CARBON COUNTING IN ARCHITECTURE: A COMPARISON OF SEVERAL TOOLS

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ABSTRACT

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. Obviously to reduce human impact on climate it is necessary to reduce building related anthropogenic warming and the first step in the emission reduction process is to be able to adequately count carbon emissions. Accurate carbon counting, including the initial phases of the design process will permit to quantify the impact of our design decisions in the project.

The objective of this paper was to compare carbon counting tools for 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 and disposing of water to and from the building, d) construction of the building and e) disposing of waste from the building. These tools were selected with the "ease of use" criteria.

These tools 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 while forty of these provided useful results in at least one of the areas mentioned. These tools are compared and and a more detailed analysis is done in the area of operational energy. Recommendations for tools in each of these areas are given at the end.

1.CARBON CALCULATING TOOLS

1.1. Types of Carbon Counting Tools

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

A building is directly responsible for the generation of CO2 by its operation, construction, providing and disposing of water, and disposing of waste (2). The building is also indirectly responsible for CO2 emissions due to transportation to and from the building. These were also included. Most carbon counting tools offer the possibility to determine emissions from energy use in buildings and from transportation. Fewer calculators can determine emissions due to water, waste or construction. A handful also offer the possibility to calculate the carbon impact from the food that we eat. Even though food could be a significant factor it was not considered because it cannot be modified by the designer.

1.2. Carbon Emissions from Buildings

Emissions from energy used to operate the buildings are usually the single largest contributor of CO2 emissions. These emissions can originate from 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 are available to calculate operational energy usually offer the most precision, because they estimate the energy use in a proposed building with energy modeling software, and it is also relatively easy to determine the energy actually used in an existing building.

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

Water provided to the building and coming out of the building usually generates CO2 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. These processes usually generate CO2 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 as methane from the landfills.

We must usually move to and from the building, and the method by which we do this generates CO2 in varying amounts. Location of the building close to public transit lines or in urban areas with higher density usually reduces the CO2 emissions.

2. COMPARING CO2 EMISSIONS FROM THE TOOLS

2.1. Comparing CO2 Emissions from Natural Gas and Electricity use in Buildings

The tools that were selected had different types of input and output screens, sometimes with different input requirements, so some assumptions had to be made. To compare the tools with each other the values in Table 1 were input in each of the tools. Not all of the tools provided results that could be compared between each other (e.g. planets) so only those that had the option to provide an accurate input and a usable result were compared. Table 2 shows these tools and what each can calculate. Gray rectangles indicate less precision.

TABLE 1: 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

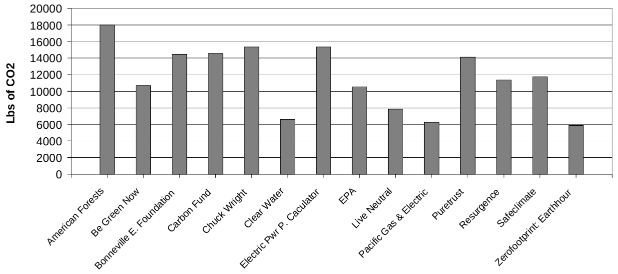


Figure 1: CO2 emissions due to electricity for 12,000 Kwh

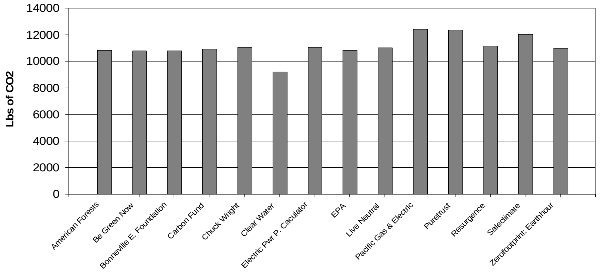


Figure 2: CO2 Emissions due to natural gas for 921 Therms

These carbon calculators gave different CO2 emissions (Fig 1 & 2), especially for electricity. Unfortunately these factors are not transparent in all calculators and it is not easy to determine the factor 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 CO2 per Therm, or 0.47 lbs CO2/kWhr, close to the value of.418 lbs of CO2 / kWhr proposed by DEFRA (3). For electricity the average value was 11,630 lbs of CO2 per 12,000 Khwr, or 0.97 lbs / Kwhr. As a reference, the Avg emission factor from Grid Electricity for 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 by the estimated or recorded electricity use in the building than to use one of these calculators.

