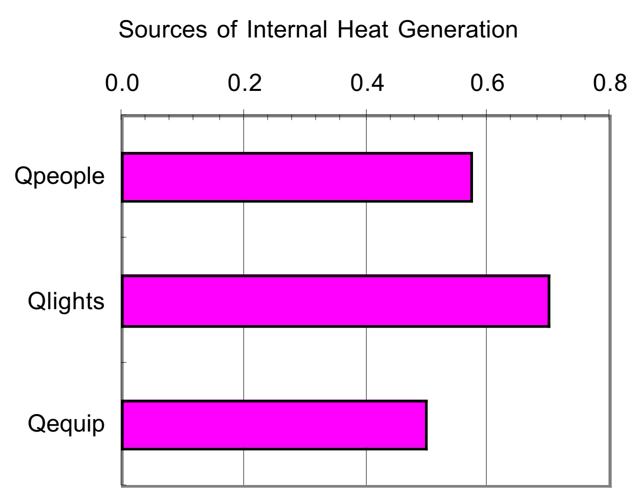
QIHG	1.8

Estimating the Internal Heat Generation Rate & Balance Point

First, mark the estimated values of **Activity Level**, **People Density**, **Qlight** and **Qequip** on the appropriate scales. Enter the **T_thermostat**, and the occupancy schedule, **t_start** and **t_end**.

Second, estimate **Qpeople** as described and plot all three sources of internal heat generation on the bar graph at right. Place values of heat generation rates on the horizontal scale as appropriate for the magnitude of the estimated heat generation rates.

Finally, estimate **QIHG**, **DTocc** and **T_balance** in the manner described at right and enter the values into the appropriate cells.



Occupancy Temperature Difference

DT_{occ}, the temperature difference across the enclosure balanced by internal heat gains, is estimated by dividing U_{bldg} into Q_{IHG}.

DTocc	2.7 °F

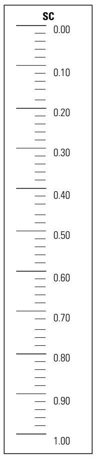
Building Balance Point Temperature

T_balance, the building balance point temperature during occupancy, is estimated by subtracting DT_{occ} from the building thermostat temperature, **T_thermostat**.

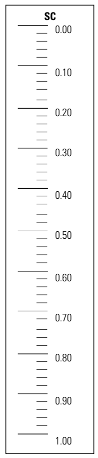
T_balance	65.3 °F

Characterizing the Solar Heat Gains **Uninsulated Solar House, Minneapolis - St. Paul**

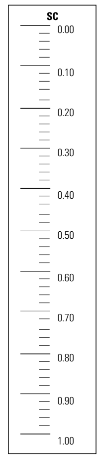
South Facing Shading Coefficient



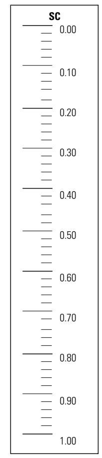
East Facing Shading Coefficient



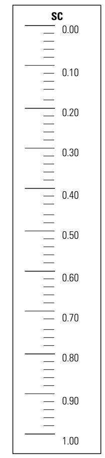
West Facing Shading Coefficient



North Facing Shading Coefficient

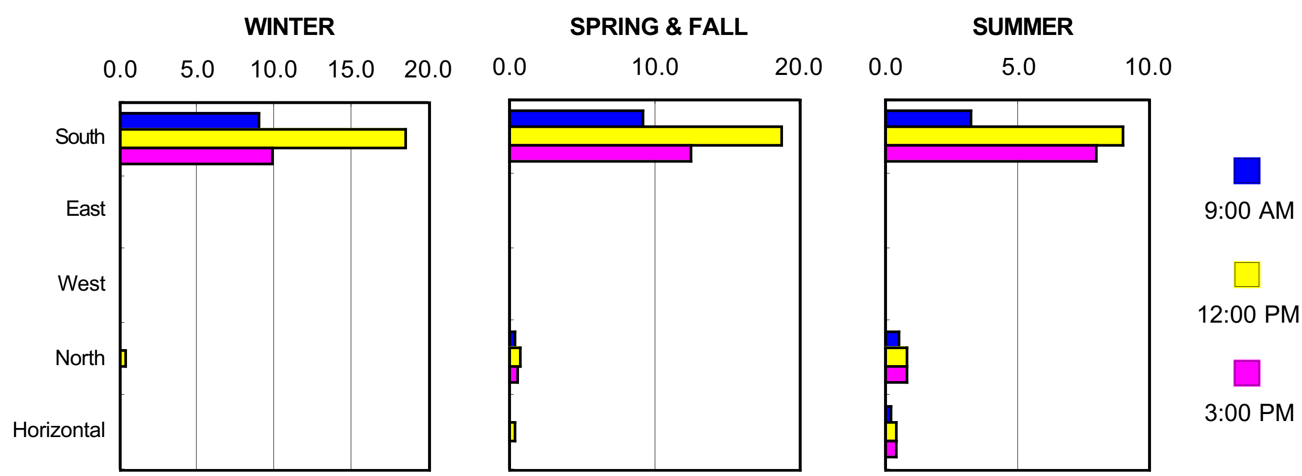


Horizontal Shading Coefficient



South Facing		East Facing		West Facing		North Facing		Horizontal	
Area	**700**	Area	**0**	Area	**0**	Area	**90**	Area	**10**
Ag,s/Af	**20%**	Ag,e/Af	**0%**	Ag,w/Af	**0%**	Ag,n/Af	**3%**	Ag,h/Af	**0%**
Winter SC	**1.00**	Winter SC	**0.90**	Winter SC	**0.90**	Winter SC	**0.90**	Winter SC	**0.80**
Fall & Spring SC	**0.75**	Fall & Spring SC	**0.75**	Fall & Spring SC	**0.75**	Fall & Spring SC	**0.75**	Fall & Spring SC	**0.80**
Summer SC	**0.55**	Summer SC	**0.75**	Summer SC	**0.75**	Summer SC	**0.65**	Summer SC	**0.80**

Average Solar Gains ~ BTU per Hour per Square Foot of Floor



GLAZING AREA & ORIENTATION AS PERCENTAGE OF FLOOR AREA

	South	East	West	North	Horizontal
Glazing Area	20%	0%	0%	3%	0%

WINTER SOLAR GAINS

	South	East	West	North	Horizontal
Shading Coefficient	1	0.9	0.9	0.9	0.8

Solar Gain per square foot of Floor - Btu per Hour per SF

						Total
9:00 AM	8.9	0.0	0.0	0.2	0.0	**9.13**
12:00 PM	18.4	0.0	0.0	0.4	0.1	**18.95**
3:00 PM	9.9	0.0	0.0	0.2	0.0	**10.16**

SPRING & FALL SOLAR GAINS

	South	East	West	North	Horizontal
Shading Coefficient	0.75	0.75	0.75	0.75	0.8

Solar Gain per square foot of Floor - Btu per Hour per SF

						Total
9:00 AM	9.2	0.0	0.0	0.4	0.1	**9.81**
12:00 PM	18.7	0.0	0.0	0.7	0.3	**19.71**
3:00 PM	12.5	0.0	0.0	0.5	0.2	**13.22**

SUMMER SOLAR GAINS

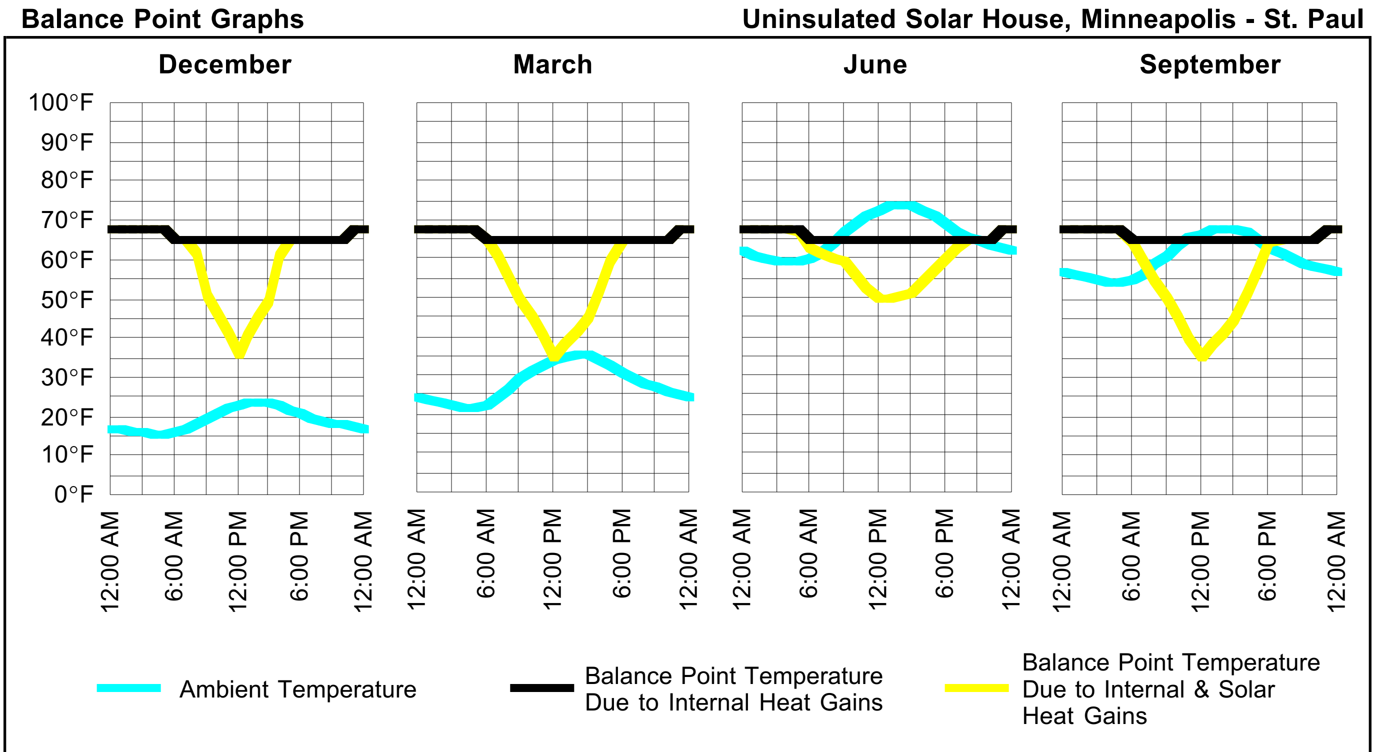
	South	East	West	North	Horizontal
Shading Coefficient	0.55	0.75	0.75	0.65	0.8

