# 524: Tools for Designing Zero Energy Homes: How Well Do They Work in Dublin

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**Abstract**

Zero Energy Homes must be designed in harmony with their local climate in order to maintain indoor comfort conditions for the occupants while minimizing the use of depletable energy (electricity and heating fuel). The widespread application of this climate-responsive design approach depends on the development of simple design tools that evaluate the resources of the local climate and that quantify the passive performance of the building in a way that is sensitive and accurate enough to reflect the impact of small architectural design changes. Climate Consultant 4 graphically evaluates weather data for thousands of sites around the world. HEED (Home Energy Efficient Design) is a powerful easy-to-use design tool intended for use at the very beginning of the design process when a building is only vaguely defined. This is when most of the decisions are made that will affect its ultimate energy performance.

Keywords: zero energy homes, energy efficient design, HEED, Climate Consultant 4

## 1. Introduction

Zero Energy Homes must be designed in harmony with their local climate in order to maintain indoor comfort conditions while minimizing the use of depletable energy (electricity and heating fuel). For this climate-responsive design approach to have wide-spread application simple free design tools must be made widely available. This paper describes two such design tools that help architects and contractors design homes that approach zero energy consumption.

To create a Zero Energy home the strategy is usually to first design the most energy efficient home possible, then to cover the remaining energy needs with photovoltaics and solar domestic hot water. The tools presented here help to answer the first half of this task:

Climate Consultant 4 can evaluate a full year of hourly climate data for any of the thousands of sites around the world that are now available in .epw format

HEED (Home Energy Efficient Design) is a powerful but easy-to-use design tool intended for use at the very beginning of the design process when a building is only vaguely defined. This is when most of the decisions are made that will affect its ultimate energy performance. HEED simulates a building's hourly energy performance using this same .epw climate data. It can display the percentage of time a building runs passively (without the need for depletable energy for heating or cooling). It is sensitive and accurate enough to reflect the impact of small architectural design changes on building energy consumption

## 2. Climate Consultant 4

With Climate Consultant 4 users begin by downloading the weather data for their chosen location, in this case Dublin, Ireland. This data can be analyzed and displayed in dozens of different ways. Four of them are shown here:

### 2.1 Monthly Average Diurnal Temperature and Radiation


***Fig.1 Monthly Diurnal Averages (click to enlarge)***

In Dublin (Fig.1) the average diurnal dry bulb temperatures (red) never get into the comfort range or below freezing, however monthly extremes occasionally do. Because the average dry bulb and wet bulb temperatures (dark red) are so close together in the winter it means that these will be very overcast conditions. This is confirmed by the wintertime plots of radiation data. This implies that the potential for winter passive solar gain will be severely compromised, as will the potential for winter photovoltaic energy production.

### 2.2 Wind Wheel

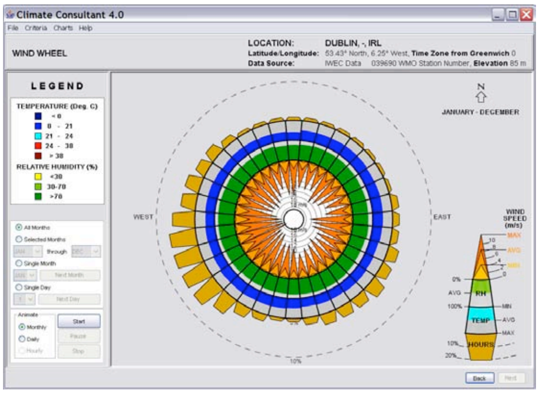


***Fig 2 Wind Wheel***

The Wind Wheel (Fig.2) shows the percentage of hours of wind from each direction (outer ring) along with the concurrent average dry bulb temperature and relative humidity (middle rings), and wind speed minimum, average, and maximum (triangles in the inner circle). For Dublin this shows that the wind most often comes from the west through southwest, which also have the highest velocities. This screen also lets you look at individual months, or even individual days, and can display an animation of this data monthly or daily.

