Enterprise Audit Modeling of Large-Scale Agencies' Energy and Carbon Dioxide Accounting

by:

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ABSTRACT:

Calculating and accounting of embodied and operational energy and carbon emissions within buildings is still not standardized. No regulations exist for standard equations, databases, or best practice methods to evaluate energy and carbon. The inaccuracies and incompatibilities found among common process, hybrid databases, and evaluation methods leave wide margins for error. This thesis proposes a standardized method, a Large-Scale Agency Analysis (LSAA), to evaluate carbon and energy emissions and proposes a new dynamic modeling method for large-scale agencies. The Comprehensive Dynamic Carbon Analysis (CDCA) method utilizes computer technology to evaluate nonlinear carbon emissions systems that can be applied to both individual buildings and large-scale agencies.

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ABBREVIATIONS

API	Application Programming Interface
ASCE	American Society of Civil Engineers
BAU	Business-as-usual
BIM	Building Information Modeling
BREEAM	Building Research Establishment Environmental Assessment Method
C&D	Construction and Demolition
CACP	Clean Air and Climate Protection (software system)
CBECS	Commercial Buildings Energy Consumption Survey
CDCA	Comprehensive Dynamic Carbon Analysis
CER	Certified Emissions Reductions
CEUS	California Commercial End-Use Survey
CO_2E	Carbon Dioxide Equivalent
CORRIM	Consortium for Research on Renewable Industrial Materials
CRIS	Climate Registry Information System
DEP	Direct Energy Paths
ECA	Enterprise Carbon Accounting
ECA	Corporate Carbon Footprinting (alternative meaning)
EFF	Efficiency
EIA	Energy Information Administration
EUI	Energy Use Intensity
GHG	Green House Gasses
HE/LC	High Efficiency/Low Carbon
ICE	Inventory of Carbon and Energy
ICLEI	International Council for Local Environmental Initiatives (Now known as "Local Governments for Sustainability")
ICT	Information and Communication Technologies

IEO-LCA	Input-Output Model
IPCC	Intergovernmental Panel on Climate Change
KDOT	Kansas Department of Transportation
KU	University of Kansas
LCA	Life Cycle Analysis
LCEE	Life-Cycle Environmental Effects
LEED	Leadership in Energy and Environmental Design
LGOP	Local Government Operations Protocol
LSAA	Large-Scale Agency Analysis
NACAA	National Association of Clean Air Agencies
NGO	Non Governmental Organization
O&M	Operations and Maintenance
OCA	Operational Carbon Accounting
R&D	Research and Development
SaaS	Software as a Service
SERT	Sustainable Research Energy Team
TCA	Transportation Carbon Accounting
UN	United Nations
USGBC	United State Green Building Council

UNITS

Though the units in this thesis do not necessarily conform to the International System of Units (SI), the units used are generally accepted within the carbon emissions field.

SI units used in this thesis include: meters (m), kilograms (kg), liters (L), and kilowatt-hours (kWh). Non SI units used include: tones (t), British Thermal Units (BTU), and, for comparison purposes within the United States, feet (ft).

To convert from ft^2 to m^2, multiply by $9.290*10^{-2}$.

To convert from kWh to BTU, multiply by $3.412*10^{3}$.

CHAPTER 1: INTRODUCTION TO CARBON DIOXIDE EMISSIONS

"'*Carbon footprint' is a new buzzword that has gained tremendous popularity over the last few years.… Debates on the appropriate use of carbon footprinting are spreading through society like rings in the water*." (Weidema et al, 2008) The increasing popularity is not unusual, except that the driving force is unusual; retail chains and "proactive companies". The call for carbon footprinting has been driven by IPCC and taken seriously by many government agencies, private companies, large corporations, and citizens. Accurate carbon and energy accounting have become increasingly important as carbon and energy will affect companies and government bottom line if carbon taxation comes into existence and energy costs continue to rise. Carbon accounting accuracy becomes critical when company profitability becomes an issue.

Weidmann and Minx (2007) pointed out that some researchers argued that carbon footprinting should only include the analysis of direct carbon emissions, such as car exhaust, which directly produce carbon dioxide. Other researchers use the term 'carbon footprinting' to include analysis of equivalent carbon and indirect emissions. Carbon equivalent emissions are "*noncarbon emissions and … carbon dioxide (CO_2) equivalent indicators*." (Weidmann & Minx, 2007)

Carbon Dioxide Equivalent (CO_2E) "… *are computed by multiplying the weight of the gas being measured by its estimated global warming potential*." (Department of Energy) CO_2E's are closely tied to the Global Warming Potential (GWP) indicator used in building life cycle assessment.

If other green-house gas (GHG) equivalents are to be used, then users must consult Table 1. CO_2 is the most common among all GHG's, contributing to 23 to 26 percent of all greenhouse effects (Kiehl & Trenberth, 1997). It is used as a multiplier for other GHG's as a result.

Table 1: Green House Gas Equivalent Multipliers

Green House Gas	Multiplier from CO_2 Equivalent
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2)	298
Sulfur Hexafluoride (SF_6)	22800
HFC-23 (CHF_3)	14800
HFC-32 (CH_2F_2)	675

Provided by (CO2 Equivalents, 2009)

"So why all this excitement about carbon footprints?" (Weidema et al, 2008) Carbon footprinting becomes a prominent and appealing topic to researchers, scientists, and corporations as it has a broad impact on industries, societies, and global communities. The concept is extremely "*catchy*" and thus has been promoted and outside the research community. (Weidema et al, 2008) Even though carbon accounting frameworks has been extensively researched, the accounting approach has been oversimplified. Too many assumptions are included in the accounting approaches and they failed to accurately address the differences between different models and regions. For example, a plane ride from Copenhagen to San Francisco generates two tons of Co_2E, which is 20 percent of the total carbon that an average European generates in an entire year. (Weidema et al, 2008)

In the search for lower carbon emissions for infrastructure and buildings, researchers around the world are investigating and documenting the embodied carbon and energy of construction materials. Fieldson et al. (2009) showed that carbon footprinting of buildings proved to be an effective CO_2 and GHG monitoring method when energy can be converted into CO_2E values and the total can then be compared to similar buildings. (Fieldson et al., 2009) There are many purposes and uses for carbon emission accounting. It can be used for everything from compliance with government regulation and deriving environmental benefits to economic savings and generating social awareness *"… and surely the method used to calculate them should reflect these differing uses*." (Matthews, 2008) Some companies merely require baseline carbon values, others require operational quantities, inter corporation quantities, or supply line quantities. The requirements are driven by the differences of and the needs of each company.

1.1 INTRODUCTION TO ENTERPRISE CARBON ACCOUNTING AND ENTERPRISE ENERGY ACCOUNTING

Enterprise Carbon Accounting (ECA) and Enterprise Energy Accounting (EEA) are the GHG tracking methods that calculate, manage, report, reduce, and trade carbon emissions of business entities. ECA and EEA focus on every aspect of business, ranging from daily operation to production processes. (Baier, 2009)

Carbon and energy calculation has become increasingly important among commercial buildings, especially after the introduction of various green building standards such as BREEAM, USGBC, and LEED. Even though average energy intensities of buildings, per square foot, has continued to decrease over the past three decades, energy use of buildings and its materials has remained high as building sizes grew (Davis & Swenson, 1998). Advances in lighting technology, reduced lighting design requirements, and increased space heating and cooling efficiency have decreased energy intensity of buildings.

Despite the continuing reduction in energy use intensities of buildings, resources and materials used become more critical. Overall, energy consumption among all buildings continues to grow. Have the industries oversimplified energy use intensity calculations? What is really behind the energy use intensity numbers? This thesis tracks their problems by proposing a quick and reliable energy and carbon emissions method that could quickly and efficiently measure energy use and carbon emissions of companies.

1.2 NEED FOR ECA AND EEA

The purpose of GHG accounting is to quantify and present emissions data for the product's life cycle. "*ISO standards for [building] life cycle analysis, product declarations, and greenhouse gas accounting [namely ISO 14040/44, ISO 14025, and ISO 14064] should be indispensable*" (Weidema et al, 2008) However, ISO standards are vague and they are kept that way to remain applicable to all situations.

Political and economic requirements may force large-scale agencies to conduct ECA and EEA audits (Qindong & Stallaert, 2010). ECA, also called corporate carbon accounting, is an efficient and cost effective approach for large-scale agencies to collect, summarize, and report GHG inventories and emissions (Peer, 2010). While many ECA methods are not tailored for the analysis of large agencies.

Carbon can be divided into a number of categories. One of the standards is operational carbon and energy, which will be further discussed later in this paper. Process based is the carbon and energy produced from independent process and production within the total value chain, while occupational carbon and energy is a result of occupying a building. It represents any other forms of carbon and energy not covered by the first two categories. Figure 1 presents a partial flow diagram of how ECA and EEA evaluate organizations.

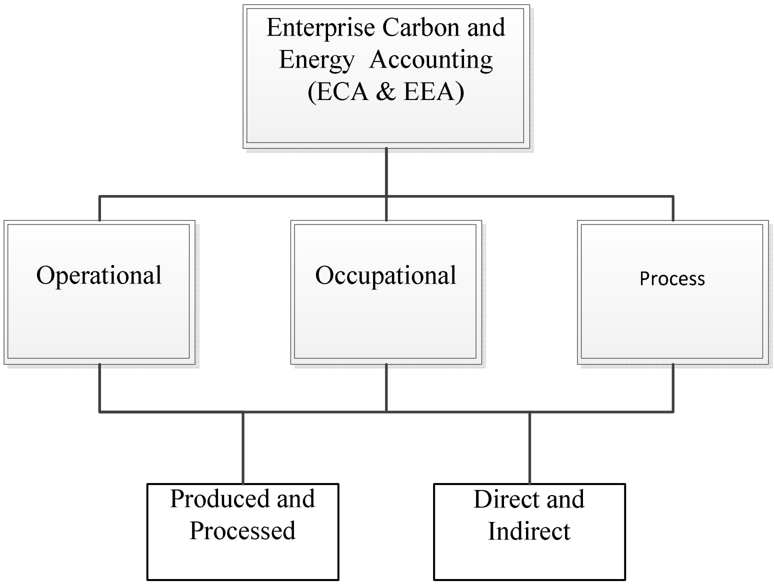


Figure 1: Enterprise Carbon and Energy Accounting

An enterprise generates the three carbon and energy types. These three elements are uncontrollable by the engineers, users, and designers, meaning each element contains a certain level of carbon and energy that cannot easily be modified. The controllable elements of the chart come in the form of the direct/indirect emissions and process/produced emissions. For example, some water filtration processes require more energy than others. Needing to filter the water is not an option for the consumers, thus it is uncontrollable, but the method to filter the water can be controlled to reduce energy and carbon demands. In order to accurately account for carbon and energy for corporations that consume carbon and energy respectively, knowledge of controllable and uncontrollable elements is necessary for future reductions.

NEED FOR ECA AND EEA IN THE POLITICAL COMMUNITY

Carbon credits and taxation were ideas developed by various agencies such as the United Nations and IPCC in 2006 to reduce global GHG emissions. Carbon credits are traded in the form of intangible assets called Certified Emissions Reductions (CER). CER is a ‘good’ that can be traded, tracked, accounted for, and held in the registry for accounting purposes. CER can also be exchanged for cash, though it is not considered a ‘turnover’ in the accounting books. Sales of CER have to be recognized and documented per governmental standards. While the basic concepts of carbon taxation and credits can easily be represented in a single equation, its application becomes limited if it fails to produce reliable and consistent results. (Agrawal, 2006)

In 1998, Sweden developed a series of methods to approach the implementation of federal carbon dioxide taxes. They found the massive costs of mitigating climate change only work to emphasize the importance establishing a cost effective option for introducing new technology and methods (Bohlin, 1998) Sweden developed two methods: the administrative and the economic approaches. The administrative method, theoretically provides adequate accounting of carbon, but is restrictive due to the costs of gathering comprehensive information. The economic method is more reasonable, but the cost is still limited by its planned cost savings. (Mishan & Quah, 2007)

1.3 ECA AND EEA IN DESIGN

Tracking and understanding how each element in Figure 1 impacts the overall carbon total allows designers, owners, contractors, and occupants to better control the energy and carbon used at the building stage. For the design phase, this thesis will offer a design decision flow chart to assist designers in making educated decisions to reduce energy use and carbon emissions.

The Consortium for Research on Renewable Industrial Materials (CORRIM) reported that certain materials could potentially generate greater benefits, such as carbon sinks and removal of existing carbon in the atmosphere, and reduce more emissions than other materials (Lippke, 2004). This becomes an important factor for selecting materials for building designs. Buchanan and Henry (1994) reported that if forests are managed appropriately, wood construction poses the greatest benefits of the three standard structural construction types (wood, steel, and concrete). Even though their study suggested that wood is the most environmentally friendly structural material, they neglected the structural limitations and recycling realities of each material. Wood is often difficult to recycle due to its high contaminates.

