The Wainwright and the Portland Buildings:

Energy Analysis using the Building Balance Point Vital Signs Protocols

MICHAEL UTZINGER and
JAMES WASLEY
University of Wisconsin-Milwaukee

The Balance Point package is a teaching resource developed under the auspices of the Vital Signs Project, which seeks to create and disseminate materials for teaching energy related building performance issues by means of case study analyses and other hands on exercises. The Balance Point is the outdoor air temperature which would result in balance between heat transfer across the building enclosure to the environment and heat gain to the building due to occupancy and absorbed solar gains. This building Vital Sign most succinctly illustrates the relationships between climate, occupancy, architectural design and the thermal dynamics of buildings. The Balance Point includes a range of background material useful for both lecture preparation and class readings, a series of experimental protocols of varying levels of sophistication, and a series of appendices outlining sources for further information.

*This paper is an excerpt from the Balance Point package; a comparative case study of two buildings, the Wainwright Building by Adler & Sullivan and the Portland Building by Michael Graves and Associates. This comparison demonstrates the power of the Balance Point as a conceptual tool and the creative use of the Excel workbook provided in the Balance Point Package to test hypotheses about building energy performance. Both the Balance Point package and Excel programs are available over the internet, the Balance Point Resource Package at http://www.ced.berkeley.*edu/cedr/vs/ and *the Excel programs at* http://www.sarup.uwm.edu/jci/vsg2.html.

THE WAINWRIGHT AND THE PORTLAND BUILDINGS

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 thin plan not only has more exterior surface to loose or gain heat, but it is more adequately lit by daylight, which reduces the heat load added by electric lighting. 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 Level I Balance Point Protocol provides a tool to answer this question. Even without access to the buildings, 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.

Building Data and Area Take-offs

With office occupancies, 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

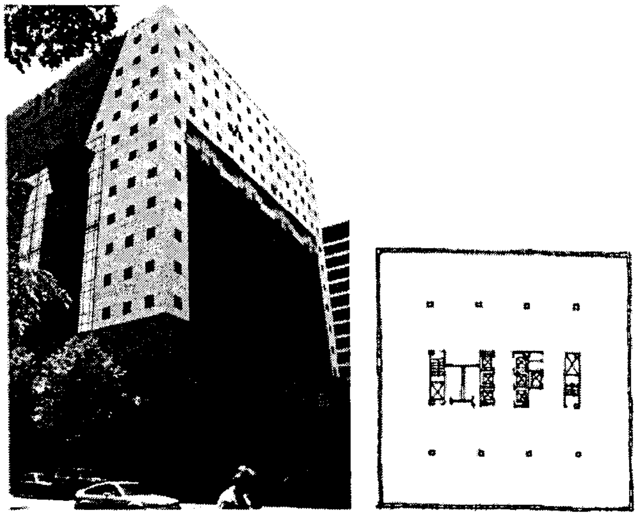


Fig. 1. The Portland Building, Portland Oregon. Michael Graves Assoc., Architects. 1980.

