Whole Building Life Cycle Energy and Environmental Impacts: The Significance of Energy and Water Services Burdens in a New University Building

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1. INTRODUCTION

Many evaluations of the environmental performance of buildings have been undertaken (Cole and Kernan 1996), (Buchanan 1994), (Suzuki and Oka 1998). Often these studies are built on generic building characteristics. This project was undertaken to conduct a comprehensive Life Cycle Assessment (LCA) of a contemporary university building based on a detailed material and operational inventory. While previous LCAs have generally indicated that operational activities dominate environmental impacts, this project stands at the extreme of that scale. This paper emphasizes the need for accommodation of individual life span building characteristics in building environmental assessment.

2. METHODS

The Sam Wyly Hall (SWH) LCA is conducted in accordance with EPA (Vigon, Tolle et al. 1993), SETAC (1993), and ISO (1997) LCA standards. Data sets come from the DEAM™ database (Ecobilan 2001), the Swiss Agency for the Environment, Forests and Landscape (1998), SimaPro software (PRe 2000), and Franklin Associates(1990). An article documenting the full SWH LCA is currently under review (Reppe, Scheuer et al. 2002). A brief recapitulation of relevant details is included here. If readers have questions about specific contents of that paper in regards to this paper please contact Chris Scheuer.

2.1. System definitions, boundaries and data sources

SWH is a 7,306 m^2, 6-story building completed in 1997 on the University of Michigan (UM) campus in Ann Arbor, Michigan. The basement and floors 1-3 are classrooms and open-plan offices, floors 4-6 are used as hotel rooms. The life cycle activities of the SWH LCA are illustrated in Figure 1. The SWH LCA covers the building structure, envelope, interior and backfill. A 75-year life span is presumed. It is further assumed that the energy mix will be constant over the life span. The following sections describe the activities and boundaries for each life cycle phase.

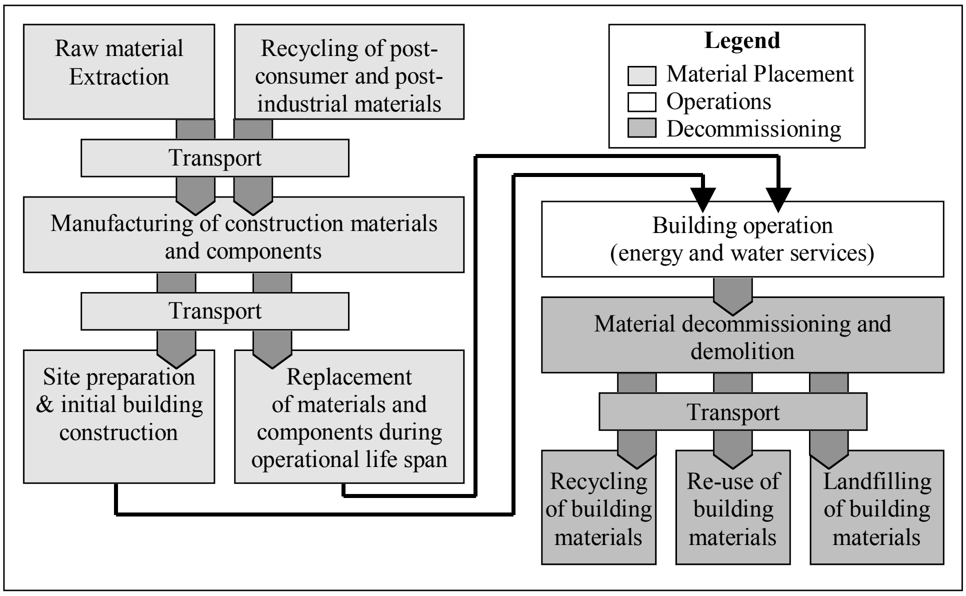

Figure 1 Life Cycle Activities

2.1.1. Material Placement. Material placement encompasses all activities required to design, construct, and renovate a building throughout its life span. These activities include material production, transportation and construction/renovation. The material inventory includes burdens associated with raw materials extraction and manufacturing. Replacement materials are modeled with the same energy and environmental burdens as the initial installed materials. "Total embodied energy" is material embodied energy plus primary energy for transportation and construction. Generally the data sets used account for transportation burdens from the point of extraction, to the manufacturer, thus transportation covers shipping of materials from manufacturing site to construction site. Energy and environmental flows associated with the construction process could not be developed directly, therefore the Canadian Athena (2001) model and work by Cole (1992), (1996) is used to estimate construction energy.

2.1.2. Operations. Operational activities consist of heating, cooling and ventilating the building, water supply and waste water treatment (based on results from a recent water services LCA)[1], water heating, lighting and equipment operation. Architectural, mechanical and internal loads and use patterns are modeled in Energy10 (NREL 1997). For SWH about 70% of the annual electricity and all of the heating and cooling steam is generated in a natural gas (NG) boiler and turbine driven combined heat and power plant (CHP). Due to difficulties in modeling the UM CHP a NG industrial boiler data set and a NG turbine data set were used to model heating/cooling and the university portion of electricity production respectively. The remaining 30% of electricity is provided by the local utility, and is modeled with an ECAR grid electrical production data set.