Concrete is infrequently reused other than as aggregate, but steel is recycled 98 percent of the time with steel members containing 93.3 percent recycled material (American Institute of Steel Construction, 2011). Recycling and reusing construction materials do not necessarily reduce carbon emissions as the process to recycle and reuse also consumes energy (Srour, Chong, & Zhang, 2010)

1.4 COST SAVINGS THROUGH CARBON EMISSION REDUCTIONS

Koomey (1998) equated cost savings to carbon emission reductions. He divided the energy, carbon, and cost savings into three business models. The three models were: ‘business-as-usual’ (BAU), ‘efficiency’ (EFF), and ‘high efficiency/low carbon’ (HE/LC) buildings. The three models presented strikingly different results. The efficiency model resulted in 5.3 percent less energy use and 4.4 percent fewer carbon emissions than the BAU model in 2010. This represented a savings of $18 billion in fuel costs annually across the US office building sector. The HE/LC model resulted in 12 percent less energy use and 11 percent fewer carbon emissions than the BAU model. This represented $33 billion in fuel cost savings across the sector. While the HE/LC model did spend $13 billion on efficiency improvements and an estimated $1 to $2 billion per year in program and policy costs, the savings still amounted to over $18 billion annually (Koomey, 1998).

1.5 RESEARCH LAYOUT

1.5.1 OBJECTIVE

This thesis will establish a quick EEA and ECA audit method to categorize and evaluate carbon emissions and energy baselines of large-scale agencies. The method will aid in developing a dynamic model to shape, develop, and model embodied carbon and energy. Results of the method will establish future guidelines in carbon and embodied energy accounting for building design, construction, and operation. The above literature distinctly indicates the need for such research.

1.5.2 QUESTIONS

Throughout the analysis, a series of research questions will be addressed. Primary among these are: (1) What factors should be considered for a quick audit? (2) What is the reliability of quick audit systems? (3) If the audit is reliable, then how can it be used to make design based decisions? (4) What would such models look like? and (5) How static or dynamic should the model be in order to achieve an accurate result?

Answers will require extensive analysis and aside-by-side comparison of existing analysis methods. The quick audit for design will be discussed to evaluate if it can become a reliable decision-making tool

The goal of this quick audit analysis method is to create a method that allows an engineer's knowledge to be interoperated and tracked by non- engineers for an increased environmental and political impact. Since business administration often lack or are unaware of the technical knowledge in a production process, the results of the audit system must be able to be translated into terms that laymen can easily comprehend and monitor.

The final questions to be addressed will be that of databases. Due to the large number of existing databases, it is important to identify the qualifying elements that make a good database. The reliability and accuracy of these databases is crucial to the social perception of carbon accounting. This will outline the elements that are requisite for a nationally recognized database for carbon and energy accounting.

5.1.3 METHODOLOGY

In order to assess the need for enterprise energy and carbon accounting and a large-scale agency analysis method, this thesis will present a literature review to asses existing documentation and research on the topic. The second chapter will review three of the existing methods, Life Cycle Assessment, Input-Output Method, and Direct Energy Paths, to assess their applicability to large-scale analysis. Quality of data and results is then discussed in chapter three with the use of a quality assessment matrix.

The body of this thesis proposes a new method to assess large-scale agencies. This method is presented in two parts to accommodate the construction, embodied carbon, of the buildings and the use, operational carbon, of the buildings. Details to the method can be found in chapter four.

Chapter five uses a current large-scale state agency to validate the new method's results. Both the embodied and the operational carbon and energy values are calculated followed by an analysis of the method and corresponding results. Additional steps to the method and alternatives are discussed in chapter six. Though these are not mandatory to the new method, they provide supplementary levels of accuracy and applicability. Final conclusions are discussed in chapter seven.

CHAPTER 2: EXISTING CARBON ANALYSIS METHODS

Of the analysis methods in popular circulation, Life Cycle Assessment (LCA), Input-Output Model (EIO-LCA), and an LCA and EIO-LCA Hybrid called Direct Energy Paths (DEP) are the three methods. Each was developed to address specific types of modeling analysis, but, as will be explained, none were developed for the purpose of comprehensive audits in mind. All three methods are time consuming and rely heavily on arbitrary and predetermined energy paths, (Junnila, Horvath, & Guggemos, 2006) which make them unsuitable to situations where reliable outputs are needed.

2.1 LCA AND PROCESS MODELS

Life Cycle Assessment (LCA) was employed by Junnila and Horvath (2003) to estimate the primary energy consumption and greenhouse gas emissions from residential buildings. The method systematically traces the lifecycle of the building from ‘cradle to grave’ to determine its environmental impacts. LCA traces the energy and carbon flow of products and processes. The analysis is helpful but time consuming and specific to the building analyzed. (Junnila, Horvath, & Guggemos, 2006) Accuracy of output is high but may not be applicable to buildings other than the precise building assessed. The ISO 14040 -1997 finds the following limitations within LCA (Junnila & Horvath, 2003):

1) Subjective choices exist such as the data sources and the system’s boundaries.

The first point identifies the subjective choices that are made to establish system boundaries that apply to the cutoff regions of the analysis. Two levels of boundaries exist. The first is a geographic boundary. A growing nation that decides to disregard carbon emissions still creates carbon dioxide that affects the rest of the planet. Importing and exporting of carbon dioxide does not stop at customs stations for visas. At what level will carbon be traded? It is possible that trade levels are balanced per nation, per state, or per city boundary. One wonders where the exact boundaries will be drawn. For this reason, it is important that consistent system boundary exist for all analysis.

The second boundary system is a more complex, internal boundary, which will be further discussed in Chapter 3.

Further boundary and ownership ambiguity is introduced when buildings are rented rather than owned. Does the level of responsibility and ownership of the building directly correlate into ownership of the carbon? When apartment owners want to install more efficient systems within their home but the apartment owner prefers a less expensive and less efficient system, who is responsible? Many offices, for example, are located in a large office building and only lease a few floors or rooms of the building. Prior to full carbon accounting, legislation must be in place to state whether the renting company or the owner is the party responsible for output carbon emissions from rented buildings and facilities.

2) Typical assessment models are limited to linear rather than nonlinear models.

Most models, including the basis of this model, are based on linear rather than non-linear analysis under the guise of time savings. Once carbon analysis becomes mainstream, a database will be required to take into account all factors impacting carbon emissions. The new database, one based on a non linear model, would account for weather, location, elevation, surrounding circumstances, and other influencing factors. Such an all encompassing database would accommodate for locations, alignments, orientations, occupants, materials, renovations, etc equally, thus creating a non linear, dynamic model on which to calculate the actual carbon within an agency.

3) Local conditions are not adequately described by regional or global values.

Currently, databases exist that cover geographically large regions. The problem with the large databases is that they tend to diminish regional differences. (Edwards & Thompson, 1998) Because the databases are one of the main influencing factors in the final carbon values, it is important that values within them are accurate.

4) Accuracy of results is limited to the accuracy of the data and its availability.

Accurate results are limited to the accuracy of the data. (Redman, 1998) When data is limited or assumed, as is inherently the case in almost all carbon accounting cases to some degree, the accuracy of the total carbon emissions value suffers. In order to determine accurate results, a system must be created which allows for complete, or as close to complete as possible, data collection and categorization. The need for a comprehensive modeling database is the single greatest limiting factor within the ECA and EEA fields.

5) Uncertainty is introduced throughout the assessment.

Uncertainty can be found in even the most well-laid research. While it cannot be completely eliminated from a carbon study, it can be tracked and monitored so that its impacts can be predicted. Through careful use of deviations, a well developed method can monitor impacts of the uncertainty element within its research.

2.2 EIO-LCA

The Input-Output method (EIO-LCA) is a process based LCA method. The United States Federal Government collects data on each sector of the economy and disassembles it into its environmental effects. Each sector is then assigned its sector-level average value. While this speeds the analysis to some degree, it creates a black box effect in which analyzers cannot trace the source of their values. Additionally, since the sector values are averaged, the actual value within a given building can be significantly higher or lower than the assigned average value.

The ISO contains a shortcomings list similar in nature to that presented for LCA. EIO-LCA does have the benefit of being the national standard, thus being representative of average national cases, but it is also a ‘black box’ analysis. Information enters the analysis data system and is extracted at the end of the analysis. Its internal path is difficult, if not impossible to trace. The greatest concern with this approach is that the paths of embodied energy cannot be readily identified through analysis or calculations. (Treloar G. , 1997)

One exception to EIO-LCA's black box analysis is with respect to other methods. "*In many cases, EIO-LCA can complement other methods*." (Hendrickson, Lave, & Matthews, 2006) Because of its compatibility with other hybrid methods, EIO-LCA can become an assistant method or base method on which to build newer analysis methods.

2.3 DIRECT ENERGY PATHS

Due to the proportionally large number of uncertainty variables in LCA and EIO-LCA methods, hybrid analysis methods were developed to bridge the gaps between the original two methods. The most popular of these hybrids is the Direct Energy Path Assessment Method (DEP). Developed by Treloar (1998), DEP is a hybrid energy analysis method that examines the decomposition of the Energy Input-Output model into mutually exclusive components that are further subdivided into energy stages. This is, of all the methods, the most time consuming analysis since DEP requires a product quantity to obtain results. (Treloar G. , 1998)

So many energy paths exist that an exponential number of paths are required to obtain the final carbon total. In a residential home, for example, Treloar found that 592 direct energy paths existed within the building, all of which total only 90 percent of the overall total construction energy (the embodied energy). The 592 paths only accounted for energy through to Stage 5 as can be seen in Figure 2. To describe 90 percent of the total energy intensity (the operational energy), both direct and indirect, of the residential home, 1748 paths were required. This means that initially with relatively little time, a proportionally high level of accuracy can be obtained, but as time passes and more Stages enter the analysis, the amount of time that must be invested in order to obtain higher levels of accuracy exponentially increases. The final point in Figure 2, that corresponding to Stage 12, is Treloar's theoretical end to infinity. Treloar (1998) believed that once all Energy Paths have been mapped up to Stage 12, then roughly 100 percent of the energy would be identified. (Treloar G. , 1998) In the case of a large agency, it would be impossible and unreasonable to calculate all of the input paths up to Stage 12. As Treloar (1998) calculated, it is only reasonable to determine carbon and energy emissions to the lower Stages, stages 0 through 5, accurately and with a healthy respect for allotted time.

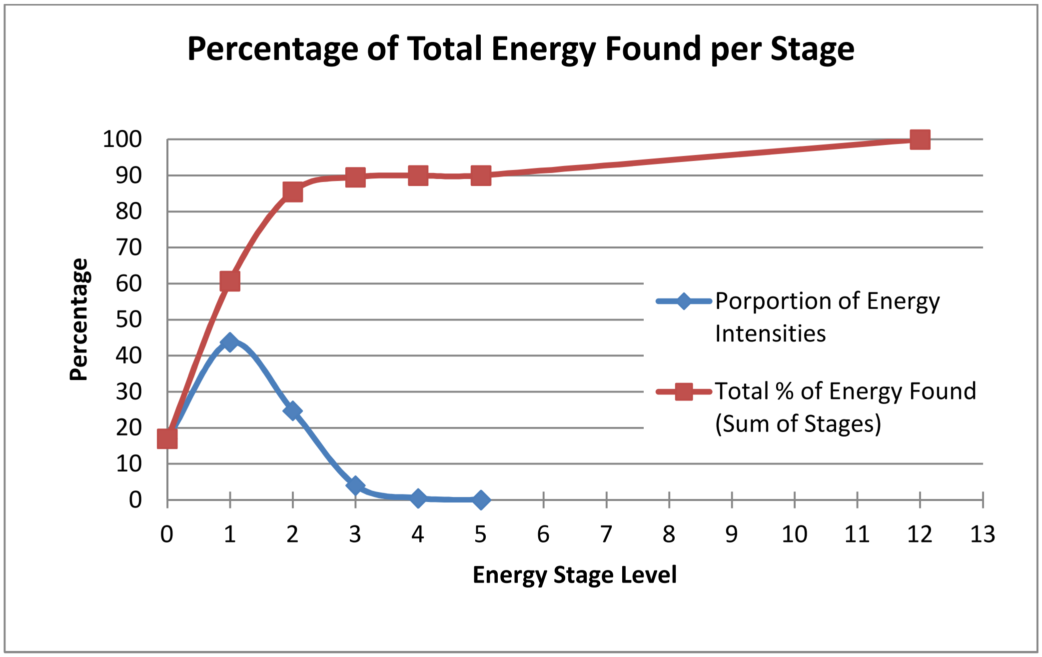


Figure 2: Percentage of Total Energy Found per Stage

To summarize the three common existing analysis methods, Figure 3 illustrates the life cycle phases that each method evaluates. The first two phases represent the energy and carbon that are embodied within the building and its materials. Both phases are documented within all three existing analysis methods. The following two phases, Building Life and O&M are the operational phases in which occupants and the building emit carbon, once again, a well researched and documented area of analysis. The final phase, End of Life, represents the demolition, recycling, or disposal of the building and its components. Though it is part of the total building emissions, it is often left out of many carbon analysis methods including EIO-LCA and DEP.