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																				■

2.2. Comparing CO2 emissions in different climates

To further compare these tools a single family dwelling was analyzed in several climates. This dwelling was 48 by 24 ft, 2304 sq ft gross building floor area about the 2005 US average, and two-stories.

Carbon emissions were determined for four locations, characterized by the typical four climates: a) HOT AND DRY: California climate zone 15 (El Centro); COLD: California climate zone 16(Bishop); TEMPERATE: California climate zone 6 (Los Angeles); and HOT AND HUMID: Miami, Florida. Assumptions were made for each of the areas in which buildings emit carbon and are explained in the following sections.

2.2.1. Operational Energy

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

TABLE 3: 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 the building running. According to Bordass (5) the process to estimate CO2 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 factor*, to get the emissions associated with each fuel.
5. *Add them up* to obtain the annual total CO2 emissions.

To calculate the CO2 factors for each energy supply we must determine the emission factors for each one and there are several methods to determine these factors (6).

The EPA Power Profiler – calculates CO2 emission factors for historical yearly average emissions for every U.S. zip code.

The EPA eGRID – a database that has hourly CO2 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 CO2 e (equivalent) which includes other important GHG besides CO2, 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 CO2 emission factors for California.

2.2.2. Construction

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

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

The following input was provided to the calculator: 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 6,500 sq ft, and 1,500 sq ft installed. The total emissions were 53 metric tons or 116,812 lbs. We estimated the life of the building as 50 years, or 2,336 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 per year would be lower. The same number was used for the house in all four sites.

2.2.3 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 from the 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 dwellers of the home recycled (plastic, aluminum, newspapers, glass, magazines, etc.) This reduced the emissions from 1021 lbs of CO2 per year to 574 lbs of CO2 per year / person since we assumed a household of four we assumed this generated a value of 2,296 lbs of CO2 / dwelling / year from waste. This value was also assumed constant for homes in all locations.

2.2.4. Water

Water provided to the building and treated from the building is also responsible for CO2 emissions. The water that is used in the building must be pumped from the source, pass through treatment plants and then provided to the building. 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. We used these numbers to estimate the energy embedded in the water for a family of four in Southern California that would use 400 gallons of water per day. For Southern California the embedded energy per MG is 13,021 kWh. This means that to provide 146,000 gallons a year to a family of four in southern California would require 1,901 kWh. If every kWh of electricity in CA generates about 0.7 lbs of CO2 (4) then the average water use for a family of four generates about 1,331 lbs of C02. This number was used for all sites even though the number for southern California is higher than the number for Northern California and probably much higher than most of the United States.

2.2.5 Transportation

A building is also indirectly responsible for CO2 emissions from transportation because 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 usually reduces transportation related carbon emissions.

We assumed that each household drove a total of 15,000 miles / year in cars with 22 MPG efficiency. A factor of 19.5 lbs of CO2/Gal (10) was used. A total yearly value of 13,295 lbs of CO2 per year for transportation from the home was obtained. This value could be assigned to the home, to the workplace or divided between both. We assigned this value to the home. We did not include carbon emissions for air travel because these are not directly affected by the location of the residence.

3. DISCUSSION: RESULTS IN DIFFERENT CLIMATES

As previously explained, the CO2 emissions due to waste, transportation and construction were kept constant in the four cases in all climates. This permits an initial rough comparison of the sources between themselves in each climate. Table 4 presents the CO2 values that are used for waste, transportation, construction and water as previously calculated. Again, these would vary with location, but were assumed constant permitting a better comparison of the relationship between operational CO2 emissions and the rest of the sources, permitting to better compare the values from operational emissions with each other and thus better compare the effect of climate on carbon emissions.