2.1.3. Decommissioning. As demolition data for SWH is not available, a Canadian study of structural deconstruction is used to estimate demolition energy (ATHENA 1997). This study assumes material recycling[2] based on common industry practices. Following the U.S. E.P.A. "Second Allocation Method" (Vigon, Tolle et al. 1993), recycling benefits SWH only by reduced waste generation, not by reduced material embodied energy.

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[1] forthcoming, from the Center for Sustainable Systems, http://css.snre.umich.edu

[2] Concrete, CMU, mortar, brick, granite, ceramics, All metals, window glass, carpets, ceiling tiles.

2.2. Omissions and modeling assumptions

The LCI is developed from a variety of sources, both national and international, which were the best available options within the scope of this project for representing the materials and systems present in SWH. Material production and manufacturing process data sets cover approximately 97.1 % (by mass) of total material requirements. For another 2.7%, surrogate data are used (e.g. bottle glass instead of flat glass), or material production data sets alone are used to model fabricated building components (e.g. gypsum and kraft paper for drywall). Finally, 0.2% are not included because no data are available. The following elements were excluded from the scope of this project: office equipment, moveable partitions, and furniture, street and sidewalk modification, site location and local infrastructure impacts, planning and design of the building, and miscellaneous construction materials.

3. RESULTS

3.1. Energy demands

3.1.1. Material placement. The total primary embodied energy is 55 $\times10^3$ GJ over the building lifecycle. This represents only 4.5% of life cycle energy demand (compared to 15% for Eaton (1998) and 12% for Cole (1996)). Of this, 91% of material placement primary energy is from material production, while transportation and construction account for 4% and 5% respectively. Replacement of materials through renovations accounts for only 1.4% of life cycle primary energy demand. In previous studies (Howard 1996), (Cole and Kernan 1996) embodied energy from renovations accumulates rapidly, and often exceeds initial material embodied energy. This is partially due to the high embodied energy of two materials commonly part of commercial renovations - carpeting and wiring. Because it is a university building, SWH will have less frequent renovation cycles than most commercial buildings, which diminishes life cycle material embodied energy. Total embodied energy in SWH equals 8.1 GJ/m^2, (compared to "initial embodied energy" of 4 to 12 GJ/m^2 reported by Cole (1996)). Another significant contributor to this project's lower embodied energy is the material production energy factors used for steel. Cole (1992) found ranges of 25-39 MJ/kg, other studies have also used high energy factors for steel (Buchanan 1994), (Eaton and Amato 1998). This study uses a range of 14 MJ/kg (hot rolled secondary steel) to 30.6 MJ/kg (galvanized steel), which generally led to lower embodied energy results.

3.1.2. Operations. Figure 2 shows the life cycle distribution of primary energy. The operational phase of SWH dominates life cycle energy consumption. Building operations represent 95% of the primary energy (1.2 x 10^6 GJ). Use of NG accounts for 63% of the total life cycle primary energy use. Grid supplied power, while only 30% of site electricity, represents 45% of electrical production primary energy, due to the low efficiency of the regional grid compared to the NG turbines.

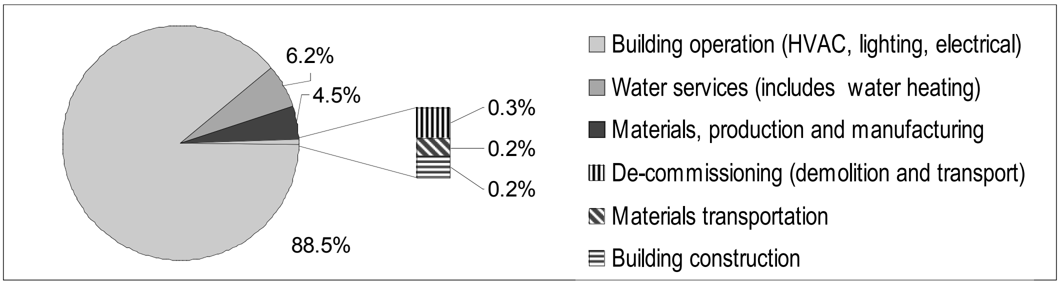


Figure 2 Life cycle energy distributions

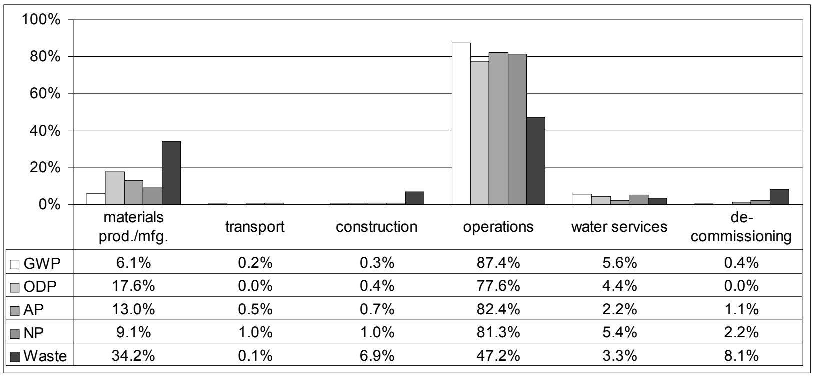
The primary energy burden for water services (75 x 10^3 GJ) is greater than total embodied energy. NG hot water heating accounts for 94% of water service primary energy, while potable water production and wastewater treatment together only account for 6%. Consumption of cold and hot water is primarily due to the hotel rooms on floors 4 - 6.