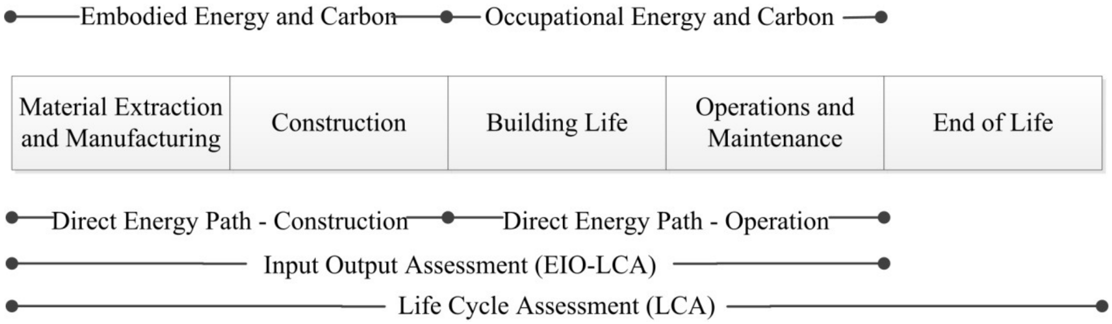


Figure 3: Life Cycle Breakdown and Analysis Methods

Living up to its ‘Life Cycle Analysis’ name, LCA is the only method of the three examined that analyses the whole life of a building. EIO-LCA focuses on the first four phases and excludes most end-of-life values. DEP analyses the same phases as EIO-LCA, but divides the phases into two sections, one for construction energy and carbon and another for the operational energy and carbon.

CHAPTER 3: EVALUATION AND QUALITY OF EXISTING ANALYSIS METHODS

The analysis method chosen, regardless of system, must contribute to the accurate identification of environmental emissions. To analyze large-scale agencies, representative data must be used from a data inventory and then applied to each grouping. For large agencies, the application of resulting policies over a large area, region, state, or nation has been found to be significant, good or bad. (Rosenblum et al 2000) and (Junnila, Horvath, & Guggemos, 2006) Per Figure 4, a method of validation must exist in tandem with data inventory and classification to monitor the final results. It is through this method of validation, cross checking and validating data and categories as the research progresses, which will provide the quality analysis within this study.

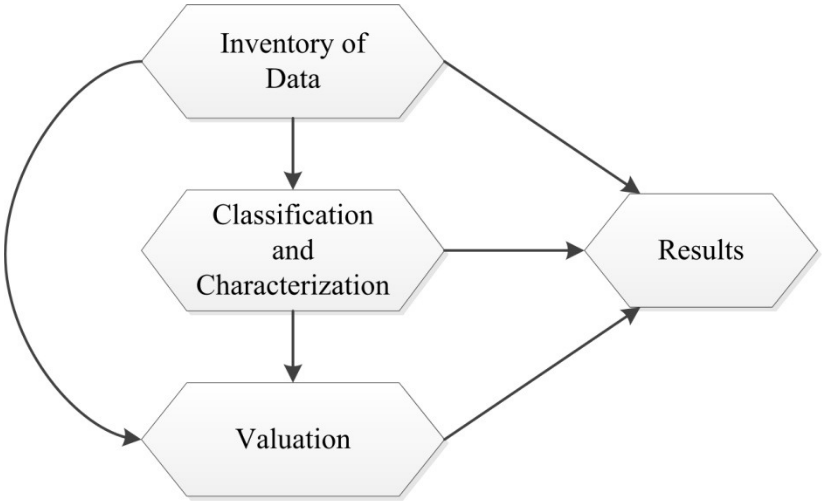


Figure 4: Method of Analysis

Uncertainly is present in all carbon assessments. While it is impossible to completely eliminate uncertainty, it is possible to put the analysis in the hands of individuals who are highly trained. When accurate data, dynamic / nonlinear models, knowledgeable professionals, and a supporting populace are all involved in the analysis, the results will prove far more representative of reality than results from the above elements acting independently. The best choice method must utilize methods to reduce uncertainty in its analysis. Reducing uncertainty is just one portion of the gauging a method's quality. Listed below are additional quality ratings for each method.

3.1 SYSTEM AND DATABASE BOUNDARIES

All analysis methods omit some indirect emissions, those "*emissions upstream and downstream of the supply chain [that are] Scope 3. Because on average more than 75 percent of an industry sector's carbon footprint is attributed to Scope 3 sources, better knowledge of Scope 3 footprints can help organizations pursue emissions mitigation projects not just within their own plants, but also across their supply chain*." (Huang, Weber, & Matthews, 2009) Direct emissions are those emissions that are emitted due to the main process, these are called Level (Treloar G. , 1998), Stage (Treloar G. , 1998), or Scope (Huang, Weber, & Matthews, 2009) 1 emissions. Stage 2 emissions are those direct and indirect emissions generated one step upstream of the main process. Similarly, Stage 3 emissions are one step upstream of the Stage 2 emissions and so forth. (Treloar G. , 1998) Based on Treloar's master thesis, these stages may, theoretically be traced upstream until Stage 12 emissions. At this point, 100 percent of emissions should be accounted for. Everything from employee travel to trash disposal counts toward carbon emissions. Rarely however, are all of these stages included in carbon analysis. It must be noted that with omissions of details such as indirect emissions, carbon values will remain inaccurate representations of the total carbon emissions.

Figure 5 and Figure 6 demonstrate how a single item, in this instance a concrete block wall, produces more carbon emissions than the limited embodied carbon within the material. Figure 5 presents a simplified model in which a few of the stages are represented. Figure 6 details some of the tasks that occur per stage for a concrete block wall. This figure omits possibilities of water or air transportation as well as carbon emissions from reuse, renovations, or additional changes. Though not all inclusive, the complexity of the figure illustrates how difficult finding all carbon emissions routes can become. Figure 6 also shows how all sources of energy, regardless of fuel source, result in carbon emissions.

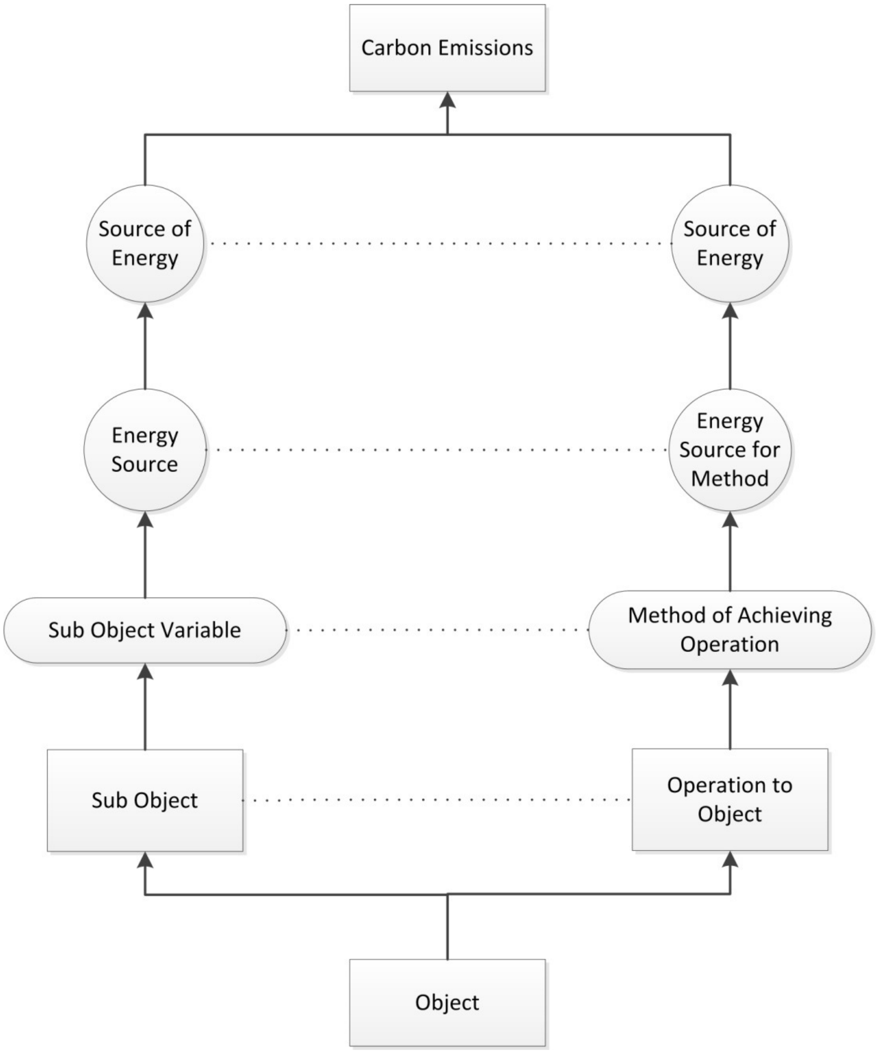


Figure 5: Simplified Energy Flow Chart

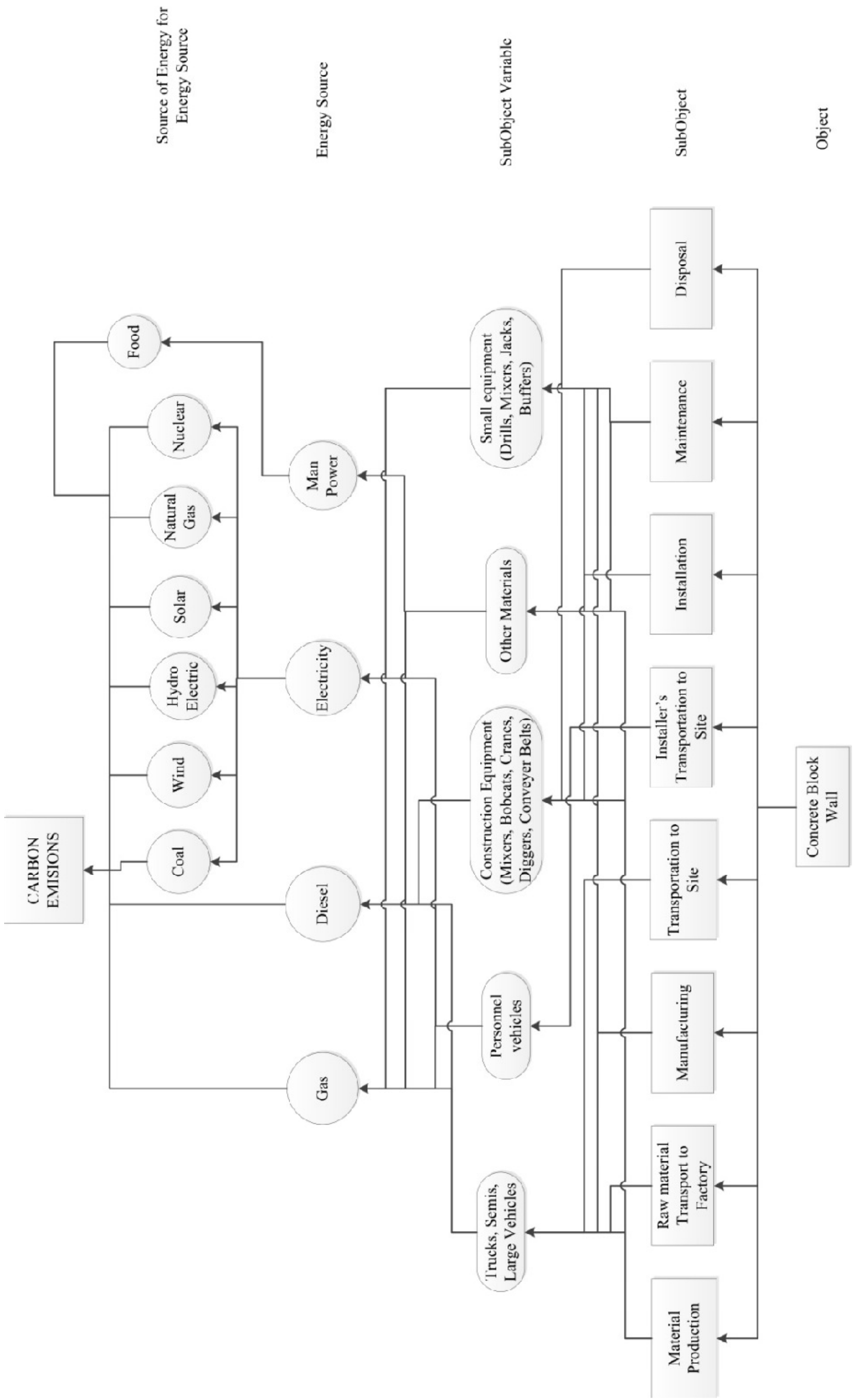


Figure 6: Energy Flow from a Concrete Block Wall

To evaluate an object’s carbon emissions, knowledge of the work done on and to the object must be established. Within Figure 6, sources of energy from coal for the electricity plant to hamburgers for the workers are considered. This complex chart can be simplified down to Figure 5 where the basic levels of energy are represented. Each object or material within a building can be fitted within the chart. The energy is converted into carbon through one of the carbon analysis methods. The resulting energy flows can then be added to flesh out the carbon emissions and energy flow associated with the given object or material. While this method is not complex, the observance of exact and consistent system boundaries obscures otherwise simplistic method.