TABLE 4: CO2 VALUES USED

Waste	2,296 lbs CO2
Transportation	13,295 lbs CO2
Construction	2,336 lbs CO2
Water	1,331 lbs CO2

3.1. Cold Climate

In the cold climate, the CO2 emissions from operational energy as determined by HEED are 15,005 lbs. The percentage distribution is expressed in Fig. 3.

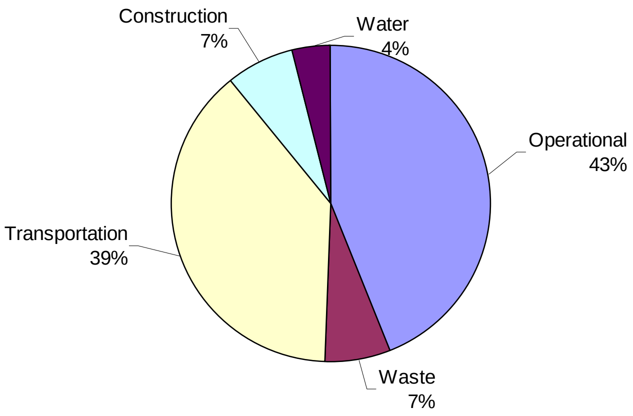


Figure 3: Distribution of Emissions in a Cold Climate

More detailed analysis was performed specifically for operational energy to determine the impact of the different areas: heating, AC, fans & blowers, appliances, water heaters, lighting. This analysis indicates that in the cold climate most of the emissions from operational energy are from heating (45%) plus an additional 7% for fans and blowers (Fig. 4).

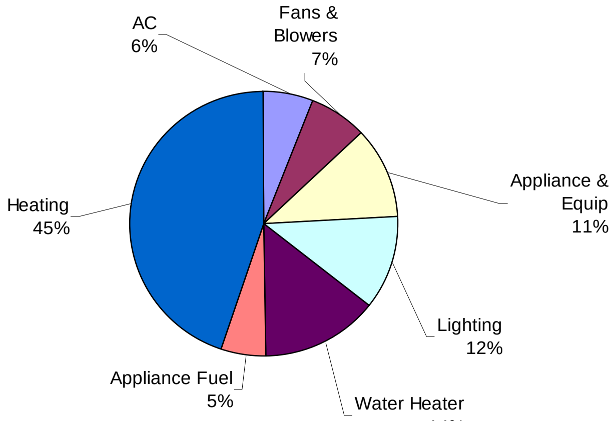


Figure 4: Operational Emissions in a Cold Climate

3.2. Temperate Climate.

In the temperate climate the CO2 emissions from operational energy as determined by HEED are 9,791 lbs of C02 and the percentage distribution is expressed in Fig. 5.

