CARBON COUNTING IN ARCHITECTURE: A COMPARISON OF CARBON ESTIMATING TOOLS

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INTRODUCTION

Climate change is caused by an increase in the concentration of green house gas emissions due to human activities and is the most pressing environmental challenge facing our civilization. Buildings are responsible for a large portion of the world's green house gas emissions and in the United States they are responsible for about half of all green house gas emissions of anthropogenic origin. To reduce human impact on climate it is necessary to reduce building related anthropogenic warming and the first step in this reduction process is to be able to adequately count carbon emissions. Accurate carbon counting, especially in the initial phases of the design process, will help to quantify the impact -in units of carbon emissions- of our design decisions in the project.

The objective of this project was to compare several carbon counting tools that can be used to quantify carbon emissions from residential buildings. Several carbon calculators and some energy modeling software were compared in the main areas in which buildings generate carbon emissions: a) operational energy, b) transportation to and from the building, c) providing water and disposing of water to and from the building, d) construction of the building and e) disposing of waste from the building.

The tools that are compared in this project had to be free and easy to use so that they could be used in the initial phases of the architectural design process, while providing sufficient precision to provide some useful input to the designer. Fifty tools were analyzed. Ten of these tools provided no useful information for designers while forty of these provided useful results in at least one of the above mentioned areas. These forty tools are compared and organized in a table that indicates the types of results that they provide. A more detailed comparison is done in the area of operational energy. At the end a protocol for carbon counting with tool recommendations is provided.

1. CARBON CALCULATING TOOLS

1.1. Types of Carbon Counting Tools

There are several types of carbon calculating tools: carbon footprint calculators, which are available online to determine personal carbon emissions; carbon estimators, also available online for estimations of carbon emissions of buildings; and carbon calculators, which are available for purchase and that work with BIM systems for a more accurate analysis (1). This paper deals primarily with carbon footprint calculators and carbon estimators. Estimators usually produce results which are more usable for the designer than footprint calculators.

A building is directly responsible for the generation of CO_2 by its operation, construction, water use, and waste generation (2). The building is also indirectly responsible for CO_2 emissions generated by transportation to and from the building, which was also included. Most carbon counting tools offer the possibility to determine emissions from energy use in buildings and from transportation. Fewer of them can determine emissions due to water, waste or construction. A handful of these also offer the possibility to calculate the carbon impact from the food that we eat. Even though this could be a significant factor it was not considered because it could not be modified by the designer.

1.2. Carbon Emissions from Buildings

Energy used to operate the buildings is usually the single largest contributor to CO_2 emissions. These emissions can be caused by energy used directly at the site (such as natural gas) or at the power plant (electricity). Emissions from operational energy include heating, cooling, lighting and appliances. The tools that we have available to calculate operational energy offer acceptable precision, because they estimate the energy use in a proposed building, usually with energy modeling software. In an existing building the energy actually used in the building can be taken from the meter.

Carbon emissions due to construction processes are usually generated a) during the fabrication of the materials used in the building; b) during the transportation of materials to the building; and c) during construction of the building. These emissions are usually more difficult to calculate because it is not easy to determine with precision the origin and the amount of materials in the building.

Water provided to the building and coming out of the building also generates CO_2 emissions. The water used in the building must be pumped from the source and treated while the waste water from the building must also be treated to remove physical, chemical and biological contaminants. These processes usually generate CO_2 emissions.

Solid waste (not transported in water) coming from the building must also be moved from the building and treated. More waste requires more treatment and usually generates more greenhouse gases in the form of methane from the landfills.

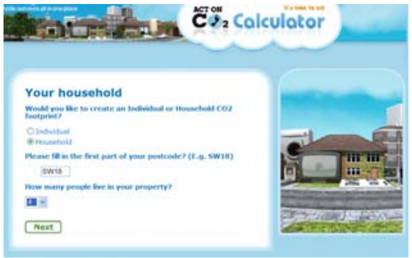
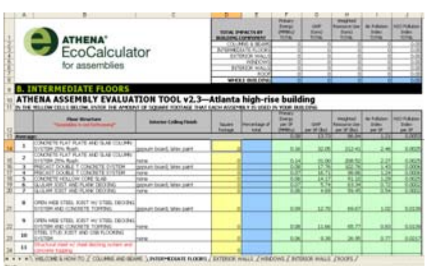
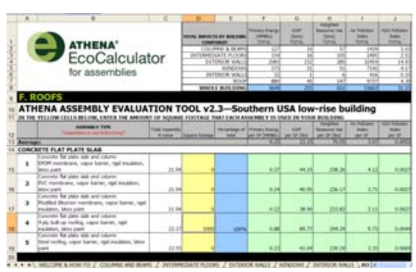
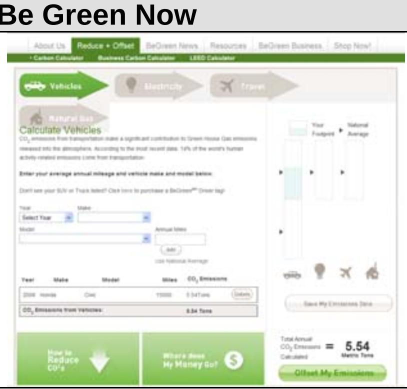
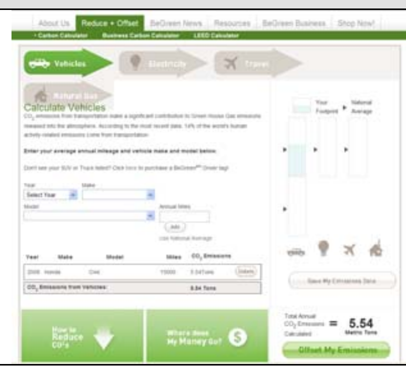
People must move to and from the building, and the method by which they do this usually generates CO_2 in varying amounts (bus, train, automobile) or non at all (walking, bicycle). Location of the building close to public transit lines or in urban areas with higher density usually helps to reduce CO_2 emissions from transportation.

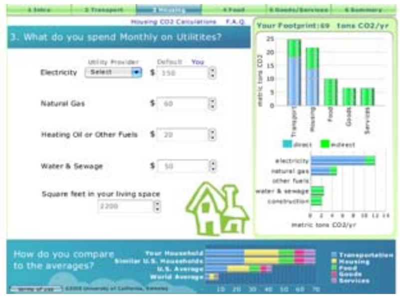
2. COMPARING DIFFERENT CARBON COUNTING TOOLS

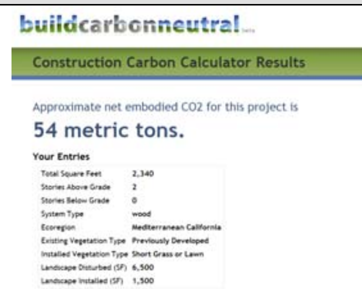
The tools that were compared had to be free and easy to use so that they could be used in the initial phases of the architectural design process, while providing sufficient precision to provide some useful input to the designer. Fifty tools were analyzed and compared. Ten of these tools provided no useful information while forty provided useful results in at least one of these areas. Recommendations for tools in each of these areas are given.

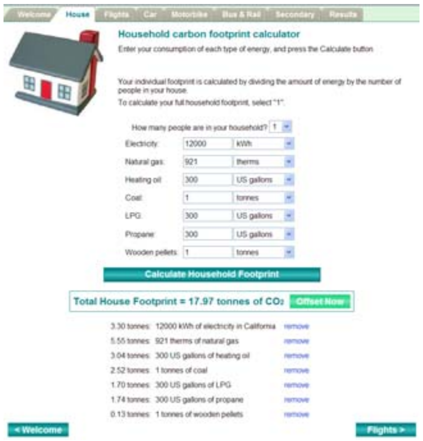
The following table compares these 40 tools. In addition to an image of a representative input and output screen, the table provides: a) the URL address; b) the areas for which the tool calculates carbon emissions and the sub areas in each of these; c) the ease of use in a three point scale: easy, moderate, difficult ; d) the time to complete the information needed measured in a scale that goes from: less than 5 minutes, between 5 and 15 minutes and more than 15 minutes; e) the units used in the output ; and f) general comments.

TABLE 1: COMPARISON OF TOOLS:

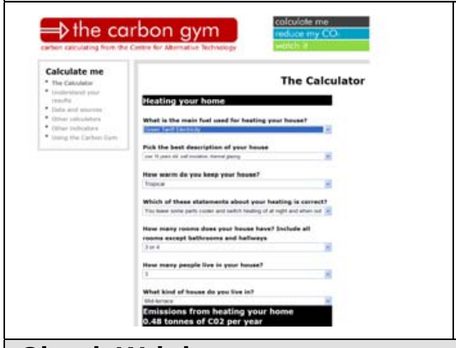
EXAMPLE INPUT SCREEN	EXAMPLE OUTPUT SCREEN	COMMENTS
Act on CO_2 calculator		
		1) Web Address: http://campaigns.direct.gov.uk/actonco2/home.html 2) Calculates: home (electricity, oil natural gas, propane, kerosene, wood stove) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): tonnes of CO_2 6) Comments: UK based, covers all the standard appliances/equipment in a house
American Forests		
		1) Web Address: http://www.americanforests.org/resources/ccc/ 2) Calculates: home (electricity, oil natural gas, propane, kerosene, wood stove), waste (garbage, recycling) and transportation (auto, motorcycles, taxis, rail, subway, city buses, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: provides number of trees needed to offset emissions
Athena: EcoCalculator for Assemblies		
		1) Web Address: http://www.athenasmi.org/tools/ecoCalculator/index.html 2) Calculates: construction 3) Ease of use: complex 4) Time to complete: 5 - 10 minutes 5) Output (units): tons of greenhouse gases 6) Comments: input requires number of square feet of materials used; region based, limited regions available
Be Green Now		
		1) Web Address: http://www.begreennow.com/reduce-offset/carbon-calculator/ 2) Calculates: home (electricity, natural gas,) and transportation (auto, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): tonnes of CO_2 6) Comments: provide opportunity to buy carbon offsets

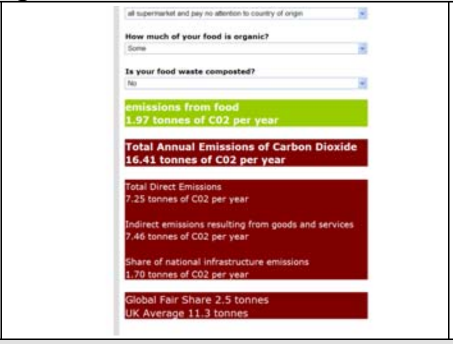
Berkeley Institute of the Environment		
		1) Web Address: http://bie.berkeley.edu/calculator.swf 2) Calculates: <u>home</u> (electricity, oil, natural gas, propane, kerosene, wood stove) and <u>transportation</u> (auto, motorcycles, taxis, rail, subway, city buses, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: provides number of trees needed to offset emissions
Best Foot Forward		
		1) Web Address: http://www.bestfootforward.com/carbonlife.htm 2) Calculates: <u>total usage based on usage relative to average user of car, travel, home size, number of people in home, renewable or non-renewable energy source, diet, and waste</u> 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): tonnes of CO_2 6) Comments: provides number of earths needed to sustain your lifestyle
Bonneville Environmental Foundation		
		1) Web Address: http://www.b-e-f.org/offsets/calculator/ 2) Calculates: <u>home</u> (electricity, oil natural gas, propane,) and <u>transportation</u> (auto, rail, subway, city buses, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: can input averages or details; provides opportunity to buy carbon offsets
BP Calculator		
		1) Web Address: http://www.bp.com/iframe.do?categoryId=9023118&contentId=7045317 2) Calculates: <u>home</u> (electricity, oil natural gas, propane, kerosene, wood stove) and <u>transportation</u> (auto, motorcycles, taxis, rail, subway, city buses, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 or kWh 6) Comments: provides option to specify energy efficient and renewable energy systems being used

BP Calculator		
		1) Web Address: http://www.bp.com/iframe.do?categoryId=9023118&contentId=7045317 2) Calculates: home (electricity, oil natural gas, propane, kerosene, wood stove) and transportation (auto, motorcycles, taxis, rail, subway, city buses, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 or kWh 6) Comments: provides option to specify energy efficient and renewable energy systems being used
Build Carbon Neutral Construction Calculator		
		1) Web Address: http://buildcarbonneutral.org/ 2) Calculates: carbon output from construction 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): metric tons of CO_2 6) Comments: based on primary structural system, size, and location
California Carbon Calculator		
		1) Web Address: www.coolcalifornia.org 2) Calculates: home (electricity, oil natural gas, water and sewage), transportation (auto, public transportation, air miles), food (meat, fish, eggs, dairy, eating out, fruits/vegetables, bake products, and goods/services(clothing, furniture/appliances, other goods, services) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): tons of CO_2 6) Comments: input based on dollars spent; provides number of acres of trees needed to offset emissions and the number of barrels of oil burned to create the same amount of emissions