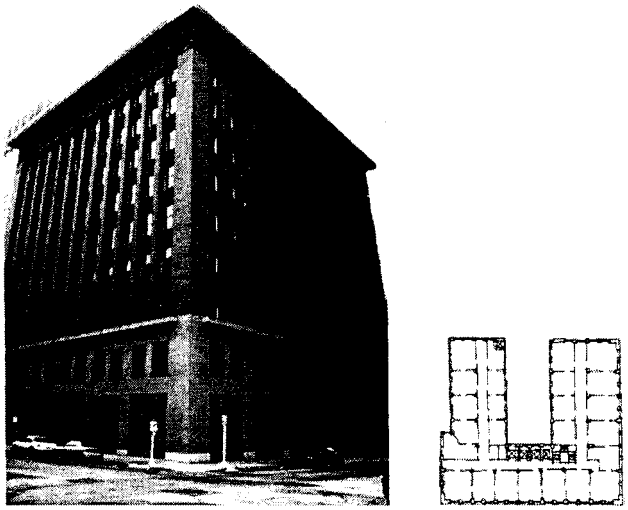
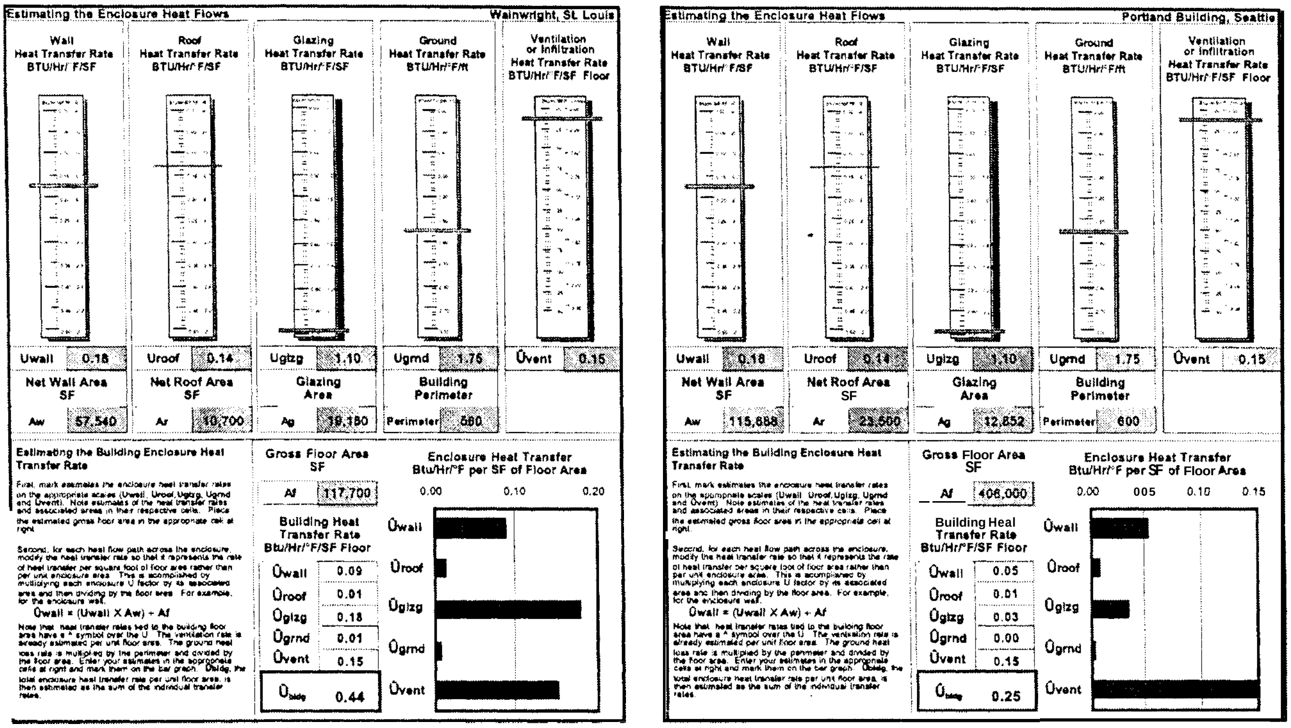


Fig. 2. The Wainwright Building, St. Louis, Missouri. Adler and Sullivan, Architects. 1890-91.



Estimating the Enclosure Heat Flows — Wainwright, St. Louis

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
Uwall 0.18	Uroof 0.14	Uglzg 1.10	Ugrnd 1.75	Ûvent 0.15
Net Wall Area SF	Net Roof Area SF	Glazing Area	Building Perimeter	
Aw 57,540	Ar 10,700	Ag 19,180	Perimeter 680	

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 accomplished 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 117,700

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

Ûwall	0.09
Ûroof	0.01
Ûglzg	0.18
Ûgrnd	0.01
Ûvent	0.15
Ûbldg	0.44

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

Estimating the Enclosure Heat Flows — Portland Building, Seattle

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
Uwall 0.18	Uroof 0.14	Uglzg 1.10	Ugrnd 1.75	Ûvent 0.15
Net Wall Area SF	Net Roof Area SF	Glazing Area	Building Perimeter	
Aw 115,888	Ar 23,500	Ag 12,852	Perimeter 600	

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.