When researching carbon footprinting, it quickly becomes evident that it is based on building life cycles. The problem is that it isn’t clear where the lifecycle stops or where values originate. For example, some database values include all five stages of a building’s life from cradle to grave, while others only include the past and present energy and carbon values, those that correspond to the first four stages. “*While the ISO 14025 requires the inclusion of all life cycle stages in environmental product declarations, it is still debated how carbon footprinting should, in practice, deal with the use stage for “active products” such as cars and electronics*.” (Weidema et al, 2008) It is difficult if not often impossible to trace the system extents or boundaries of a carbon analysis; therefore, a standard set of system boundaries must exist to ensure a high method quality, regardless of chosen method.

In practice, time and resources are never as abundant as one would wish. Because of the restrictions, practical boundaries need to be established in order to create a consistent and quantitative method for comparative studies (Raynolds, Fraser, & Checkel, 2007) Unreasonable results will occur if some materials track carbon emissions through to their supply lines, upstream Stages, while other materials only contain base material carbon emissions, Stage 0 emissions. A consistent, defined boundary is essential to ensure a quality analysis.

3.2 DATA QUALITY ASSESSMENT

To monitor the data accuracy of the new method, a quantitative quality assessment must be kept throughout the analysis process. To maintain a standard quality assessment, this report will base its data quality from a Pedigree Matrix developed from a matrix by Weidema and Wesnæs (1996) as seen in Table 2.

Table 2: Pedigree Matrix Used for Data Quality Assessment (Based on Weidema and Wesnæs 1996)

	Indicator Score				
Item	1	2	3	4	5
Method of Acquisition	Measured data	Data calculated from measurements	Calculated data from assumptions	Qualified estimate	Nonqualified estimate
Independence of Source	Verified data from independent source	Verified information from source within study	Independent source, but based on unverified information	Unverified information	Unverified information from source within study
Data Representation	Data from sufficient sample of sites over an adequate period to even out normal fluctuations	Data from smaller number of sites but for adequate periods	Data from adequate number of sites, but from shorter periods	Data from adequate number of sites, but shorter periods	Unknown or uncompleted data from smaller number of sites and/or from shorter periods
Time Relevance	Fewer than three years of difference to year of study	Fewer than five years of difference	Fewer than 10 years difference	Fewer than 20 years of difference	Age unknown or more than 20 years of difference
Geographical Representation	Data from area under study	Average data from larger area around studied area	Data from area with similar conditions	Data from area with slightly similar conditions	Data from unknown area or area with very different conditions
Technological Representation	Data from organizations materials under study	Data from materials under study, but from different organizations	Data from materials under study, but from different technology	Data on related materials, but same technology	Data on related materials , but different technology

Using the Pedigree Quality Matrix, Table 3 analyzes the quality of resulting data from each of the three methods assuming that each method, using the same ideal data, is analyzed for a large-scale agency in a quick audit system by a third-party source.

Table 3: Theoretical Method Quality Matrix for KDOT

	Method					
	LCA		EIO-LCA		DEP	
Item	EC	OC	EC	OC	EC	OC
Method of Acquisition	2	2	2	2	2	2
Independence of Source	1	1	1	1	1	1
Data Representation	1	1	1	1	2	1
Time Relevance	2	1	2	1	1	1
Graphical Representation	2	1	2	1	2	1
Technological Representation	2	1	2	1	2	1

* Using a large agency in a quick audit system
* All values come from ideal information from the same source
EC = Embodied Carbon OC = Operational Carbon

The Pedigree Matrix allows agencies to evaluate on a per element basis. While the above matrix is foreshortened, additional categories can and should be added to accommodate specific desired outcomes. Additional agency adjustments can include weighting the quality matrix. "*In a weighted rating system, each measure … is assigned a weight based on its perceived importance in shaping success*" (Thompson, Strickland, & Gamble, 2010). The weights vary based on importance, with high importance factors corresponding to higher values, 0.75, 0.8, etc. And lower importance factors corresponding to lower values, 0.1, 0.25, 0.05, etc. The sum of all of the weights must equal 1.0.

Other statistical analysis methods offer only numeric results. While the numeric results may prove an adequate method of evaluating some agencies, the simplified quality method not only reveals equal amounts of information but also is more easily communicated outside of the engineering discipline to building occupants, owners, and visitors.

CHAPTER 4: PROPOSED LARGE-SCALE AGENCY ANALYSIS METHOD (LSAA)

4.1 NEED FOR NEW METHOD

Large-scale agencies are agencies that possess, operate, or control multiple buildings across an area. They may be as large as a government agency and its thousands of satellite buildings across the nation or as small as a privately owned business with a dozen operations buildings around a metropolis. Often large-scale agencies are those who are among the first to try a new energy, carbon, or cost reduction program, but, due to their size, implementing the new standards is difficult.

The first carbon analysis method, LCA covers all five stages of a building's life and is the most comprehensive of the methods. Its comprehensiveness is the reason it is incompatible with large agencies, due to the inherent time constraints of analysis (Treloar G. , 1998) and lack of full data for each agency building. In order to apply LCA to a large-scale agency, each calculation would need to be repeated hundreds of times. The detail and time required for each building of a large-scale agency makes this method unsuitable for a quick audit method.

Basic EIO-LCA, though capable of utilizing national averages, is unable to determine which buildings within the agency are operating at, below, or above agency average. It is especially difficult to determine if agency buildings as a whole are operating at, below, or above national averages. This means that detailed results for the agency are difficult to procure. Because large-scale agencies often operate their utilities locally, it becomes difficult to impossible to obtain the same data, utilities, and quantities for every building. This fact alone disqualifies basic EIO-LCA methods from large-scale agency assessments.

Direct Energy Paths is the most time consuming of the three methods, but, when applied to a large agency and its many buildings, the energy paths become too complex to track quickly and efficiently. Therefore, DEP is unfit for quick audits of large-scale agencies.

A new analysis method must be developed to quickly and accurately assess the embodied and operational carbon of large-scale agencies and organizations. The aforementioned methods, though each possessing many benefits in their own right, are found deficient when confronted with a limited time and multiple buildings, suppliers, utilities, and regions. The new method must be capable of accurate and reproducible results that work towards the eventual reduction of environmental impacts.

To analyze multiple building sets in a reasonable time frame, the new method must be capable of categorizing and grouping systems into manageable divisions if it is to be considered successful. Divisions should follow the distribution of Carbon and Energy Accounting Elements and their respective databases. Each division must then be answerable to an averaging or normalizing system that portrays the building accurately while also describing all other buildings within the grouping’s spectrum. Examples of such systems can be found under the United States Department of Energy where average values are normalized per square foot of space and are posted for building energy intensities. (U.S. Department of Energy, 2011) Data quality must be representative and of high reliability. As with all previous energy process methods, a hybrid life cycle analysis methods will be needed that borrows working elements of LCA and EIO-LCA and adds additional dimensions to the analysis to solve omissions that occur within the other methods.

Enterprise Carbon Accounting has developed an infant version of an analysis method that utilizes a hybrid of EIO-LCA and basic accounting principles to calculate carbon emissions through the aid of computer software. ECA is still in its initial stages of evolution, and an urgent need exists for more comprehensive and scalable approaches to carbon accounting. As the political spectrum places more emphasis on ECA, more companies are designing solutions to the broader topic of Enterprise Sustainability.

Below is a proposed analysis method that is suited to both large-scale analysis and quick audit systems. The method, called Large-scale Agency Analysis (LSAA) Method, is designed in two parts. The first portion determines the embodied carbon in building materials while the second portion calculates the operational carbon of the buildings from their annual energy consumption.

4.2 LSAA FOR EMBODIED CARBON

To introduce the LSAA method for embodied carbon, the flow chart presented in Figure 7 will detail an outline. The method as a whole can be simplified into five main steps, each represented by a dashed box in the flow chart below. The exception is the results box, which is not counted as a step; rather, it is a result of the successful completion of the other five steps.

1. Initial Set-up and Material Inventory
2. Sort and Categorize
3. Determine Database
4. Calculations
5. Analysis

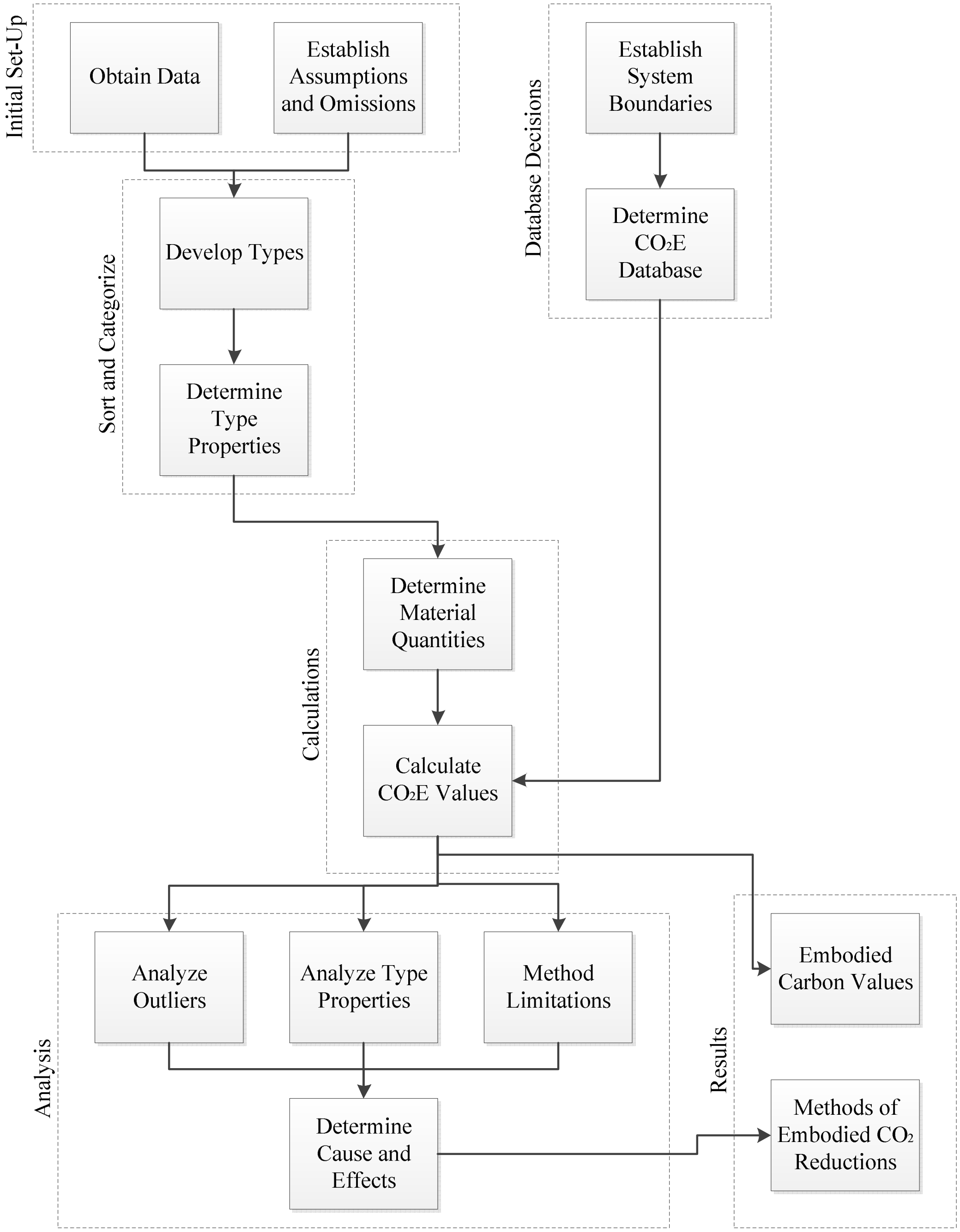


Figure 7: Embodied Carbon Method Flow Chart

4.2.1 STEP 1: DATA COLLECTION AND MATERIAL INVENTORY

Prior to analyzing any data, the data must first be collected and compiled. The following is a basic list of those details needed from all buildings in the agency prior to beginning calculations and analysis to. The following sections will detail the initial setup of the embodied carbon analysis.