Carbon Footprint		
		1) Web Address: http://www.carbonfootprint.com/calculator.aspx 2) **Calculates:** <u>home</u> (electricity, oil natural gas, heating oil, coal, LPG, propane, wooden pellets), <u>transportation</u> (auto, motorbike, taxis, rail, subway, bus, coach, tram, tube air miles) and Secondary (food, fashion, packaging, furniture & electrical, recycling, recreation, car and finance) 3) Ease of use: easy 4) **Time to complete:** less than 5 minutes 5) **Output (units):** tonnes of CO_2 6) **Comments:** allows input by gallons/ therms/ kWh; provides graphic showing size of footprint relative to country average and world average
CarbonCounter.org		
	Does not calculate carbon emissions any more	1) Web Address: http://www.carboncounter.org/ 2) **Calculates:** <u>home</u> (electricity, oil natural gas, propane, kerosene, wood stove) and <u>transportation</u> (auto, motorcycles, taxis, rail, subway, city buses, air miles) 3) Ease of use: easy 4) **Time to complete:** less than 5 minutes 5) **Output (units):** lbs of CO_2 6) **Comments:** provides number of trees needed to offset emissions
Carbon Fund		
		1) Web Address: http://www.carbonfund.org/site/pages/carbon_calculators/ 2) **Calculates:** <u>home</u> (electricity, oil natural gas,), <u>transportation</u> (auto, rail, city buses, air miles) and <u>event/wedding</u>(cars, flights, trains, hotel rooms, meals) 3) Ease of use: easy 4) **Time to complete:** less than 5 minutes 5) **Output (units):** tons of CO_2 6) **Comments:** provides cost of offset

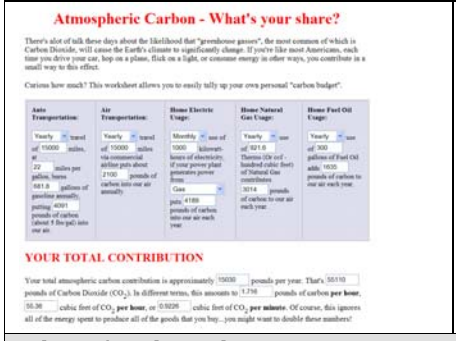
Center For Alternative Technologies

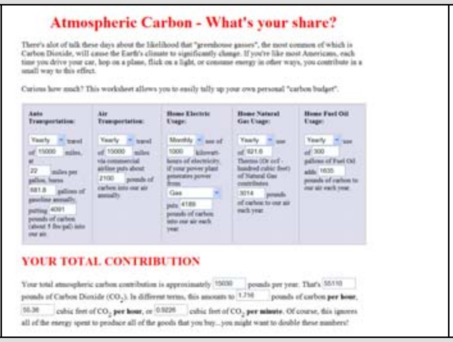




1) Web Address: http://carbongym.cat.org.uk/
2) Calculates: home (electricity, oil natural gas, propane, kerosene, wood stove), transportation (auto, other, air miles) and food (packaged, organic)
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): tonnes of CO_2
6) Comments: provides direct and indirect emissions

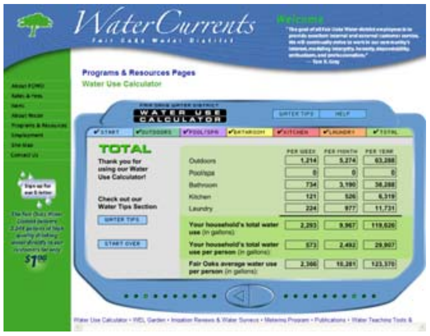
Chuck Wright





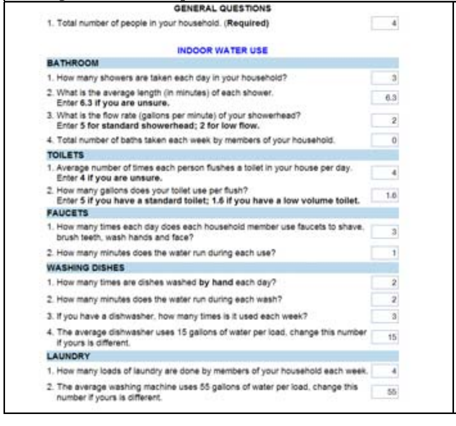
1) Web Address: http://www.chuck-wright.com/calculators/carbon.html
2) Calculates: home (electricity, oil natural gas) and transportation (auto, air miles)
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): lbs of CO_2
6) Comments: breaks down emissions by years, hour and minute

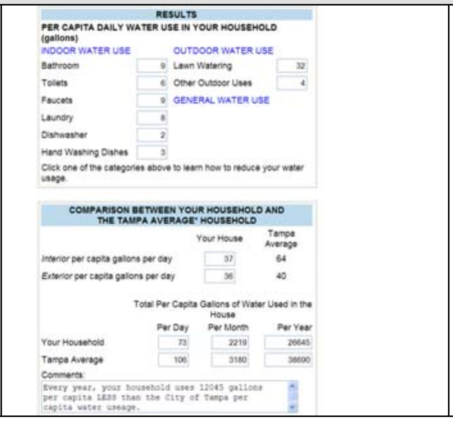
City of Fair Oaks, CA Water Use Calculator



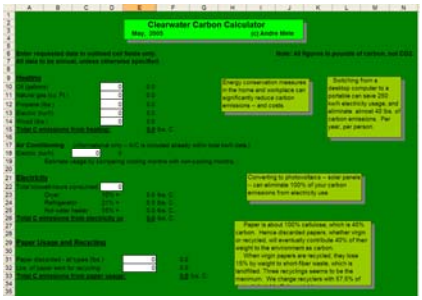
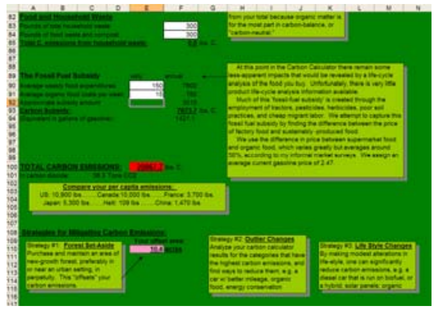
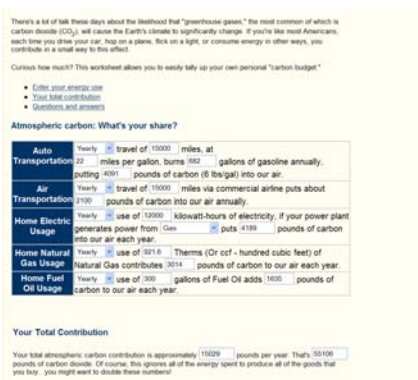
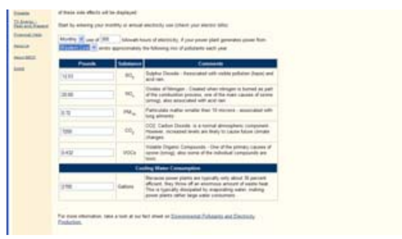
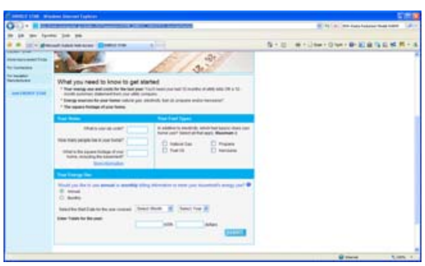
1) Web Address: http://fowd.com/program_watercalculator.html
2) Calculates: water (lawns, bathing, dishes, laundry)
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): gallons of water
6) Comments: provides per capita and per household water usage per week, month and year

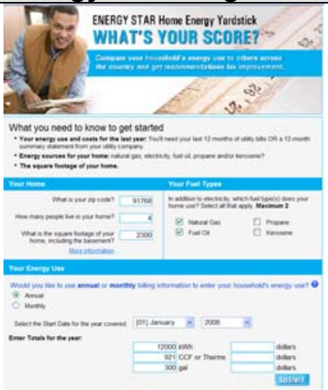
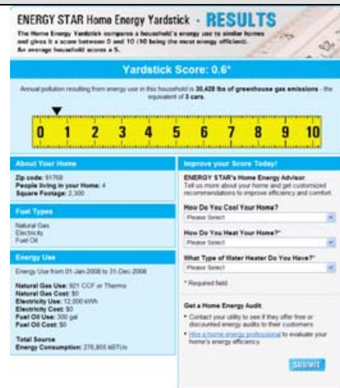
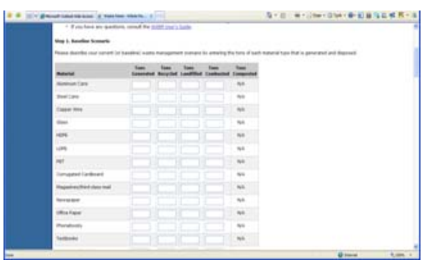
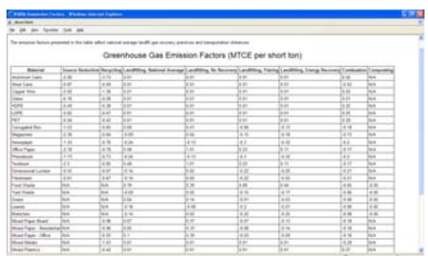
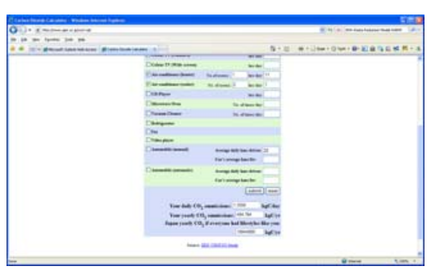
City of Tampa, Florida Water Use Calculator

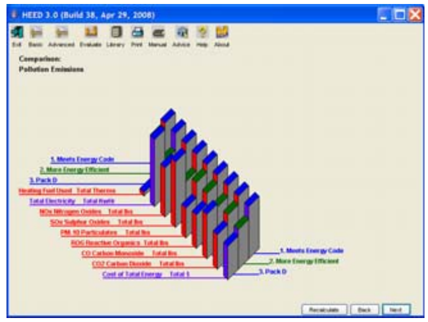
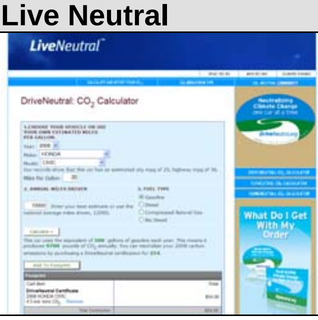
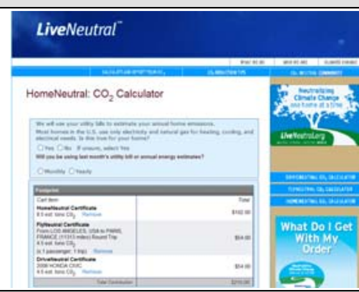


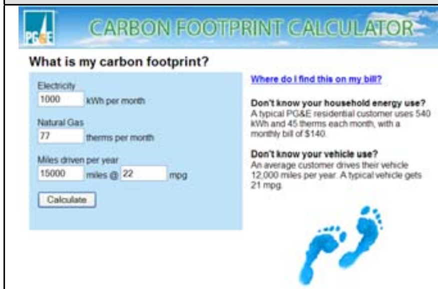
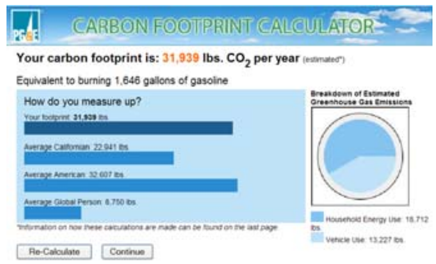
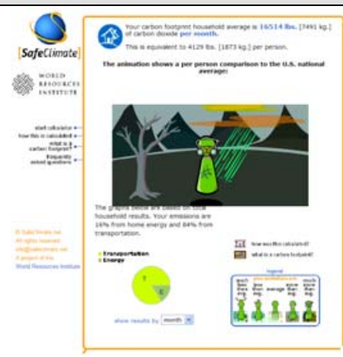


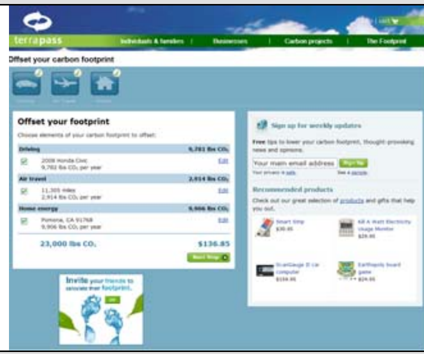
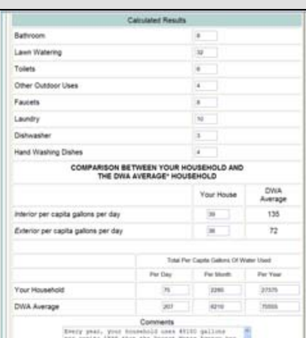
1) Web Address: http://www.tampagov.net/dept_Water/information_resources/Saving_water/Water_use_calculator.asp
2) Calculates: water (lawns, bathing, dishes, laundry)
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): gallons of water
6) Comments: provides per capita water usage per day, month and year

Clear Water		
		1) Web Address: http://www.clearwater.org/carbon.html 2) Calculates: home (electricity, oil natural gas, propane, kerosene, wood stove), transportation (auto, air miles), waste (paper, food) and food (commercial versus organic) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: provides acres of forest needed to offset emissions
Electric Power Pollution Calculator		
		1) Web Address: http://infinitepower.org/calc_electric.htm 2) Calculates: home (electricity, oil natural gas,) and transportation (auto, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: can choose alternative fuel sources for the electricity generation; also provides calculator showing all emissions for various fuel sources for generating electricity
Energy Star Home Energy Yardstick		
		1) Web Address: http://www.energystar.gov/index.cfm?fuseaction=HOME_ENERGY_YARDSTICK.showGetStarted 2) Calculates: home (electricity, oil natural gas, propane, kerosene, wood stove) and transportation (auto, motorcycles, taxis, rail, subway, city buses, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: provides number of trees needed to offset emissions

