ASHRAE Workshop on Forecasting Carbon Emissions from Buildings
April 18, 2007
Washington, DC

INTRODUCTION

On April 18, 2007, ASHRAE convened a workshop of experts in various fields related to estimating the carbon emissions impact of buildings in the design phase. Participants in the workshop were:

- Hal Levin, Building Ecology Research Group (Committee Chair)
- Harvey Sachs, ACEEE (Committee Vice Chair)
- Art Diem, US EPA (carbon emissions)
- Brendan Owens, U.S. Green Building Council (sustainability)
- Costas A. Balaras, National Observatory of Athens (*EHC Consultant*)
- Dave Godwin, US EPA (carbon emissions)
- Doug Reindl, University of Wisconsin-Madison (Committee Member)
- Ezra Hausman and Alice Napoleon, Synapse Energy Economics (Electricity markets, avoided emissions)
- Jeff Haberl, Texas A&M University (carbon and criteria pollutant emissions, by phone)
- Katie Coughlin, Lawrence Berkeley National Laboratories (by phone)
- Michael Deru, NREL
- Snuller Price, E3, Inc.

The Agenda for the conference is included as Appendix A to this report. Presentations are included as Appendix B.

The ultimate goal of the process initiated through this workshop is to design a tool with which heating, cooling and ventilation engineers could estimate the carbon ”footprint” of a building during the design phase, so that decisions could be made which would improve building performance and reduce greenhouse gas (GHG) emissions, as well as energy costs, over the lifetime of the facility. Residential, commercial, and industrial buildings represent roughly one third of total global greenhouse gas emissions; improved energy design may be able to reduce the contribution of new buildings by 50 - 80% over the next few decades.[2]

The short term goal of the April 18 workshop was to begin to identify the key questions and uncertainties that must be addressed in designing and producing such tools, and to begin to identify the steps and resources that will be required to make a more advanced tool a reality.

As summarized by committee vice-chair Harvey Sachs, the overall goals of the tool from ASHRAE’s perspective would be as follows:

- To enable meaningful carbon accounting for the energy side of the building industry;
- To provide building architects and designers with predictive information and benchmarks regarding lifetime GHG emissions;
- To provide guidance in for designers in reducing the carbon footprint of new buildings;

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[2] For example, see the New Buildings Institute webpage on “Getting to 50” at http://www.newbuildings.org/gtf/index.htm.

- To “move HVAC designers up the feeding chain” so that they would be involved in designing energy efficiency into structures from the beginning of the design process;
- To provide simplicity and accuracy in the energy use and emissions estimation process, but to avoid “wild goose chases” where additional accuracy or precision is not possible or not useful.

An additional application for the tool suggested by meeting participants was to facilitate carbon emissions tracking under a future cap and trade system of carbon regulation.

The goal of the current report is to document the discussion and views presented at the workshop, to identify unanswered questions and areas for future research, and to serve as a guide to what are likely to be the most fruitful research topics in this area.

Definition of the problem

Before a tool for estimating carbon emissions can be defined, the scope of the problem has to be defined. A number of scoping decisions were stipulated at the outset of the workshop:

- The initial focus will be on emissions associated with operational energy use in buildings, rather than on “embodied emissions” associated with the construction of the building.
- Pre-consumption carbon emissions associated with delivering non-electric energy to the building will not be considered.
- Only carbon, methane, and nitrous oxide emissions associated with the energy consumed in the building will be considered; emissions of other Greenhouse Gases (GHGs) associated with, for example, leakage of refrigerants, will not be considered.
- Emissions associated with delivery of water to, and removal of sewage from, the building will not be considered. This area may be significant, however, and it was identified as a topic for future research.
- For emissions associated with electric energy, it was left open whether to consider only fuel combustion-associated emissions, or to include emissions associated with production and transport of fuel to power plants. It may be that for the purpose of the current effort, national average correction factors could be used for this purpose.

It was also agreed that the primary goal of the analytical tool under consideration is to assist in making design decisions, and to assist engineers in assessing the impact of specific design decisions on the future carbon footprint of individual buildings. Because of the inherent uncertainties presented by future uses of any building (discussed below), it will never be possible to predict with confidence the carbon emissions footprint of any structure. However, it should be possible to quantify relative impacts of design decisions on the overall GHG footprint, given a set of agreed-upon conditions, so that the costs and benefits of such decisions can be assessed.

A number of issues were raised and discussed related to tool characteristics, which were not answerable at this early stage. One key question was the degree of time resolution that should be used in representing building energy use and associated emissions. The participants were in general agreement on the advantages of having a high degree of time resolution. This could be based on simulated hourly building operations coupled with an hourly electricity dispatch model, or could be based on Time of Use (TOU) operations, which differentiate between on-peak and off-peak hours during the week and weekdays vs. weekends, as well as representing seasonal variations.