System Boundaries

Analyzers must determine what scale of analysis they plan on pursuing. This phase creates the boundaries of the research. While some agencies wish to investigate the carbon emissions of their structures only, others may want to determine their supply line carbon emissions as well. Regardless of the extent of the system analysis, the boundaries must be consistent throughout analysis.

Floor Plans and Site Plans

Floor plans and site plans must be located for all available buildings. Older building plans are not always up-to-date if additions have been made, while other buildings plans are not always available; these buildings require individual site visits. Buildings that will serve as representative members of their Type (Type buildings described shortly) will also require site visits. In general it is good practice to visit a number of the buildings to obtain a feel for the agency and its buildings and operations.

Buildings that are unavailable due to the lack of plans or excessive travel distances will need alternative assessment methods. These methods include, but are not limited to additional floor plans, conversations with tenants, aerial maps, or discussions with builders.

Materials

Generally blue prints will note materials and types. In some cases, such as with older or damaged prints, it is impossible to identify a material or a dimension. In these instances, good judgment or a phone call will be needed. Using knowledge and images from site tours, identification of the unknown materials is often at the researcher's judgment. If the building in question is not a building that was toured, but is a building Type that was toured, the example Type is a practical identifier of the material. If the building and none of its Type were toured, then either a phone call or educated guess will be necessary.

Building Age

Building age is important for the quality and type of materials. Older buildings often have higher quality materials, but lack the insulation that is available in newer buildings. Materials themselves change with age, whether from wear and tear or from technological advance in the materials' construction.

Renovations will be included with the building age. An old office building may be 50 years old but outfitted with five-year-old windows. Alterations can make a drastic difference on a building's carbon footprint because a fifty- year-old building, after renovations, can perform like a ten-year-old building in its energy and carbon use. For this reason, categorizing buildings based on age or latest renovations will prove prudent to later result analysis.

Assumptions and Omissions

Assumptions are inevitable. Regardless of the thoroughness of the survey, some assumptions will be necessary to complete the analysis. When assumptions are required, it is important to only base assumptions on reasonable or standard values.

Likewise, some omissions will be necessary unless the agency is remarkable well documented and accessible. In the case of omissions, the best solution is to document the omissions, note them wherever applicable, and make a special case in which to determine how those omissions would impact the final carbon results. For example, an omission of a few street lights would have a far lesser effect than the omission of all interiors from the analysis.

Adjustments

Adjustments will be necessary.

Analysis will contain elements of unknown data either in the form of assumptions or group categorization. Because most unknowns will result from time constraints, the quick audit becomes a powerful tool. With unlimited time, every employee in every building could be interviewed and every material, dimension, and detail could be checked resulting in the full data needed to run a LCA analysis. But, due to the reality of imposed limits and the availability of data and resources, the LSAA system will prove more adaptable. Make certain to retain flexibility to cope with new or last minute data.

4.2.2 STEP 2: CATEGORY DEVELOPMENT

Results of the new LSAA method will rely heavily on the grouping of buildings into building Types. Calculations will be conducted per Type and then averaged so as to provide a representative value for the building Type. While this method will create some inaccuracy, within the evaluation phase, methods of gauging error will be provided. Due to the use of building Types, buildings within a Type will possess similar characteristics so, through normalization, outlying values will be canceled by outliers to the opposite extreme.

Once buildings have been identified based on size, materials, occupancy, locations, use, and any other influencing factors, the categorization begins.

It is important to begin this section with a clear knowledge of the desired outcome. If the goal of the analysis is to determine the impact of renovations on buildings, then it is important to categorize accordingly. For the renovations example, buildings are grouped in Types based on renovation age or style. Each renovated Type should have a corresponding un-renovated Type so that the two Types can be compared in analysis. Similar groupings can be made for material, use, size, occupancy, or age, though the categories are by no means limited to the presented groups.

Depending on the size of the agency, the types of buildings within the agency, and the flexibility of the analyzer's mind, it is advisable to create cards representing buildings (or sets of similar buildings) to shuffle about in order to optimize organization. By auditioning buildings with others prior to categorizing them, additional categories and connections can be developed that were previously not in the developer's mind.

Categorization

Once a basic categorization scheme has been developed, that explained above, the final categorization must be chosen and organized.

Final choices should naturally group themselves into some form, but it is the responsibility of the one doing the analysis to separate from the clutter an organized tree that is based on the desired outcome and analysis of the agency. The organizational tree will begin at a base level and branch at each consecutive level based on the groupings such as age, occupancy, use, and size. The final limbs of the organizational tree will be the building Types determined in the previous section.

Figure 8 provides a basic example organizational tree. In this sample tree, the buildings are initially divided into wood and metal sheeting and brick, stone, and concrete. The progressing categories include building use, size, age, and finally, the Type. The values in the sample tree are just sample values and do not represent necessary groupings. Pre- and post- 1980, in this example, represent the asbestos break point in construction, while the 2,000 square feet divides small and medium sized structures. LSAA users can create organization and breakpoints in any manner that best suits their agency.

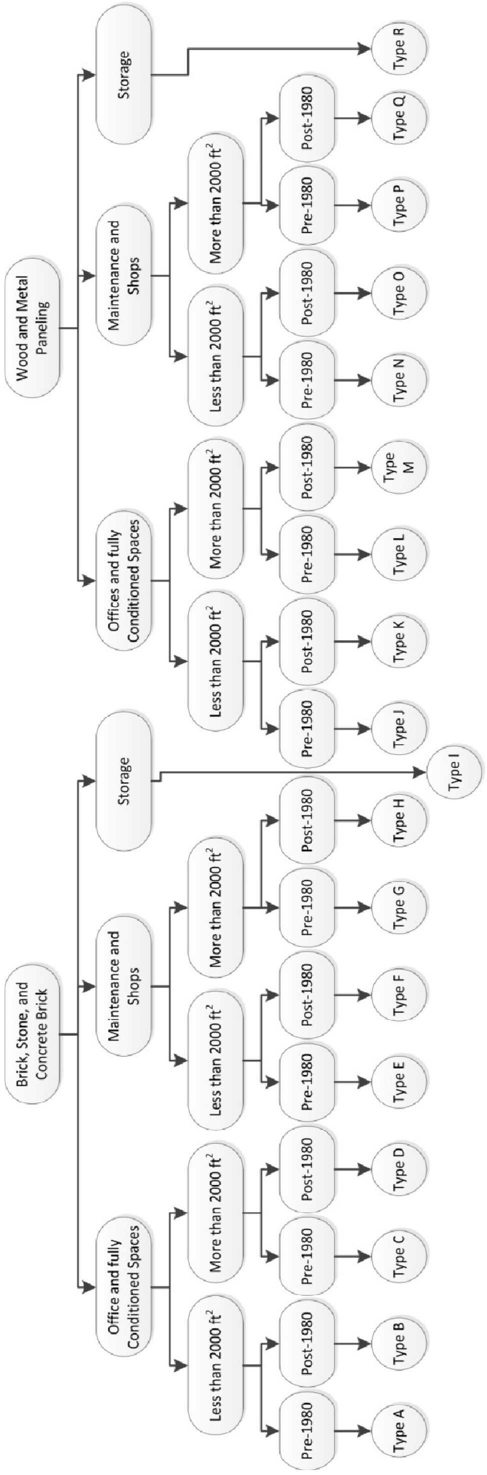


Figure 8: Sample Organizational Tree

Additions at this phase of development will not affect final analysis but it is important to evaluate implications of different type arrangements. Later, this study will fully evaluate the repercussions of varying categorization on the final analysis results.

Evaluation Charts

Once all categorizes have been chosen, evaluative charts must be developed to aid in final calculations. Evaluation charts consist of basic information on building Types, numbers, locations, and the beginnings of a material inventory. These charts can be self developed Excel charts or generated from carbon calculator software. Regardless of the method, details must be tracked on paper or computer from this point onward.

Scope of Elements

The scope is a time and contract dependent element. If an unlimited number of man hours are available, then it is reasonable to evaluate buildings to the square footage of carpet and tile in each building. Time restrictions will cause buildings to be broken into more basic elements such as exterior, foundation, basic interior, roofing, and openings. Though energy is embodied in furniture, given the limited scope, interior furnishings will often be excluded from the total evaluation. This, obviously, decreases the accuracy but in many cases is necessary. If interior furnishings are included, it is imperative that the addition is noted in final result so appropriate comparisons can be made.

Type Properties & Material Itemization

Each Type can be evaluated in many different ways based on time constraints.

If short on time, a single representative building from each Type must be evaluated and assumed to be the Type ideal. This method, though the quickest, is potentially the most inaccurate. In employing this method, one must determine that the single building for analysis is the best representation of the group as a whole.

With additional time, multiple buildings or all buildings within a Type will be analyzed and averaged to create a true Type representation. This allows for extremes to cancel one another and leaves the best average to represent the Building Type.

Once a time-based course is chosen, all material quantities are to be noted based on weight, volume, or area and itemized in the evaluative charts. The most simplified evaluation chart breaks the buildings into individual elements with a corresponding element area. Each material must have a section for its quantity values with a summation of materials at the bottom. Included in each chart should be the total number of buildings that fall within each Building Type.

To calculate the total carbon, additional columns are added to convert material areas or weights into embodied carbon.

4.2.3 STEP 3: CARBON DATABASES

The most important decision for the carbon analysis process, more important than even the categorization, is the choice of carbon equivalent database. Many databases exist that quantify the embodied carbon of materials. (Hammond & Jones,

2008) & (Junnila & Horvath, 2003) All published databases are based on true values; however, differences appear in the geographic locations and method system boundaries.

For a location example, materials from Canada that are delivered to south Florida must be shipped further than those delivered to Wyoming. On a broader scale, proximity to resources differs based on location and culture, such as in Hong Kong, Kathmandu, or Kansas City.

Boundaries create more extreme differences than even locations can produce within a database. While some databases only calculate the embodied energy in manufacturing a material, other databases include the manufacturing, transportation, installation, and construction energies. (Raynolds, Fraser, & Checkel, 2007) Many organizations including the EPA and ICE have developed carbon dioxide emission equivalent databases and will gladly provide example databases.

Database Choice

Divisions in database boundaries such as the one discussed above make carbon comparisons meaningless. The only method to realistically compare separate agencies or buildings is to have both agencies use the same database with the same system boundaries. While this works for a small number of agencies within a given region, comparison on a broad scale remains complicated.

The question of which database to use can be a both simple and complex task. In order for the United States to create a viable carbon credits system, the government must establish a standard database. It becomes a simple matter; the government chooses one of the reliable, thorough, and current databases. This database does not need to be restricted to a specific boundary condition so long as it uses the same, consistent boundary throughout its calculations. This database would then act as the national comparison database. The only accommodating element is that the database is broad enough to cover all regions within its adopted expanse. On an international basis, the same standard applies: consistency. If the United Nations, or a governing international body, chooses a standard prior to the United States' adoption of one, then it would be good practice for the United States to adopt the international standard as the national standard to avoid confusion or the need to conduct duplicate calculations.

For the time being, until a standard database is established, it would be advisable for agencies to use the same database that competitors are using. Companies of a similar size or use can all use the same database so that, within their group, comparisons would act as equivalent representations of their carbon emissions.

4.2.4 STEP 4: CALCULATIONS

Evaluation Charts

Most of the carbon databases present embodied carbon in either tons of carbon per volume, weight, or area of materials. In any of these cases, it is possible, using the pre-established knowledge and assumptions, to convert between areas, volumes, and weights of materials using basic mathematics.

Once the required weight of carbon per unit has been calculated, the final calculations are simple. Multiply the weight of carbon per unit with the number of material units within the buildings, repeating this formula for each material. A total of the resulting carbon will produce the carbon emissions of the calculated buildings.

It is important to note that the calculations are not difficult to perform. The emphasis and effort within this method is the organization, collection, and analysis of the data

4.2.5 STEP 5: ANALYSIS

Analysis occurs on a series of levels. First, it is the responsibility of the data collector to analyze Building Types for illogical placements or groupings. The groupings can minimally influence final results. Manipulation of numbers is critical to final results so accurate equations and carbon conversions must be ensured by the managing member of the group.