In SWH, operational primary energy exceeds initial embodied energy after only 2.5 years (3.5 years for total embodied energy). This number is on the lower end of results from Cole (1996), and Eaton (1998)[3], who found 2.6 - 4.6 years and 5 - 8 years, respectively.

3.1.3. Decommissioning. The energy requirements for decommissioning (demolition and transportation) represent only 0.3% (4.0 x 10^3 GJ) of life cycle primary energy demand.

3.2. Life cycle environmental impacts

The measured environmental impacts from SWH (based on current literature (Leiden University 2000)), followed closely the energy consumption profile in many aspects, a notable exception being that water burdens while consuming more energy produce less environmental impacts than material placement. The largest contributors in most of the impact categories were emissions related to fossil fuel combustion during the operational phase. Relative impact assessment results are summarized in Figure 3 with details provided below.



	materials prod./mfg.	transport	construction	operations	water services	de-commissioning
□ GWP	6.1%	0.2%	0.3%	87.4%	5.6%	0.4%
▨ ODP	17.6%	0.0%	0.4%	77.6%	4.4%	0.0%
▨ AP	13.0%	0.5%	0.7%	82.4%	2.2%	1.1%
▨ NP	9.1%	1.0%	1.0%	81.3%	5.4%	2.2%
■ Waste	34.2%	0.1%	6.9%	47.2%	3.3%	8.1%

Figure 3 Life cycle distribution of environmental impacts

3.2.1. Measured Impact Categories. Life cycle Global Warming Potential (GWP) over a 100-year time horizon for SWH was 74000 tonnes of CO_2 equivalent. Operational phase CO_2 releases alone account for 84% of life cycle GWP. Life cycle Ozone Depletion Potential (ODP) for SWH is 0.4 kg of CFC-11 equivalent. Operational phase electricity production accounts for 75% of life cycle ODP. The total life cycle Acidification Potential (AP) for SWH is 222 tonnes of SO_2 equivalent. SO_X and NO_X emissions from operational phase grid-electricity generation and NG production cause 57% and 17% of total AP respectively. The life cycle Nutrification Potential (NP) for SWH is 24 tonnes of PO_4 equivalent. NO_X emissions from operational phase grid-electricity generation and NG production cause 39% and 20% of total NP respectively. SWH life cycle waste generation is 6,867 tonnes. Material production wastes were primarily mining/extraction wastes from cement, copper and sand production. Just over half of life cycle waste generation comes from the operational phase, unspecified process wastes and slags and ashes from grid electrical production account for 38% of life cycle waste. Landfilled materials (7.8%) are relatively low due to the assumption

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[3] Cole (1996) considers embodied energy to include burdens from transportation and construction, but not replacement of materials. Eaton (1998) considers embodied energy to include burdens from transportation but not construction or replacement of materials.

that the most massive building materials will be recycled or reused (e.g., concrete, sand, gravel, CMU, Brick, all metals, carpets).

4. CONCLUSIONS

Life cycle distribution of energy consumption, environmental impacts and solid waste generation is concentrated in the operational phase of this case study building. In all measurements, except waste generation, operations account for more than 78% of the burdens and impacts. In two key measures, primary energy and GWP, operations accounts for over 93% of life cycle burdens. While energy burdens from water services exceed energy burdens for material placement, for other measured environmental impacts water services account for less than material placement.

Two factors specific to this building contribute most directly to the higher than expected concentration of operational phase environmental burdens. First, several materials frequently renovated (especially carpeting and wiring) are found to have high embodied energy. However, SWH is an institutional building with replacement schedules significantly lower than those found in other commercial buildings, so this expected impact is minimal in this case. The combination of hotel rooms with a classroom/office building greatly intensifies water consumption. While these two factors exacerbate operational phase impacts, the 70% CHP / 30% grid power model utilized does reduce total operational impacts because of the higher efficiency of NG versus the grid. In a setting with more frequent replacement cycles, and no hotel rooms, but with grid only power sources the operational phase emphasis could be as extreme.

While material choices for environmental performance have received a large amount of attention, this study revealed that at least in some cases their contributions to lifecycle environmental performance could be minimal. University buildings often have unique profiles so individual assessments of life span demands at an early stage can assist in developing appropriate choices for environmental improvements. Existing generalizations about buildings may be inappropriate for a university or other institutional building. Based on this project, a consideration of water needs, and renovation schedules are among the parameters that should be accurately assessed to provide a more thorough environmental profile of a building. Not before the magnitude of material placement environmental impacts more closely approximates life cycle operational impacts, should material strategies be emphasized over strategies for improving operational performance.

4.1. Acknowledgments

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