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Gross Floor Area SF

Af 406,000

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

Ûwall	0.05
Ûroof	0.01
Ûglzg	0.03
Ûgrnd	0.00
Ûvent	0.15
Ûbldg	0.25

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

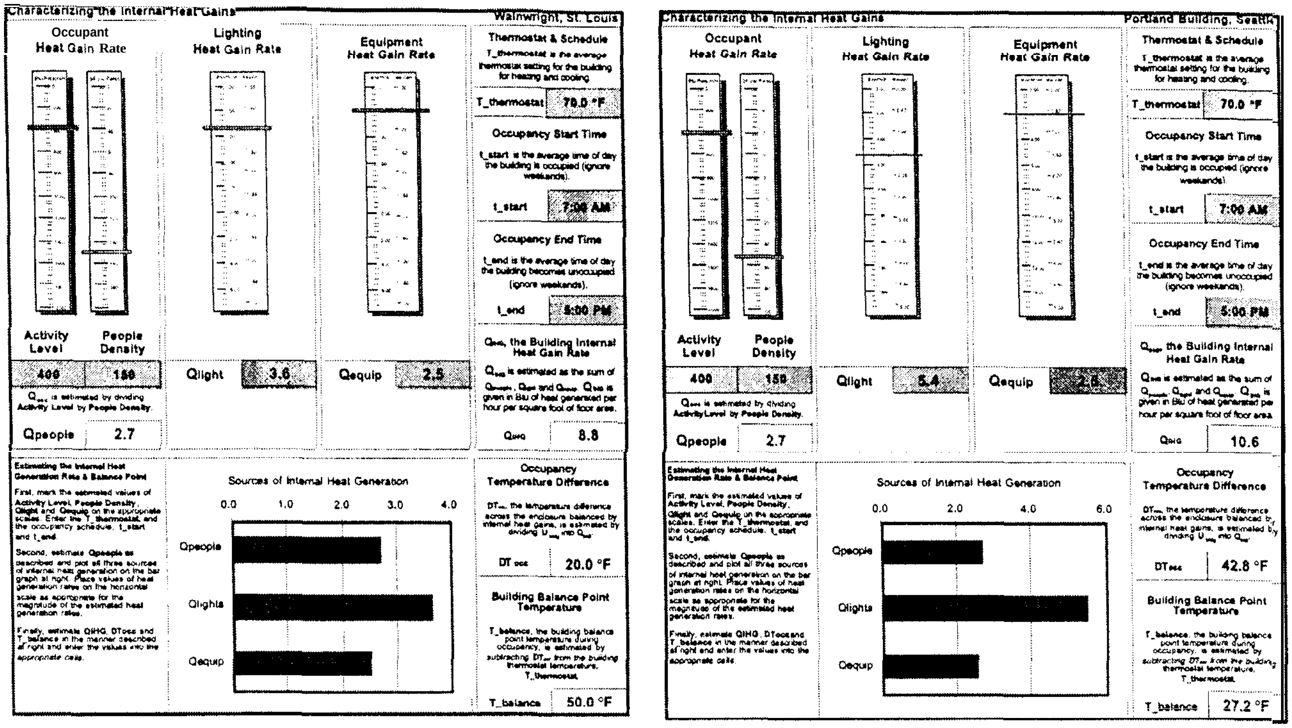
Fig. 3. Excel Balance Point Templates for Enclosure Heat Flows, Wainwright and Portland buildings.

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 gray rectangles in Figures 3 through 6 represents a variable that has been estimated using the individual scales worksheets or building area take-offs. The summary scales have been marked by hand for visual reference. In Figure 3, 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 and 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 in Figure 3 are


Characterizing the Internal Heat Gains — Wainwright, St. Louis

Occupant Heat Gain Rate — Activity Level 400, People Density 150. Q_{people} is estimated by dividing Activity Level by People Density. Qpeople 2.7

Lighting Heat Gain Rate — Qlight 3.6

Equipment Heat Gain Rate — Qequip 2.5

Thermostat & Schedule: T_thermostat is the average thermostat setting for the building for heating and cooling. T_thermostat 70.0 °F