Solar Gain per square foot of Floor - Btu per Hour per SF

						Total
9:00 AM	3.2	0.0	0.0	0.5	0.2	**3.93**
12:00 PM	9.0	0.0	0.0	0.8	0.4	**10.19**
3:00 PM	8.0	0.0	0.0	0.8	0.4	**9.14**

SOLAR TEMPERATURE DIFFERENCE

	Winter	**Spring**	**Summer**
9:00 AM	**13.9 °F**	**15.0 °F**	**6.0 °F**
12:00 PM	**29.0 °F**	**30.1 °F**	**15.6 °F**
3:00 PM	**15.5 °F**	**20.2 °F**	**14.0 °F**


Balance Point Graphs
Uninsulated Solar House, Minneapolis - St. Paul
December
March
June
September
100°F
90°F
80°F
70°F
60°F
50°F
40°F
30°F
20°F
10°F
0°F
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
Ambient Temperature
Balance Point Temperature Due to Internal Heat Gains
Balance Point Temperature Due to Internal & Solar Heat Gains

VITAL SIGNS

BUILDING BALANCE POINT
Appendix 4: Climatic Data for Balance Point Analysis

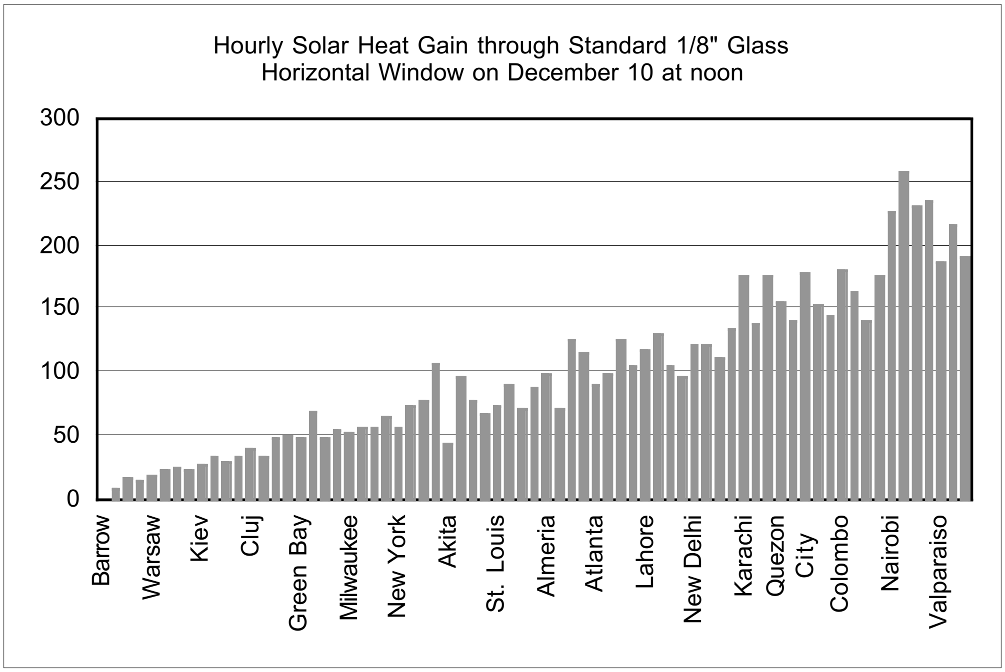
This appendix provides climatic data for use in hand based calculations of the building balance point. In addition, the cities with climatic data included in the *BPgraph.xla* Excel spreadsheet are listed at right. The North American cities with climatic data provided (starting on page Apendix4_4) include: Atlanta, Boston, Chicago, Denver, Houston, Los Angeles, Miami, Minneapolis, New York, San Francisco, Seattle, St. Louis, Toronto and Washington, DC.

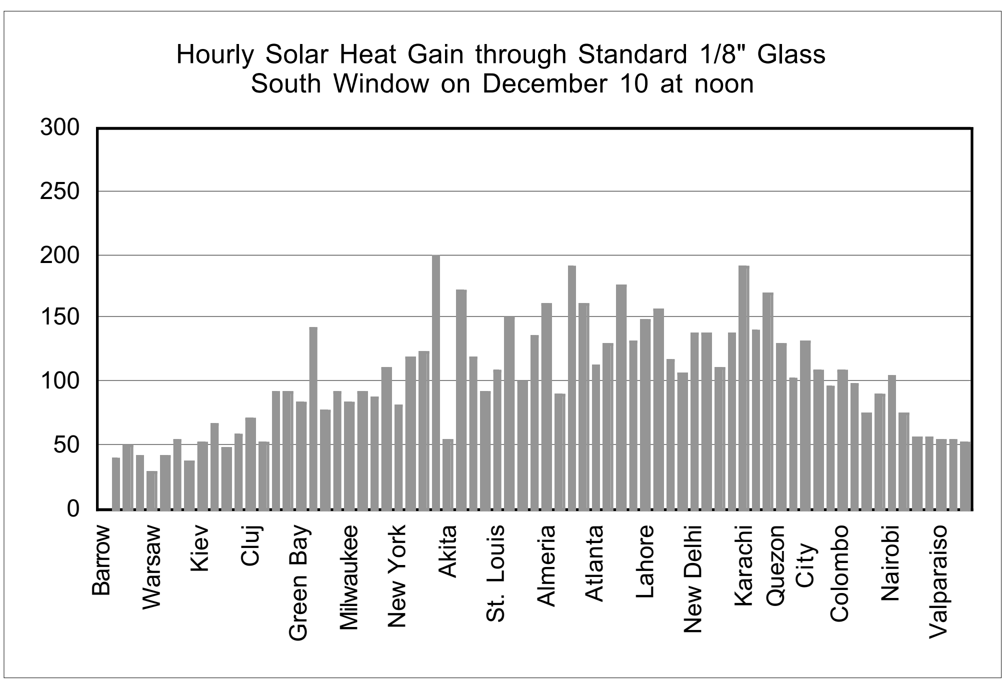
If the building being studied is not close to any of the cities listed in the appendix or included in the spreadsheet, pick the city that most nearly represents the climate where the building is located. The climatic variables which should be similar include latitude, temperature and cloudiness.

CITY	STATE	LATITUDE	CITY	COUNTRY	LATITUDE
Barrow	Alaska	71.3°	St. Petersburg	Russia	60.0°
Seattle	Washington	47.5°	Copenhagen	Denmark	55.8°
Montreal	Quebec	45.5°	Moscow	Russia	55.8°
Minneapolis	Minnesota	44.9°	Warsaw	Poland	52.3°
Green Bay	Wisconsin	44.5°	London	Great Britian	51.5°
Toronto	Ontario	43.7°	Vlissigen	Netherlands	51.5°
Madison	Wisconsin	43.1°	Brussels	Belgium	50.8°
Milwaukee	Wisconsin	43.0°	Kiev	Ukraine	50.4°
Boston	Massacheusetts	42.4°	Stuttgart	Germany	48.8°
Chicago	Illinois	42.0°	Zurich	Switzerland	47.5°
New York	New York	40.8°	Cluj	Romania	46.8°
Pittsburg	Pennsylvania	40.5°	Odessa	Ukraine	46.5°
Philadelphia	Pennsylvania	39.9°	Nice	France	43.7°
Denver	Colorado	39.8°	Rome	Italy	41.9°
Ely	Nevada	39.3°	Akita	Japan	39.7°
Kansas City	Missouri	39.3°	Lisbon	Portugal	38.7°
Washington	DC	38.9°	Athens	Greece	38.0°
St. Louis	Missouri	38.8°	Almeria	Spain	36.8°
San Francisco	California	37.8°	Casablanca	Morocco	33.6°
Nashville	Tennessee	36.1°	Lahore	Pakistan	31.5°
Albuquerque	New Mexico	35.1°	Cairo	Egypt	30.0°
Los Angeles	California	33.9°	New Delhi	India	28.6°
Atlanta	Georgia	33.7°	Karachi	Pakistan	24.8°
Phoenix	Arizona	33.4°	San Juan	Puerto Rico	18.4°
Dallas	Texas	32.9°	Quezon City	Phillipines	14.6°
New Orleans	Louisiana	30.0°	Bangkok	Thailand	13.7°
Houston	Texas	30.0°	Madras	India	13.0°
New Delhi	India	28.6°	Caracas	Venezuela	10.5°
Orlando	Florida	28.6°	Colombo	Sri Lanka	6.9°
Brownsville	Texas	25.9°	Benin City	Nigeria	6.1°
Miami	Florida	25.8°	Singapore	Singapore	1.0°
Key West	Florida	24.6°	Entebbe	Uganda	0.1°
Honolulu	Hawaii	21.3°	Nairobi	Kenya	-1.3°
			Huancayo	Peru	-12.1°
			Pretoria	South Africa	-25.8°
			Perth	Australia	-31.9°
			Valparaiso	Chile	-33.0°
			Buenos Aires	Argentina	-34.6°
			Wellington	New Zealand	-41.3°

Average hourly solar heat gains admitted by standard glass at noon on December 10th for horizontal and south vertical windows are presented for 70 cities as a function of latitude. Barrow, Alaska is the most northerly city and Wellington, New Zealand is the most southerly. As would be expected, the solar dariation admitted through horizontal glazing will increase as the glazing moves south. The admittance by vertical south glazing peaks between 20° and 40°N lattitude. Nearly half the cities modeled are in this range.