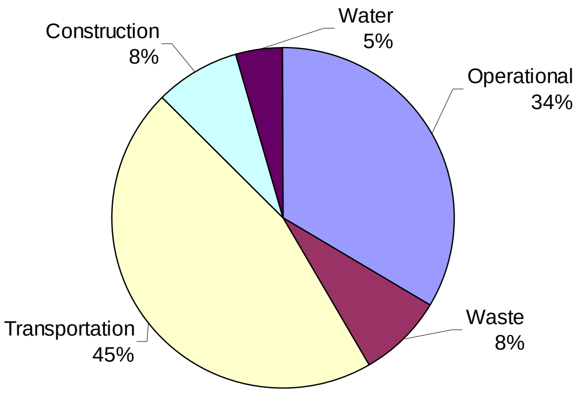


Figure 5: Distribution of Emissions in a Temperate Climate

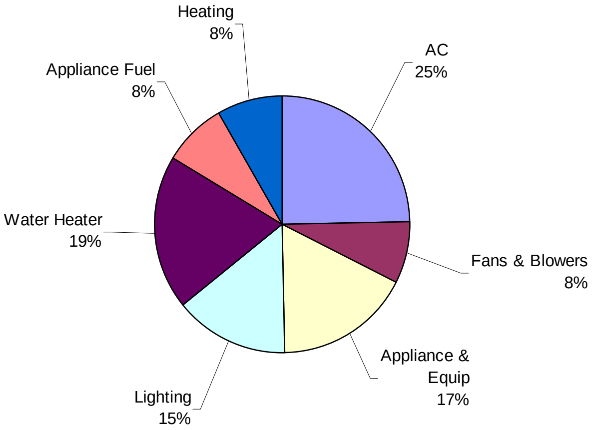


Figure 6: Operational Emissions in a Temperate Climate

Analysis of the operational emissions indicates that the emissions are more evenly distributed between all the operational energy sources (Fig 6).

3.3. Hot and Dry Climate

For a hot and dry climate the CO2 due to operational energy as determined by HEED is: 13,453 lbs of C02 and the percentage distribution is expressed in Fig. 7.

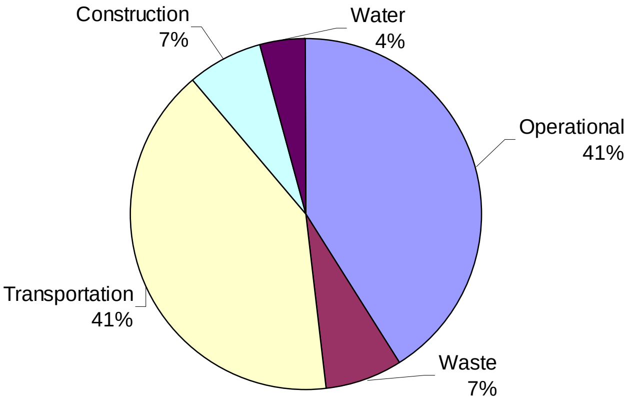


Figure 7: Distribution of Emissions in a Hot-Dry Climate

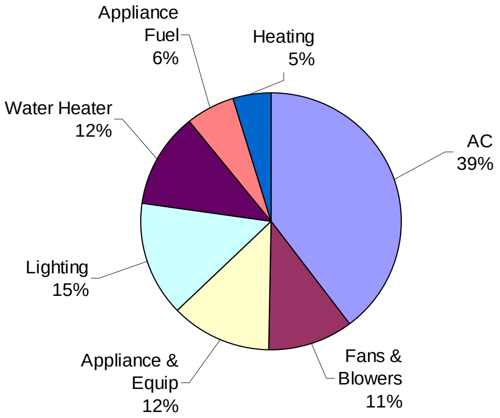


Figure 8: Operational Emissions in a Hot & Dry Climate

Analysis of the operational emissions indicates that in a hot and dry climate most of these (39%) are from cooling plus 11% for fans and blowers (Fig. 8).

3.4. Hot and Humid Climate

In a hot and humid climate the CO2 emissions from operational energy as determined by HEED are 11,528 lbs of C02 and the percentage distribution is as expressed in Figure 9.

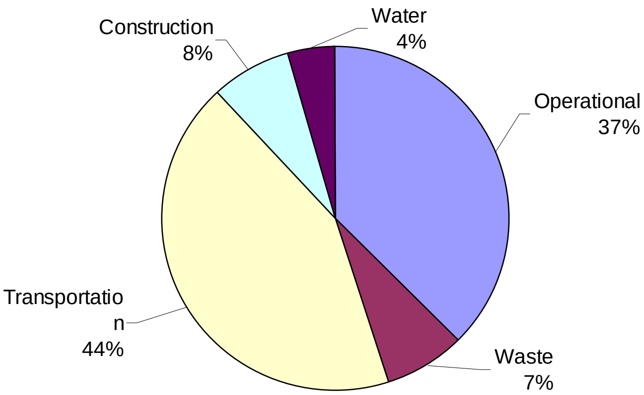


Figure 9: Distribution of Emissions in Hot & Humid Climate

Further analysis indicates that most of emissions from operational energy in a hot and dry climate (36%) are from cooling plus 9% for Fans and Blowers (Fig. 10).