Energy Star Target Finder		
		1) Web Address: http://www.energystar.gov/index.cfm?fuseaction=HOME_ENERGY_YARDSTICK.showGetStarted 2) Calculates: home (electricity, oil natural gas, propane, kerosene) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: provides recommendations on how to reduce emissions
EPA Personal Emissions Calculator		
		1) Web Address: http://www.epa.gov/climatechange/emissions/ind_calculator.html 2) Calculates: home (electricity, oil natural gas, propane, kerosene, wood stove), transportation (auto) and waste 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: calculates emission reductions based on materials recycled
EPA Waste Reduction Model WARM		
		1) Web Address: http://www.epa.gov/climatechange/wycd/waste/calculators/Warm_home.html 2) Calculates: waste 3) Ease of use: easy 4) Time to complete: 5-15 minutes 5) Output (units): metric tons of carbon equivalent (MTCE) or metric tons of carbon dioxide equivalent ($MTCO_2e$ 6) Comments: includes many materials and a web based and excel based calculator
Global Environment Information Centre (GEIC) Calculator		
		1) Web Address: http://www.geic.or.jp/co2-cal/ 2) Calculates: electronics/electric appliances and transportation (auto) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): kg of CO_2 6) Comments: provides total Japan emissions based on inputted usage

HEED		
		1) Web Address: http://mackintosh.aud.ucla.edu/HEED/ 2) **Calculates:** home (electricity, natural gas) 3) **Ease of use:** Complex 4) **Time to complete:** 30 minutes for initial design, alternative designs 5 minutes 5) **Output (units):** lbs of CO_2 6) **Comments:** provides 30 different charts/tables of temperatures, loads, energy usage and emissions
Home Energy Saver Calculator		
		1) Web Address: http://hes.lbl.gov/hes/db/zip.shtml 2) **Calculates:** home (electricity, oil natural gas, propane), and appliances 3) **Ease of use:** moderate 4) **Time to complete:** less than 15 minutes 5) **Output (units):** lbs of CO_2 6) **Comments:** extensive list of choices for heating/cooling/lighting/appliances/insulation levels
Inconvenient Truth		
		1) Web Address: http://www.climatecrisis.net/takeaction/carboncalculator/ 2) **Calculates:** home (electricity, oil, natural gas, propane) and transportation (auto, air miles) 3) **Ease of use:** easy 4) **Time to complete:** less than 5 minutes 5) **Output (units):** tons of CO_2 6) **Comments:** based on $ spent, can specify the percentage of electricity that comes from renewable resources
Live Neutral		
		1) Web Address: http://Liveneutral.org 2) **Calculates:** home (electricity, natural gas) and transportation (auto, air miles) 3) **Ease of use:** easy 4) **Time to complete:** less than 5 minutes 5) **Output (units):** tons of CO_2 6) **Comments:** provides opportunity to buy carbon offsets

Pacific Gas and Electric		
		1) Web Address: http://www.pge.com/carbonfootprint/ 2) Calculates: <u>home</u> (electricity, oil natural gas) and <u>transportation</u> (auto) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: provides state, national and global averages of CO_2 emissions
Puretrust		
		1) Web Address: http://www.puretrust.org.uk/Home/Personal/Calculator.asp 2) Calculates: <u>home</u> (electricity, oil, natural gas, biomass, coal, LPG) and <u>transportation</u> (auto, motorcycles, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): tonnes of CO_2 6) Comments: UK based, provides opportunity to purchase carbon offsets
Resurgence		
		1) Web Address: www.resurgence.org/carboncalculator/ 2) Calculates: <u>home</u> (electricity, oil, natural gas, coal, wood stove), <u>transportation</u> (auto, taxi, train, bus, air miles), <u>leisure</u> (activities use gas/diesel/kerosene) and industry(per capita portion of business) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): kg and tonnes of CO_2 6) Comments: UK based; two versions – based on $ or based on bills
Safeclimate		
		1) Web Address: www.safeclimate.net/calculator/index.php 2) Calculates: <u>home</u> (electricity, oil, natural gas,) and <u>transportation</u> (auto, air miles) 3) Ease of use: easy 4) Time to complete: less than 5 minutes 5) Output (units): lbs of CO_2 6) Comments: choice of countries; provides animation showing output relative to national average

<table>
<tr><th colspan="3">TerraPass</th></tr>
<tr><td></td><td></td><td>1) Web Address: http://www.terrapass.com/
2) Calculates: <u>home</u> (electricity, oil natural gas, propane,) and <u>transportation</u> (auto, air miles)
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): lbs of CO_2
6) Comments: provides opportunity to purchase carbon offsets and energy saving products</td></tr>
<tr><th colspan="3">The Nature Conservancy's Carbon Footprint Calculator</th></tr>
<tr><td></td><td></td><td>1) Web Address: http://www.nature.org/initiatives/climatechange/calculator/
2) Calculates: <u>home</u>, <u>transportation</u> (auto, air miles), <u>food & diet</u> and <u>recycling & waste</u>
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): tons of CO_2
6) Comments: provides graph comparing results to U.S. average</td></tr>
<tr><th colspan="3">Yahoo Green Calculator</th></tr>
<tr><td></td><td></td><td>1) Web Address: http://green.yahoo.com/calculator/
2) Calculates: <u>home</u> and <u>transportation</u> (auto, air miles)
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): tons of CO_2
6) Comments: provides opportunity to purchase carbon offsets</td></tr>
<tr><th colspan="3">Water Conservation Calculator</th></tr>
<tr><td></td><td></td><td>1) Web Address: http://www.csgnetwork.com/waterusagecalc.html
2) Calculates: <u>water</u>
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): gallons of water used
6) Comments: provides water usage per day, month and year</td></tr>
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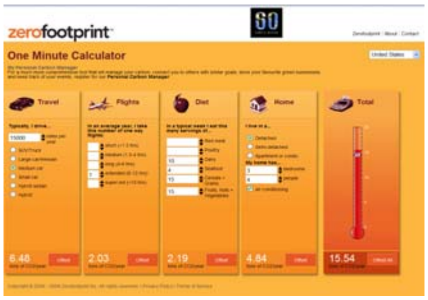
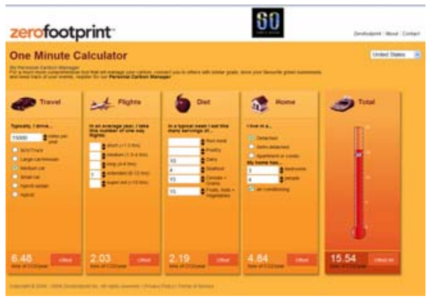
Zerofootprint: Earthhour





1) Web Address: http://www.zerofootprint.net/one_minute/earthhour
2) Calculates: home, diet, and transportation (auto, air miles)
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): tons of CO_2
6) Comments: allows you to choose country; more thorough calculator available by registering

Zerofootprint: Unilever Go Blue

1) Web Address: http://zerofootprint.net/one_minute/unilever?language=en-C
2) Calculates: water
3) Ease of use: easy
4) Time to complete: less than 5 minutes
5) Output (units): gallons per year
6) Comments: allows you to choose country

The information presented above is condensed in table 2. This table includes all the areas in which the tool can calculate carbon, a lighter gray color means that function is available but results are not as complete.

TABLE 2: COMPARISON OF CARBON CALCULATING TOOLS

APPLICATIONS	OPERATIONAL															TRANSPORTATION		WASTE	CONSTRUCTION	WATER
	ELECTRICITY	LIGHTS	FANS	A/C	APPLIANCES	NAT GAS	PROPANE	HEAT OIL	WOOD	COAL	LPG	KEROSENE	BUTANE	WATER HEATER	FURNACE	AUTO	AIRPLANE			
Act on CO2 calculator																				
American Forests	■					■	■	■	■			■				■	■			
Athena: EcoCalculator for Assemblies																			■	
Be Green Now	■					■									░	■	■			
Berkeley Institute of the Environment																				░
Best Foot Forward	■															░				
Bonneville Environmental Foundation	■					■	░	░								■	■			
Bonneville Environmental Foundation (BEF)	■																			
BP Calculator	■															■	■			
Build Carbon Neutral Construction Calculator																			■	
California Carbon Calculator	■															░	░			
Carbon Footprint	■					■										░	■			░
CarbonCounter.org	░					░										░	░			
Carbon Fund	■					■											■			
center for alternative technologies	░					░										░	░			
Chuck Wright	■					■		■								■	■			
City of Fair Oaks, CA Water Use Calculator																				■
City of Tampa, Florida Water Use Calculator																				■
Clear Water	■					■		■	■							■				
Electric Power Pollution Caculator	■					■		■								■	■			
Energy Star Home Energy Yardstick	■					■	■	■												
Energy Star Target Finder	■																			
EPA Personal Emissions Calculator	■					■	■	■								■		■		
EPA Waste Reduction Model WARM	■					■	■	■								■		■		
GEIC calculator				░	░										░					
HEED		■	■	■	■	■	■	■						■	■					
Home Energy Saver Calculator		■	■	■	■									■	■					
Inconvenient Truth	■					░									■					
Live Neutral	■					■										■	■			
Pacific Gas and Electric	■					■										■				
Puretrust	■					■				■						■	■			
Resurgence	■					■	■	■		■	■									
Safeclimate	■					■	■	■		■	■	■				■	■			
TerraPass	░															■	■			
The Conservation Fund	■														■	■	■			
Calculator	■														■	■	■	░		
Yahoo Green Calculator	■	░				░	░	░							■	■	■			
Water Conservation Calculator																				■
Zerofootprint: Earthhour	■					■	■	■	■			■				■	■			
Zerofootprint: Unilever Go Blue																				■

3. COMPARING CO_2 EMISSIONS IN CARBON COUNTING TOOLS DUE TO NATURAL GAS AND ELECTRICITY

The tools that were selected had different input and output screens, sometimes with different input requirements, so some assumptions had to be made. The values in table 3 were input in each of the tools to compare them. Not all of the tools provided results that could be compared between each other (e.g. planets vs kilograms) so only those that had the option to provide a reasonable input and output were compared.

TABLE 3: INPUTS FOR THE TOOLS

Electricity	Average Annual Use: 12,000 KWh
Natural Gas:	92,160 cubic feet or 921.6 therms/year
Propane or heating oil	300 gallons (when asked)
Coal	300lbs or 0.1119 tonnes (when asked)
Vehicle Transportation	15,000 miles a year per household @ 22 MPG or a 2008 Honda Civic with 24 mpg.
Air transportation	15,000 miles a year or R/T flight LAX/CDG

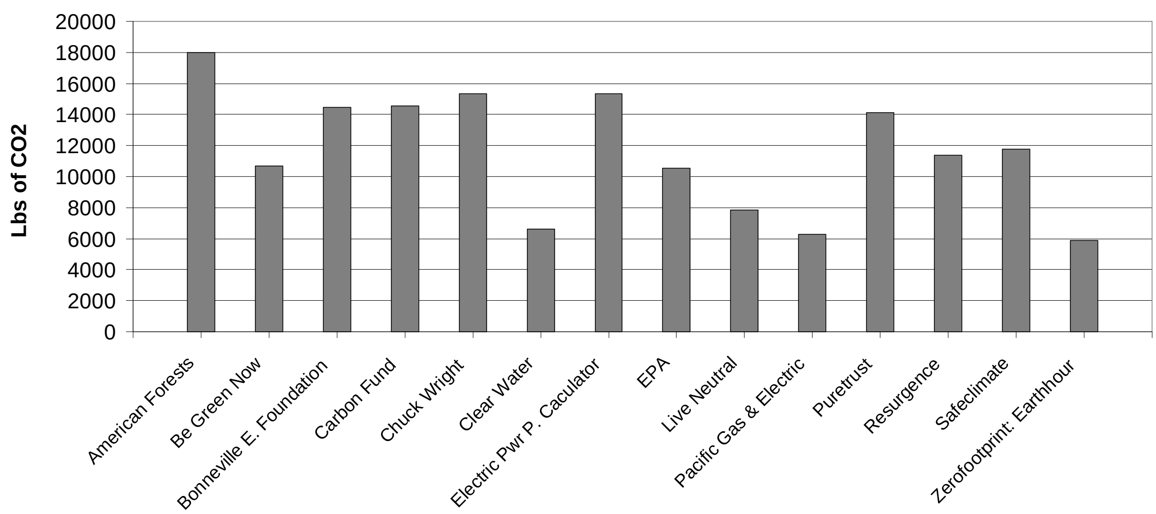


Figure 1: CO_2 emissions due to electricity (12,000 KWh)

The carbon calculators that were compared all give different CO2 emissions (Figs 1 & 2), especially for electricity. There is much variation in the results. For electricity the emissions ranged from 6,000 lbs of CO_2 per year to 13,000 lbs of CO_2 per year and for gas it ranged from 8,600 lbs of CO_2 / year to 12,000 lbs of CO_2 / year. Unfortunately most of these tools are not transparent and it is not easy to determine the equations and conversion factors used for calculations. The average result for natural gas was 11,630 lbs of CO2 for the 921.6 Therms of gas, equivalent to 12.62 lbs of CO_2 per Therm, or 0.47 lbs CO_2/kWhr, close to the value of .418 lbs of CO_2 / KWh proposed by DEFRA (3). The average value for electricity was 11,630 lbs of CO_2 per 12,000 KWh or 0.97 lbs / KWh. As a reference, the average emission factor from grid electricity in the USA was 1.363 lbs / kWh (4). This variability in the calculators indicates that it is probably better to select a conversion factor and multiply this factor by the calculated or recorded energy used in the building.

