The Future of Carbon Neutral Design

A Carbon Methodology for the Built Environment

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JULY 2019

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We're changing the way we think about energy use and greenhouse gas emissions

Atelier Ten is leading the design industry in developing an accurate methodology for predicting operational greenhouse gas (GHG) emissions. Building on our expertise in energy analysis we've created a process to make carbon-based recommendations at every stage of design.

We've always designed from first principles to reduce the amount of energy use on a project. And we've been getting smarter about when that energy is used. New availability in hourly GHG data have given us the opportunity to not only lead the industry in accuracy of GHG accounting for our projects, but also evaluate design options to go beyond net zero energy (NZE) towards true carbon neutrality.

As our buildings and our electric grids integrate increasing amounts of renewable energy, our projects must move beyond simply reducing annual energy demand – they must become nimble in response to a variable supply of renewable energy. We must consider when a building uses energy and how the grid uses that energy in the real world, so we can align our energy demand with renewable energy supply. We must determine the smartest ways to meet our buildings' energy demand through on-site renewable energy production, short term and long-term energy storage and smart controls to manipulate time of use for energy resources both on- and off-site. To accomplish all this, we must understand each building's operational carbon emissions in detail.

Our team is dedicated to making a positive change in low carbon design. We are sharing our carbon calculation methodology with the larger community of designers and energy analysts, in the hopes that our industry can quickly tackle the critical issue of operational carbon emissions. Interested? Read on to learn more.

The Future of Carbon Neutral Design

GETTING TO ZERO: DESIGNING FOR CARBON NEUTRALITY

In recent years 'Net Zero Energy' (NZE) or 'Zero Energy Building' (ZEB) has been the benchmark for high performance buildings. However, Net Zero Energy is not synonymous with carbon neutrality. A 'Net Zero Energy' project may not necessarily be 'carbon neutral' due to variation in time of use and where in the grid it is located. Take the example of a net zero energy building in California with on-site photovoltaics: the building is likely to be sending electricity to the grid in the middle of the day when grid GHG emissions are low and pulling electricity from the grid in the evenings when grid GHG emissions are high. While the net electricity being sent to the grid and pulled from the grid is equal, the GHG footprint of this electricity is not.

Figures 1 and 2 show annual electricity use of a typical commercial building (Figure 1) and hourly electric grid GHG emissions (Figure 2). It is evident from the two graphs below that the highest building demand may align with the time of highest grid emissions. The ability to shift time of use is critical to controlling a building's demand on the grid and enabling it to respond to favorable grid conditions.

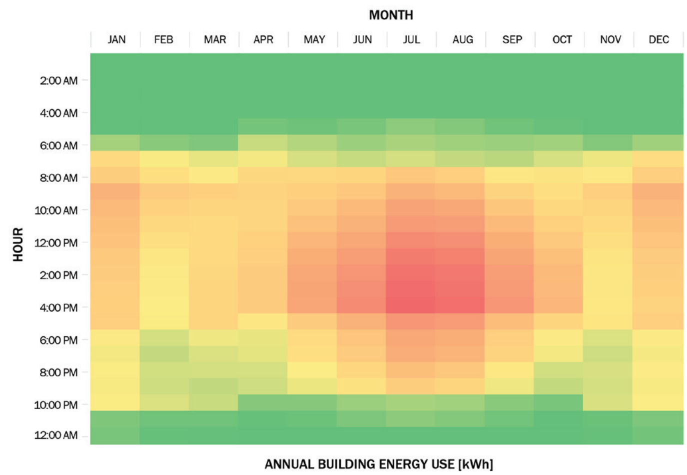

Figure 1: Commercial Building Energy Use using typical daily profiles, kWh electricity

