EMBODIED CARBON IN MEP SYSTEMS: A SIMPLIFIED LIFE CYCLE ASSESSMENT (LCA) METHOD FOR MEP SYSTEMS IN STANDARD COMMERCIAL OFFICE BUILDINGS IN THE PACIFIC NORTHWEST

Abstract

This paper presents a preliminary study to estimate material quantities and embodied carbon of building systems in commercial office buildings with the aim to advance the understanding of the role that mechanical, electrical, and plumbing (MEP) systems play in whole building embodied carbon. Previous studies on building embodied carbon using Whole Building Life Cycle Assessment (WBLCA) have expanded extensively over the last 10 years. However, often these studies encompass the structural scope of the building. In order to answer the research question, a simplified LCA method is proposed. The first part involves the development of a systematic framework to assess embodied carbon in MEP systems. A second stage involves the application of the assessment framework to measure the embodied carbon of MEP systems in a set of hypothetical representative office buildings in Oregon and Washington. The preliminary results show that total material quantities of MEP in typical standard commercial office buildings in the Pacific Northwest (PNW) weighs around 20 kg/m², and the GWP is around 150 kg CO_2 eq/m² on average across four typical building size categories.

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Introduction

The building sector is the largest single contributor to global greenhouse gas (GHG) emissions (Häkkinen, et al., 2015). The life cycle energy cost and GHG impacts of individual buildings can be divided in two: operational and embodied impacts (De Wolf et al., 2017). A broad myriad of policy efforts and innovations around the world have enabled the successful reduction of operational GHG, yet many challenges still remain for the assessment of and reduction of embodied impacts. Many of these challenges are related to methodological choices during the process of carrying out a life cycle assessment (LCA) to estimate the embodied carbon in buildings. LCA is an objective process that aims to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying the energy and material uses and releases to the environment (Chau et al., 2015). Whole Building Life Cycle Assessment (WBLCA) is a compilation and evaluation of the inputs, outputs, and potential environmental impacts of a whole building throughout its life cycle (ASCE, 2017).

In recent years, an increasing number of literature reviews have found different challenges that affect the comparability of WBLCA studies (Soust-Verdaguer, et al., 2017). These challenges can be summarized as: (1) a lack of consistent methods to carry out the assessments, (2) differences in the stated purposes of the building assessments, (3) poor description of system boundaries, and (4) incompleteness of inventory and quality of data (Rasmussen, et al., 2018).

Traditional methods of life cycle assessment are time consuming and pose several barriers to their wide implementation in the industry (Verghese et al., 2010). Therefore, arguments are being developed in favor of simplified tools to be used in the earlier stages of design (Giesekam & Pomponi, 2017). It has been widely suggested that simplified LCA methods, including input-output (I-O) LCA, could increase the utilization of LCA in industry (Junnila & Horvath, 2003). Simplified approaches for the building industry are becoming available (Glaumann et al., 2010), but no current LCA methods address MEP systems.

In addition to these methodological challenges, recent studies demonstrate that the majority of LCA studies for buildings have focused exclusively on the structural scope (Simonen et al., 2017). Tenant improvement, site development, and MEP systems, for the most part, have remained unexamined (Basbagill, et al., 2013). This may be due in part to current standard requirements to exclude MEP systems because these systems would have "relatively insignificant embodied environmental impacts compared to the building structure and envelope" (ASTM E2921 – 13, 2013). In recent years, however, an increasing interest to understand embodied impacts in LCA has demonstrated that MEP, also called "building services," may represent up to 15% of initial embodied carbon (Medas, et al., 2015).

This paper describes the development of a simplified LCA method for MEP systems to be used at an early design stage by architects engineers and contractors that complies with current WBLCA standards. Preliminary results are provided for standard hypothetical generic buildings in four building size categories.

Methodology

The research plan for this study followed a four-step approach. The first substage was defined as a "Characterization Stage," where in conjunction with an Industry Advisory Committee, the research team identified representative office buildings and typical MEP systems, including a list of materials and equipment for each type of system. During the second stage, called "Estimation of Material Quantities," the research team quantified material unit quantities for each system type. In the third stage, called "LCA Impact Data," LCA impacts from different data sources (such as EPDs, LCA studies from peer reviewed articles and reports, and open databases) were compiled. The impact data was then compiled into a spreadsheet and recorded for Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Acidification Potential (AP), Eutrophication Potential (EP), and Smog Formation Potential (SFP). Finally, in the fourth stage, the research team developed an open source database as a matrix model to calculate LCA impacts of MEP systems.

The project scope is limited to evaluating hypothetical buildings by working with a group of industry experts that assist in defining the systems and establishing material quantity estimates. The data in this study are limited to the material quantity data provided by contractors available to work on this research within the timeline of the research project (Winter and Spring 2018). The data are from different estimation methods and depends largely on each firm's experience and project historical data.