### 2.3 The Psychrometric Chart

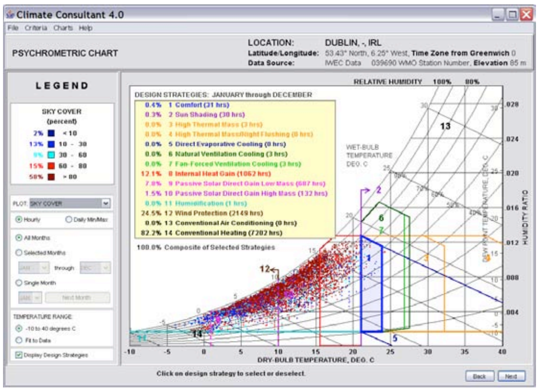


***Fig 3 Psychrometric Chart with Sky Cover shown in color (double click to expand image)***

The heart of Climate Consultant 4 is the Psychrometric Chart (Fig.3). Here for Dublin it shows the temperature/humidity points for all 8760 hours per year. In this case each hour is colored for sky cover (red is over 60% sky cover, dark blue is less that 30%). It shows how various Passive and Low Energy design strategies can be used to modify outdoor conditions to produce indoor comfort. The percentage of hours in each Design Strategy area is given to help the designer identify the most important strategies.

For Dublin these percentages are:

1. 0.4% Comfort Zone (blue) 31 hours
2. 0.3% Sun Shading (purple) 30 hours
3. 0.0% High Thermal Mass (orange)
4. 0.0% High Mass Night Flushing (orange)
5. 0.0% Direct Evaporative Cooling (dk blue)
6. 0.0% Natural Ventilation Cooling (green)
7. 0.0% Fan Forced Ventilation (lt. green)
8. 12.1% Internal Heat Gains (red) 1062 hrs)
9. 7.8% Passive Solar Low Mass (887 hrs)
10. 1.5% Passive Solar High Mass (132 hrs)
11. 0.0% Humidification (turquoise)
12. 24.5% Wind Protection (brown) 2149 hrs
13. 0.0 Conventional Air Conditioning (black)
14. 82.2% Conventional Heating (7380 hrs)

While some of these areas overlap, it is clear from this analysis that heating might be required at some time during the day almost all year long, even though internal gains from lights, equipment, and people provide for about 12.1% of the hours. Passive Solar Direct Gain into Low Mass structures will also provide useful heating for 7.8% of the hours. Note that Wind Protection is also required for about a quarter of the year, usually when the temperature is below 10ºC. According to this analysis Dublin's outdoor conditions match indoor comfort for only about 0.4% of the year or 31 hours if the indoor comfort range is defined here at 21ºC to 24ºC. It must be emphasized that on the Criteria screen the specification can be changed for this comfort zone or for any of the other zones, to respond to the local context, preferences, and technology.

### 2.4 Design Guidelines

Based on an analysis of the Psychrometric Chart, Climate Consultant 4 will develop a list of about two dozen design guidelines. Each list is different for the each of the thousands of .epw climate stations because each psychrometric chart is different. They are listed in order of importance (Fig.4). Each of them also has an accompanying design sketch to help interpret how to apply that guideline.

## 3. HEED (Home Energy Efficient Design)

In HEED users begin by giving four facts about their project, in this case:

1. Building Type: Single Family Home
2. Number of Stories: 3
3. Floor Area: 2000 sq.ft. (186 sq.m)
4. Location: Dublin, Ireland

HEED can use .epw format climate data for any of thousands of stations world wide. With this information HEED's expert system automatically designs 1, a building that meets the California Energy Code and then Scheme 2, a second building that in California is usually about 30% more energy efficient. However here in Dublin it is only 4% better. The user can then copy either of these schemes and then modify it to create their own design. A total of nine schemes can be created by copying prior schemes and changing only one or two aspects of the building.