The variation between neighbooring cities is due to level of cloudiness as indicated by the clearness index. For a given city, the clearness index is the ratio of daily average solar energy incident on a horizontal surface to the amount that would be received if the atmosphere were perfectly transparent. The methodology used to model solar admittance is from *Solar Engineering of Thermal Processes*, 2nd ed. by J. Duffie and W. Beckman. *BPsGain.xla* was used to generate this data. It can be modifyed for different orientations and glazings.

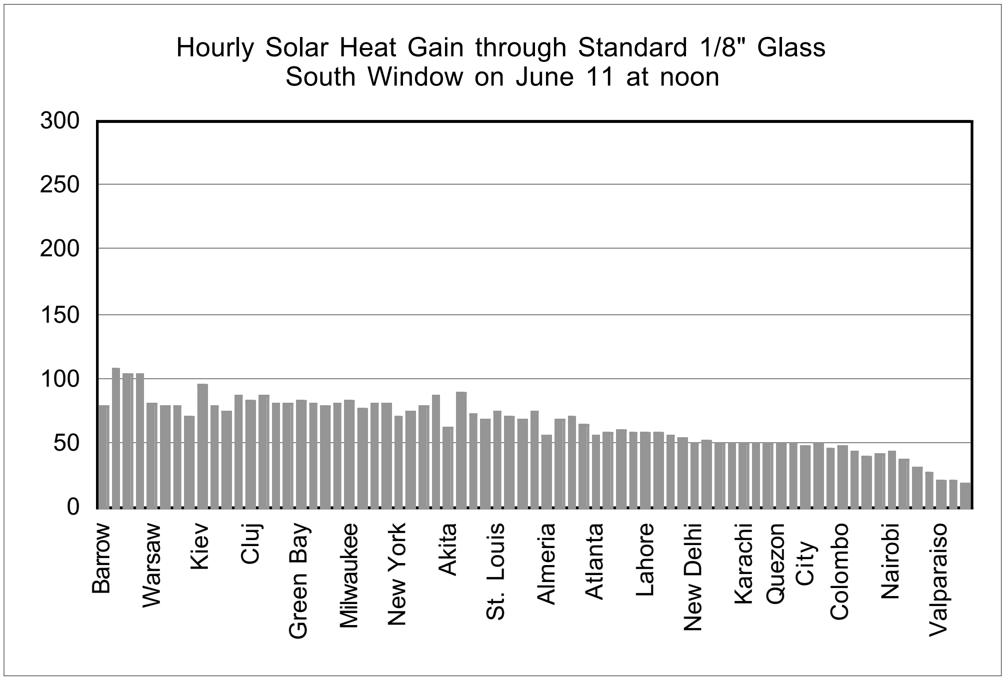


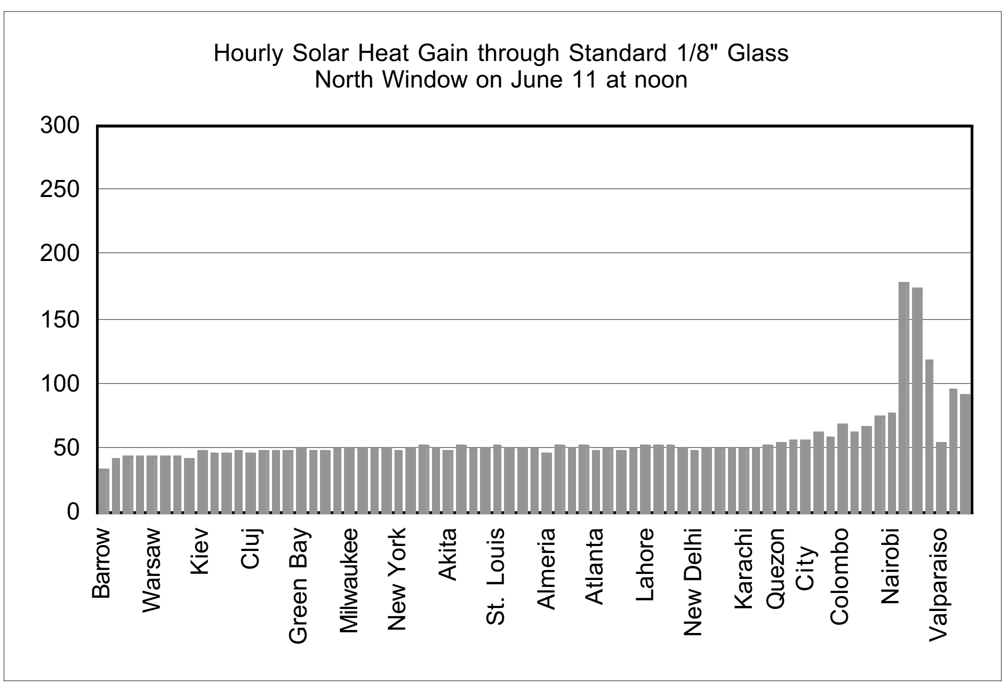


Average hourly solar heat gains admitted by standard glass at noon on June 11th for south and north vertical windows are presented for the same 70 cities on this page.

In June, a south window is facing the high summer sun in northern latitudes and facing away from the low winter sun in southern latitudes. Hourly admittance is greatest near the north pole, but little more than half the peak admittance for a south facing vertical window in December as illustrated in the previous page.

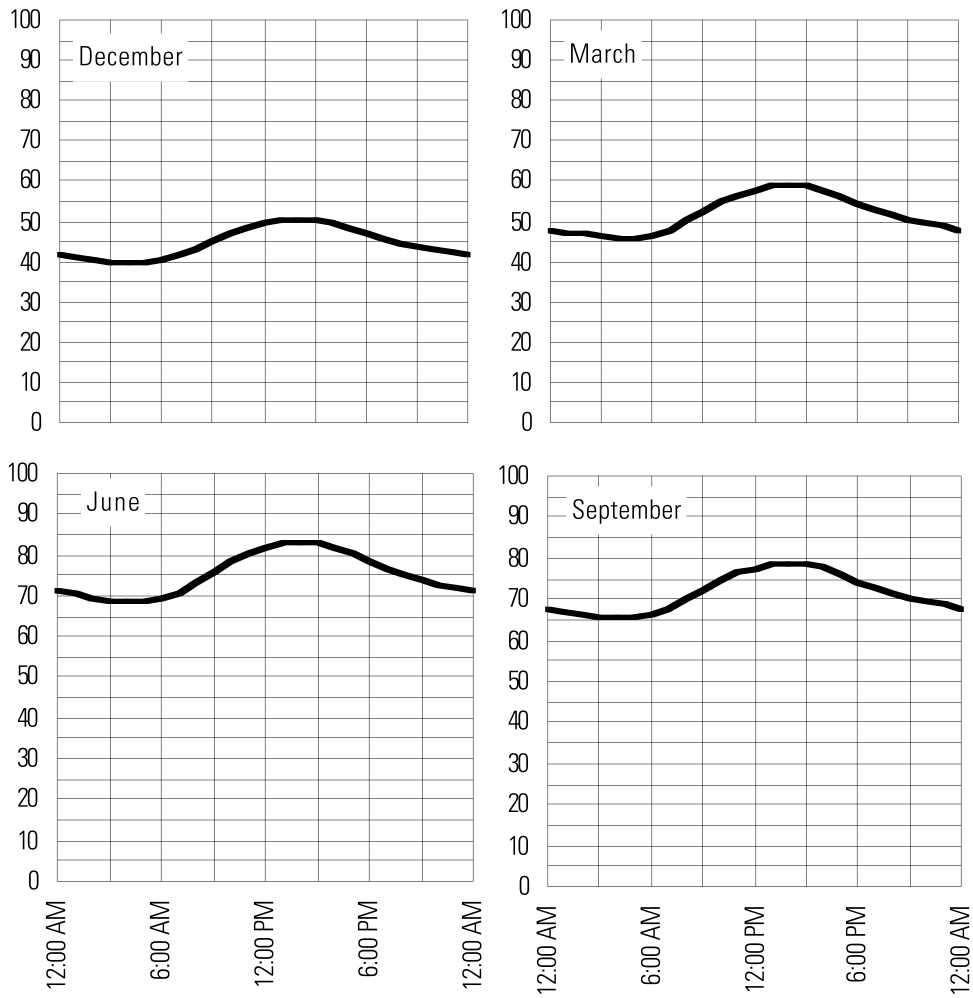
The north facing vertical glazing is facing away from the summer sun and the values are nearly identical to solar admittance of south facing vertical windows in December south of the equator. The peak values on the left are at latitudes from 12° to 40°S when the low winter sun shines on the north facade. The reason for the difference in shape between this plot and the south facing December plot on the previous page is the small number of southern latitude cities (7) to northern latitude cities (63).