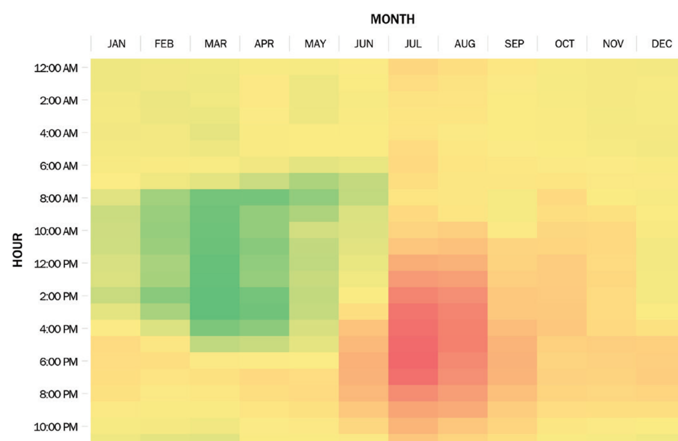

Figure 2: Marginal Greenhouse Gas Emissions Profile for CAISO, Source: WattTime: relative CO_2lbs/kWh electricity

We propose a fundamental shift in the way that we calculate GHG emissions for our buildings. The following steps should be followed to integrate hourly GHG emissions data into predictive energy analysis during the design phase.

1. Use hourly energy demand and GHG emissions data, rather than annual values
2. Identify the appropriate grid region
3. Select the appropriate GHG metric (average vs. marginal)
4. Translate historic grid emissions data into hourly emissions profiles
5. Combine the emissions profile with energy analysis results

These are outlined in detail in the following sections and the appendix of this document.

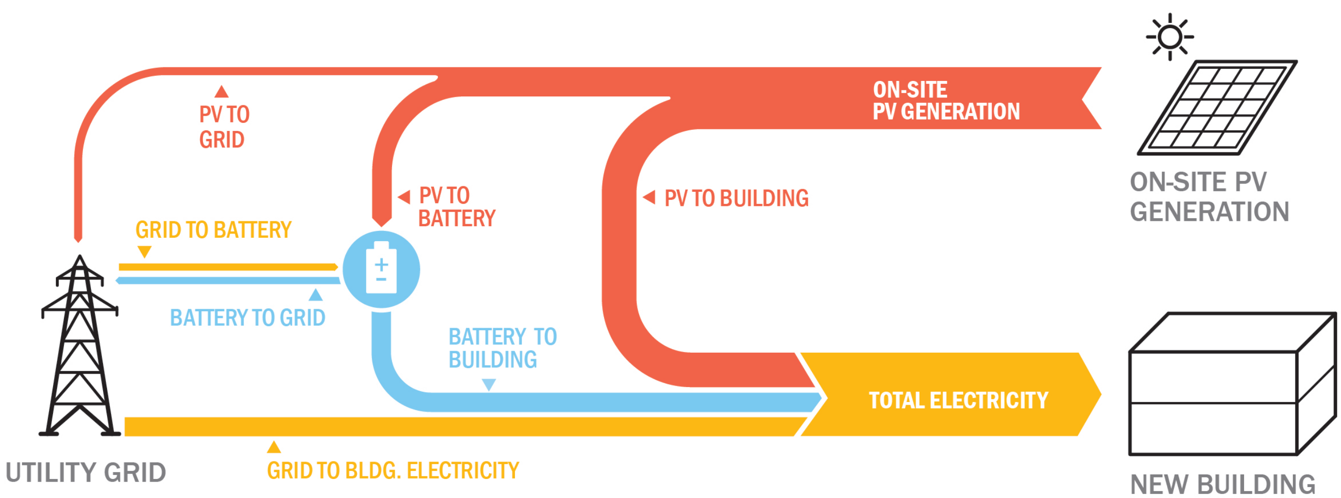

Figure 3: Summary diagram of annual GHG emissions derived from hourly GHG grid emission data

WHY HOURLY DATA MATTERS

Atelier Ten has developed, in conjunction with support from WattTime, a methodology that accurately quantifies operational greenhouse gas emissions by using hourly emissions data to account for variations in the "cleanliness" of the grid throughout the year. Atelier Ten's approach to estimate the GHG impact of a building uses scientifically sound, peer-reviewed emissions data that accurately reflects grid operation. This emissions data is combined with hourly data from an energy model and the results enable design teams to make emissions-driven design decisions on energy efficiency measures, fuel source, and time of use.