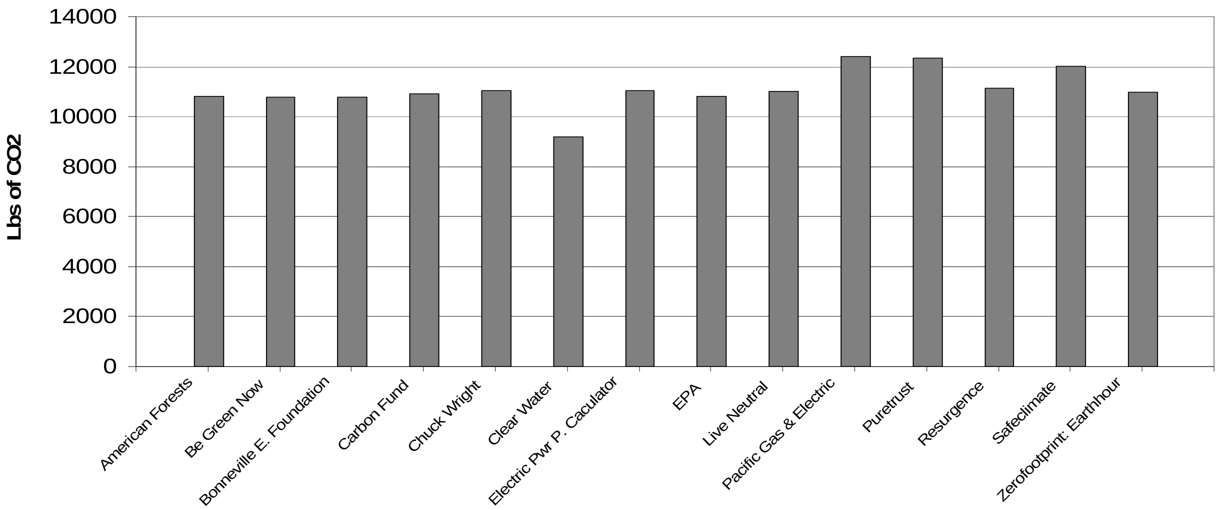


Figure 2: CO_2 Emissions due to natural gas (921 Therms)

4. COMPARING CO_2 EMISSIONS FROM CARBON COUNTING TOOLS IN DIFFERENT CLIMATES

To further compare results with these tools a single family dwelling was analyzed in four climates. This dwelling was two stories high and 48 by 24 ft, with 2300 sq ft gross building floor area, which is close to the 2005 US average. The four climates regions were: a) HOT AND DRY: California climate zone 15 (El Centro); COLD: California climate zone 16; TEMPERATE: California climate zone 6 (Los Angeles); and HOT AND HUMID: Miami, Florida. The psychrometric charts in Figures 3, 4, 5 and 6 illustrate the conditions in these climates. Much more extreme climates (warmer in the hot climates or colder in the cold climates) for each of these could have been selected but these were deemed as representative without being too extreme.

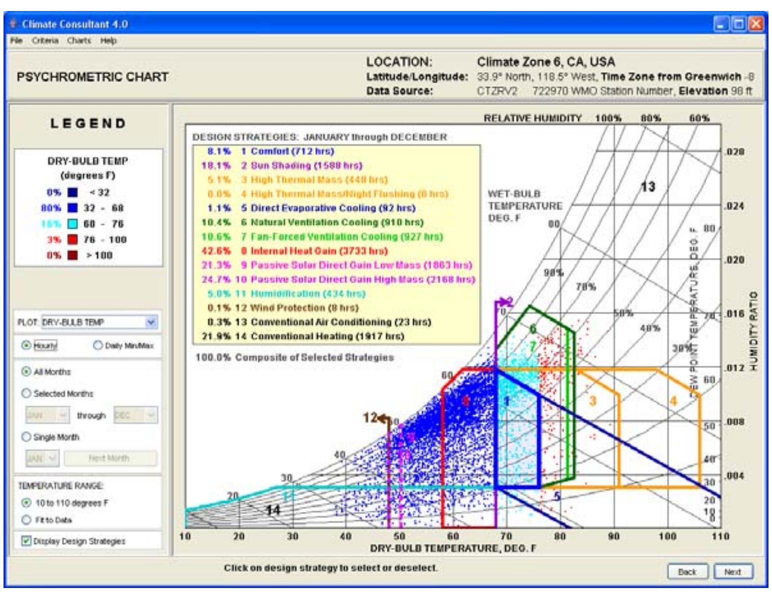


Figure 3: Psychrometric chart for the Temperate Climate (California climate zone 6)

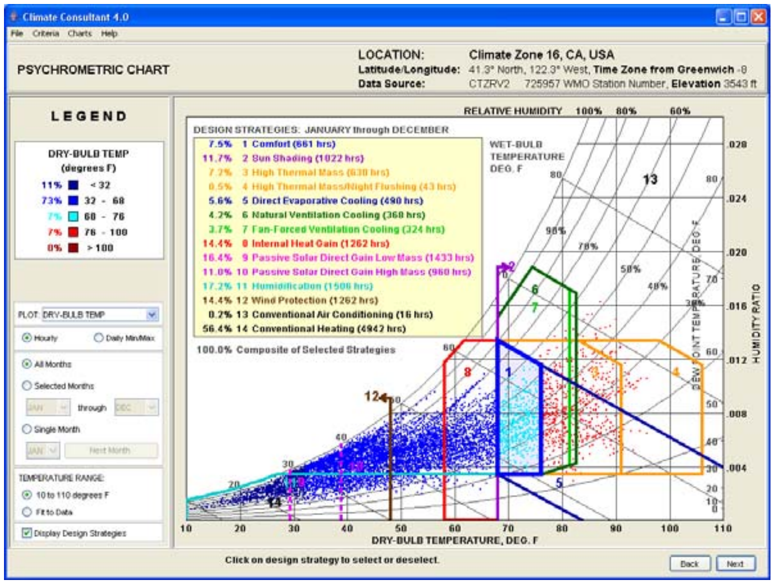


Figure 4: Psychrometric chart for the Cold Climate (California climate zone 16)

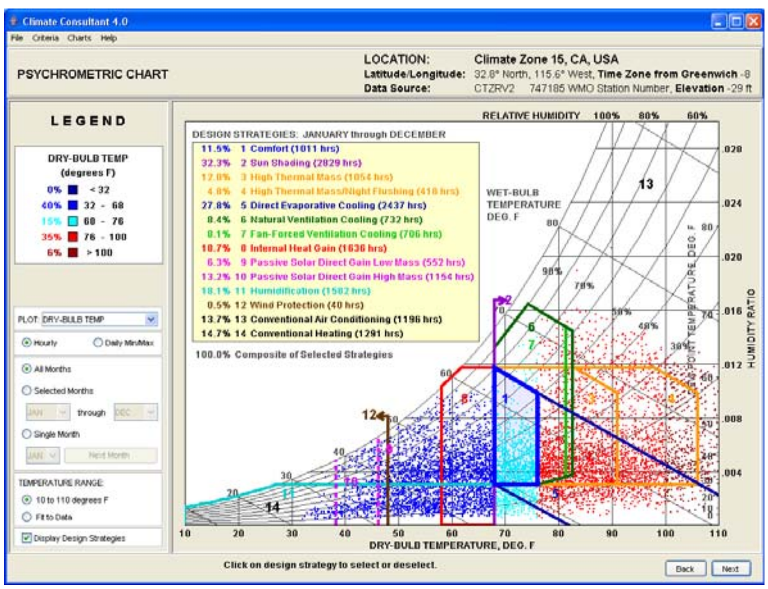


Figure 5: Psychrometric chart for the Hot Dry Climate (California climate zone 15)

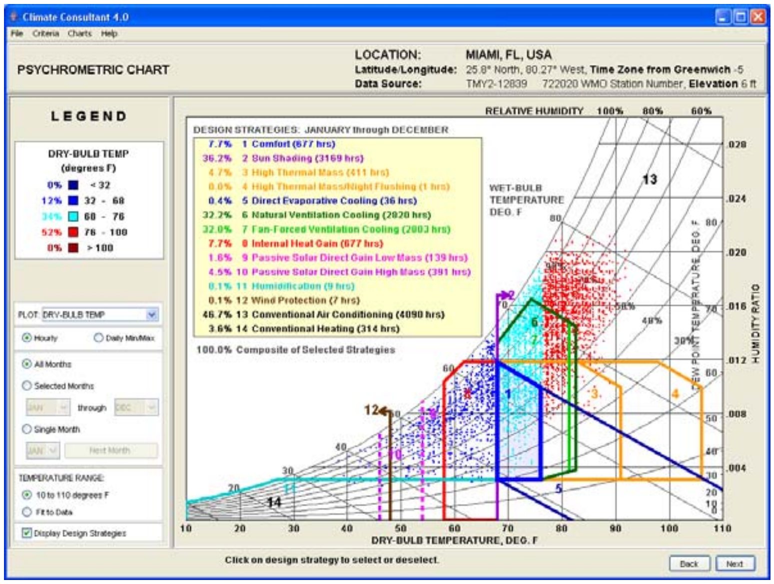


Figure 6: Psychrometric chart for the Hot Humid Climate (Miami)

Several assumptions were made for each of the areas in which buildings emit carbon (operational energy, construction, waste, water and transportation) and are explained in the following sections.

4.1. Operational Energy

Title 24 was used to define the building envelope for all climate zones. Package D for homes with natural gas was used. The same envelope requirements were used for hot and humid and hot and dry climates (Table 4).

TABLE 4: ENVELOPE CHARACTERISTICS

		Title 24 Package C				Title 24 Package D			
	Reference City	Ceiling	Wood Frame Walls	Glazing U-Value	EGR (Glazing Max Area)	Ceiling	Wood Frame Walls	Glazing U-Value	EGR (Glazing Max Area)
Calif CZ 16 Cold	Bishop	R49	R29	0.42	14%	R38	R21	0.55	20%
Calif CZ 15 Hot & Dry	El Centro	R49	R29	0.38	16%	R38	R21	0.55	20%
Miami Hot & Humid	Fresno	R49	R29	0.38	16%	R38	R19	0.57	20%
Calif CZ 6 Temperate	Los Angeles	R38	R21	0.42	14%	R30	R13	0.67	20%

Operational energy includes all the energy to keep the buildings and everything inside it running. According to Bordass (5) the process to estimate CO_2 emissions from operational energy use in buildings involves five steps:

1. *Define the boundary of the premises.* Boundaries should be where they make practical sense in terms of where the energy can be counted (e.g. the area fed by the meters) and how the area is run (a tenancy, a building, a site; or even a district or a city). One may look at more than one boundary, e.g. for a university the campus, specific buildings, and individual departments; and for a rented building the whole building, and each tenancy.
2. *Measure the flows of each energy supply across the defined boundary.* Normally this will be annual totals by fuel, though details of load profiles could sometimes be included.
3. *Define carbon dioxide factors for each energy supply*.
4. *Multiply each energy flow by the appropriate carbon dioxide facto* to get the emissions associated with each fuel.
5. *Add them up.* to get the annual total of CO_2 emissions.

To calculate the CO_2 factors for each energy supply we must determine the emission factors for each one. There are several methods to determine these factors (6):

- The EPA Power Profiler – calculates CO_2 emission factors for historical yearly average emissions for every U.S. zip code.

- The EPA eGRID – a database that has hourly CO_2 emissions for every U.S. power plant. However, this data is also historical and it is a non-trivial task to estimate marginal generation from this database.

- The NREL Model – they developed direct and indirect impacts for typical building fuels and used CO_2 e (equivalent) which includes other important GHG besides CO_2, like methane (CH4) and nitrous oxide (N2 O). This model generated emission factors for all U.S. regions as well as the nation.

- The CEC/E3 Model – used the output of a production simulation dispatch model to forecast average and marginal CO_2 emission factors for California.

Because different locations would use different electrical and gas utilities which would further muddle the numbers, the same values were used for electricity and gas in all the projects: 1.363 lbs of CO_2 per kWh for electricity, which is the average value for the United States and 11.924 lbs of CO_2 per therm for gas.

4.2. Construction

Carbon emissions from construction processes are usually generated a) during the fabrication of the materials used in the building, b) during transportation of materials to the building and c) during construction of the building. Construction related emissions are usually more difficult to calculate because it is not easy to determine with precision the manufacturing process, origin, and transportation modes of the materials from its place of origin to the site. It is also difficult to determine the amount of each material in the building.

Emissions for construction were calculated using buildcarbonneutral, (7) a very simple calculator that provides rough results. More precise data can be generated using Athena Ecocalculator for assemblies. However this is not available for all regions.