One important benefit of analyzing buildings with fine temporal resolution (or a proxy such as time of use) is that it allows the engineer explicitly to model technologies that shift loads, such as thermal storage, controls, and on-site energy generation. Thermal storage can be specifically included in a building design in order to increase the efficiency of heating and chilling or to take advantage of lower energy prices during off-peak periods. Even without this kind of dedicated infrastructure, however, all buildings have some thermal storage associated with the thermal mass of the building itself. One aspect of zero energy buildings is on-site electricity generation. We need hourly or TOU emissions profiles to understand what impact the on-site generation has on emissions. Controls can be used to limit demand or shift loads and may increase or decrease emissions. To the extent that engineers can simulate this impact, they can take these issues into consideration in HVAC design and in assessing the emissions impact of the building.

The participants also agreed that the hourly reconciling of a building's energy use and associated GHG emissions requires that the regional weather data and the historic power plant emissions data be synchronized. Such weather data must include temperature, humidity, wind speed and direction, and potentially other data.

However, participants noted that modeling this level of temporal resolution adds a significant level of complexity to the problem, and also substantially increases the types of uncertainty that have to be accommodated. It is extremely difficult to project hourly variations in electric system emissions characteristics into the future, and data from a single historic year are unlikely to be representative of the range of hourly variations a building is likely to encounter over its lifetime. Finally, as thermal storage mostly impacts the time of energy use and only secondarily the quantity, it would be particularly difficult to quantify the future emissions impact of this kind of application based on an unknown future generation mix. As a compromise, it was decided that the working concept for a future version of the tool would include TOU resolution.

The question of setting reasonable goals for a forecasting tool was posed early in the discussion. This was related to the many sources of uncertainty presented by making such forecasts. Some of these sources of uncertainty may be mitigated through future research, but some are inherent in predicting the future. Inherent sources of uncertainty include:

- How will the future uses of the building differ from that envisioned in the design phase? The carbon footprint of the building will be highly sensitive to both the types of use and the density of occupancy, neither of which can be known with certainty in advance.
- How efficiently building operations will be executed over the life of the building.
- The future carbon footprint of a building will depend on the nature of electricity generating sources in the future. If regional electricity is produced with lower per-MW emissions of carbon in the future, this will lower the overall benefit of building energy efficiency in terms of reduced carbon emissions.
- Uncertainty associated with future energy and carbon policy—for example, if carbon is regulated under a cap-and-trade system, increases in efficiency for a given structure may lead to economic benefits but to no net reduction in overall carbon emissions.

Perhaps the most significant overall source of uncertainty in total carbon emissions associated with a building is the first of these, because the total energy use over the building's lifetime is heavily dependent on the uses to which it is put. However, this still leaves room for assessment of the *relative* impact of design decisions on the building's footprint, holding assumptions about future uses constant. Assessment tools in use today are not even capable of this level of analysis; models such as DOE-2 and EnergyPlus are not designed for quick consideration of design alternatives, and generally are complex enough to require specialists to apply them.

With respect to uncertainties that can be addressed through research, the following areas were identified as amenable to more precise quantification with some effort:

- Current and near-term sources of electricity serving a given region, and the emissions characteristics of those resources;

- Fuel lifecycle emissions for both electricity production and direct fuel use, including emissions associated with fuel production and transport prior to electricity production at the power plant;
- Forecasting of future generation stock that will serve the building, or that may be avoided through increased building energy efficiency.

Both areas of uncertainty (inherent and rectifiable) may be expected to grow as projections are made further into the future. While it is important to recognize the limits on the accuracy and precision of the tool can be over any given time horizon, it is also important to provide a meaningful and useful analytical basis for making assessments in the face of this uncertainty. One solution, presented and widely supported at the workshop, is to base emissions calculation on a single base year. This would minimize uncertainty by limiting the analysis to known conditions, and these results can then be projected into the future taking into account known future modifications to the regional power plant mix. This is similar to the approach used in formulating State Implementation Plans (SIPs) under the EPA Acid Rain program. While the accuracy of forecasts based on this approach is open to question, it would at least offer some quantifiable basis for comparison of design alternatives. This is a key organizing principle for the tool design.