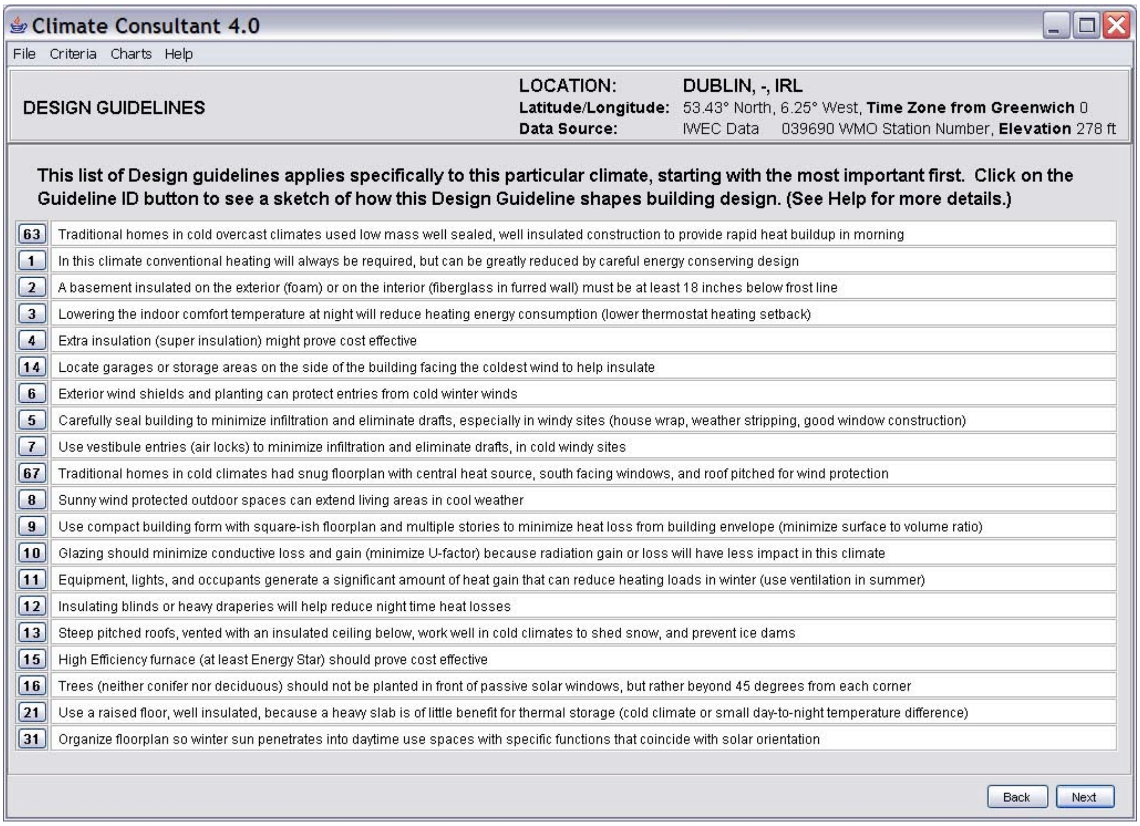


*Fig 4 Design Guidelines*

### 3.1 Floor Planner Screen

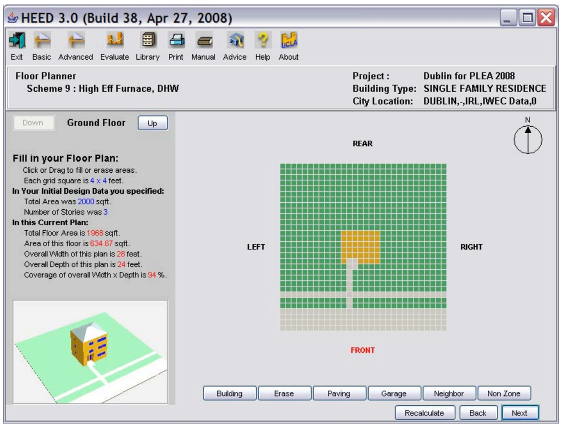


***Fig. 5 Floor Planner screen: User can fill in the squares to create any shape floorplan***

HEED's Basic Design mode lets users draw in their floorplan using a simple fill-in-the-squares technique (Fig.5), here showing the first of the three floors. This shows a very basic 3-story design, although each floor can be any shape and each story can be different. The little 3-D image on the lower left can be rotated around to look at any side. Like most images in HEED when clicked on they will either move or give additional information. Other things like garages, neighbors, or paving for walkways or streets can be added on this screen.