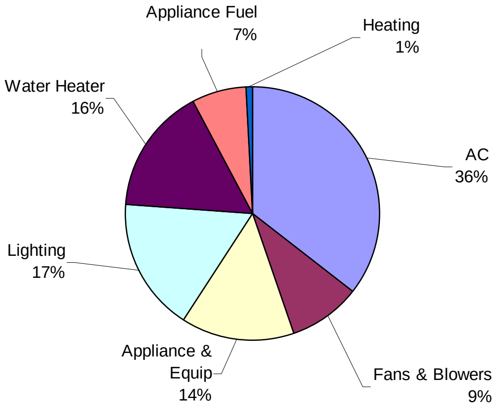


Figure 10: Distribution of Operational Emissions in a Hot & Humid Climate

4. DISCUSSION:

Results indicate that most of the carbon emissions in a building are 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.

If all sources are considered, including transportation, and are averaged in the four climate zones (Fig. 11) it is evident that transportation and operational energy are the two sources with the largest impact on emissions. The strategies that affect these two will have the most impact on emissions (e.g. location, energy).

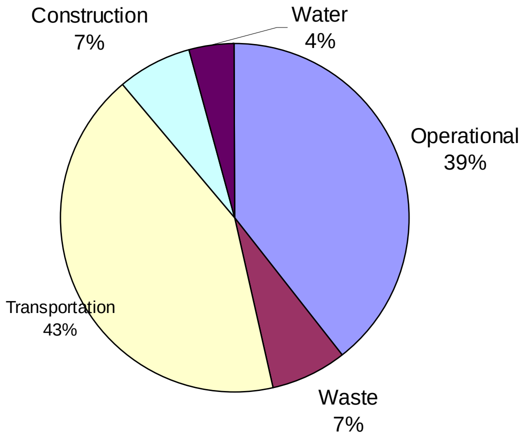


Figure 11: Distribution of Emissions including Transportation.

If however carbon emissions from transportation are considered as indirectly originated from the building then all of the directly related factors to the building have a larger impact, especially operational energy (Fig 12).

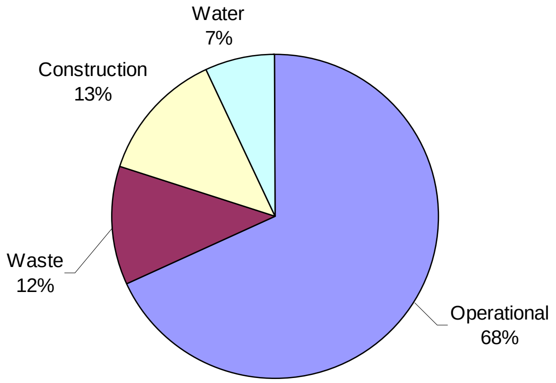
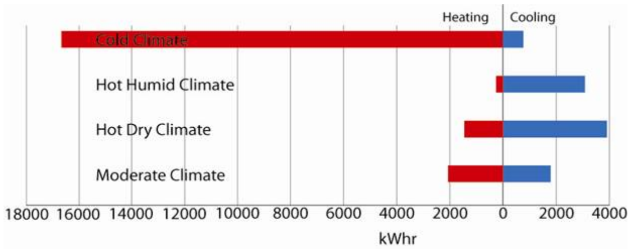


Figure 12: Distribution of Emissions excluding transportation.

Energy used for heating and cooling is the biggest component of operational energy. Simple diagrams or figures should be generated to express the CO2 performance of buildings in different climates. One such graph is shown in Figure 13 in which only the energy used for heating and cooling are expressed.