Traditional GHG emissions data from local utilities and eGrid averages are insufficient to accurately predict operational GHG emissions, because they all use a single emissions factor to represent emissions over the course of a year. Any carbon analysis completed with this data does not consider the constant variability in GHG emissions of a given grid region, and therefore should not be used in carbon-based design decisions.

The difference between simplified local utility data and hourly grid-emissions data can be significant. Figure 4 highlights the differences in predicted GHG emissions for three project typologies in different climate zones around the US. In some cases, the results using single emissions factors varies by as much as 60-70% when compared against results which use detailed hourly emissions data. The table highlights the importance of using the most accurate and granular GHG emissions data available.

	Lab	Office	Residential
Los Angeles	-64%	49%	-64%
Austin	-6%	-7%	-6%
Oshkosh	16%	15%	15%
Minneapolis	-14%	-15%	-14%
Boston	28%	27%	27%
NYC	26%	24%	25%
Long Island	60%	59%	59%
Syracuse	-59%	15%	-61%
Chicago	30%	30%	30%
St. Louis	-68%	-70%	-69%
Lexington	27%	27%	27%
Philadelphia	-8%	-8%	-8%

Figure 4: Percentage of variation between GHG emissions calculated using eGrid data vs hourly marginal emissions data

Hourly calculated shows less than +/- 25% deviation

Hourly calculated shows +/- 25% - 50% deviation

Hourly calculated shows +/- 50% deviation or more

IDENTIFYING THE APPROPRIATE GRID REGION

The electric grid in the United States is comprised of different regions where each region is regulated by a 'balancing authority.' The balancing authority manages electricity within each region and between neighboring regions to maintain a balanced supply and demand. This balance is maintained by turning on or off energy generating power plants or by exporting or importing electricity with neighboring grid regions. Because the grid is drawing from different fuel sources at various times, the generation mix and associated GHG emissions of each grid region are constantly in flux.

The balancing authority grid region is used as the basis of this methodology because it is representative of how the grid is controlled and managed. The largest balancing authorities are called Independent Services Operators and Regional Transmission Organizations (ISOs/RTOs). A map of WattTime's marginal emissions coverage can be seen in Figure 5. The design team should use the most granular, reliable hourly GHG data available for the project's grid region.

Marginal vs Average Emissions: Selecting the right metric

Once the grid region is determined, accurate hourly GHG emissions data for that region should be referenced. This paper addresses two ways to measure hourly GHG emissions: Average Emissions and Marginal Emissions. Marginal Emissions should be used to evaluate design decisions and in carbon neutral calculations.

AVERAGE HOURLY EMISSIONS

The average emissions of any electric grid region are the cumulative emissions of all generators on the grid divided by the total electricity generation on the grid for each hour. This creates an emission rate per unit of electricity consumed that reflects the distribution of all energy generated. While this emission rate is based on real-world grid conditions and can be used for GHG accounting, it does not reflect the impact that changes to electricity consumption have on the grid.