### 3.2 Window Design and Layout screens

Users can define different kinds of windows and doors for any façade, and they can click and drag to resize them. On the Window Layout once a window is defined it is instantly delivered to the curb from where it can be dragged into its correct layout on each façade (Fig.5).

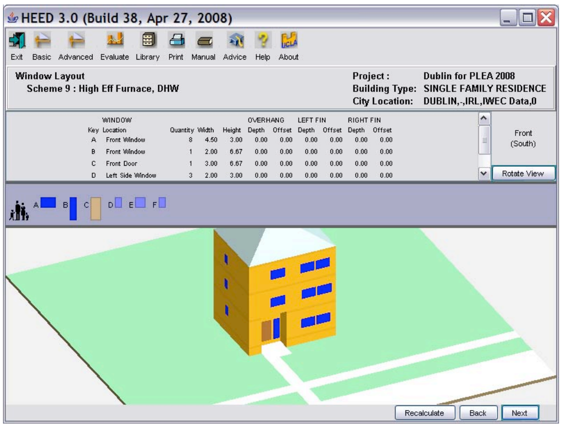


***Fig.6: Window Design Screen: User can click and drag windows and doors onto each facade***

Windows are the dominant elements of a building's thermal performance, and so this technique helps eliminate these critical errors by showing if there are too many or too few windows or if they are of the wrong size. Even beginning users can see if the windows on their building are not correct.

All other aspects of the building's design can be selected from a set of check lists. HEED also has an Advanced Design mode in which users can enter exact values for all of the hundreds of variables describing their building's design.

### 3.3 Energy Cost screen: Site Energy

By the process of copying schemes and making small changes, users can gradually evolve a set of designs that use less and less energy.

The Energy Cost screen can show the annual Energy Cost of each scheme for electricity, fuel, and for their total using utility rates that the user chooses or that are loaded automatically for each California zip code. This screen can show much more, including Site Energy total or per unit floor area, and also Carbon Footprint in the form of CO2 production total or per unit floor area.

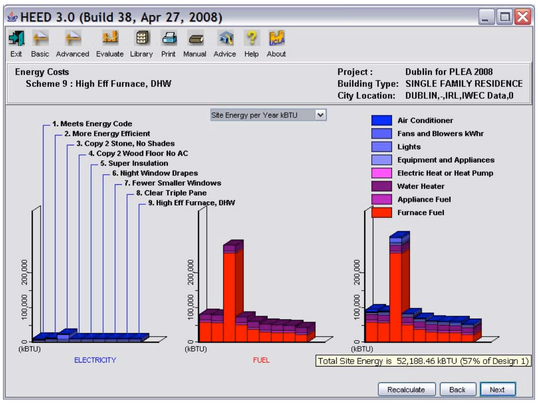


***Fig.6 Total Site Energy in kBTU/Year***

In this case (Fig.6) the final Scheme 9 evolved to use only 57% as much Site energy as Scheme 1, the building that complies with the California Energy Code. To get to this point the user tried a number of different design changes:

Scheme 1 is designed automatically by HEED based on the user's four initial inputs to meet the code for California's Climate Zone 1 (that most closely matches Dublin). It has a square floor plan with the code maximum of window area equally distributed on all 4 sides. It is a low mass building with a wood raised floor. It has the required number of people and equipment loads. The glazing meets hypothetical code minimums and is unshaded.