The following input was provided to the calculator to determine emissions due to construction materials: floor area of 2300 sq ft, two stories high, structural wood system, Mediterranean California ecoregion, previously developed existing vegetation, short grass installed, disturbed landscape of 6500 sq ft and 1500 sq ft installed. The total emissions from construction were 53 metric tons or 116,812 lbs. of CO_2 / year. We estimated a building lifespan of 50 years, which is equivalent to 2336.2 lbs/year over the life of the building. If construction components could be recycled or the life of the building could be extended then the impact would be lower. If the building required major renovations then construction related CO_2 emissions would be higher. The same number was used in the building in all sites.

4.3 Waste

Waste generated from the building must also be treated. More waste requires more treatment and sometimes generates methane, which is a potent greenhouse gas produced in landfills.

To determine emissions due to waste, we used the waste portion of the carbon emissions calculator developed by the EPA (8). We assumed that the home recycled 50% of its waste (plastic, aluminum, newspapers, glass, magazines, etc.) This reduced the emissions from 1,021 lbs of CO_2 per year / per person to 574 lbs of CO2 per year / person. Since we assumed a household of four we assumed this generated 2,296 lbs of CO_2 / dwelling / year from waste . This value was also assumed equal in all locations.

4.4. Water

Water provided to the building and coming from the building must also be treated in a process which usually is also responsible for the generation of CO_2 emissions. The water that is used in the building must be pumped from the source, then treated to be made potable, and then pumped to the building for consumption. The waste water from the building must also be treated, which also generates carbon emissions by using energy for these processes.

A study on Water-Related Energy Use in California by the Assembly Committee on Water, Parks and Wildlife (9) calculated the water embedded energy for southern and northern California. They estimated the amount of energy needed for each sector of the water-use cycle in terms of the number of kilowatt-hours (kWh) needed to collect, extract, convey, treat, and distribute one million gallons (MG) of water, and the number of kWh needed to treat and dispose of the same quantity of wastewater. For Southern California the embedded energy per MG is 13,021 kWh. We used these numbers to estimate the energy embedded in the water for a family of four that would use 400 gallons of water per day. This means that to provide 146,000 gallons a year to a family of four in southern California would require 1901 kWh. If every kWh of electricity in California generates about 0.7 lbs of CO_2 (4) then the average water use for a family of four generates about 1,331 lbs of C02 / year. This number was used for all sites even though the number for southern California is higher than the number for Northern California and probably higher than for the rest of the United States.

4.5 Transportation

A building is also indirectly responsible for CO_2 emissions from transportation. By its location it affects how the building users move to and from the building. A location close to public transit lines or in urban areas with higher density and walkable neighborhhoods usually reduces transportation related carbon emissions.

We assumed that each household drove a total of 15,000 miles per year in cars with 22 MPG efficiency. A factor of 19.5 lbs of CO_2/Gal (10) was used. A total yearly value of 13,295 lbs of CO_2 per year for transportation from the home was determined. This value could be assigned to the home, work or divided between both. We assigned this value to the home.

We did not include carbon emissions for air travel because these are not affected by the location of the residence.

5. RESULTS: CARBON EMISSIONS IN FOUR CLIMATES

As previously explained, the CO2 emissions due to waste, transportation and construction were kept constant in the buildings in the four climates and are presented in table 5. Keeping these values as fixed variables makes it easier to determine the relationship between operational CO2 emissions and the effect of climate on these variables.

TABLE 5: CO_2 VALUES USED IN ALL SITES

Waste	2296 lbs CO_2
Transportation	13295 lbs CO_2
Construction	2336 lbs CO_2
Water	1,331 lbs CO_2

Two programs, HEED and Design Builder, were used to calculate energy use in the four locations. HEED (Home Energy Efficient Design) (11) is an energy analysis tool that shows designers the building's performance at every step of the way. When HEED is first launched it asks four questions about the project (building type, square footage, number of stories, and climate location). With this information it creates Scheme 1, a building that meets the California Energy Code. It then designs a second Scheme that is usually about 30% better. Next it suggests other strategies that designers can test using the remaining seven schemes. HEED makes it very easy for users to change any aspect of the building's design. After each design change HEED shows how the building's performance compares with the initial schemes.

DesignBuilder is a user interface to the EnergyPlus dynamic thermal simulation engine. DesignBuilder features an OpenGL solid modeler, which allows building models to be assembled by positioning, stretching and cutting 'blocks' in 3-D space. 3-D elements provide visual feedback of actual element thickness and room areas and volumes. Data templates allow to load common building constructions, activities, HVAC & lighting systems into the design by selecting from drop-down lists. These templates can also be added. The user can switch between Model Edit View and Environmental performance data which is displayed without the need to run external modules and import data.

5.1. Cold Climate

In the cold climate, the CO_2 emissions from operational energy as determined by HEED are 15005 lbs. and 11616 as determined by Design Builder. Emissions as determined by energy use calculated with HEED and DesignBuilder are compared in Figure 7 and its distribution in Figures 8 and 9.

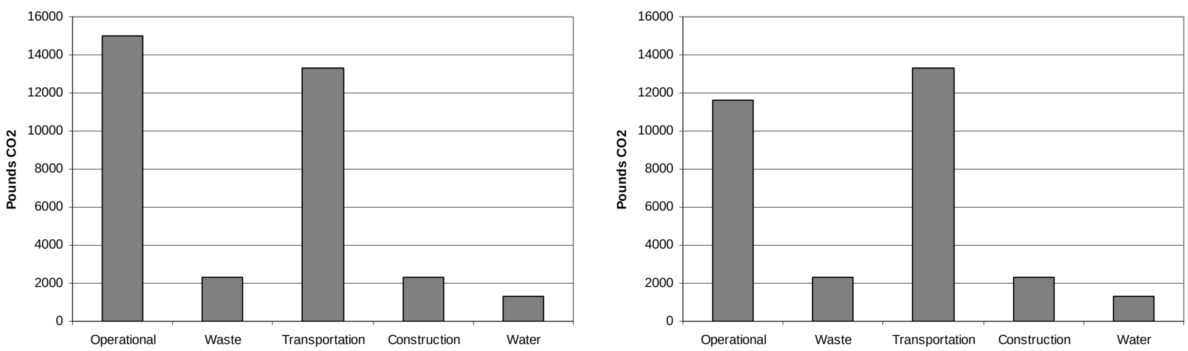


Figure 7: Quantitative distribution of CO_2 emissions in a Cold Climate. HEED results are on the left and Design Builder on the right.

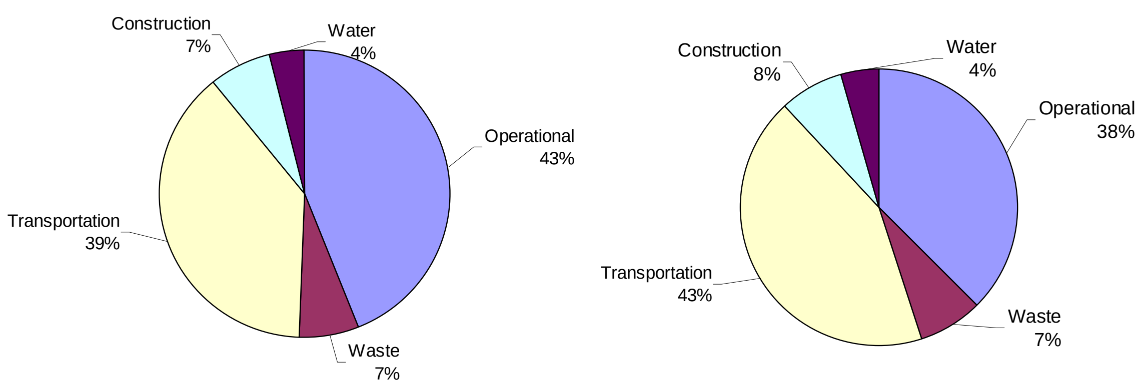


Figure 8: Distribution of CO_2 emissions in a cold climate. HEED results are on the left and Design Builder on the right

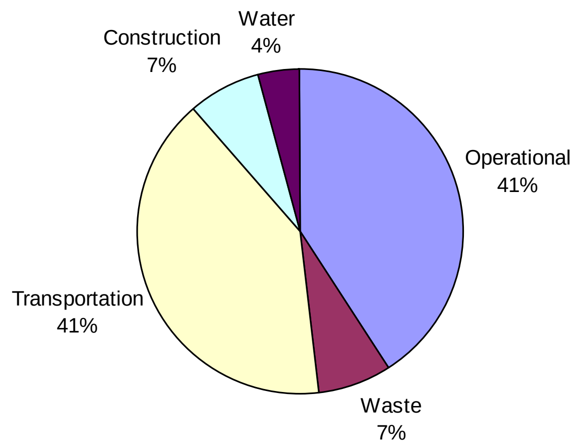


Figure 9: Distribution of emissions in a Cold Climate. Average from HEED and Design Builder

If vehicular transportation is considered, the emissions due to operational energy and transportation are the most significant, about 41% each (Fig. 9).

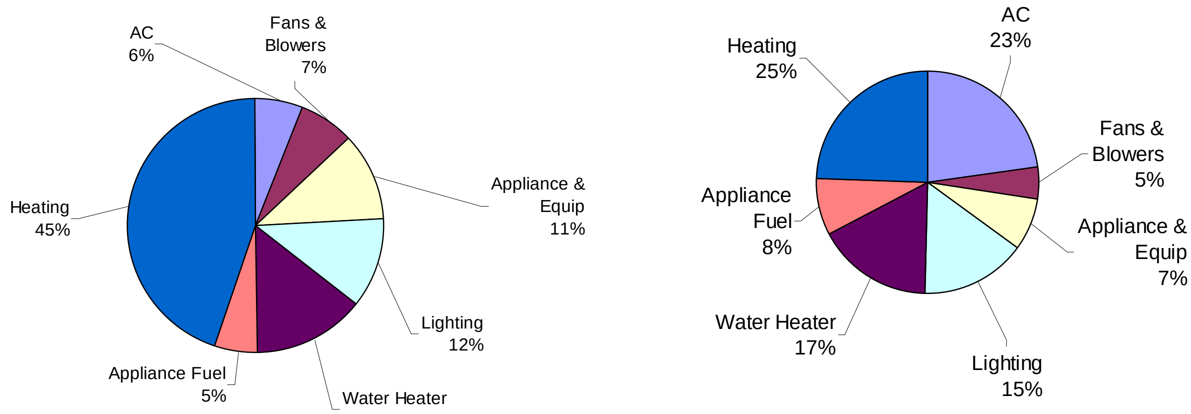


Figure 10: Operational Emissions in a Cold Climate (Bishop, CA). Left chart obtained with HEED and right with Design Builder.

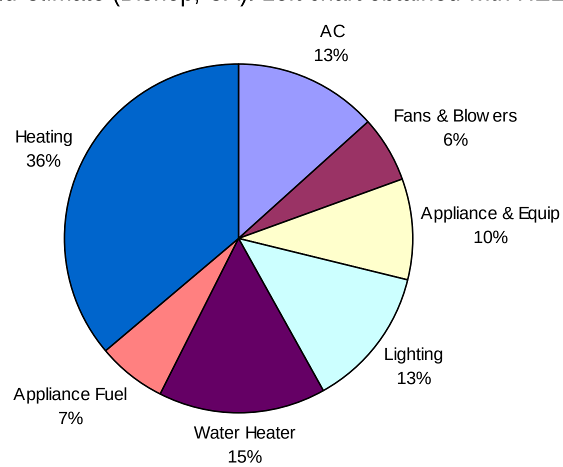


Figure 11: Operational Emissions in a Cold Climate (Bishop, CA). Average obtained using HEED and Design Builder.

To determine the impact of the different areas in operational energy a more detailed analysis (Fig 10, 11) was performed. This analysis included heating, AC, fans & blowers, appliances, water heaters, and lighting. It indicates that in the cold climate selected, according to both HEED and Design Builder, most of the emissions from operational energy are from heating, 45% according to HEED plus an additional 7% for fans and blowers, and 25% according to Design Builder plus an additional 5% for fans and blowers. Averaging results from both tools indicates that 36% of the emissions come from heating. A gas furnace with an AFUE of 80% was used. Design Builder indicates a need for more cooling during many mid season days than HEED to maintain indoor conditions in the comfort zone, which is probably the reason for the additional cooling energy indicated by that program.