City	**Atlanta**
Latitude	**33.65°**

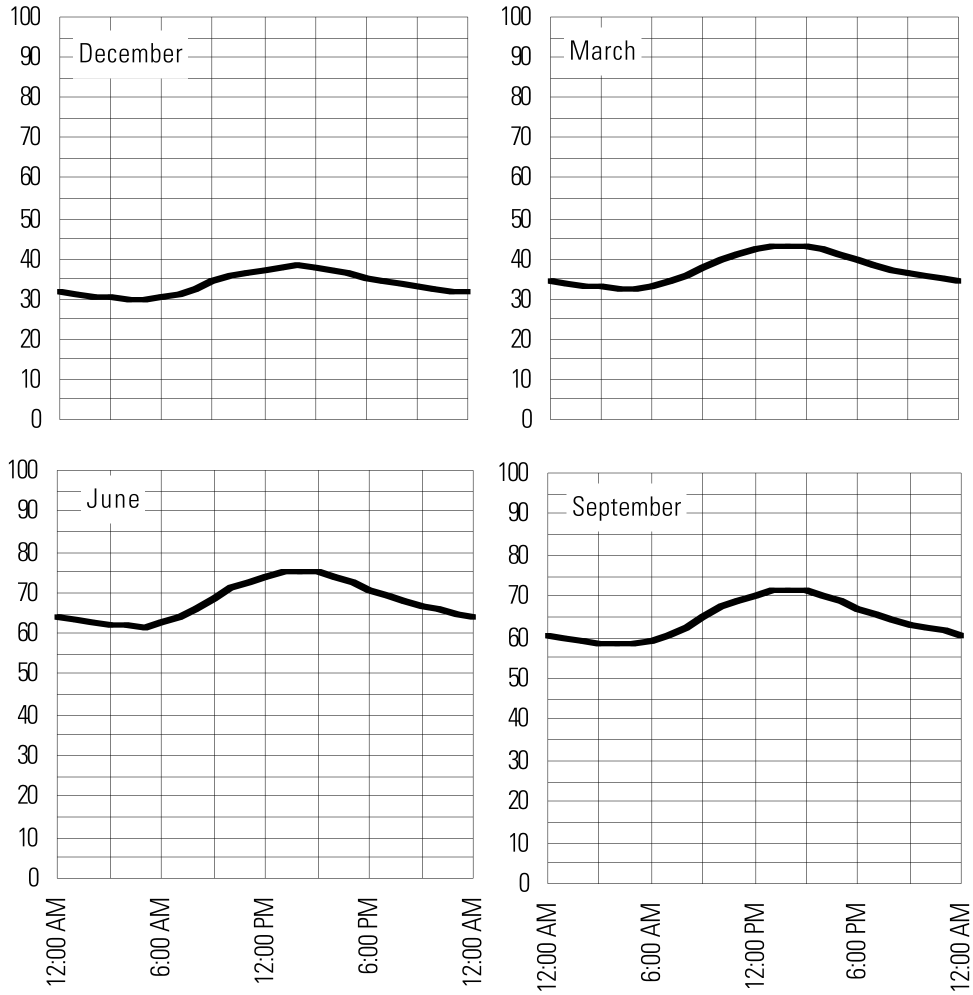
Average hourly temperatures and solar gains are illustrated for 14 cities starting with Atlanta, Georgia at right. The *BPgraph.xla* spreadsheet can generate similar information for any of the 70 cities in the data base. These 14 cities are provided for those who wish to perform the building balance point analysis by hand.



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	53	61	12	12	28
	12:00 PM	114	32	28	28	90
	3:00 PM	81	19	64	19	55
SPRING & FALL	9:00 AM	44	93	22	22	63
	12:00 PM	109	57	43	43	152
	3:00 PM	85	36	92	36	120
SUMMER	9:00 AM	24	103	24	30	74
	12:00 PM	55	87	49	49	179
	3:00 PM	58	50	81	50	184

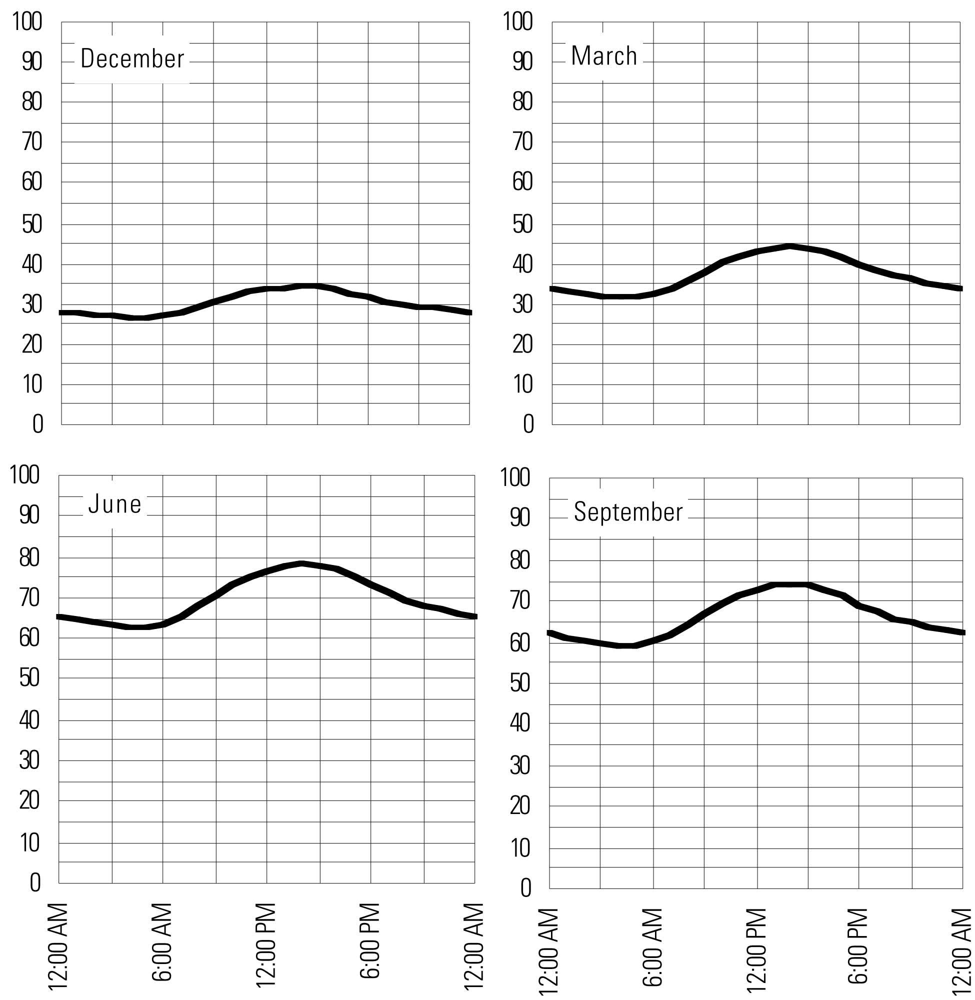
City	**Boston**
Latitude	**42.37°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	58	45	12	12	28
	12:00 PM	92	20	22	20	56
	3:00 PM	39	8	41	8	15
SPRING & FALL	9:00 AM	63	78	26	26	73
	12:00 PM	105	37	37	37	120
	3:00 PM	58	24	78	24	67
SUMMER	9:00 AM	34	106	33	33	106
	12:00 PM	77	59	49	49	175
	3:00 PM	57	43	95	43	149

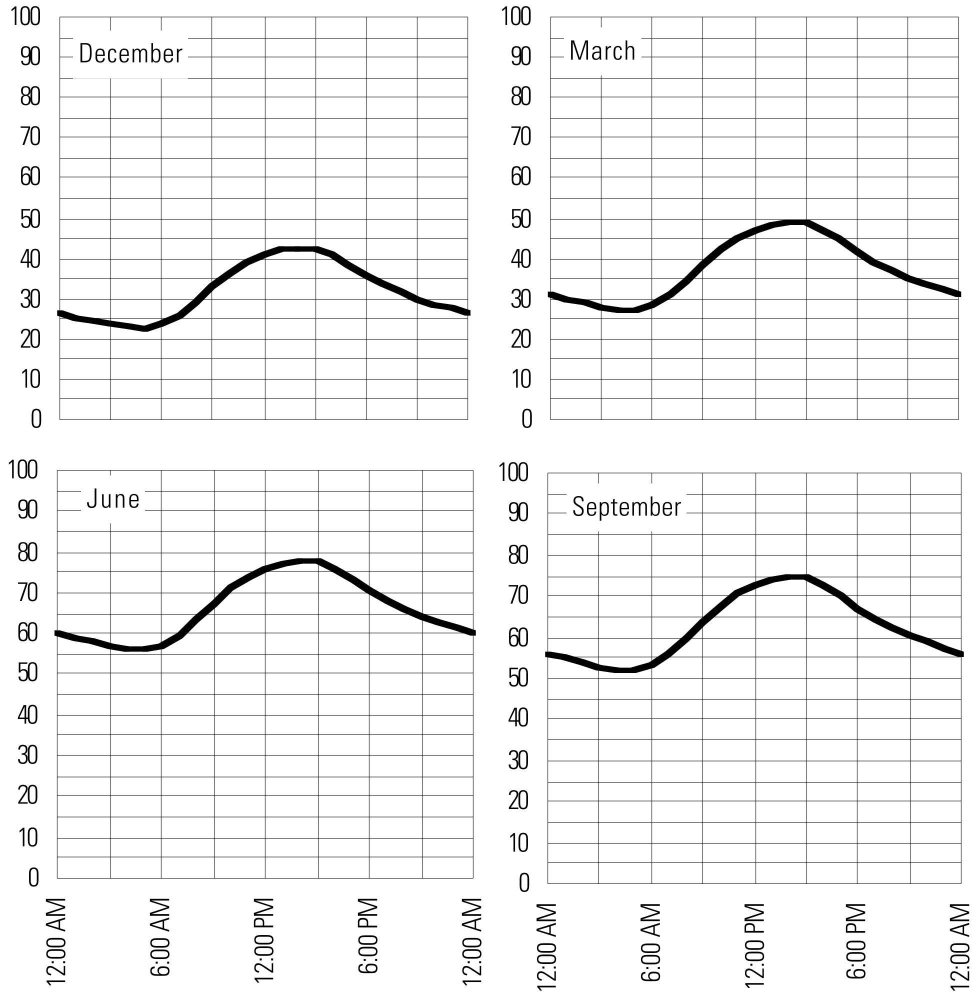
City	**Chicago**
Latitude	**41.98°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	53	43	12	12	27
	12:00 PM	89	20	21	20	56
	3:00 PM	40	9	40	9	17
SPRING & FALL	9:00 AM	68	89	26	26	77
	12:00 PM	117	39	39	39	132
	3:00 PM	67	26	89	26	77
SUMMER	9:00 AM	33	120	33	33	112
	12:00 PM	81	65	50	50	193
	3:00 PM	62	45	103	45	167