Occupancy Start Time: t_start is the average time of day the building is occupied (ignore weekends). t_start 7:00 AM

Occupancy End Time: t_end is the average time of day the building becomes unoccupied (ignore weekends). t_end 5:00 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 8.8

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}. DT occ 20.0 °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 50.0 °F

Characterizing the Internal Heat Gains — Portland Building, Seattle

Occupant Heat Gain Rate — Activity Level 400, People Density 150. Q_{people} is estimated by dividing Activity Level by People Density. Qpeople 2.7

Lighting Heat Gain Rate — Qlight 5.4

Equipment Heat Gain Rate — Qequip 2.5

Thermostat & Schedule: T_thermostat is the average thermostat setting for the building for heating and cooling. T_thermostat 70.0 °F

Occupancy Start Time: t_start is the average time of day the building is occupied (ignore weekends). t_start 7:00 AM

Occupancy End Time: t_end is the average time of day the building becomes unoccupied (ignore weekends). t_end 5:00 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 10.6

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 42.8 °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 27.2 °F

Fig. 4. Excel Balance Point Templates for Internal Heat Gains, Wainwright and Portland buildings.

the gross floor areas of the two buildings **(A,)** 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 wall and glazing transfer rates in the Portland Building are not significant heat transfer paths.

Characterizing internal heat gains

As seen in Figure 4, the Occupant Heat Gain Rate ($\mathbf{Q}_{people}$), Equipment Heat Gain Rate ($\mathbf{Q}_{equip}$), 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 ($\mathbf{Q}_{light}$) 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 of choices 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 ($\mathbf{Q}_{IHG}$) is different because of the different lighting loads. The Wainwright gains 8.8 Btu/hr/s.f.