Scheme 2 is identical except that HEED automatically designed it to have most of its glass facing south, with very little on the west or east. The glazing is an actual commercially available product that slightly exceeds the code minimums; in this case it is dual pane low-E in wood or vinyl frame. The south windows have a large overhang. For this climate HEED designed a low mass building with a slab floor, although in most other California climates it would have designed it with high mass walls. It is unusual that the "more energy efficient" building that HEED created is only about 4% better than Scheme 1 in Dublin's climate (it is usually about 30% better in California climates).

Scheme 3 is the first building that the user designed by copying Scheme 2, and changing the walls to stone and removing the sunshades. The intention was to simulate something like a traditional building with modern windows and equipment. Note that it uses almost three times more energy than Scheme 1.

Scheme 4 is a copy of Scheme 2, the low mass building but with a wood floor raised above grade, and no sunshades. The Air conditioner is also removed because there are no significant cooling loads in Dublin. It is 7% better than Scheme 2.

Scheme 5 is a copy of the prior Scheme but is changed to super insulation in the walls, roof, and floor, essentially twice what the California Code requires. It produces a 15% improvement.

Scheme 6 is a copy of the prior Scheme but added operable night insulation to the windows, presumably in the form of heavy drapes. It produces an additional 10% reduction in energy consumption.

Scheme 7 uses fewer smaller windows, cutting the total window area from 20% of floor area to 11%. Although it produces only a 1% reduction in annual energy consumption, the reduced construction cost of windows might be worth it. This design results in a reduction in heating energy but a smaller increase in the cost for electric lighting. However the differences are so small that the occupants might prefer the psychological sense of the greater amount of daylighting in the prior Scheme.

Scheme 8 is a copy of the prior Scheme but the glazing is changed from dual pane low-E to triple pane clear. It produces only a 1% improvement, but it shows that in Dublin's climate some glazing options are virtually equal from the point of view of energy performance, so might be determined by local availability and construction cost.

Scheme 9 is a copy of Scheme 8 but with the substitution of a high efficiency furnace and water heater. This produced a 7% reduction in annual energy consumption. Overall this means that Scheme 9 used 57% of the energy of Scheme 1, for an annual reduction from 92,113 to 52,188 kBTU (26,997 to 15,274 kWh).

The overall performance of this final design is 26 kBTU/sq.ft. (82 kWh/sq.m). In California good energy efficient homes run from 10 to 20 kBTU/sq.ft., so this is relatively good performance given Dublin's overcast climate and high northern latitude.
Other design options were tried which produced additional improvements. A 6% improvement could be produced by changing the building type from a single family detached home to a row

house, which eliminates almost half of the wall losses and six small windows, but added additional electric lighting loads. Another change could be lowering the thermostat comfort heating set point by 2ºF (1.1ºC), which produces a 7% reduction in annual heating energy. Other changes that could produce smaller reductions in annual energy consumption include more efficient appliances and home electronics, and more efficient lighting (more CFLs).

Other design options that do not improve energy performance are adding mass to the interior of the building, using a high mass envelope with exterior insulation, or converting the first floor to a finished basement.

### 3.4 Energy Cost screen: Carbon Calculator

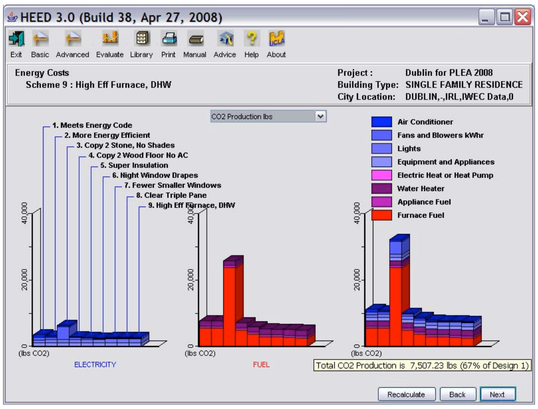


**Fig.7: CO2 Production, in Pounds**

A home's carbon footprint can be measured by its CO2 production, which is generated by combustion of fuel on-site or by the CO2 released when electricity is generated off-site. In the US each utility is required to publish how much CO2 is produced for each kWh generated. HEED lets the user input local values if available, but in this example we use the values for Southern California Edison, California's second largest utility.