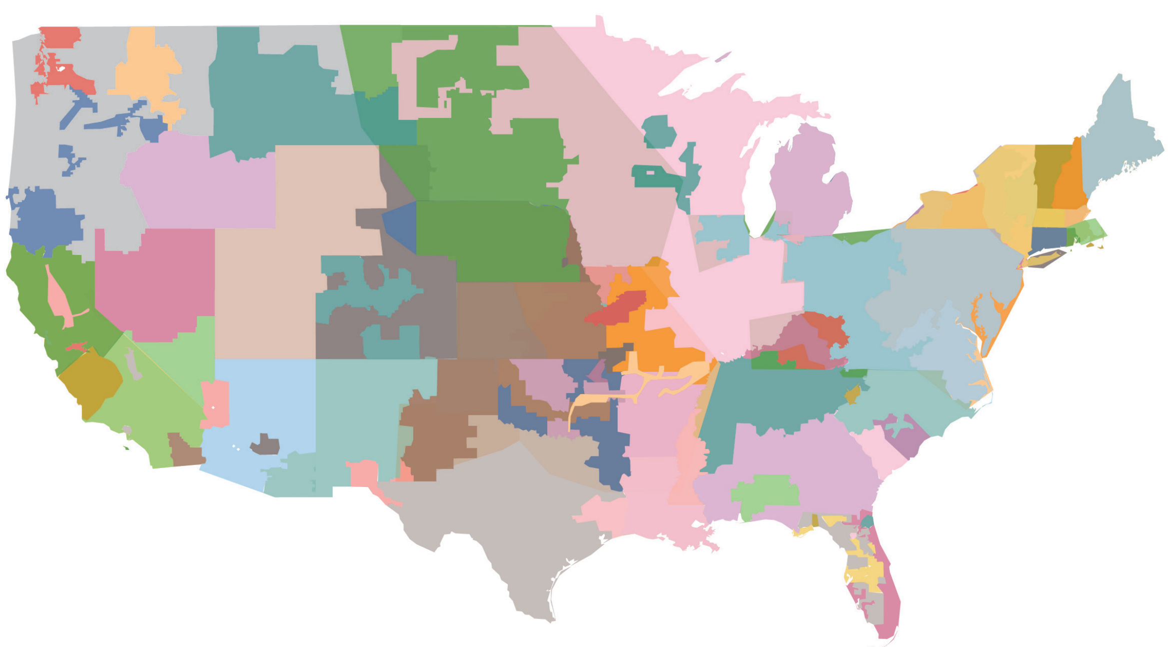

Figure 5: Marginal carbon emissions coverage: Retail and wholesale electric power markets. Source: WattTime

MARGINAL HOURLY EMISSIONS

Adding an additional unit of electrical demand or supply to a power grid at a specific place and time changes the load on the power plants that produce electricity at that time, otherwise known as the marginal power plant(s). The specific properties of the marginal power plant(s), including efficiency and fuel type, determine the magnitude of the emissions of that plant. Because marginal plants vary greatly by both time and location, changing demand on the electric grid has significantly different reductions in emissions depending on the siting and timing of the change in demand.

An example of this can be seen in Figure 6. This diagram illustrates changing grid conditions and emissions throughout the day. For example, the cleanest period on the graph shows a time when renewable generation exceeds the total load on the grid. During this time renewables are being curtailed, so additional load added to the grid will have low or zero GHG emissions.

The dirtiest period shows a time when renewable production is low and net fossil generation is high to meet the additional demand. During this time the grid operator is either bringing on additional dirtier fossil fuel plants or importing electricity from neighboring grids so load added to the grid at this time will have the highest GHG emissions. The dirtiest period does not necessarily align with the highest total load, as can be seen in the chart.

Because the marginal unit responds to changes in load, the marginal emissions rate should be used to define the building baseline and assess all decisions that affect electricity demand including fuel switching, building scale battery operation, load shifting, renewable contribution, and efficiency strategies.