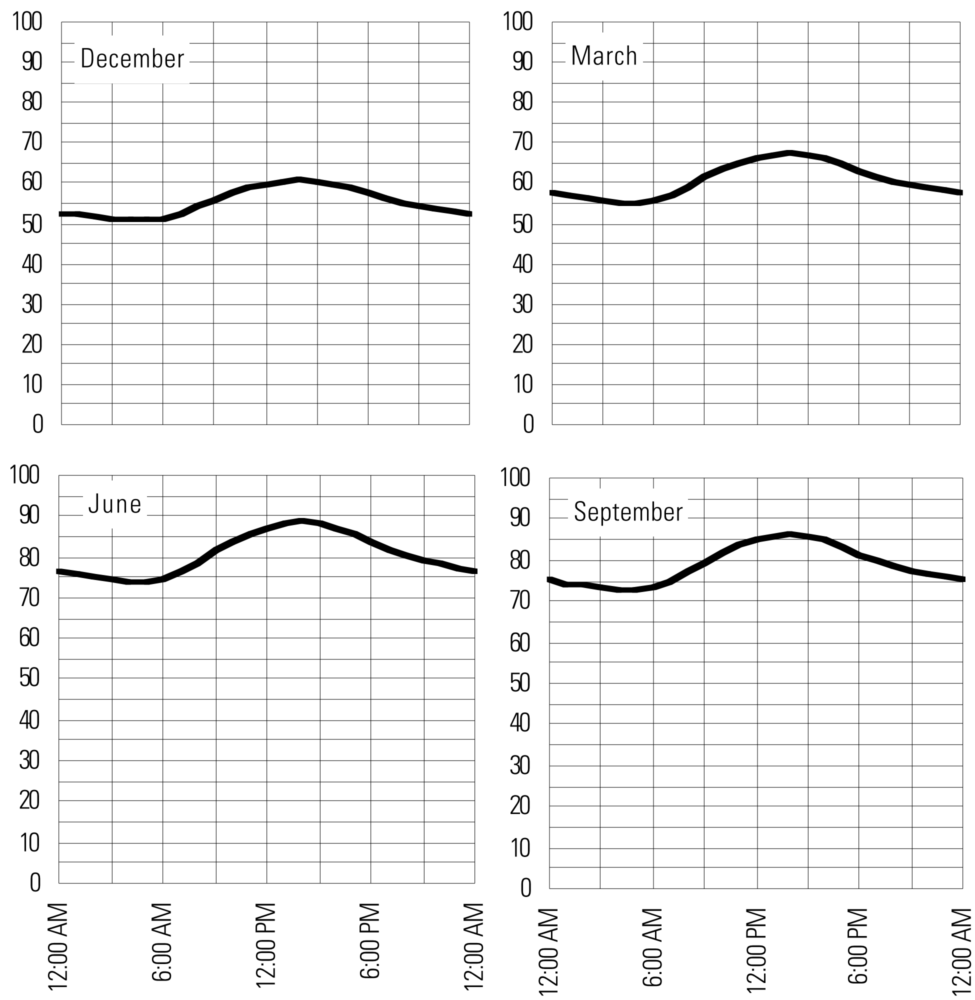
City	**Denver**
Latitude	**39.75°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	127	109	13	13	43
	12:00 PM	200	25	25	25	107
	3:00 PM	117	12	111	12	36
SPRING & FALL	9:00 AM	99	153	26	26	109
	12:00 PM	180	41	41	41	200
	3:00 PM	112	29	149	29	124
SUMMER	9:00 AM	31	165	31	31	134
	12:00 PM	86	79	50	50	245
	3:00 PM	68	46	126	46	219

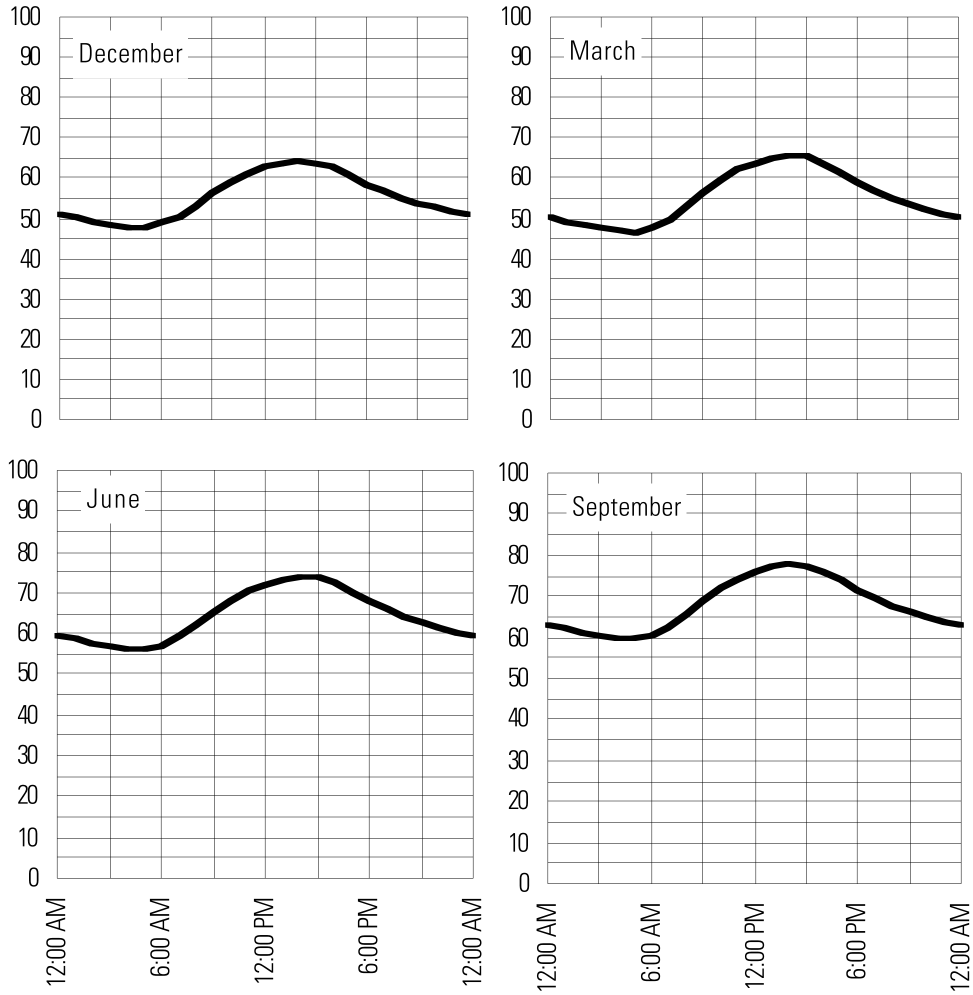
City	Houston
Latitude	29.97°



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	57	61	16	16	40
	12:00 PM	106	31	30	30	97
	3:00 PM	70	20	63	20	54
SPRING & FALL	9:00 AM	47	89	26	26	73
	12:00 PM	99	51	45	45	152
	3:00 PM	70	35	89	35	110
SUMMER	9:00 AM	27	105	27	32	83
	12:00 PM	53	80	50	50	186
	3:00 PM	51	49	88	49	179