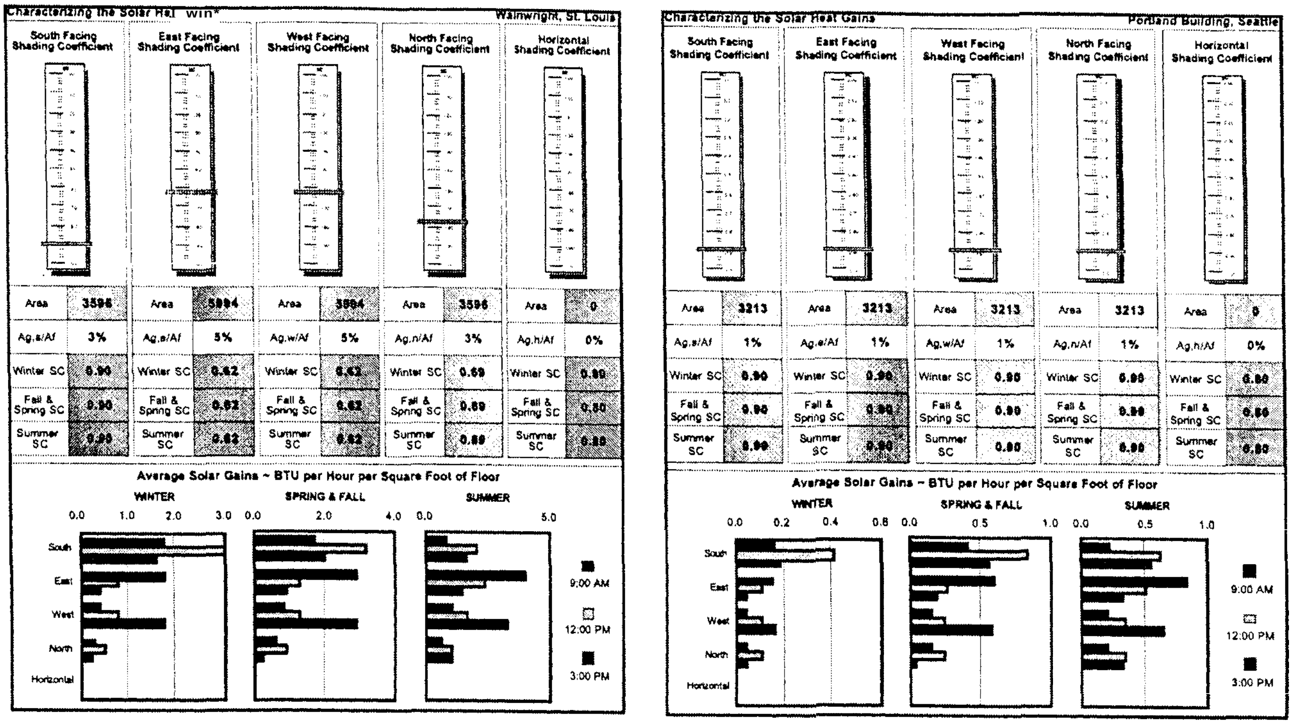


Fig. 5. Excel Balance Point Templates for Solar Heat Gains, Wainwright and Portland buildings.

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

In Figure 5, 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.

Evaluating the Balance Point Graphs

The Balance Point Graphs in Figure 6 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 retains than the Wainwright.

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

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

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. First, lets return to the Portland Building and use the protocol to reconsider our assumptions.

TESTING ASSUMPTIONS: VARIATIONS ON THE PORTLAND BUILDING

As seen in Figure 8, 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** on the left 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** on the right explore various lighting and glazing parameters to first establish their importance and then to imagine the best possible redesign of the building given its massing.

Alternate A: Increased Insulation

Add insulation to reflect actual construction: U_{wall}=0.09, U_{roof}=0.07. The Portland Building's wall outside to in is known: 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.

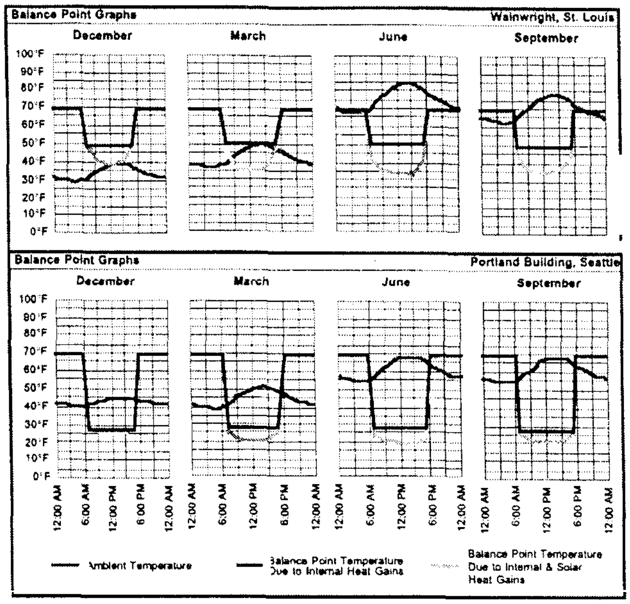


Fig. 6. Excel Balance Point Graphs with Internal and Solar Heat Gains, Wainwright and Portland buildings.

Alternate B: Increased Lighting Load

Assume energy efficient standards for late 1970's rather than the present. No daylighting. 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 Building 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%.by 50%;

Decrease glazing from 10% to 5% of wall area.

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

Alternate E: Match Wainwright Glazing Estimate

Increase glazing to 25% of wall area. Leave electric lighting load as is.