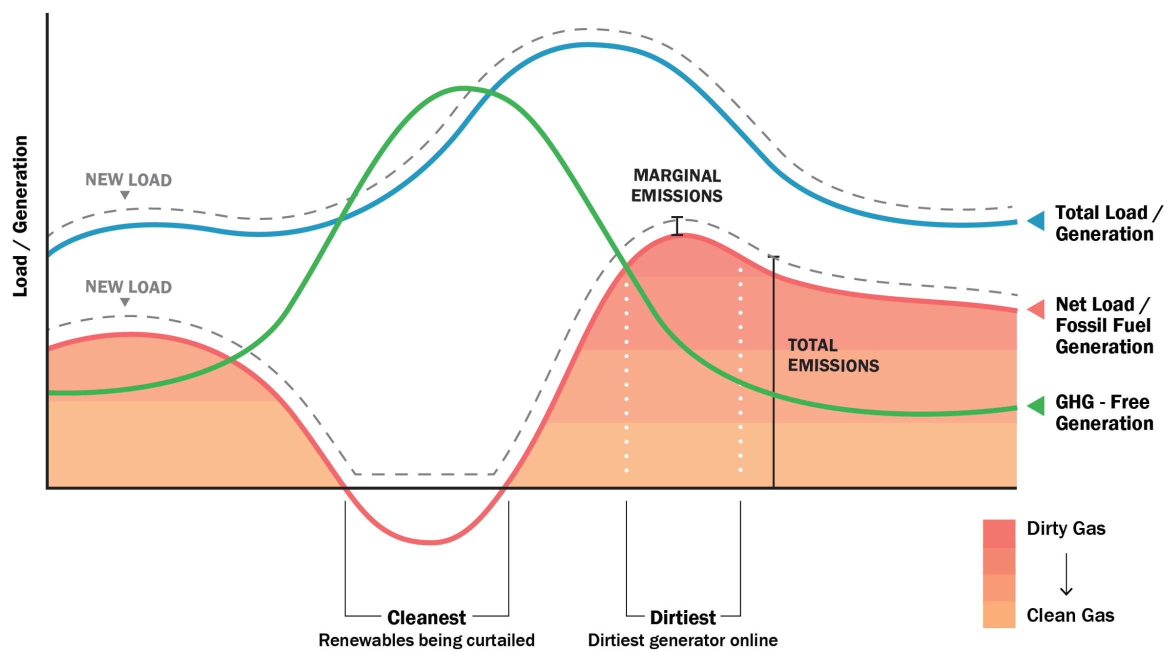

Figure 6: Net Load: Variability in cleanliness of marginal emissions

DEVELOPING AN HOURLY EMISSIONS PROFILE

Historic grid emissions data should be translated to hourly typical marginal emissions profiles that can be applied to whole building energy model results. Figure 7 shows the marginal emissions profile within the California Independent System Operator (CAISO) region. Red indicates relatively high GHG emission while green indicates relatively low GHG emissions. The process for developing this profile is described in detail in the Appendix.

APPLYING HOURLY EMISSIONS PROFILES TO ENERGY ANALYSIS

Building-related GHG emissions from electricity are calculated by multiplying predicted hourly electricity consumption by the marginal GHG emissions rate for each hour. The emissions from other fuels can be determined using standard emissions rates by fuel type. Atelier Ten used the marginal annual hourly emissions profiles to create a GHG Emissions Assessment Tool which is used in conjunction with whole building energy model data to predict the GHG emissions of a project, compare design options and establish a path to carbon neutrality.