Scheme 9 for the Dublin house produces 7,507 pounds of CO2 (3,412 kg). This represents 57% of Scheme 1. (coincidentally this is the same percentage reduction as Site Energy although this does not always happen). This well designed house produces roughly the same amount of CO2 as a sub-compact American car.

### 3.5 Energy Efficient Design

To establish a home's Passive Performance, HEED calculates the number of hours when either heating or cooling is required to maintain indoor comfort conditions. The remainder of the 8760 hours per year is defined as its Passive Performance. A simple bar chart shows which of the nine designs is best (Fig.8).

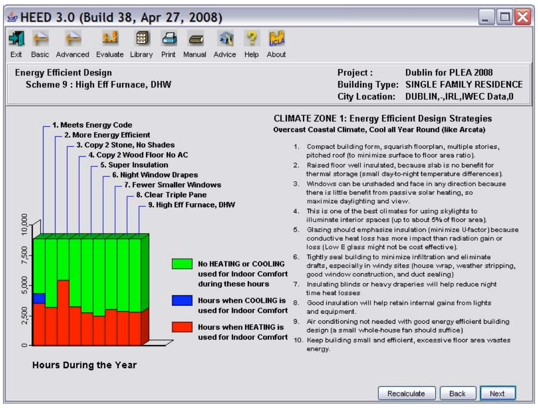


***Fig.8: Energy Efficient Design screen***

This home in Dublin ended up with 2745 hours per year when heating is required (red), which means that for 6015 hours the building 'free wheels' without the need for heating energy (green). Note that Scheme 3, the Stone building requires heating for almost two thirds of the hours per year. Scheme 6 that adds operable night window insulation (drapes) is able to hold in some of the daytime heat gains. However later schemes that use less energy and require smaller furnaces actually require those furnaces to run for slightly more hours per year.

This screen also contains a list of Design Guidelines intended for California's Climate Zone 1, which is an overcast coastal climate, cool all year round (like Arcata California). However these guidelines also apply quite well to Dublin's climate (Fig.9).

1. Compact building form, squarish floorplan, multiple stories, pitched roof (to minimize surface to floor area ratio).
2. Raised floor well insulated, because slab is no benefit for thermal storage (small day-to-night temperature differences).
3. Windows can be unshaded and face in any direction because there is little benefit from passive solar heating, so maximize daylighting and view.
4. This is one of the best climates for using skylights to illuminate interior spaces (up to about 5% of floor area).
5. Glazing should emphasize insulation (minimize U-factor) because conductive heat loss has more impact than radiation gain or loss (Low E glass might not be cost effective).
6. Tightly seal building to minimize infiltration and eliminate drafts, especially in windy sites (house wrap, weather stripping, good window construction, and duct sealing)
7. Insulating blinds or heavy draperies will help reduce night time heat losses
8. Good insulation will help retain internal gains from lights and equipment.
9. Air conditioning not needed with good energy efficient building design (a small whole-house fan should suffice)
10. Keep building small and efficient, excessive floor area wastes energy.

***Fig.9: Design Guidelines from Energy Efficient Design screen (click to enlarge)***

### 3.6 Performance Evaluation Plots

One of HEED's great strengths is the way complex technical information is presented in a variety of easy-to-understand graphics.