This increases solar load and thermal loss. Compared to

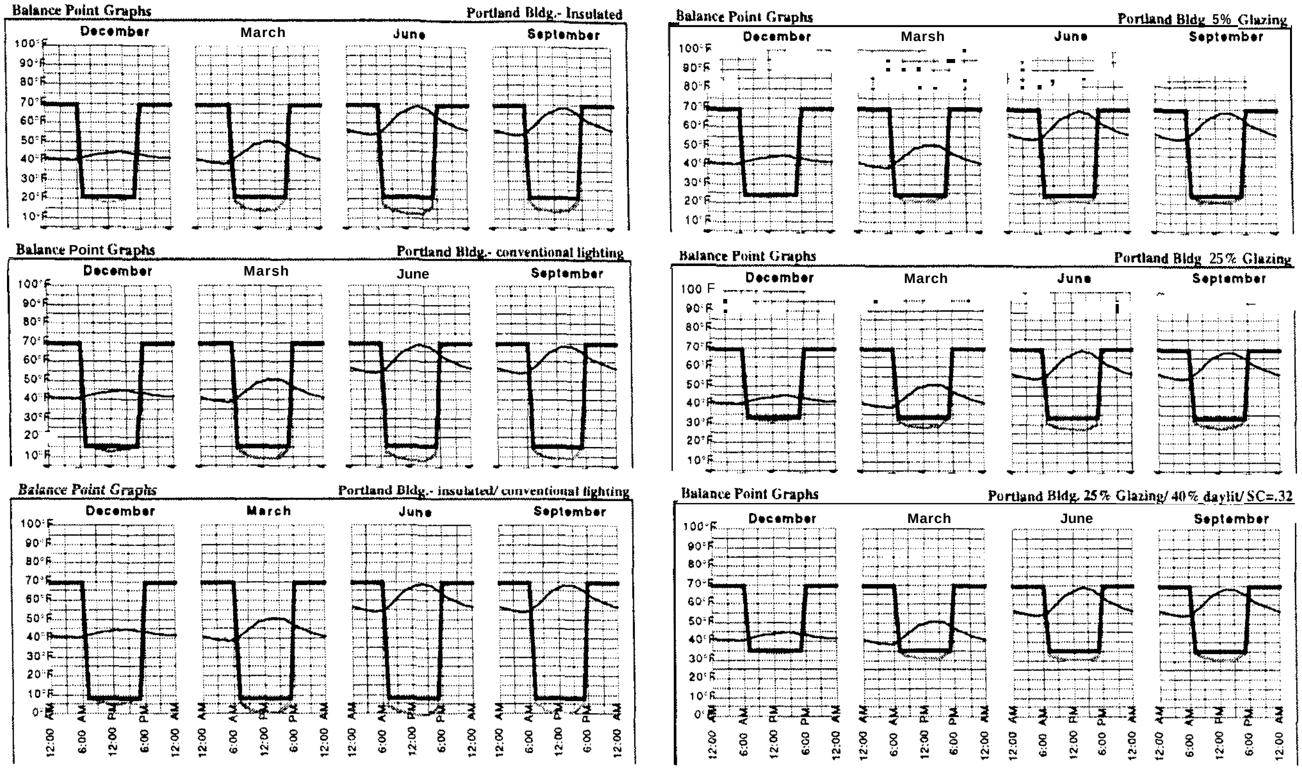


Fig. 7. Excel Balance Point Graphs with Internal and Solar Heat Gains, Portland bldg. Alternates A-F.

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

Alternate F: Redesign for Best Lighting Performance

Increase glazing to match Wainwright. Increase daylighting contribution from 20% to 40%, reducing elec. lighting load by an additional 10%. Decrease SC to 0.32 by use of "cool glazing".

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

CONCLUSION

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

In the design discussion we will see a more confusing range of situations and profiles. The most important lesson that the Portland Building introduces in its simplicity is that its thermal profile represents a 'type.' Some buildings are too hot, others too cold. Some swing between being too hot and too cold daily and others seasonally. These character profiles are as real and as suggestive for design as the more familiar use types of 'house' and 'office', 'warehouse' and 'hospital.'

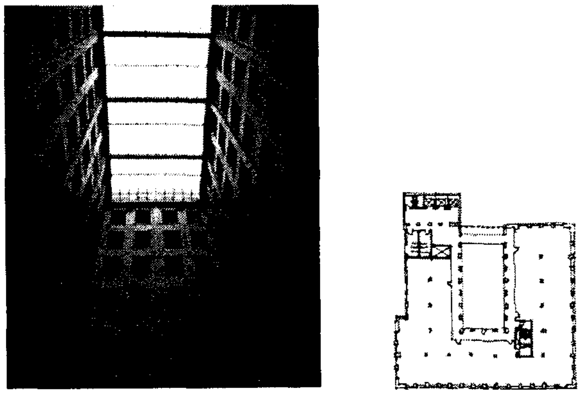


Fig. 8. Atrium and typical floor plan, Wainwright State Office Complex, Mitchell/ Guirgola, Architects in association with Hastings and Chivetta Architects, 1981.

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. 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.

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