One final element of the analysis is the usefulness of the quick audit method. This analysis may take the form of a post evaluation similar to the one Bohlin uses to determine the effects of carbon taxes on the population. A variation, presented below, of his evaluation sheet can be used to determine the effects of monitoring and reducing carbon within a large-scale agency.

(Bohlin, 1998):

1. Environmental efficiency - To what extent has the quick audit had the intended environmental effect?
2. Cost effectiveness - Has the audit met its environmental objective at a competitive cost?

3. Revenues – Are they important and how are they used?
4. Wider economic effects – To what extent has the audit influenced price levels, competitiveness, and employment?
5. Dynamic effects and innovation – To what extent has the audit stimulated innovation and other dynamic effects?
6. What would happen without the quick audit?

Efficiency asks if the quick audit has the desired outcome. If the audit proves more difficult than the original life cycle analysis methods, then it is no longer serving its purpose. The same may be said about the audit's cost effectiveness. It is important for businesses that this method helps turn a profit, not a loss. If revenue is to be earned from the audit, it is important that plans are made to manage the funds appropriately.

Investigating the wider effect of carbon audits will help evaluate the final performance and legitimacy of the audit. Goals such as community involvement, cost savings, inter-corporation competition, or social standing will vary since all goals are agency dependent. Some agencies are looking for environmental savings while others look for political gains or economic savings. It is part of the post analysis to determine if the goals set for the quick audit were achieved.

Verifying Legitimacy

Verification of legitimacy is crucial to establishing an accepted carbon emissions value. A number of methods can be employed to work towards proving legitimacy but will never erase all doubt from quick audit calculations.

One method requires that a full LCA or other carbon accounting method be used on a number of buildings from within the Building Types. Comparison of existing method results to quick audit results will help identify areas where LSAA results are higher or lower than should be expected. This method of cross checking is quite accurate, assuming the use of LCA or EIO-LCA is correct. Difficulty occurs when time constraints restrict the use of full evaluation methods and require quick audits to validate quick audits.

Testing values against known values presents another solution. Energy Benchmarking of Buildings and Industries suggests using "*peer groups*", similar to Building Types. (Lawrence Berkley National Labratory, 2011) If one building has a recent and known carbon emissions value, that value may be compared to quick audit values to determine the quick audit's accuracy. If other buildings with similar use, size, and construction have known values, it would be reasonable to examine their values in order to place one's own evaluation.

Method Limitations

Limitations to the quick audit for large-scale agencies are based on data and averages. Large gaps in data will result in less accurate results. Because the quick audit relies on Building Types, or peer groups, the method of finding averages will cause some inaccuracies in the data. Through the use of good choice, most averaging inaccuracies can be minimized.

4.3 LSAA FOR OPERATIONAL CARBON

The second half of the LSAA method is accounting for the operational carbon emissions produced from the day to day life of a building. Operational carbon is the carbon emissions that are produced due to occupying a building. This includes energy used to heat and cool, run equipment, operate computers, and power lights. Operational carbon is calculated though the conversion of operational energy into its resulting carbon.

Figure 9 presents a flow chart for the Operational Carbon side of LSAA. Similar to the Embodied Carbon section, LSAA for OC contains five simplified steps that are each denoted by a dashed box in the flow chart.

1. Initial Set-up and Material Inventory
2. Sort and Categorize
3. Determine Database
4. Calculations
5. Analysis

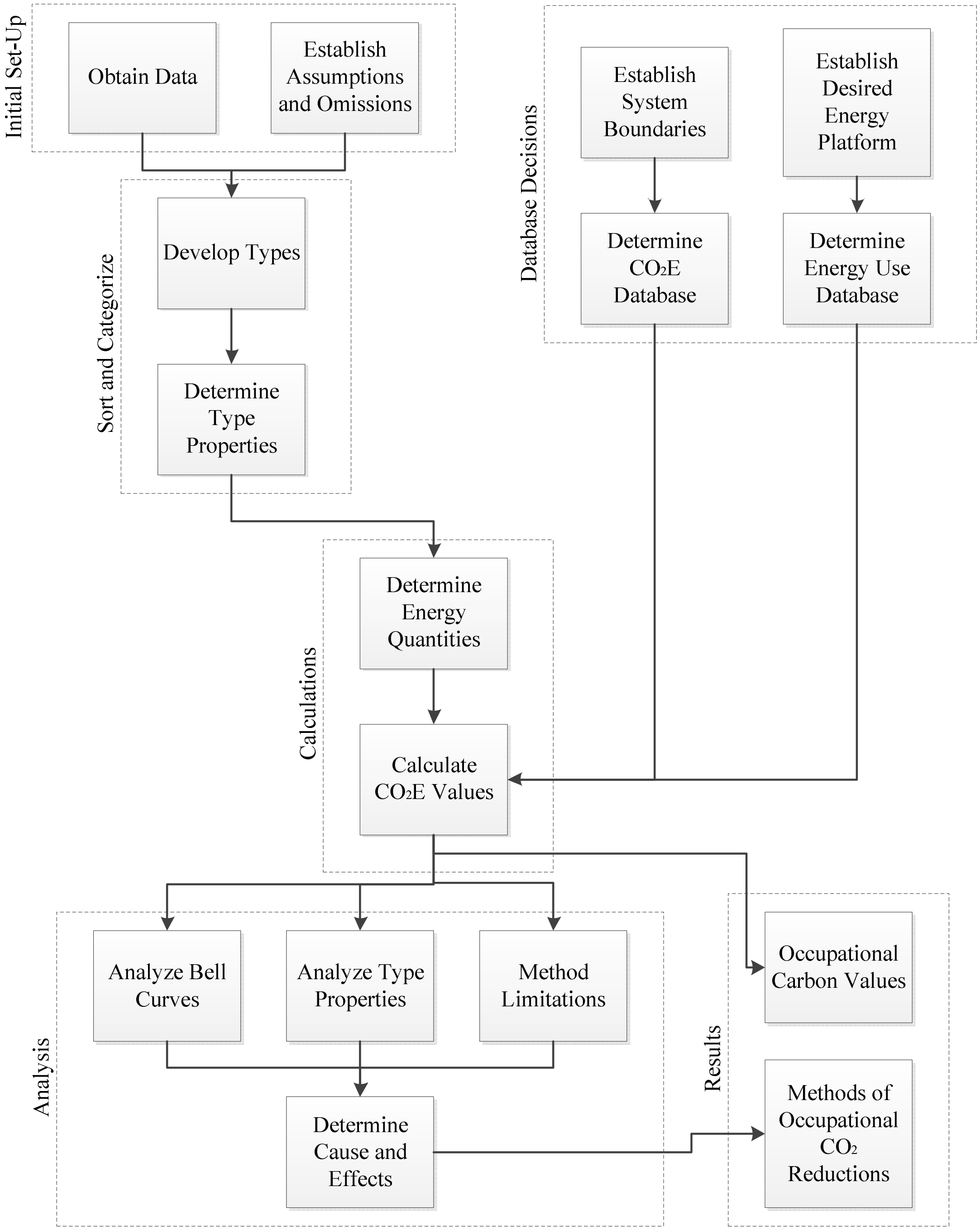


Figure 9: Operational Carbon Method Flow Chart

Operational carbon is the largest portion of carbon emissions emitted by a building. (Junnila & Horvath, 2003) While embodied carbon covers the carbon used to produce and install materials, their construction, and installation, occupation carbon includes minor maintenance, electrical services, heating services, and other services within the building.

Only energy use data is required to calculate operational energy, but, in order to analyze operational carbon usage, definitions of strategies, plans, possible reductions, and objectives must be formulated to make use of the resulting calculated results. This portion of LSAA method outlines how to obtain energy data for a large agency and then describes methods to evaluate the results.

4.3.1 STEP 1: DATA COLLECTION

Utility Accounts

The first and arguably most time consuming task within the OC energy analysis, is obtaining the required data. For this portion, utility information for all accounts within the agency must be amassed from each of the supplying utility companies. Large buildings and campuses are often contained under a single account number but can be broken into several smaller accounts. Each account then consists of multiple meters.

Some large-scale utility providers may hold many of the agency's accounts, in which case obtaining the account information in mass will proceed quickly. Other agencies use small, local utility providers, in which case many phone calls will be necessary to obtain the data. When contacting providers, four key pieces of information are required:

1. Years
2. Locations
3. Value Quantities (costs and power quantities)
4. Meter Details and Extents

Based on the intent of the analysis, either a long term energy value or a current energy value is needed. If a long term value is required, then seeking utility records from the past decade would prove beneficial. Younger buildings do not often have ten years' worth of data, but obtaining records from the present billing period to the first billing date will be adequate. For current energy analysis, a span of three to five years will provide a strong averaged value for the analysis.

Each account number is then assigned to its corresponding address. Some addresses, such as those attached to large campuses, contain multiple account numbers with multiple meter numbers per account, so if possible, it is important to obtain as much meter data as the utility provider has available. An alternative is to sum the meter values to create a total value per account number rather than meter number, though this lowers the resolution of the results.

Origin of Energy

Depending on the utility companies in the area, detailed source data may or may not be available to the general public for the desired region. Energy source data represents the sources the power is drawn from. Some combination of electricity, coal, nuclear, hydroelectric, wind, and solar power are usually combined to make up the total power provided by the utility. Oils and gases are also used for energy and can be included in the analysis. Often gases, especially those housed in portable tanks, are forgotten in large-scale analysis.

This element of analysis is a time dependent variable that can be excluded if time constraints limit analysis time. If time is available, energy source information adds an intriguing dimension to the analysis. For example, some electrical companies supply 100 percent of their electricity from coal fired plants while others use nuclear power. Depending on the region, solar, wind, or hydroelectric power may supplement the US standard coal power. Some areas even use the aforementioned alternatives as their primary power. Data for this section is often calculated by the region, city, state, or nation, but if the agency operates outside of a pre-established area, then quantities and percentages will need to be individually calculated by researchers.

Since energy can be converted into equivalent carbon dioxide emissions, some energy suppliers provide a lower carbon footprint than others. Through the inclusion of source information, agencies that have a choice of power companies can use the information to make more educated choices for future utility providers.

Occupancy

Occupancy is not needed for the calculations, but it is an integral part of the final analysis for operational carbon.

What is the expected and actual occupancy of each building? Some buildings are designed to comfortably house dozens of people; however, those individuals may rarely if ever be in the facility during operating hours because their work is on the road or traveling. Circumstances such as these require a conversation with a member of the building rather than a member of payroll.

Offices tend to be the simplest buildings to obtain occupancy values for since each employee tends to occupy a given space and may thus be counted. Occupants in these areas may be divided into full time and part time occupants. Payroll employees can provide these numbers per building. Other Building Types may prove more difficult to tract occupancy values for. In these instances, conversations with actual occupants result in more accurate data.

Building Age

Building age does not factor into the energy calculations as it did with the carbon content of materials in the carbon analysis. Rather, building age aids in the final analysis of energy results. By being able to attribute ages to buildings, correlations emerge between age and energy use. Buchanan and Honey (1994) found that "*industrial processes and economic activities vary widely between countries.* [For example] *Modern factories are generally far more energy-efficient than older ones, as a result of recent concerns about energy efficiency and carbon emissions*" (Buchanan & Honey, 1994)

Energy analysis helps large-scale agencies identify buildings, machinery, or campuses that are performing below or above average. Whether below or above average for the company-wide standard, the regional standard, or the international standard is unimportant in this phase of the analysis. Identification occurs within the final analysis. What matters in this phase is the identification of a problem based on a correctable issue.

Operation and Maintenance

Operations and Maintenance (O&M) is divided into two categories: maintenance of the facilities and daily operations. Maintenance includes the state of equipment and materials. This categorizes and details items such as functioning furnace burners, the numbers of burned out lights, the presence of cracked windows, and dirty air filters. All of these maintenance issues will result in poor efficiency in an otherwise highly functioning building.

Operations are those activities that are repeated on a regular basis. Are maintenance problems fixed immediately or left until they cause a problem? Operations require conversations with employees and maintenance officials to determine daily conditions. Some offices operate under the motto of energy efficiency, some under cost savings, while others operate under employee comfort. While these examples are not mutually exclusive, often they represent drastically different uses of energy within the building.

The O&M of buildings does not directly factor into the energy analysis; it becomes a cause behind the result. Buildings that have unexpectedly high energy values are often the buildings that have broken, old, or out of date equipment and facilities while buildings with low energy values often are the buildings with high levels of insulation and efficient equipment.