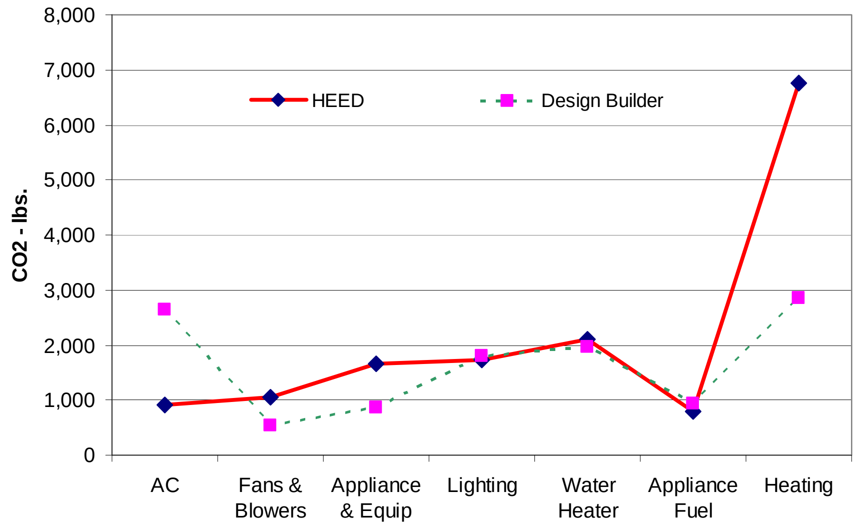
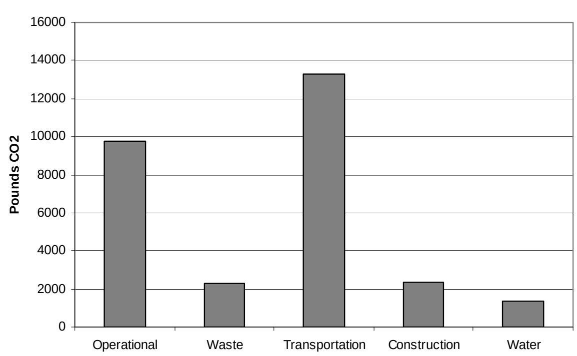


Figure 12: Operational Emissions in a Cold Climate (Bishop, CA), values with HEED and Design Builder.

5.2. Temperate Climate.

In the temperate climate the CO_2 emissions from operational energy are a smaller portion of all emissions. Transportation becomes much more important, assuming the values previously used. Figure 15 shows how CO_2 from transportation can be responsible for about half of all emissions in a temperate climate because of the reduction in emissions from operational energy due to the milder climate. Operational emissions can be reduced even more if appropriate design strategies are implemented.



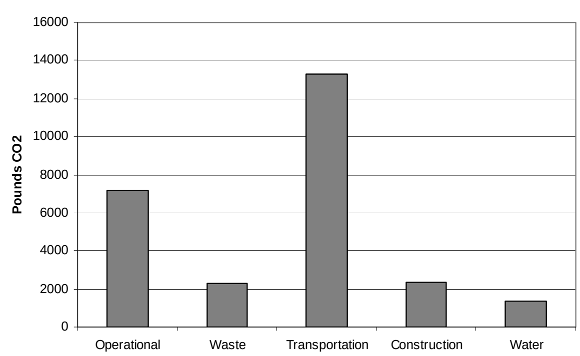
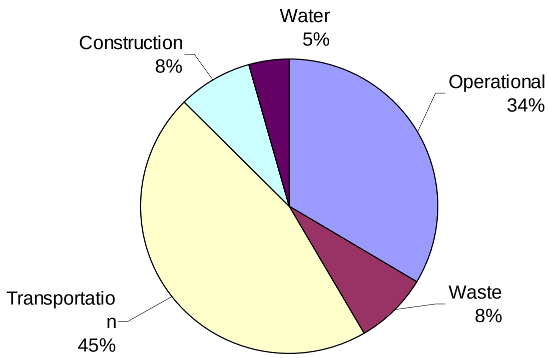


Figure 13: Quantitative distribution of Emissions in a temperate climate. HEED results are on the left and Design Builder on the right.



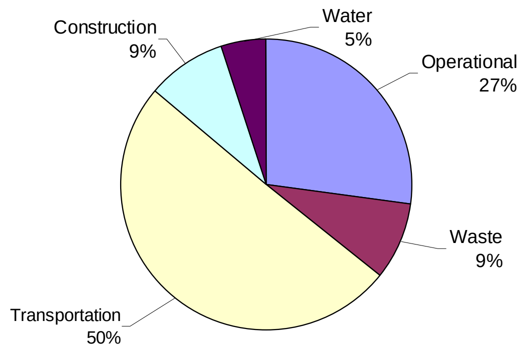


Figure 14: Distribution of Emissions in a Temperate Climate. HEED on the left and Design Builder on the right.

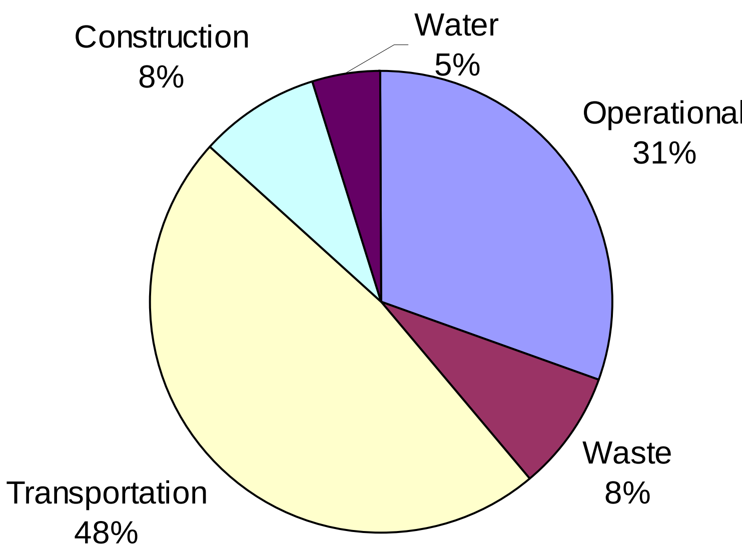
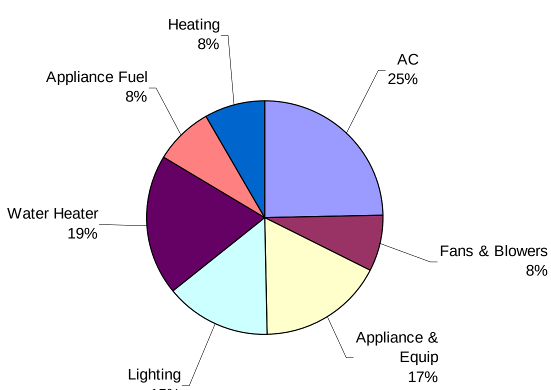


Figure 15: Distribution of Emissions in a Temperate Climate. Average of HEED and DesignBuilder.



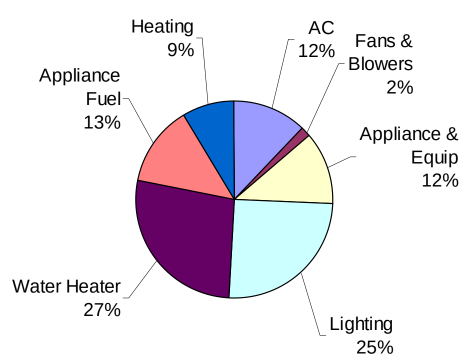


Figure 16: Operational Emissions in a Temperate Climate (Los Angeles, CA). Left with HEED and right with Design Builder.

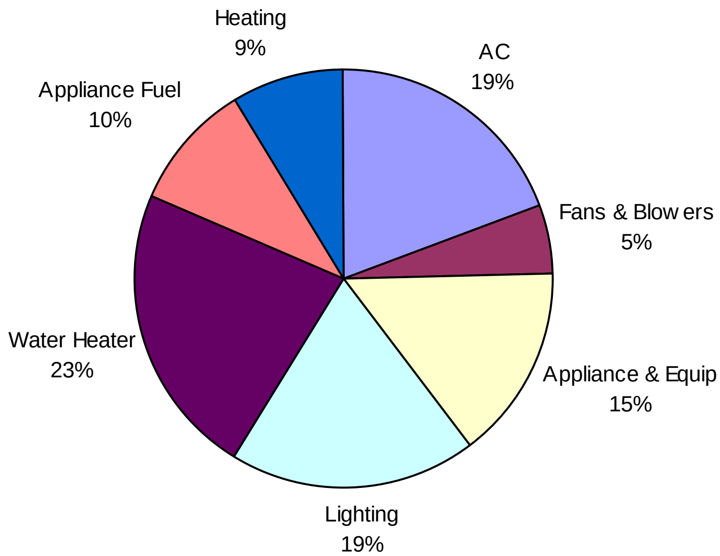


Figure 17: Operational Emissions in a Temperate Climate average from HEED and Design Builder.

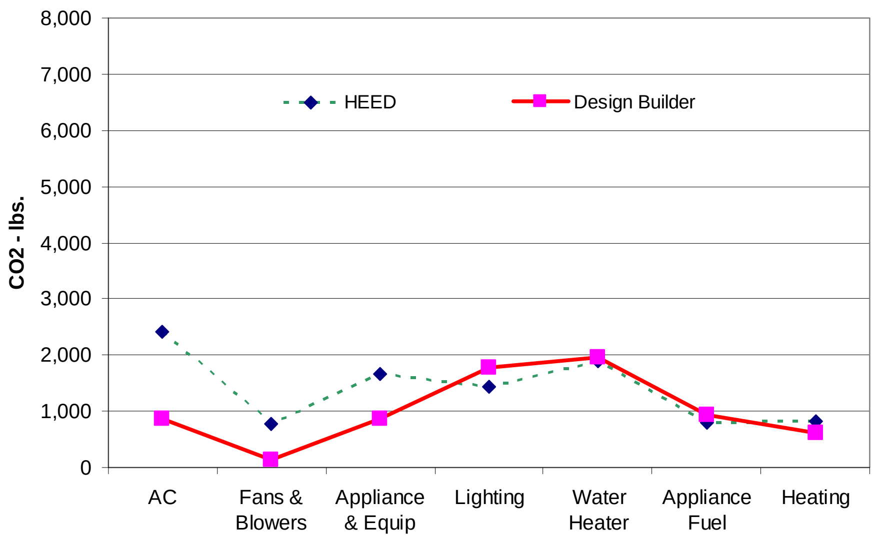
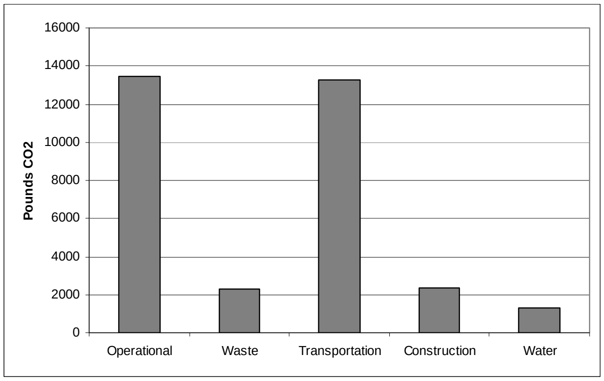


Figure 18: Operational Emissions in a Temperate Climate, values with HEED and Design Builder.

In the temperate climate the CO_2 emissions from operational energy are 9,791 lbs/year of C02 as determined by HEED and 7,181 lbs/year by Design Builder (Fig 19). Analysis of the operational emissions indicates that the emissions from the different areas inside operational energy are more evenly distributed between all these sources (Figs 22 & 23). Since heating and cooling are not as critical because the climate is more moderate, water heating and lighting become more important components of operational energy emissions.

5.3. Hot and Dry Climate

For a hot and dry climate the CO_2 due to operational energy is: 13,453 lbs of CO_2 for HEED and 12,098 lbs for Design Builder (Fig 19). These are a large portion of total emissions (40%).



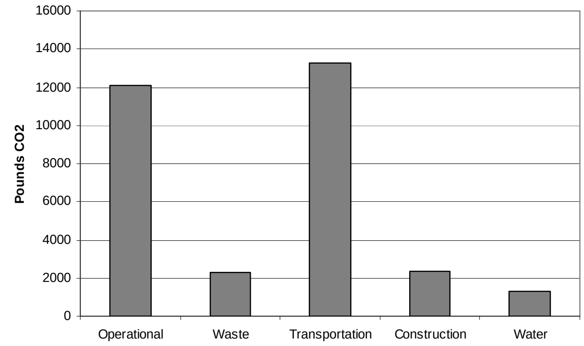
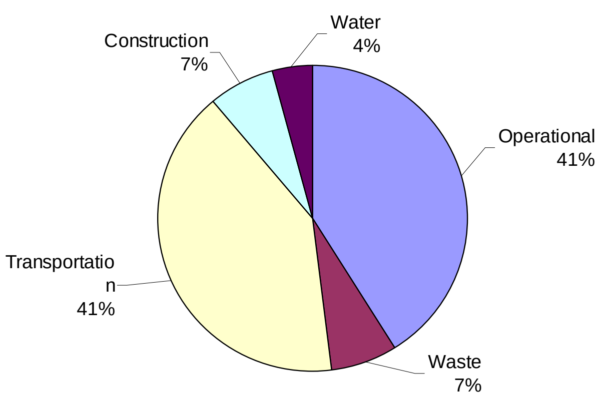


Figure 19: Quantitative distribution of Emissions in a Hot and Dry climate. HEED results are on the left and Design Builder on the right.



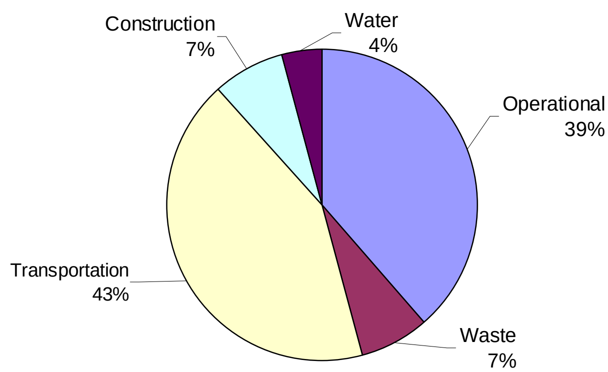


Figure 20: Distribution of Emissions in a Hot and Dry Climate. HEED on the left and Design Builder on the right.