Preliminary Results

SUBSTAGE 1: CHARACTERIZATION OF BUILDINGS AND MEP SYSTEMS

Once the advisory committee was established, the first step was to propose several hypothetical building models that would represent typical commercial office buildings in the PNW. Based on these hypothetical buildings, the advisory committee proposed a series of typical MEP systems, then listed typical equipment and material types for each system. During this process, the advisory committee agreed on the following observations:

First, MEP system design depends largely on state and city local codes. Within the PNW, the current 2015 Washington State Energy Code (WSEC) is more stringent than the 2014 Oregon Energy Efficiency Specialty Code (OEESC). According to the U.S. Department of Energy (DOE) Building Energy Codes Program,[1] the OEESC is equivalent to ASHRAE 90.1-2010 standard while the WSEC is more efficient than ASHRAE 90.1-2013. Therefore, for this study, a "standard building" (SB) is defined as a building designed under the Oregon code.

Second, MEP system design is a multidisciplinary effort dependent on several building variables such as: cost, operational efficiency, noise requirements, space distribution, among which building size plays a key role. Building sizes expressed in total area (gross square footage) determine design requirements and types of MEP systems. The number of stories above ground is not considered a key variable in the MEP system choice. As a result, four building models were established as shown in Table 1.

Lastly, MEP systems are inherently different and have diverse levels of equipment complexity and material selection. Plumbing is the least complex of the three systems and is defined primarily in the selection of piping material rather than particular equipment as shown in Table 1. Mechanical systems, also known as Heating, Ventilation, and Air Conditioning (HVAC) and electrical systems are much more complex systems with many intricate components. Mechanical systems are diverse and are available in a broad myriad of combinations in the marketplace. For this study, only one of the most representative mechanical systems are considered for each one of the four building size categories as shown in Table 1.

Note

1. The U.S. Department of Energy (DOE) Building Energy Codes Program reviews adoption of energy codes for buildings. State adoption is reviewed based on the national model energy codes–the Standard 90.1 for commercial buildings (42 USC 6833) (U.S. DOE, 2018).

Office building size category	Area range (ft²)	Area range (m²)	Plumbing systems	HVAC systems	Electrical systems
Large	120,000 – 800,000	11,148 – 74,322	Water/Copper Waste & Vent/ Cast Iron	Packaged rooftop AC+ Furnace	Basic LTG & Power
Medium	20,000 – 300,000	1,858 – 27,870	Water/Copper Waste & Vent/ Cast Iron	Packaged rooftop heat pump	Commercial LTG/PWR
Small	10,000 – 80,000	929 – 7,432	Water/Copper Waste & Vent/ Cast Iron	Variable Air Volume Air Handling Unit with Parallel Fan Powered (VAV AHU w/ PFP)	Commercial LTG/PWR
XSmall	2,000 – 25,000	185 – 232	Water/Copper Waste & Vent/ Cast Iron	Water Source Heat Pumps (WSHP)	Commercial LTG/PWR

Table 1: Typical plumbing systems for standard commercial office buildings.

SUBSTAGE 2: ESTIMATION OF MATERIAL QUANTITIES

The total material quantity range for MEP of typical commercial office buildings is 15 to 20 kg/m² (where m² refers to the total floor area of the building) for standard buildings across four typical building size models. Material quantities in standard buildings can be divided into: 13 kg/m² for mechanical systems (HVAC), 4 kg/m² electrical systems; and 3 kg/m² for plumbing systems. Mechanical systems represent a significantly larger amount of material quantities per square meter than electrical and plumbing due to the larger specific weights of specific equipment across the building as shown in Figure 1. The results also show that with increasing building size, relative material quantities per square meter are higher than for smaller building size categories. An exception to this trend would be the small building size category (929-7432 m²), where the electrical system changes to commercial LTG/PWR. Commercial LTG/PWR incorporates transformer equipment, which adds significant mass relative to the total floor area.

SUBSTAGE 3: COMPILATION OF LCA DATA

LCA data of typical MEP equipment and materials are commonly available through open databases and journal articles. The ÖKOBAUDAT, the German mandatory data source within the Bewertungssystem Nachhaltiges Bauen (BNB), offers the largest amount of data for mechanical components (210 out of 1186 datasets are Mechanical Systems LCA data). All ÖKOBAUDAT datasets are compliant with EN 15804 and have been generated based on GaBi background data and other EPD data. There are only a few valid EPDs for HVAC equipment in current EPD programs. The PEP Ecopassport program, the International EPD System, and the IBU have the largest number of English-language EPDs for HVAC equipment. In the US, the UL EPD program holds two EPDs for centrifugal chillers and 39 EPDs for insulation types.