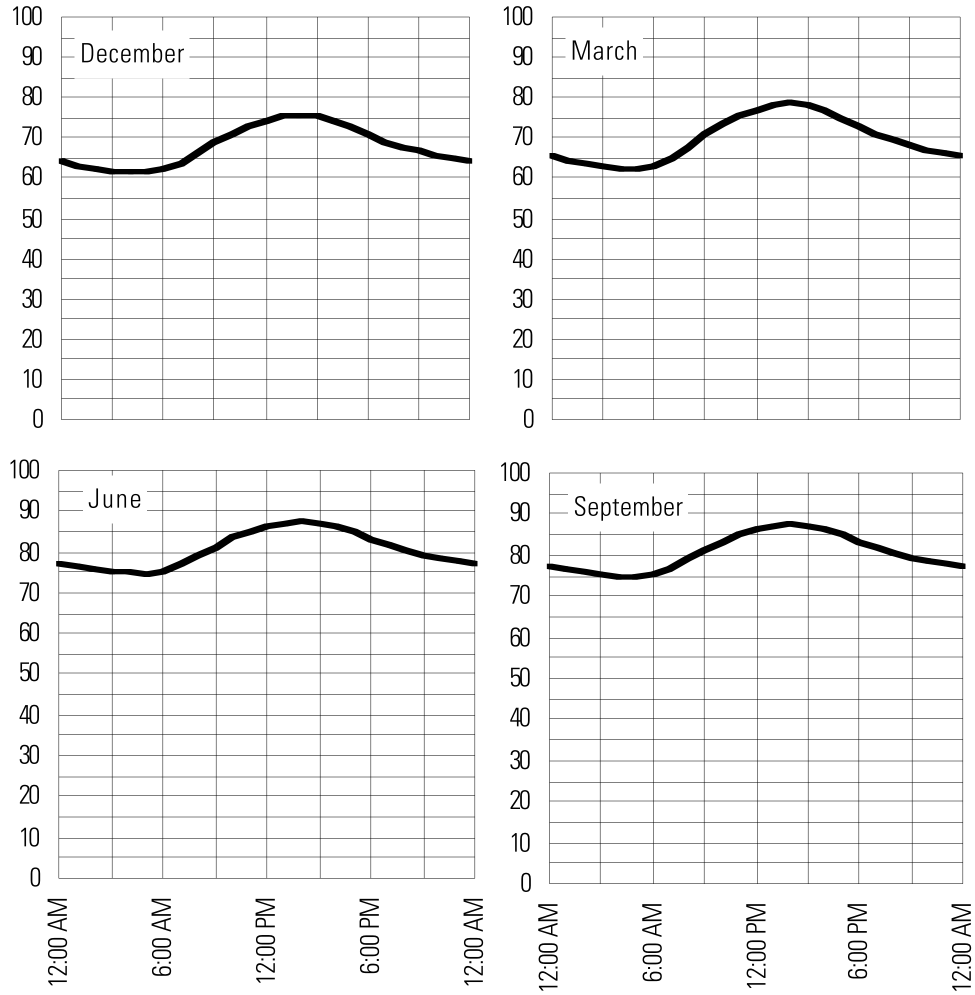
City	**Los Angeles**
Latitude	**33.93°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	107	93	18	18	58
	12:00 PM	161	29	30	29	116
	3:00 PM	92	15	94	15	44
SPRING & FALL	9:00 AM	83	133	30	30	113
	12:00 PM	145	46	46	46	196
	3:00 PM	87	31	132	31	118
SUMMER	9:00 AM	32	129	32	33	116
	12:00 PM	65	71	52	52	214
	3:00 PM	52	46	110	46	186

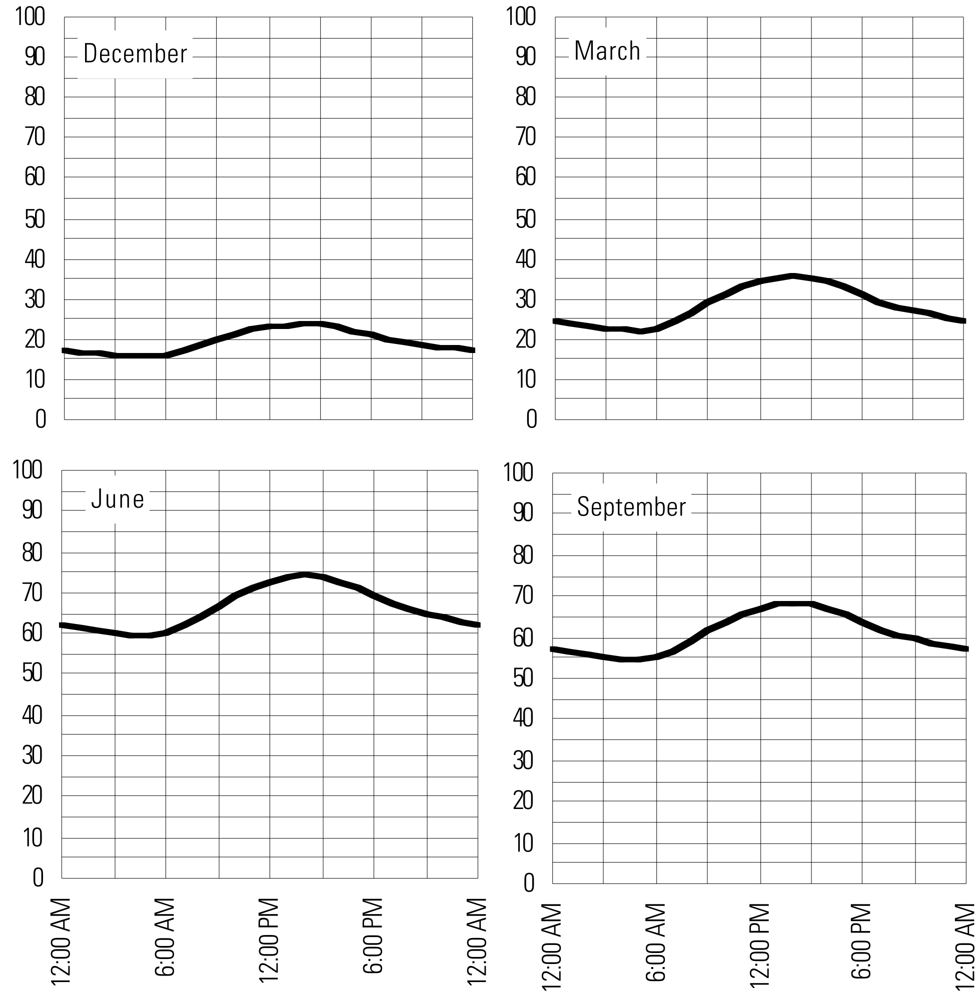
City	**Miami**
Latitude	**25.78°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	81	90	19	19	58
	12:00 PM	139	36	35	35	133
	3:00 PM	95	23	90	23	76
SPRING & FALL	9:00 AM	53	117	28	28	93
	12:00 PM	111	56	49	49	191
	3:00 PM	79	38	113	38	138
SUMMER	9:00 AM	26	89	26	33	73
	12:00 PM	49	74	49	49	168
	3:00 PM	48	48	81	48	161

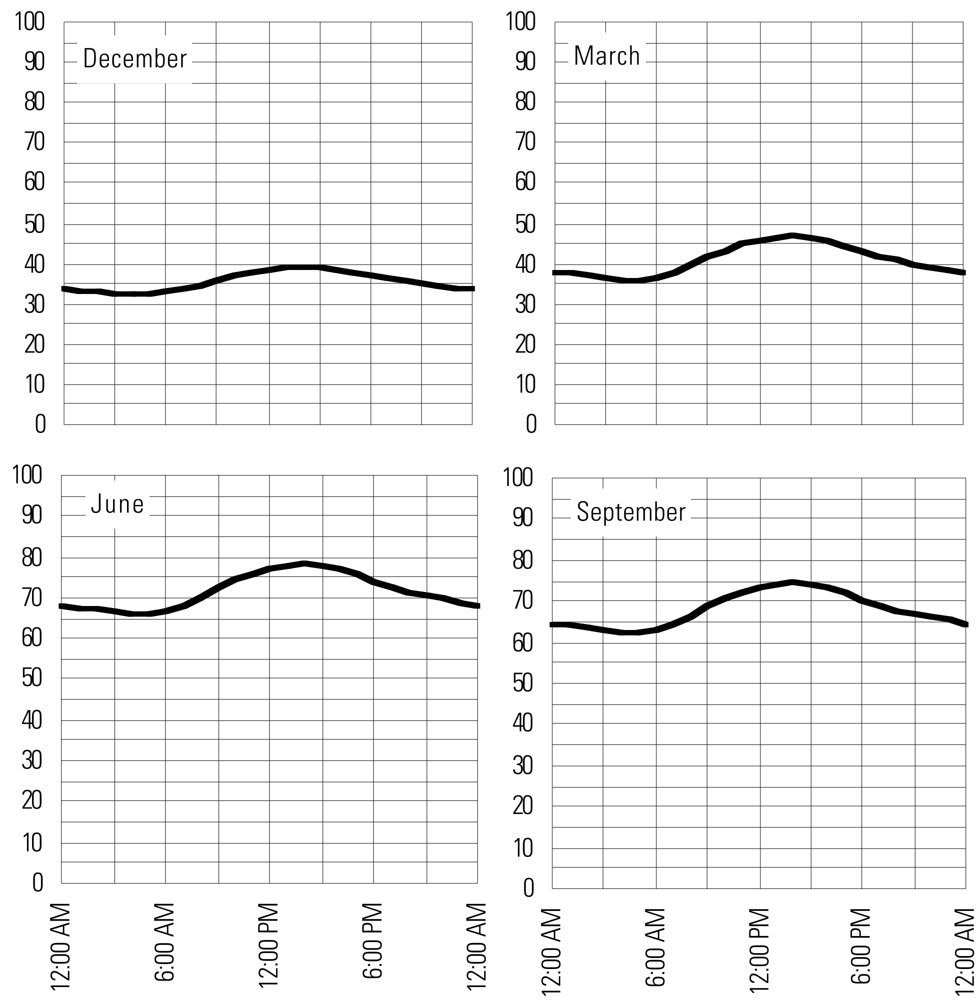
City	Minneapolis - St. Paul
Latitude	44.88°