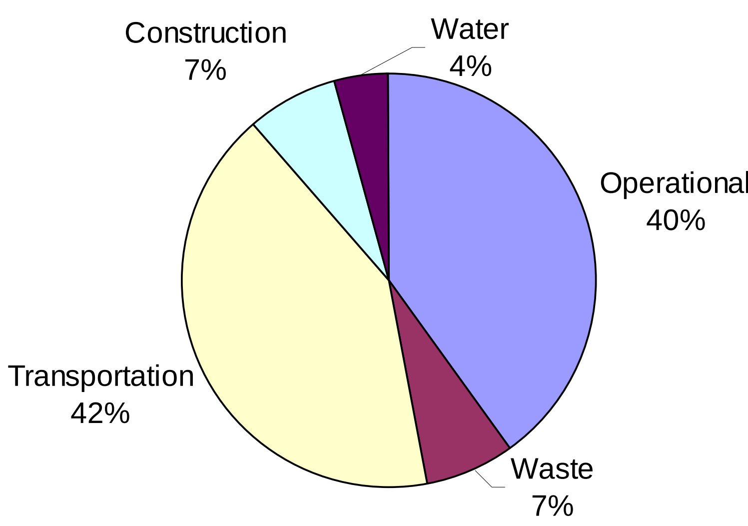


Figure 21: Distribution of Emissions in a Hot and Dry Climate. Average of HEED and Design Builder.

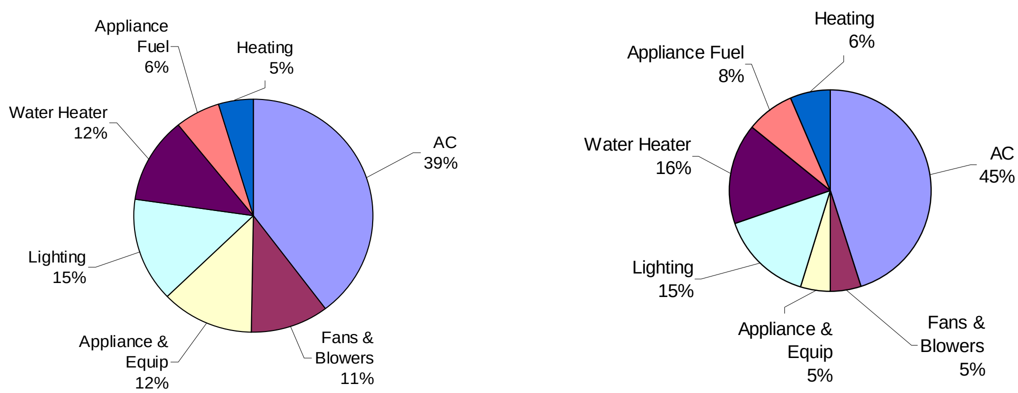


Figure 22a: Operational Emissions in a Hot and Dry Climate. Left with HEED and right with Design Builder.

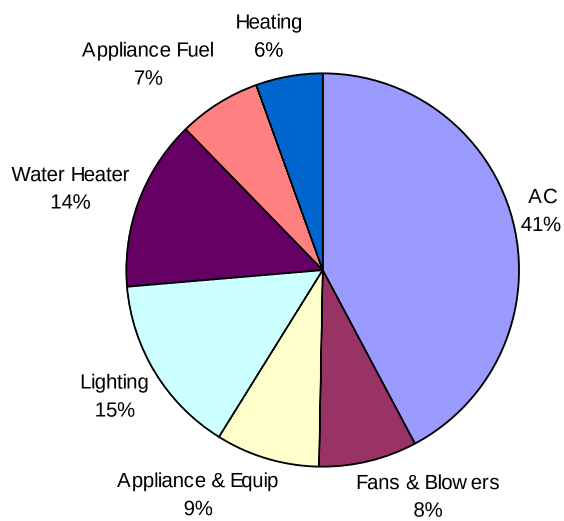


Figure 22b: Operational Emissions in a Hot and Dry Climate average from HEED and Design Builder.

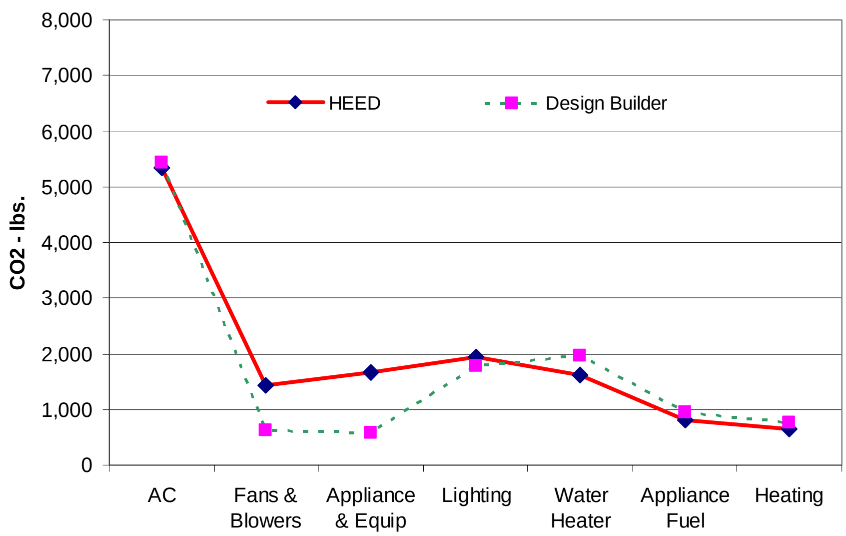


Figure 23: Operational Emissions in a Hot and Dry Climate, values with HEED and Design Builder.

A more detailed analysis of the operational emissions indicates that in a hot and dry climate most of these emissions (41%) are from cooling plus 11% for fans and blowers (Fig 23). There is close agreement between the results with HEED and Design Builder.

5.4. Hot and Humid Climate

In a hot and humid climate the CO2 emissions from operational energy are 11,528 lbs of CO_2 as determined by HEED and 10,700 lbs of CO_2 (37% of total) as determined by Design Builder (36% of total). Operational emissions constitute 37% of the total building emissions when averaged.

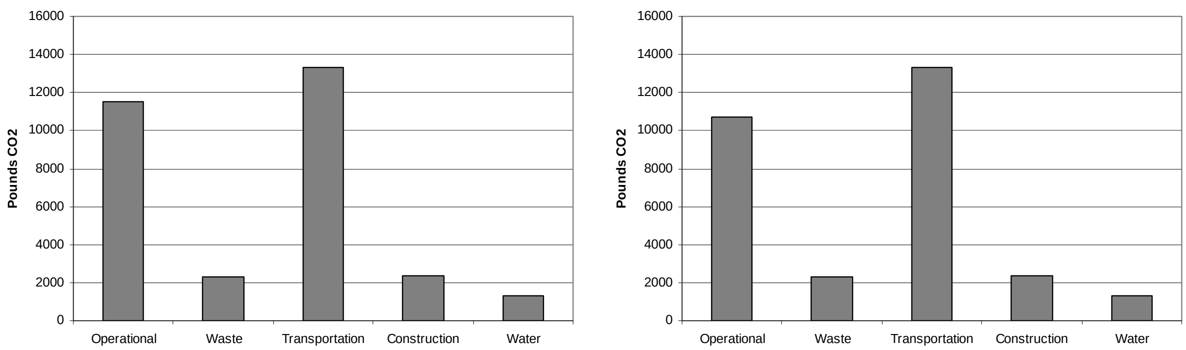


Figure 24: Quantitative distribution of Emissions in a Hot and Dry climate. HEED results are on the left and Design Builder on the right.

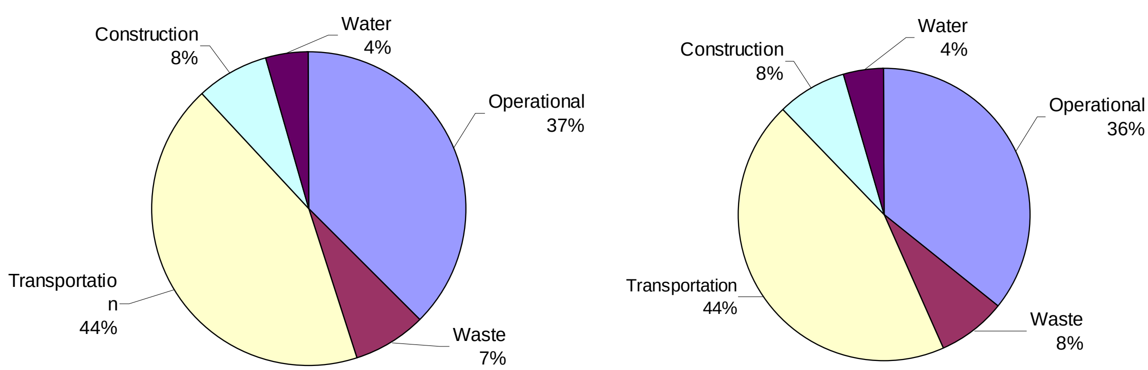


Figure 25: Distribution of Emissions in Hot & Humid Climate Design Builder is on the right.

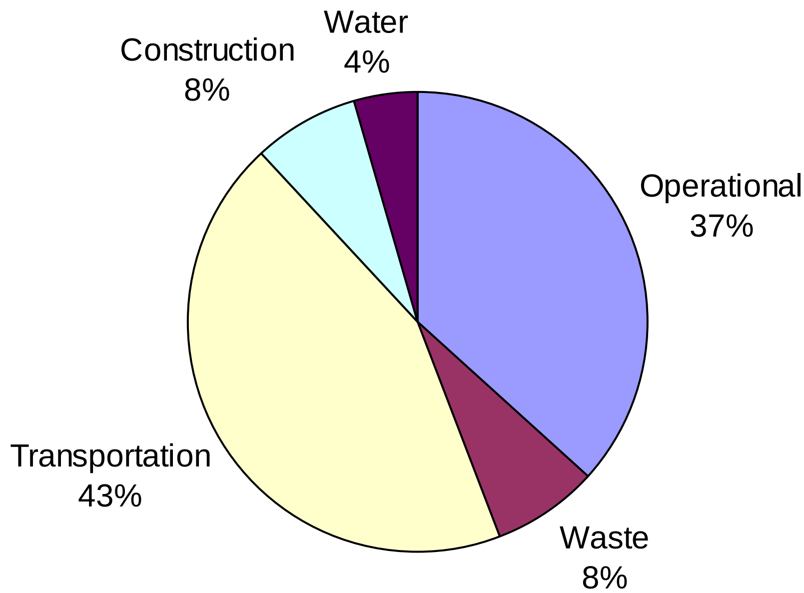
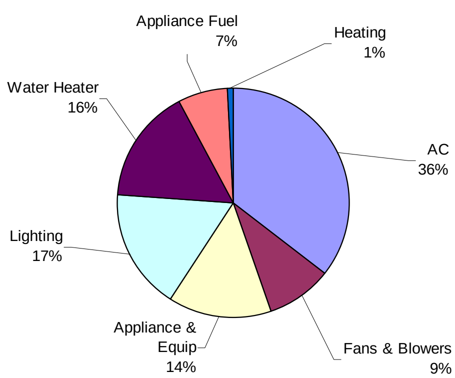


Figure 26: Distribution of Emissions in a Hot and Humid Climate. Average of HEED and Design Builder.



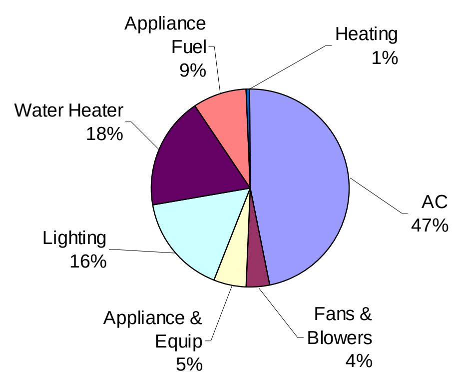


Figure 27: Operational Emissions in a Hot and Humid Climate. Left with HEED and right with Design Builder.

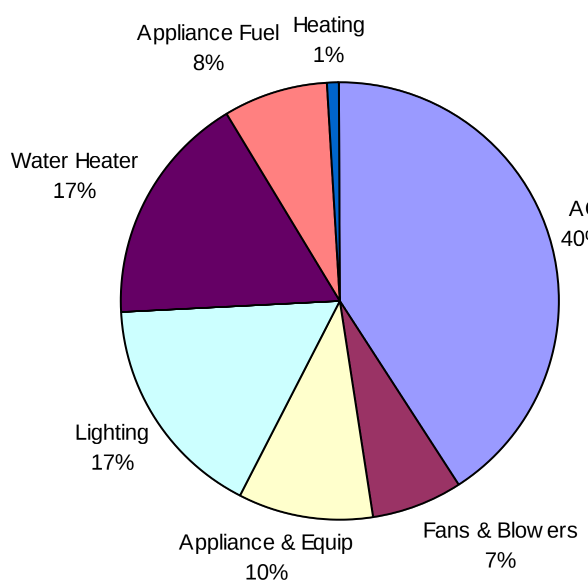


Figure 28: Operational Emissions in a Hot and Humid Climate. Average with HEED and Design Builder.