Maintaining O&M tracking sheets is a time consuming task, but it allows for conclusive causes to energy intensity values.

Building Usage

Building usage is determined by the actual use of the building rather than the intended or built use. It is important to contact occupants to discern the exact use of the space. The building usage field separates buildings based on energy usage and space conditioning. Office spaces are typically high energy / high conditioned spaces while a shop, though high energy due to equipment is often low conditioning. It is good practice to speak to tenants to see if the building plans are portraying an accurate building usage.

Prior to passing final judgment on any building or facility, it is imperative that researchers know the use of the building. Without building usage, a building with an energy intensity of 93 thousand Btu per square foot would seem perfectly average for an office building, based on current US Department of Energy values. If the building was operating as an office, then the energy value is to be expected. If the building was operating as a warehouse though, 93,000 Btu would be over twice the expected energy intensity. By knowing the use of the building, researchers may determine if the resulting energy intensity is above average, at the standard, or below average.

Policy and Practices within Buildings

Policies and practices is the most variable of the data to be collected. This category includes small details that make large impacts on total energy consumption.

Space conditioning is the single greatest energy consumer. Within residential homes, space conditioning, heating and cooling, consumes 44 percent of the total energy used within the home (Gardner & Stern, 2008). For this reason it is important to note if occupants alter their interior temperatures based on exterior temperatures. Are temperatures kept cooler in winter and hotter in summer? Are individual employees permitted thermostat control? Does the space receive air conditioning and/or heat? Most importantly, are extreme temperatures acceptable, inevitable, unavoidable, or intolerable? While a shop worker might expect to wear gloves in winter and return home sweaty in the summer, a high level office worker would not tolerate fluctuations in temperature. National, regional, or office culture differences can also impact expectations and requirements.

Some companies employ polices directed at individual employee energy use. Many companies employ a "*lights-out*" policy that forces lights to be turned off when no one is in a room. Some offices turn off lights on hot sunny days as well to lower the energy and heat drawn from the bulbs. Some areas utilize the windows rather than the thermostat to control the temperature. Is window use by one employee causing another employee to overuse the thermostat or is window use mutually useful? Is equipment left running even when no occupants are in the area? When equipment is faulty or needs to be replaced, are the replacements more energy efficient or more cost effective?

Assumptions and Omissions

It is rare to find a large-scale organization that is able to, in a short time, obtain all requested data. Because of this, assumptions and omissions will be inevitable to some degree. In this instance, it is important to document and note all assumptions and omissions so the repercussions can be traced through to the results.

4.3.2 STEP 2: CATEGORY DEVELOPMENT

Grouping buildings based on conditioning and energy demands is a simple but powerful method to assess a building's energy intensity values. Some buildings, such as offices have a highly conditioned spaces and a high energy draw, due to equipment and computers while other buildings such as a mechanic's shop have low space conditioning but still maintain a high energy draw due to the use of power tools and equipment.

The best grouping method for this portion of the analysis is found under the Commercial Building Floor Space Energy Consumption and Energy Intensity by Building Activity chart provided by the US Department of Energy (DOE) in the 2010 Buildings Energy Data Book. The DOE publishes representative energy intensities for standard operations buildings. (U.S. Department of Energy, 2011) These values act as a model for comparison within the United States. To make the best use of the provided assets, it is good practice to assign building usage based on the categories presented in the Building Energy Data Book so that a comparison value is readily available.

Impact of Units

For much of this section the Energy Use Intensity (EUI) will be used. "[EUI] *is a unit of measurement that describes a building's energy use. EUI represents the energy consumed by a building relative to its size*." (Energy Star, 2011) "*EUI's are an attempt to normalize energy use relative to a primary determinant of energy use* (building floor area in this case) *such that the energy use of many buildings is comparable. By normalizing out primary determinants, it is hoped that wide differences between building EUI's will be indicators of inefficient buildings of systems where improvements can be made*." (Sharp, 1996)

Units of energy are calculated in the energy per square foot of the building. "*Expressed as kWh/sqft, it* [energy intensity] *is the preferred unit of analysis for commercial end-use [that] demands forecasting*." (Eto, 1990) "*The way that the carbon footprint results are presented to the consumer is an important issue. Today, the unit of measure for most results is* CO_2 *equivalents per product*." (Weidema et al, 2008)

Another unit, also commonly used by the DOE, is the Btu per square foot. The US Department of Energy favors this unit as it is comparable with work conducted in British founded nations. Regardless of the final unit involved, the division of total energy over the building footprint standardizes the value to ease future comparisons.

Categorization

The method of categorization is the same as that for the carbon portion of the analysis. Careful choice of categorizes can simplify or complicate the final energy analysis values, so some amount of time must be devoted to grouping buildings and campuses into like Types.

If final energy results are to be compared to another agency or organization, it is preferable to use a categorization similar to that of the buildings the agency wants to be compared to. By creating similar building divisions, the final results will prove comparable without additional calculations. If the agency is unsure of who would act as a comparable model, the US DOE publishes an Annual Building Energy Data Book that provides normalized energy intensities for commercial buildings. The published categories act as strong starting organization methods. (U.S. Department of Energy, 2011)

Final category choices will be determined prior to beginning data calculations. If changes are made to the categories after calculations have begun, rework will be necessary. To simplify data analysis, a short listing of the categories with their call name or number should be listed separately from the database so as to provide a quick reference while entering types into the final spread sheets.

Final organization is based on the desired traits to be examined in the results. If the user wishes to evaluate different energy intensities based on district, then the grouping needs to be based on district. Likewise building type, region, size, and renovation level can prove to be useful categories.

4.3.3 STEP 3: CONVERSION DATABASE

In order to compare the embodied carbon from the first analysis method with the operational carbon of the second method, both sets of results must be presented in the same units. For this analysis, tones of carbon will be the common unit.

All forms of energy from grid electricity to industrial coal are converted into carbon equivalents through the use of charts, such as the example one in Table 4.

Table 4: Conversion Chart for Energy Forms into CO_2E's

Energy Source	Units	Kg CO_2E per unit
Grid Electricity	kWh	0.54522
Natural Gas	kWh	0.18523
LPG	kWh	0.21445
	liters	1.492
Gas Oil	kWh	0.27533
	liters	3.0212
Fuel Oil	kWh	0.26592
	tons	3219.7
Burning Oil	kWh	0.24683
	tons	3164.9
Diesel	kWh	0.25301
	liters	2.672
Petrol	kWh	0.24176
	liters	2.322
Industrial Coal	kWh	0.32227
	tons	2336.5
Wood Pellets	kWh	0.03895
	tons	183.93

Provided by (Carbon Trust, 2011)

4.3.4 STEP 4: CALCULATIONS

Calculations begin by calculating the monthly utility averages. This allowed for seasonal variations to appear. The average is then graphed alongside the yearly values to produce the first of a series of comparative charts.

Conversion from units of energy, kWh, into tons of carbon is a simple calculation based on an equivalent value presented by a third party research firm such as the DOE or EPA. Complications arise when exact values must be determined. Until a national standard, or nationally approved regional standard, is established it is up to the researcher to determine a comparable, representative database from which to draw a conversion value. Once the researcher has energy converted into tons of carbon emissions, the data can easily be manipulated through normalization, comparison, or application.

Evaluation Charts

Data must be organized per building, meter, or campus, depending on the supplied information from the utility providers. Each year of data should be listed along with the twelve months worth of energy draw and resulting costs. Though the costs are not initially intended for analysis, they prove interesting from a comparison standpoint later in the analysis.

Evaluating Legitimacy

Legitimacy of results will be evaluated on a per building basis. The energy analysis system is less of a quick audit system than the carbon analysis because of the inherent characteristics of OC. OC, in and of itself tends to be a faster calculation set than EC. Because exact energy values per building are available, it is a simple matter to average the energy quantities over a period of time and divide the quantity by the building's floor area.

This simple and quick calculation can be used to evaluate the accuracy of results. In many cases, once the energy evaluation has been completed, certain buildings exhibit higher or lower intensities than the average. These buildings are ideal candidates for a legitimacy evaluation to determine if the outlying value represents a true problem, a misplacement of Building Type, or just a rounding error.

4.3.5 STEP 5: ANALYSIS

Initial analysis of the operational carbon values can be broken into three main methods. These methods consist of the Statistical, the Input-Output, and the Process Analysis Methods. (Alcorn & Baird, 1996)

The Statistical Analysis Method uses published statistics to compare industries, as was done for the Energy Intensities by the Energy Administration (EIA values). This method is only useful in industries where consistent, thorough, and up-to-date statistics are available. Fortunately for the United States, the DOE has published the required results, thus making the statistical method easily accessible to all large-scale agencies.

Input-Output Analysis Method utilizes the economy to determine energy flows based on the flow of money per sector. While this method is capable of nationwide analysis, its disadvantages lie in the approximation of energy into monetary values.

In large regions, such as the US, the monetary value of energy varies depending on location, rendering this method unsuitable for large-scale agencies spread across large regions. Even within the United States, the cost per kWh for electricity in 2007 varied from $0.0657 per kWh in Kentucky to $0.2070 per kWh in Hawaii. (State Electricity and Emissions Rate, 2007)

The final method, Process Analysis, is the most accurate of the three methods since it tracks direct and indirect energy flows. The problem with this method arises in the time and effort required to achieve usable results.

While hybrid analysis methods exist, they remain based off the three original energy analysis methods and generally contain disadvantages similar to those found in the original methods.

Analysis Method

Final analysis, that which dissects method results to obtain locations for CO_2 reductions takes place through a number of techniques. First and foremost however, it is up to the researcher to determine his or her preferred method and work from that point. This section will describe methods to analyze operational carbon emissions.

The most prominent technique in the environmentally-aware researcher's repertoire is the ISO 14000. While ISO 14000 does not specify levels of performance or required guidelines, it does present good practices, standards, and suggestions to aid in environmental analysis. In particular, ISO 14001:2004 is "*a management tool enabling an organization of any size or type to: 1) Identify and control the* *environmental impact of its activities, products or services, 2) improve its environmental performance continually, and 3) implement a systematic approach to setting environmental objectives and targets, to achieving these, and to demonstrating that they have been achieved*." (ISO, 2011)

In the past few years the International Organization for Standardization has published ISO 19011: Guidelines to Quality and Environmental Management Systems Auditing. ISO 19011 is intended to "*supersede a number of standards, including ISO 14010, 11, and 12*." (ISO, 2007) Once again, while not presenting regulations for methods, "*BS EN ISO 19011:2002 … offers guidelines for quality and/or environmental management systems auditing. It is intended that by using this new standard, organizations can save time, effort, and money*." (ISO, 2002)

A visual method of analyzing results is described in the following section on the development of bell curves.

Developing Bell Curves

The discussion on result legitimacy prompts the question of what purpose categorization serves within the energy audit. If simple calculations can obtain the desired energy intensities, the use of grouping only introduces new variables. The benefits of categorization are found at the end of the energy audit. Once buildings and campuses have obtained energy intensity values, those values are combined to form a bell curve to analyze an agency's own buildings.

Each Building Type receives its own bell curve with individual Type members plotted along side. Through this comparison, outliers can be quickly identified.

Comparison of an agency's building and an average building value such as those provided by the DOE only provides the agency's standing based on the national average. If an agency prides itself on high performing buildings, then identification of agency-wide outliers would aid in increasing the overall performance of the agency. The same remains true for agencies that perform below the standard. For agencies that operate under a strict budget, identification of its own outliers helps it to remedy the most problematic buildings first and work upward as the budget allows.

Once the bell curve is developed, outliers become readily apparent. They appear as buildings that plot at the highest or lowest ends of the bell. Those that plot at the low end of the chart are those buildings that should be used as example buildings when renovating or adjusting other buildings within the Type. Exceptions arise when the high, or low, plotted buildings are buildings that do not adequately fit within the building or campus Type. In this instance, those buildings should be reevaluated for correct Type properties.

Buildings that are plotted at the high end of the bell curve are those buildings that need immediate attention because they are drawing more energy per area than similar buildings. Whether changes are in the form of adjusted thermostats, closed doors and windows, or new insulation and renovations, it is up to the building users and officials to determine the best corrective course of action. Once again, it is important to note that some buildings are not true outliers as it is possible to have incorrectly categorized them in the initial method steps.

4.4 LSAA ANALYSIS

4.4.1 COMPARING EMBODIED AND OPERATIONAL CARBON TO THE TOTAL EMISSIONS

Thus far, this study has calculated embodied and operational carbon values separately. For this study, the separation was an organizational aid. In practice, all carbon dioxide emissions remain carbon dioxide emissions regardless of source. This section converts the remaining operational carbon into CO_2E values and then compares those values to the embodied carbon results previously established.