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	45	41	8	8	16
	12:00 PM	92	18	18	18	50
	3:00 PM	49	9	42	9	19
SPRING & FALL	9:00 AM	62	92	22	22	64
	12:00 PM	125	40	37	37	129
	3:00 PM	83	27	91	27	87
SUMMER	9:00 AM	29	113	29	29	96
	12:00 PM	82	73	48	48	178
	3:00 PM	73	46	90	46	167

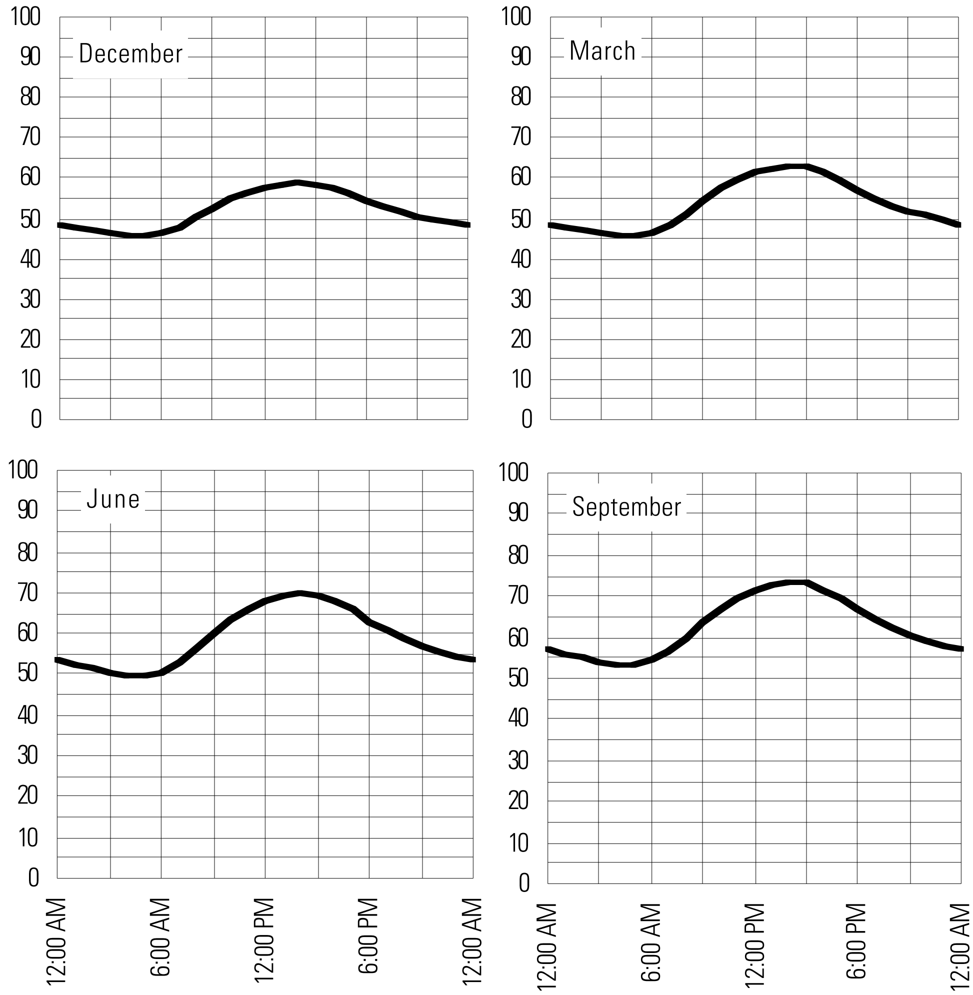
City	**New York**
Latitude	**40.77°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	46	40	12	12	26
	12:00 PM	82	21	21	21	56
	3:00 PM	39	10	38	10	20
SPRING & FALL	9:00 AM	58	79	25	25	70
	12:00 PM	104	39	39	39	123
	3:00 PM	62	27	79	27	75
SUMMER	9:00 AM	31	96	31	31	93
	12:00 PM	69	62	48	48	164
	3:00 PM	56	44	86	44	145

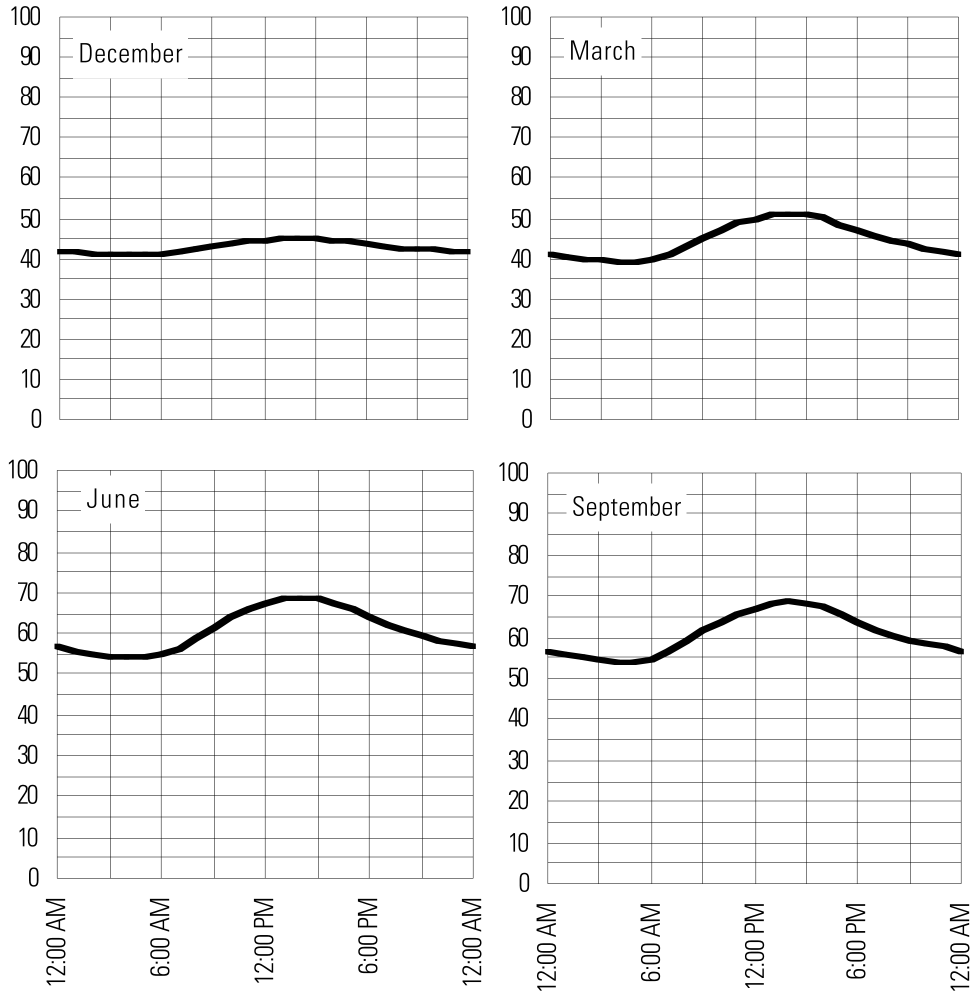
City	**San Francisco**
Latitude	**37.78°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	77	73	13	13	35
	12:00 PM	136	26	26	26	89
	3:00 PM	81	14	73	14	38
SPRING & FALL	9:00 AM	73	122	26	26	89
	12:00 PM	144	46	43	43	175
	3:00 PM	95	31	118	31	116
SUMMER	9:00 AM	29	149	29	30	117
	12:00 PM	75	85	51	51	229
	3:00 PM	65	47	113	47	212

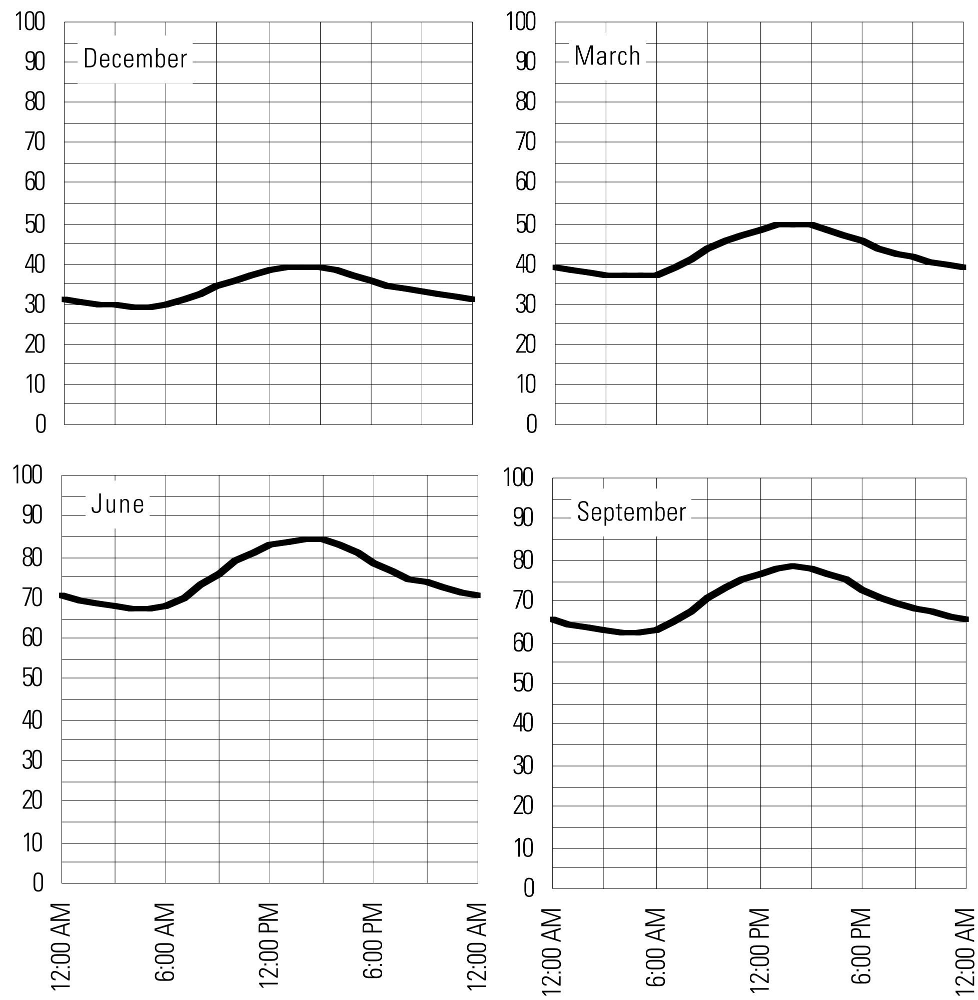
City	**Seattle**
Latitude	**47.45°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	24	22	6	6	11
	12:00 PM	58	15	15	15	34
	3:00 PM	26	7	22	7	12
SPRING & FALL	9:00 AM	59	83	21	21	58
	12:00 PM	117	37	35	35	115
	3:00 PM	76	25	82	25	75
SUMMER	9:00 AM	30	115	30	30	98
	12:00 PM	88	71	47	47	175
	3:00 PM	77	45	91	45	164