Figure 13: CO2 Emissions from Heating and Cooling



5. CONCLUSIONS:

There are many carbon counting tools available, most of these online, but there is no single tool that permits to calculate all of the building related emissions. We propose a series of tools that can be used to determine emissions for residential buildings (Table 5). The input for these tools can be totalled in a spreadsheet to obtain the final number. Further research should be done to develop a webpage that includes all the inputs and calculations of these tools in one site.

TABLE 5: RECOMMENDED CARBON COUNTING TOOLS FOR RESIDENTIAL BUILDINGS

Carbon Emissions	Tool
OPERATIONAL ENERGY	HEED Home Energy Efficient Design Provides separate results for heating, cooling, lights, appliances, fans and water heater. http://www2.aud.ucla.edu/energy-design-tools/
CONSTRUCTION	Build Carbon Neutral For simple rough analysis http://buildcarbonneutral.org/ or Athena Eco Calculator for Assemblies Provides a more detailed analysis but is not available for all regions http://www.athenasmi.org/tools/ecoCalculator/index.html
WATER	C02 factor per Million Gallons. For this analysis 1,331 lbs of CO2 / MG was used (Southern California Factor).
WASTE	EPA Personal Emissions Calculator (waste section) for simple analysis http://www.epa.gov/climatechange/emissions/ind_calculator.html EPA WARM model for a more detailed analysis. http://yosemite.epa.gov/oar/globalwarming.nsf/content/ActionsWasteWARM.html
TRANSPORTATION	19.56 lbs of CO2 per gallon of gas and 22 MPG. Number of miles per year must be determined.

It is also very important to establish relationships between carbon emissions and design strategies. Many different strategies affect carbon emissions (e.g. installing overhangs, adding insulation to the walls, using better windows, using passive solar strategies, living close to work, working at home, recycling). We should start quantifying the impact of design decisions on carbon emissions and think in these numbers

Pacala and Socolow (11) suggest that humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. A portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit atmospheric CO_2 to a trajectory that avoids a doubling of the preindustrial concentration. Although no element is a credible candidate for doing the entire job (or even half the job) by itself, the portfolio as a whole is large enough that not every element has to be used.

To keep the focus on technologies that have the potential to produce a material difference by 2054, they divide the stabilization triangle into seven equal “wedges.” A wedge represents an activity that reduces emissions to the atmosphere that starts at zero today and increases linearly until it accounts for 1 GtC/year of reduced carbon emissions in 50 years. It thus represents a cumulative total of 25 GtC of reduced emissions over 50 years. To “solve the carbon and climate problem over the next half-century” means to deploy the technologies and/or lifestyle changes necessary to fill all seven wedges of the stabilization triangle. A portion of the wedge Efficiency and Conservation” is to do “More efficient buildings”. There potential for reductions in all of the areas previously indicated contributing to reduce the “efficiency” wedge even more (Fig 13).

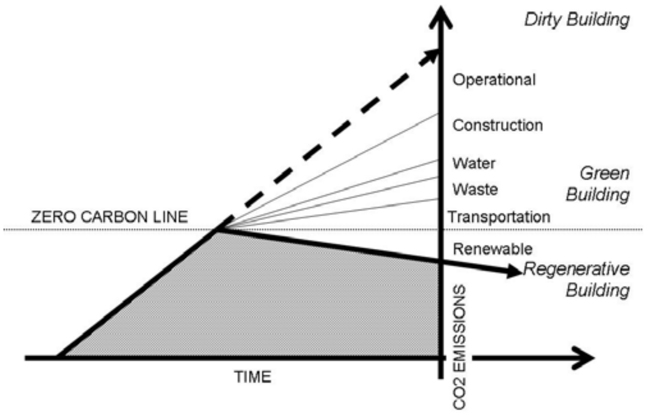


Figure 13: Potential for CO2 reductions in buildings

6. ACKNOWLEDGMENTS

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