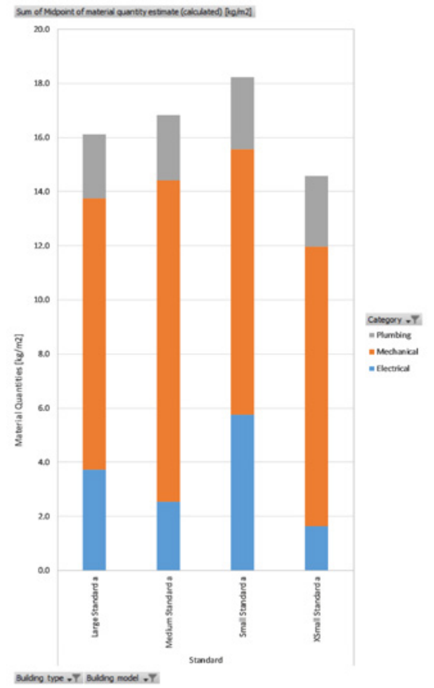

Figure 1: Material quantities for MEP systems in standard commercial office buildings.

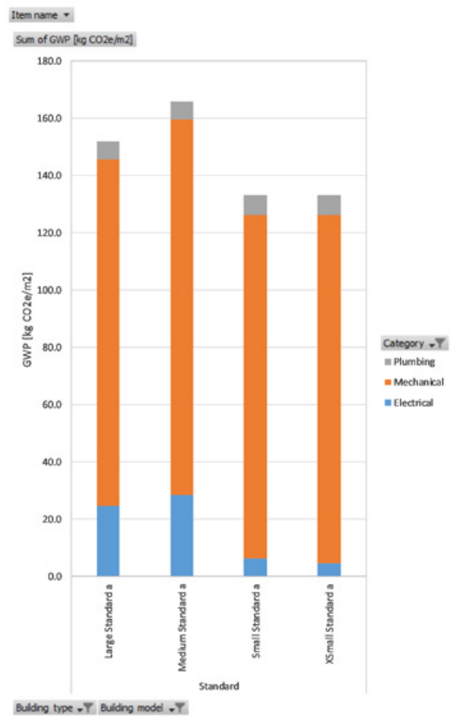

Figure 2: Global Warming Potential (GWP) for MEP system types.

SUBSTAGE 4: LCA MATRIX: LCA DATA X MATERIAL QUANTITIES

During the final stage of this project, the LCA results were calculated by multiplying the life cycle impact data by the material quantities from the second substage. Figure 2 shows the Global Warming Potential (GWP) for all building systems for the four building models.

The total material GWP range for MEP of typical commercial office buildings in the PNW is 150 kg CO_2 eq/m² for standard buildings across four typical building size models. Embodied carbon in standard buildings is around 130 kg CO_2 eq/m² for mechanical systems (HVAC), 13 kg CO_2 eq/m² for electrical systems, and 7 kg CO_2 eq/m² for plumbing systems. The relative differences across the building size categories is associated to the specific combinations of different types of equipment and materials across the different building MEP systems.

Conclusion

The simplified LCA method described in this study will allow design teams to find reasonable estimates of LCA impacts in different MEP system types across building size categories in early stages of design. The preliminary results show that total material quantities of MEP in typical standard commercial office buildings in the Pacific Northwest (PNW) is around 20 kg/m², and the GWP is around 150 kg CO_2 eq/m² on average across four typical building size categories.

Future research is suggested by including a more comprehensive list of equipment and material types for each mechanical, electrical, and plumbing system. Material quantities assessed for specific case studies in built projects could also contribute to more accurate results.

LIMITATIONS

The inherent limitations of this study should be acknowledged in all publications of the data. A summary of the limitations per research stage are as follows:

LIMITATIONS ON THE CHARACTERIZATION OF GENERIC BUILDINGS AND SYSTEMS

- The database of generic office buildings does not represent a statistical sample of buildings in the region, and is weighted to larger, more prominent buildings than those that make up the complete building stock in the Pacific Northwest (PNW) region.
- The MEP systems described for generic office buildings used in this study are not statistically representative of current building MEP design choices and instead should be considered as simplified models of typical systems used in standard buildings in the PNW region. The building size categories and the systems were described by the contractors based on professional judgment.

LIMITATIONS ON CALCULATING MATERIAL QUANTITIES OF TYPICAL MEP SYSTEMS

- Calculation of MEP system equipment in lb per sf is not a standard practice for most MEP contractors. In order to provide the data required for this study, most contractors sized the equipment assuming particular design requirements, then calculated the weight per unit of the equipment, and finally they estimated a total for the entire building.

LIMITATIONS ON COMPILING LCA DATA OF BUILDINGS

- The available LCA data for MEP systems were scarce and come from different geographical regions. Therefore, these data are not directly comparable.
- The available LCA data are limited to only some types of MEP equipment and materials. In order to complete this study, EPDs and openly available LCA data from standard equipment were used to represent other equipment of similar material composition and weight.
- This study uses only LCA data for MEP equipment for life cycle stage A.
- This study uses only LCA data available in EPDs, databases, and published journals available in English.

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