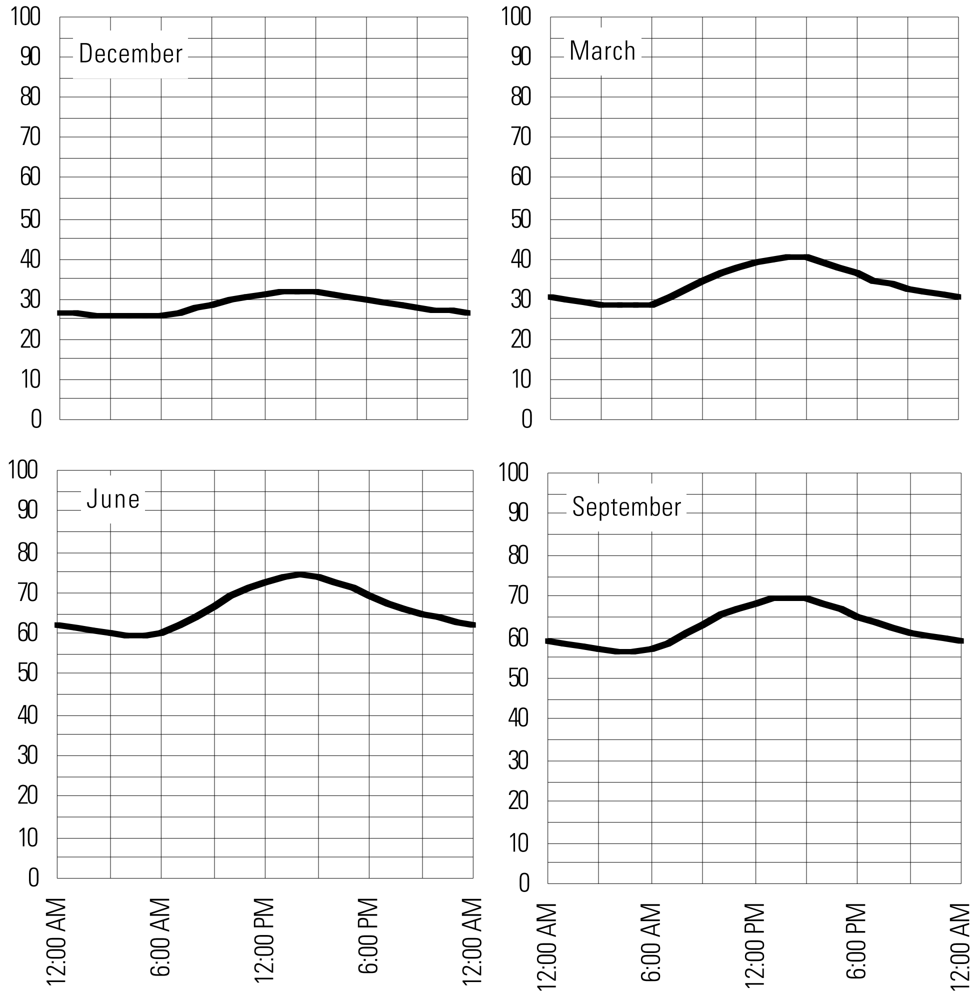
City	**St. Louis**
Latitude	**38.75°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	63	56	13	13	32
	12:00 PM	108	24	24	24	73
	3:00 PM	58	12	55	12	28
SPRING & FALL	9:00 AM	63	93	26	26	78
	12:00 PM	116	41	41	41	142
	3:00 PM	72	29	92	29	90
SUMMER	9:00 AM	31	128	31	31	111
	12:00 PM	75	73	51	51	205
	3:00 PM	61	47	105	47	184

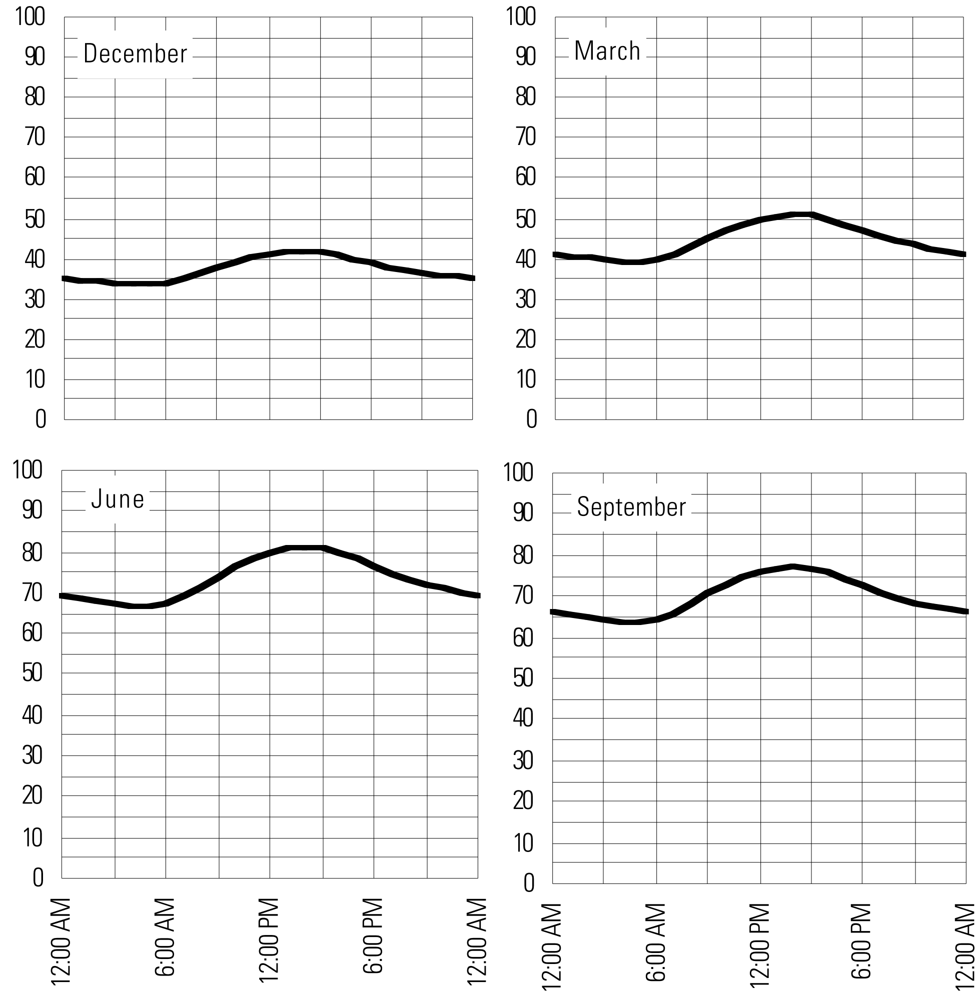
City	**Toronto**
Latitude	**43.70°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	34	33	8	8	15
	12:00 PM	77	19	19	19	48
	3:00 PM	42	10	36	10	21
SPRING & FALL	9:00 AM	54	84	21	21	59
	12:00 PM	114	41	37	37	124
	3:00 PM	78	28	83	28	86
SUMMER	9:00 AM	29	112	29	29	92
	12:00 PM	78	76	48	48	178
	3:00 PM	72	46	88	46	170

City	**Washington**
Latitude	**38.85°**



AVERAGE HOURLY SOLAR GAINS ADMITTED BY 1/8" GLASS in BTU/Hr/SF

		South	East	West	North	Horizontal
WINTER	9:00 AM	50	47	12	12	27
	12:00 PM	93	23	23	23	66
	3:00 PM	51	12	47	12	28
SPRING & FALL	9:00 AM	55	84	25	25	69
	12:00 PM	107	42	40	40	133
	3:00 PM	70	29	84	29	88
SUMMER	9:00 AM	30	108	30	30	95
	12:00 PM	69	72	50	50	181
	3:00 PM	60	46	92	46	167