However, even calculating emissions impacts based on a single base year raises questions that were noted by several workshop participants. These include:

- How often should base year information be updated?
- Different regions show a different amount of interannual variability in emissions. For example, average carbon emissions associated with electricity generation in the western US are heavily influenced by the availability of hydropower, which can very a great deal from year to year.
- Climate change is itself a reason to expect non-stationarity in conditions, because of long-term trends in water availability, because of future policy changes affecting the generation mix, and perhaps for other reasons.
- Weather normalization would be important in ensuring that the base-year characteristics were reasonably reflective of "normal" conditions. Weather affects dispatch order and marginal units, hydropower availability, and wind power availability. However, in order to implement any form of weather normalization, data sources for weather and other variables have to be clearly and correctly associated with each other on an hour-by-hour basis.
- Relative fuel prices vary from year-to-year and may be expected to affect generating unit dispatch order, and therefore marginal carbon emissions rates.

Even if the future energy use of a facility were known with precision, it would still be an analytical challenge to forecast what the carbon emissions associated with that energy use would be over the life of the facility.

Several meeting participants gave presentations on concepts and technologies for estimating the emissions impact of decreasing energy use through building energy efficiency. Summaries of these presentations are as follows; the PowerPoint presentations are included as Appendix B.

Jeff Haberl on eCalc

Jeff described eCalc, a program developed at Texas A&M University for the US EPA that can tie simulated hourly building electricity use to annual or Ozone Season Day (OSD) emissions in specific geographic locations in Texas during a defined base year.. The program is based on EPA's eGrid database, which is in turn based on the Emissions Tracking System (ETS) data from the EPA Acid Rain program. eGrid provides annual values for heat input and emissions, by boiler, for most of the fossil-powered electricity generating plants in the country. The examples shown at the workshop were all for reductions in NOx emissions; however, the model also provides coverage for other pollutants, including CO_2.

eCalc identifies the specific resources owned by each utility in the ERCOT region to identify the power “source” serving each location. The advantage of this approach is that it provides a precise, quantitative way of associating emissions with energy use such that the total emissions for the entire state would be attributable. The disadvantage is that it uses a specific set of assumptions about power flow on the grid in lieu of a dispatch model. In reality, power flows and load-following resources are not constrained by which resources are owned by which companies, and the loads that these companies serve.

Art Diem on eGrid and Power Profiler

eGRID is a data resource, developed by the EPA, which provides regional annual average emission rate data by eGRID subregion, specifically tailored for use in the EPA analytical tools. These tools include:

- Power Profiler
- Personal GHG emission calculator
- Climate leaders (based on year 2000 eGRID data)—used to calculate indirect emissions from purchases and sales of electricity and steam

eGrid is compiled from various federal databases, including the Emissions Tracking System (ETS) database of hourly emissions. To the extent that the ETS data are incomplete, fillers are used based on reported fuel use. Biomass resources are considered to have zero CO_2 emissions, and combined heat and power (CHP) resource emissions are adjusted to attribute some of the emissions to the steam load instead of to electricity production. The data include only smokestack emissions, not taking any fuel processing or transport emissions into account.

The database also provides annual average non-baseload emission rates, which may better characterize the emissions of load-following resources.

Michael Deru on Source Energy and Emission Factors for Building Energy Use

Michael reported on ongoing work at NREL to “create standard energy and emission factors based on fuel life cycles”. In contrast to much of the other work presented at the workshop, this effort explicitly takes into account the emissions associated with production, handling and transport of fuels to the power plant and/or building. NREL is producing a Life Cycle Inventory (LCI) database, which includes emissions associated with the mining, processing, and transporting of fuels such as natural gas and coal. However, these emissions components remain difficult to establish due to the great variability in distances and other factors associated with fuel production and transport.

For application to end uses, the analysis also takes into account transmission and distribution losses associated with the electric grid. Emissions associated with fuel combustion are taken from the EPA Air-42 and GREET databases.

According to this analysis precombustion energy use comprises between 5% and 12% of total energy use, depending on the region under consideration. Also presented was the percentage of emissions of different pollutants associated with precombustion activities. For methane, precombustion emissions are close to 100% of the total emissions.

Ezra Hausman and Alice Napoleon on Calculating Avoided Emissions

The Synapse team discussed some of the issues that must be taken into consideration in calculating avoided emissions associated with energy efficiency programs. These include:

- Time horizon—short term (dispatch margin timescale) vs. long-term (build margin timescale.)

- Loading order of power plants—avoided emissions are generally associated with the marginal resource type, especially over shorter timescales.

Synapse showed data to demonstrate that the relationship between loading order and marginal emissions rate is often quite complex. However, they also showed that the emissions rate as a function of system load can be well approximated by a linear function, and that this can be further refined by limiting the hours considered by season and perhaps by other factors.

Snuller Price on Modeling Avoided Emissions in California

Snuller presented data on hourly avoided emissions factors in use in California under Title 24, based on the assumption that natural gas is always the marginal fuel in the state. Data have been developed to represent a "typical meteorological year" in each of the sixteen identified climate zones in the state.