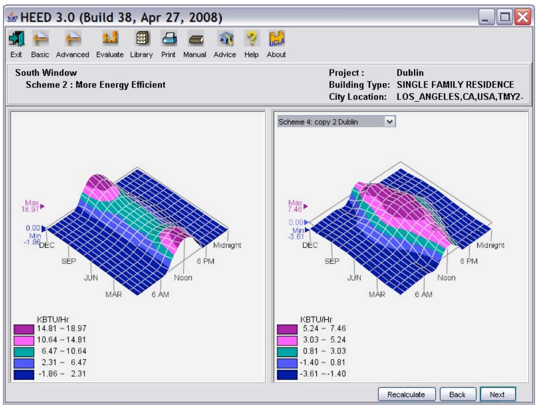


*Fig.10: South Window Performance in Los Angeles (left) vs. Dublin (right)*

For example, one of HEED's classic plots is the average heat gain and loss of south windows (Fig.10). Note that hours during the day are plotted along the lower right, and months of the year along the lower left. Good passive buildings have 'saddle shaped' plots as shown for Los Angeles (left), where the south window gains more in the winter than in the summer. But in Dublin (right), the pattern is reversed, in which case the exact same window gains much more in summer and very little in winter. In Los Angeles this window assembly produces five times more heat gain during winder days than it looses at night. In Dublin the opposite is true, primarily due to its high latitude and more overcast winter climate.

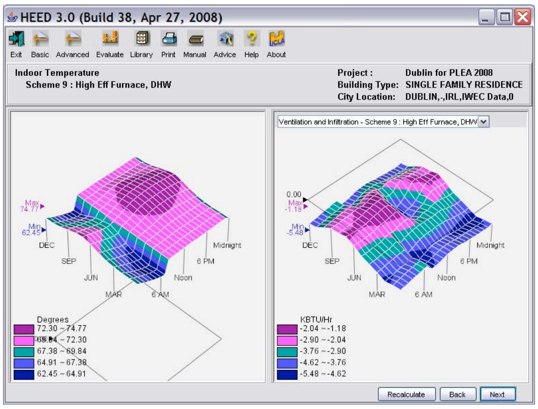


*Fig.11: Indoor Air Temperature (right) compared to Ventilation and Infiltration in Dublin*

Another type of performance evaluation plot can compare two different variables within the same scheme. In this case the plot of average Indoor Air Temperature (Fig.11 left) shows that it drops down to 62.45ºF (17ºC) on winter nights but at 8AM the thermostat turns on the furnace and raises the indoor temperature to the comfort low set point of 70ºF (21.ºC). Note also that indoor temperatures on summer afternoons are kept below the comfort upper set point of 75ºF (24.ºC).

The reason this peak indoor temperature is so well behaved is revealed on plot of the heat loss from Ventilation and Infiltration (right), which shows a big dip on summer afternoons. This is when the home's occupants open their windows and natural ventilation prevents overheating. This provides over 5 kBTUh (1.5 kW) of effective cooling. Note that this same amount of cooling could have been provided by a whole-house fan or even an air conditioner.

## 4. Conclusion

To create a Zero Energy home the strategy is usually to first design the most energy efficient home possible, and then to provide the rest of the needed energy with roof mounted photovoltaics and solar domestic hot water systems. The tools presented here help to answer the first half of this question:

How close did we come to designing a Zero Energy Building in Dublin's overcast northern latitude? An analysis with Climate Consultant 4 using Dublin's climate data showed that although winters rarely get below freezing, they are often overcast (more that 60% sky cover), which reduces the efficiency of passive heating or of photovoltaic electricity generation or of solar water heating. HEED shows that in Dublin's climate it is possible to design a home that uses 43% less energy than a home designed to meet California's stringent energy code, but that 15,274 kWh would still have to be provided by photovoltaics or solar domestic hot water, or by other sources. The Passive and Low Energy problem is to design a building that brings this energy consumption down even further.

It must be emphasized that in both these tools the comfort range criteria and design strategies can be adjusted to respond to local definitions of indoor comfort, local construction systems, and local code requirements.

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## 5. Acknowledgements

The Development of Climate Consultant 4 was supported by the University of California Energy Institute. HEED was supported by the California Public Utilities Commission and the ratepayers of the four major investor owned utilities.

## 6. References

1. HEED and Climate Consultant 4 are available at no cost from www.aud.ucla.edu/energy-design-tools along with an extensive bibliography.

2. EPW climate data is available from http://www.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm

3. The greenhouse gases produced by various utilities in the US is available from http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html