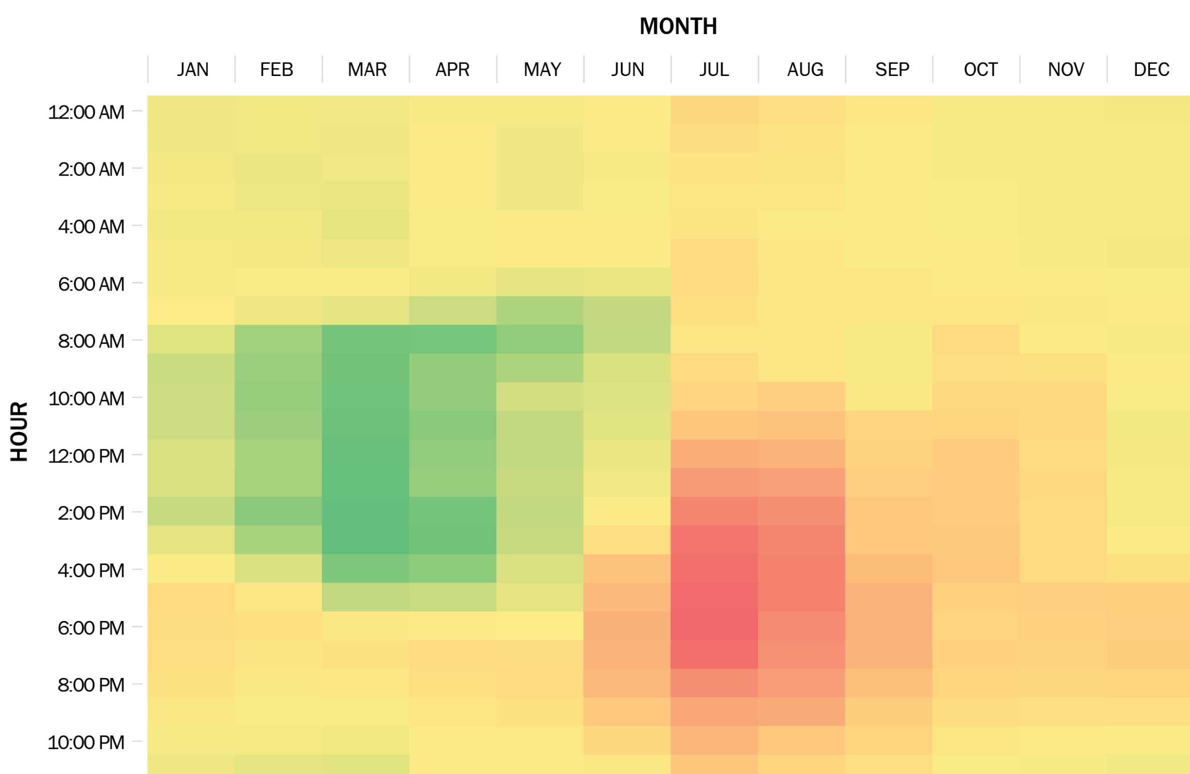

Figure 7: Marginal Greenhouse Gas Emissions Profile for CAISO, Source: WattTime: relative CO_2lbs/kWh electricity

CONCLUSION

The methodology of using hourly data to predict operational GHG emissions can be adopted by codes, standards, and rating systems to ensure consistency across carbon calculations and move from cost or energy-based metrics to carbon metrics. The discussion on how to apply average vs marginal GHG emission to early stage energy analysis is evolving. While it is possible that a different consensus may emerge regarding the use of marginal emissions data to baseline building GHG emissions, marginal emissions are the appropriate metric for any change in demand on the grid. As such, we believe that marginal emissions are appropriate for both comparing efficiency measures as well as for calculating the emissions associated with bringing a new building online.

This paper focuses on the development of an accurate methodology for operational GHG emissions and the process that can be used by project teams to make carbon-smart design decisions. However, operational GHG emissions are just one component of a building's carbon footprint. In order to continue to address the urgency of global greenhouse gas reductions, the design community must also focus on minimizing embodied carbon and making smart decisions about refrigerant use in buildings.

CONTRIBUTORS

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Appendix: Creating and Applying Annual Emissions Profiles

HOURLY GHG EMISSIONS PROFILES & METHODOLOGY

The GHG emissions profiles are based on an average of data from the previous three years. Using data across a three-year time period reduces the impact of natural climate and weather variations that may affect energy generation. The three-year timeframe aligns with the duration of building code cycles (i.e. California Title 24, Part 6 and ASHRAE 90.1) and ensures that regular updates capture ongoing changes to the grid such as increasing renewable energy penetration. To accommodate seasonal, weekly, and hourly variation, sub-hourly emissions data were used to create typical weekday and weekend/holiday hourly profiles for each month. These typical daily weekday and weekend profiles are expanded into an annual hourly profile.

Creating annual hourly typical marginal emissions profiles that can be applied to energy model results requires a two-step process. First, for each grid location, historical marginal emissions data is processed into reference tables organized by month and hour. Second, these standardized tables are expanded into annual hourly profiles based on energy model settings.

Detailed Methodology Description

GENERATE REFERENCE TYPICAL EMISSIONS LOOKUP TABLE

- Using three years of marginal emissions rate data, tag each datapoint with date, month, day of week, hour of day, and holiday
- Create a summary table with a row for each hour of the day and two columns for each month one for each weekday and weekend
- Populate the table by averaging the historical marginal emissions data for each hour of each month, distinguishing between weekdays and weekends/holidays

CONVERT TO HOURLY ANNUAL PROFILE

- Based on year used for the energy model simulation, determine which day of the week the year starts on and any national holidays.
- Create annual hourly timestamps with month, day, and weekday and weekend/holiday tags. Omit leap days.
- Using the reference table, match the timestamp tags with the reference table to determine the representative marginal emissions in each hour.

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