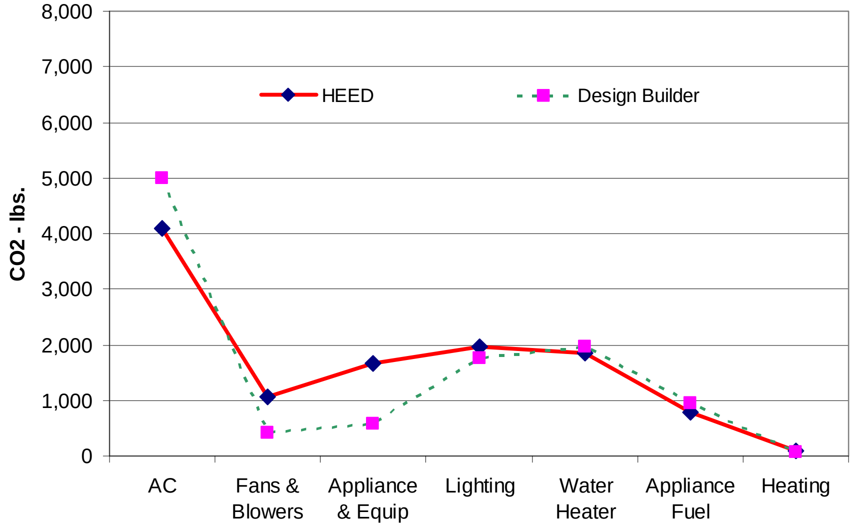


Figure 29: Operational Emissions in a Hot and Humid Climate, values with HEED and Design Builder.

Further analysis indicates that most of emissions from operational energy in a hot and dry climate are from cooling (40%) plus 7% for Fans and Blowers (Figs. 27, 28).

6. DISCUSSION:

Results indicate that most of the carbon emissions in a building are generated from operational energy and most of these are due to cooling and heating. Understanding the origin and quantity of these emissions will permit to better develop strategies to reduce them. These strategies also reduce energy use.

Figure 30 shows the percentages of emissions from all sources, including transportation, averaged for the four climate zones. This figure gives a very general idea of where the emissions that are directly related to buildings (construction, water, operation, waste) and indirectly related (transportation to and from the building) come from. Operation is the single largest direct contributor and transportation to and from the building is also very important but can vary widely.

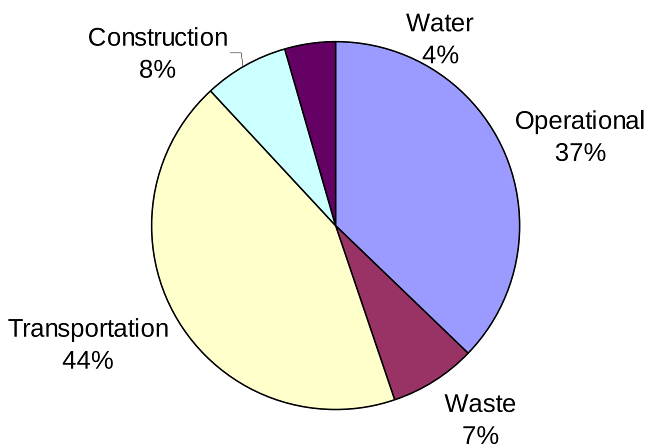


Figure 30: Average Distribution of Emissions including Transportation.

If carbon emissions from transportation are not considered then of course, these percentages are modified and carbon emissions from operational energy have a much larger impact, about 66%.

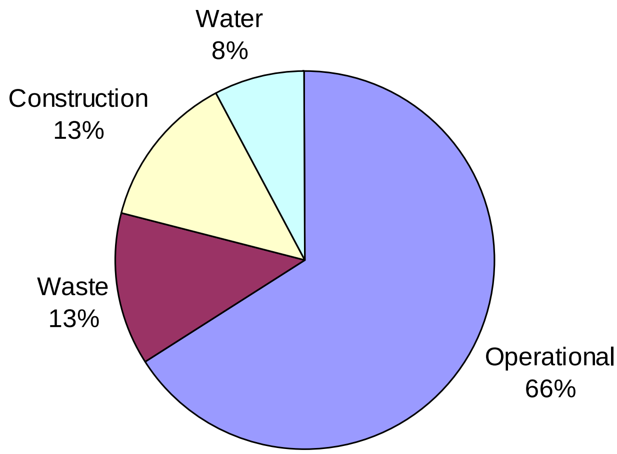


Figure 31: Average Distribution of Emissions averaged for the four climates using Design Builder and HEED (excludes transportation)

Energy used for heating and cooling is the biggest component of operational energy. Different graphs can be generated to express building performance as a function of CO_2 emissions from operational energy in different climates. Design strategies such as passive cooling and heating can be implemented in buildings to reduce these emissions.

Figure 32 shows energy use for heating and cooling in the different climate zones. Charts like these could help identify types of climates.

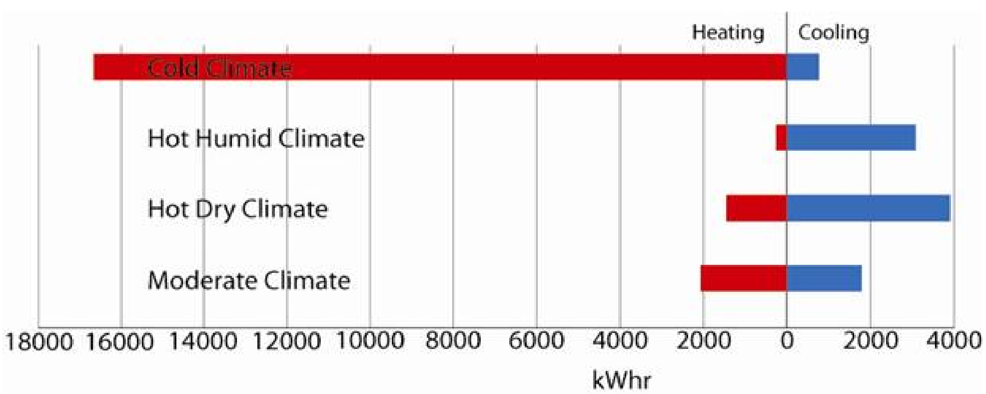
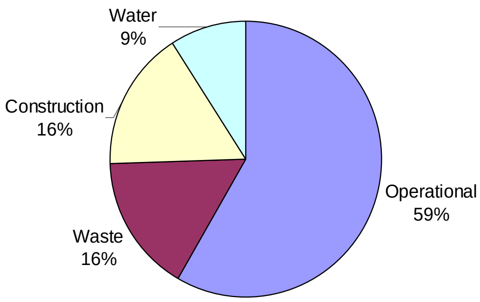
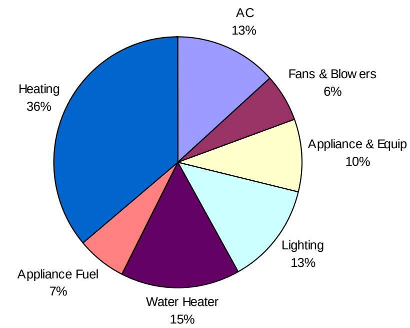
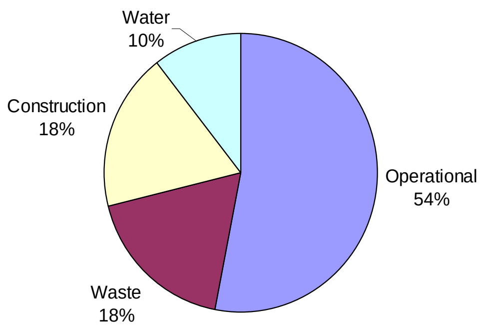
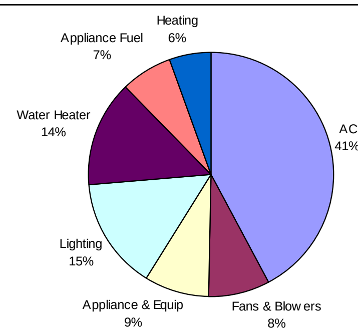
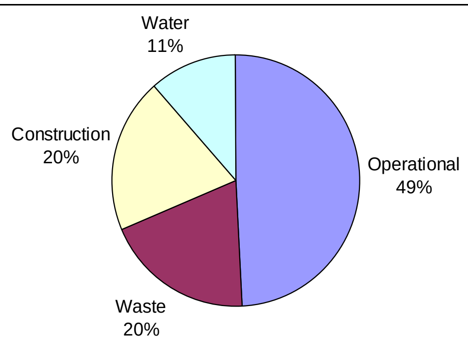
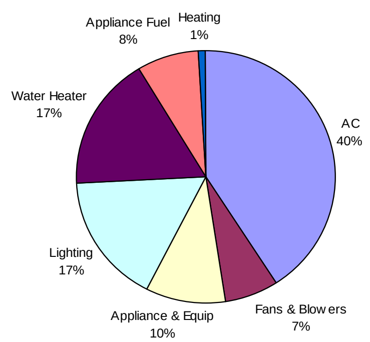
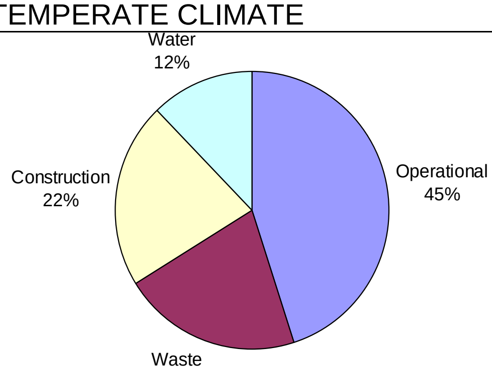
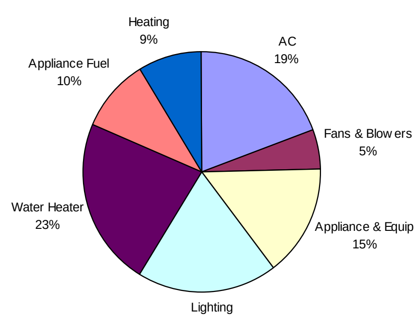


Figure 32: kWhrs from Heating and Cooling. Gas is used for heating and electricity for cooling.

Pie charts such as those presented in this paper can help define design strategies for specific climates. Depending of the distribution of the emissions in these charts, different strategies could be implemented to reduce these emissions. Table 6 includes the distribution of the emissions in the different climates. Operational energy constitutes the largest portion of the emissions in all climates and is most significant in the cold climate (59%) and least significant in the temperate climate (45%). The emissions from heating constitute the most significant factor in the cold (36%) climate while cooling is the most significant in the hot and dry climate (41%) and in the hot and humid (40%). In the temperate climate cooling and lights are the most significant, 19% each and appliances are significant sources.

TABLE 6: DISTRIBUTION OF EMISSIONS IN DIFFERENT CLIMATES

Emissions in Different Climates. Average with HEED and Design Builder.	Emissions from Operational Energy in Different Climates. Average with HEED and Design Builder.
COLD CLIMATE	
	
HOT AND DRY CLIMATE	
	
HOT AND HUMID CLIMATE	
	
TEMPERATE CLIMATE	
	

7. CONCLUSIONS AND RECOMMENDATIONS:

There are many carbon counting tools available but there is no single tool that permits to calculate all of the building related emissions. I propose a series of tools that can be used to determine emissions in residential buildings.

TABLE 6: RECOMMENDED TOOLS TO CALCULATE CARBON EMISSIONS IN RESIDENTIAL BUILDINGS

Carbon Emissions	Tool
OPERATIONAL ENERGY	HEED for quick analysis to determine energy use. Then multiply by appropriate conversion factors.
CONSTRUCTION	Build Carbon Neutral for quick analysis or Athena Eco Calculator for Assemblies for more detailed analysis
WATER	CO_2 factor per Million Gallons. For this analysis 1,331 lbs of CO2 per MG was used.
WASTE	EPA Personal Emissions Calculator (waste section) for simple analysis EPA WARM model for a more detailed analysis.
TRANSPORTATION	19.56 lbs of CO_2 per gallon of gas and 22 MPG. Number of miles driven per household per year must be proposed. There are other factors for public transportation that can be included to make the numbers more accurate.

8. REFERENCES

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(3) United Kingdom Department for Environment Food and Rural Affairs (DEFRA) fuel emission factors (July 2005)
(4) eGRID2006 Version 2.1 (April 2007) Summary Tables were used:
(5) B. Bordass, fr*om* Solar Cities: the Fundamental Documents. S Roaf and R Gupta. With contributions from Dr Bill Bordass, Chiel Boonstra, Catherine Bottrill and Robert Cohen. An outcome of the meetings of the Carbon Counting Working Group
(6) Bryan H., Trusty W., Developing an Operational and Material CO2 calculation protocol for buildings. SB08 Melbourne, Australia.
(7) http://buildcarbonneutral.org/
(8) personal emissions calculator at http://www.epa.gov/climatechange/emissions/ind_calculator.html
(9) http://www.energy.ca.gov/2007publications/CEC-999-2007-008/CEC-999-2007-008.PDF
(10) http://www.fueleconomy.gov/Feg/co2.shtml
(11) Milne, Murray. A Design Tool for Meeting the 2030 Challenge: Measuring CO2, Passive Performance, and Site Use Intensity. American Solar Energy Association Conference 2007, Cleveland, Ohio.

9. ACKNOWLEDGMENTS

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