Finally, the following modeling choices were presented for consideration in calculating avoided emissions:

- Marginal emissions vs. average emissions (marginal for changes, average for lifecycle)
- Current generation resource mix vs. forecasted mix
- Hourly vs. time-of-use (TOU) vs. annual average emissions characteristics as appropriate for analysis
- Whether utility contract or physical powerflow should be considered when attributing emissions.

Conclusions and Next Steps

The meeting concluded with general agreement on the characteristics of a "version 1.0" emissions impact analysis tool, to be followed with research steps toward the development of a more sophisticated approach. Specific conclusions include:

- For Version 1, a building's electrical energy consumption for a specific base year can be calculated adequately using Power Profiler.
- Power Profiler must be made more available and visible to ASHRAE members, including availability on the ASHRAE website and publication of at least one journal article on its use for this application. Other ideas include an annotated bibliography of resources on the website, and a seminar to be held in New York City.
- For the Version 1 tool, based on Power Profiler, electrical energy use input may be only on an annual basis, i.e., MWh per year. However, the tool may have some standard regional profiles that it can apply to this number for the electrical energy emissions impact analysis.
- Emission factors should be based on a "base year" calculation for comparison purposes (i.e., to model the impact of specific design decisions.) This eliminates the complexity and uncertainty associated with projecting emissions characteristics of the energy sector into the future. However, it compromises the value of the tool for predicting actual carbon footprints that may depend on near-term weather variability or climate trends. The base year approach can be considered to be conservative with respect to these unknowns. Emissions factors will be defined as annual, time-of-use (TOU), and by region. To start, the granularity of tool will be based on 26 eGrid subregions as defined by US EPA; however, this is an important area for future research and refinement.
- Similarly, the uncertainty in future building uses and operations can be avoided by considering only year-one uses, assuming occupancy, use, and operations according to specification. This may be adequate for a tool that is just supposed to report differences (a

decision assistant), although it would not provide robust results representing a full range of uses and operating practices.

- Because it is based on annual use data, the initial version cannot include a sophisticated treatment of explicit load shifting technologies such as thermal storage design. This may be an important element for future refinement.

With regard to the next steps beyond version 1.0, it may be useful to make a mock-up of a more sophisticated tool, even if the underlying data are not yet available to support implementation. This would be useful to demonstrate the utility of such an analysis, and may help to produce momentum for its development.

No specific conclusions were reached on what sort of funding would be required to achieve these goals, nor on what the specific funding sources might be.

Areas for future research

The following areas for future research were identified by workshop participants:

- Embodied energy and emissions associated with water use in the building (this would be highly site specific depending on characteristics of the local water supply and treatment system)
- For purposes of including precombustion emissions associated with fuels, it may be possible to identify a fuel-specific "precombustion factor", which would adjust emissions associated with each fuel back to the ground. In addition, it will be important to quantify the embodied emissions associated with renewable resources such as solar and wind, as well as both the embodied and continuous emissions associated with nuclear power plants and production and handling of nuclear fuel.
- Similarly the carbon associated with fuel transport could be researched. This would include emissions associated with coal transport, gas pipeline, oil tankers, and LNG liquefaction and regasification. Some of these would be extremely variable; for example, energy associated with mine-mouth coal would be significantly less than long-distance transport. (One estimate offered by J. Haberl was 200 Watts per ton-mile of coal for transport.)
- What is the appropriate metric for avoided emissions over different time scales? When is it appropriate to rely on short term changes in operations, and when on the long-term build margin (i.e., avoided generating plants)?
- When is it appropriate to assume every energy efficiency measure affects the marginal plant? Is it reasonable to assume that each user is the "marginal" user for analysis purposes, or will this bias the results?
- What is the impact of PV on peak demand? To what extent can expanded use of PV delay or obviate fossil power plants?
- Policy issue: Assuming a national carbon policy some time in the future, how will this affect the carbon footprint analysis? If cap & trade, it is just an economic benefit (because total emissions will be predetermined.) Policy trajectories may also affect the future generation mix and the dispatch order of existing units. It may be that a range of possible future policies can be represented in the tool, or it may be that just some descriptive caveats would cover this issue.
- Left open for research was the question of how often the database underlying the model would have to be updated, both in terms of energy use profiles and regional avoided

emissions characteristics. However, it was agreed that old databases and model versions should be kept “on line” and any analysis based on the model should be tagged with the model and database version ID, to facilitate auditing in the future.

- How can building energy use be “weather normalized” automatically, on a large or small scale? i.e., how can you develop a generic year profile based on the range of historical conditions?