4.4.2 LIFE TIME COMPARISON

It is critical to assess buildings over their lifetime rather than just over a single year or set of years. Buildings wear, age, and eventual become obsolete. The difference is that buildings that no longer serve their purpose can be recycled. Figure 10, presented by Junnila's study of the Life Cycle of an office building, breaks the CO_2 emissions emitted over the life of the building into sections based on the source of the emissions. The majority, over 50 percent, of the carbon emissions come from electrical draw. (Junnila & Horvath, 2003)

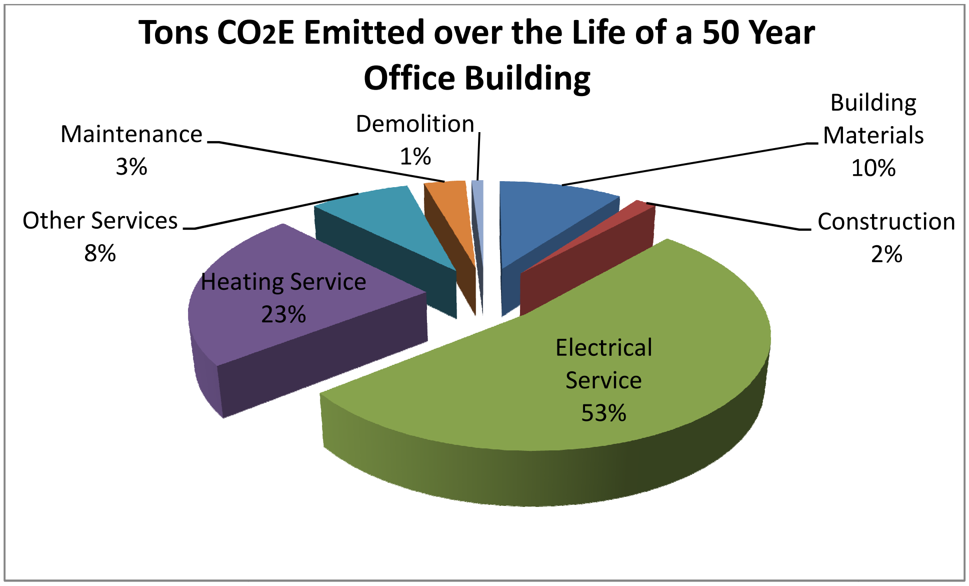


Figure 10: Tons of CO_2 Emitted over the Life of a 50 yr Office Building (based on values from (Junnila & Horvath, 2003))

In order to assess the carbon emissions over the life of the building, a linear equation must be used. It is recognized that as renovations, standard aging, and changes in efficiency evolve over time, the OC value will change. Though this equation is based on the assumption that the operational carbon value will remain constant over the given time frame, the future estimate does represent a best guess value for carbon emissions. It must be noted that the quantity of carbon at any given year is roughly the sum of the initial embodied carbon added to the carbon emissions for each year starting at the baseline year and ending at the given year.

Total carbon = Embodied carbon + (Operational carbon * Years of occupation)

$$TC = EC + (OC*Y)$$

- TC = Total Carbon of Building
- EC = Embodied Carbon within Building
- OC = Operational Carbon per Year
- Y = Years of Occupation

Due to knowledge of the high impact of operational carbon emissions over the low impact of embodied carbon, it is important that care and educated decisions are responsible for choosing those factors that impact operational carbon emissions. Fortunately for building occupants, the operational emissions are the one field that is most easily manipulated by the occupants. Attention to where and how energy is used will result in the ability to further reduce carbon emissions.

CHAPTER 5: LSAA CASE VALIDATION

This study validates the new Large-Scale Agency Analysis (LSAA) method by examining the Kansas Department of Transportation's (KDOT) buildings for energy use and embodied and emitted. The new method will be put through a quality analysis and comparison testing to determine if the quick audit system designed for LSAA is an adequate alternative for more time consuming methods when analyzing large-scale agencies for a quick audit system.

KDOT is a complex, large-scale, state agency. The agency owns, operates, and inhabits 941 buildings of varying size across 265 campuses throughout the state of Kansas. The agency has allocated 0.4 percent of the state highway funds toward its buildings; budgeting is critical to the agency. With a budget of $1,362,700,000 for the entire agency in 2010 and $1,040,900,000 in 2011, buildings receive a mere $5,450,900 and $4,163,800 for the fiscal years 2010 and 2011, respectively. (Kansas Department of Transportation, 2009) In their efforts to save money on the maintenance of the 941 buildings, reduce costs, and improve operations, KDOT has undertaken an agency wide analysis of carbon emissions. For KDOT, the goal of this analysis is to improve operations within the agency as well as establish a baseline carbon emissions value prior to state or federal enforcement of carbon credits.

5.1 EMBODIED CARBON

5.1.1 STEP 1: DATA COLLECTION

System Boundaries

The System boundaries for KDOT are set quite narrowly. This is due to the restrictive schedule and labor constraints. Likewise, this caused the transportation carbon accounting (TCA) to be excluded since it falls outside the scope of this particular analysis. Similarly, supply lines are not included within the system boundaries of this example.

Floor Plans and Site Plans

KDOT provided a disk containing all building floor plans in their known records. While this disk contained hundreds of plans, many were badly damaged by age. In particular, one set of old blue prints, or what was assumed to be old blue prints, resembled paper that had passed through a washing machine, with the only coloration being in clouded patches.

The scanned in PDF files only contained one or two drawing of each building, which, conveyed the intent of the building well enough, but was not always adequate for a full assessment. In the end, the site tours proved the key to the plans. Once each building was identified based on photographs from site tours, or similarity to photographed buildings, floor plans and building areas could be determined.

Site plans for KDOT were not recorded in any data provided by KDOT. Though the information was invariably in their records somewhere, the individuals gathering information from within the agency were not able to locate it. Therefore, Google maps were used as a close companion. Aerial images from satellites provided building orientation, proximities, and campus compositions. Comparing the aerial data to the known data provided the missing information.

Building Age

Building age was determined, if able, from the blue prints. KDOT buildings were built in roughly two main time frames. Initial buildings were constructed in around 1930's with a second large batch built around the 1960's.

Though this time break sounded ideal for a comparison, the uniform process of updates and renovations combined with the relatively timeless stone and concrete block obscured any age related discrepancies. A few buildings, built in the last 5 years did exist, but their inherent newness prevented them from possessing any accessible data.

Assumptions and Omissions

Within KDOT, many blue prints and records were either missing or grossly out-of-date. To fulfill the required values, the following table of assumptions was used. Based on the assumed thickness of the material, a weight per area was calculated. This value is important since many of the carbon databases present carbon quantities in tons of carbon per ton of material. Through the conversion found in Table 5, later calculation sheets, as will be demonstrated, only required a single multiplier.

Table 5: Material Assumptions

Material	Thickness	Weight per area		Other Notes
Plaster	15.88 mm	13.48	kg/m^2	
Glass	3.18 mm	8.19	kg/m^2	single pane
	54 mm	16.38	kg/m^2	double pane with 3.2 to 6.4 mm air gap
Gravel	101.6 mm	170.88	kg/m^2	
Common Red Brick	standard	195.30	kg/m^2	101.6 x 67.7 x 203.2 mm
Cast Iron	6.35 mm	45.77	kg/m^2	
Rolled Steel	9.53 mm	75.53	kg/m^2	
Wood	50.8 mm	13.43	kg/m^2	solid doors
Sandstone	203.2 mm	472.13	kg/m^2	value used
	304.8 mm	707.95	kg/m^2	not standard assumption
Concrete Wall	152.4 mm	361.30	kg/m^2	not standard assumption
	203.2 mm	481.90	kg/m^2	value used
	304.8 mm	722.60	kg/m^2	not standard assumption
Fiberglass		4.88	kg/m^2	Assumption
Shingles		4.88	kg/m^2	Assume soft wood
Siding		4.88	kg/m^2	Assume heavy duty plastic siding

Based on information from (Forming and Framing) and (Walker, 2009)

Most omissions were caused by discrepancies within the drawings. Steel in particular was not included. It is noted that steel represents a large quantity of carbon emissions and acts as an important structural material alongside concrete. (Junnila & Horvath, 2003) Lack of lengths, depths, and shapes of those few steel members represented in KDOT drawings, resulted in the decision to omit this important material. Fortunately, KDOT has used concrete and concrete block as their major source of building structure. Roughly half of the KDOT buildings use minimal open web joists for roof support, so, though the omission introduces error, the majority of the structural carbon emissions have been included.

Independent building décor, (e.g. furniture) was omitted due to each building's unique composition. From site tours it was discovered that buildings varied greatly based on the occupants. New facilities were almost bare of furnishings, additional tools, and individual possessions. Older facilities were generally full of tools, furniture, and personal artifacts. Omission of these materials is due in part to the variability between buildings but also due to the original scope of the KDOT buildings.

Due to time constraints and resource availability, highway rest stops were excluded from the overall carbon report. The rest stops, numbering in the hundreds throughout the state, are the responsibility of KDOT but are not necessarily under their direct control. Because these areas are unstaffed except for occasional maintenance crews, it was not possible to obtain the required data in the allotted time frame.

Within the KDOT analysis, the omission of steel heavily impacted the final evaluation of KDOT design. While not necessarily altering the embodied carbon values any more than the omitted interiors would, the omission of steel precluded a concrete and steel structural carbon comparison.

5.1.2 STEP 2: CATEGORIZATION

For KDOT, the organizational tree branched into three main stalks: high energy / high conditioned spaces, medium energy / low conditioned spaces, and low energy / low conditioned spaces. After organizing the chart, it became necessary to add one more, smaller branch for high energy / low conditioned spaces for the specialized laboratories.

The LSAA example organization concept was not the ideal grouping for KDOT's case. The first division, materials, became unnecessary due to the material similarities throughout KDOT's buildings. In the same way, the fourth division, age, was eliminated because of the relative uniformity among buildings. The second division, building use was kept, but in a modified form. Rather than divisions based solely on operational usage, the divisions are divided based on energy and conditioning use.

Much of the final organizational scheme was based on building use and size. For example, the six district offices were each unlike any other buildings. For this reason, in the initial tree, the six district offices each represented a Building Type. Size and use also determined the categorization of storage buildings. Because storage used so little energy, a few bare light bulbs and no space conditioning, they posed little impact on the total energy used by each campus. For this reason, storage buildings were grouped based on overall size and material rather than what materials they were intended to store.

Within KDOT's buildings, only a few main material types exist. Concrete, stone, and brick predominated with some uses of sheet metal and a minimal use of wood. The lack of complex material types or combinations simplified categorization of these elements.

The final, full organizational tree can be found further below in Figure 12. The final categorization includes 36 Building Types that contain the 941 KDOT buildings. To help verify LSAA, the categories will be altered following analysis to determine impact on the final carbon emissions result.

Type Properties and Material Itemization

To evaluate each of the Building Types, the blueprints and drawings were used. Each of the 941 buildings had been assigned to a Building Type. Once categorized, the material itemization began.

Each drawing file was opened and the materials and material areas were recorded. Once two to three buildings of each Type had been recorded, additional buildings within the Type were not recorded. Rather, their size, materials, and corresponding areas were compared to the written values for that type. If the buildings agreed, then no new values were listed. If they varied significantly, then the outlier was temporarily recorded until an explanation or more adequate categorization could be reached. By this system, all buildings received a material listing and material area value. This completed the second step of the LSAA method.

5.1.3 STEP 3: DATABASES

This study utilized three reputable carbon databases, the LCEE-ASCE 2003, ICE v. 2.0, and Energy 161-2008.

LCEE-ASCE 2003 is a publication of the Journal of Infrastructure System from 2003. The article, Life-Cycle Environmental Effects (LCEE) of an Office Building by Junnila and Horvath, presents research following the full life cycle of materials.

Materials within this database contain expected carbon emissions for creation, transportation, construction, installation, maintenance, demolition, and disposal. LCEE presents "*a comprehensive environmental life-cycle assessment, including data quality assessment… [with] detailed information for establishing the causal connection between the different life-cycle elements and potential environmental impacts*." Results show that most associated impacts result from the use of electricity and the manufacturing of a building's materials. (Junnila & Horvath, 2003)

The University of Bath in the United Kingdom publishes the Inventory of Carbon and Energy Database (ICE v. 2.0). The most recent publication from January of 2011 was published in conjunction with the Sustainable Research Energy Team (SERT). ICE was first published in 2005 and has received six updates in the past half a decade. The most current update includes recycled materials and updated carbon emissions data from the timber and concrete industries in the United Kingdom. While based in and intended for the UK, this database is a comprehensive, if not regionally correct, example of a database. (Hammond & Jones, 2011)

The database Energy 161-2008 is a publication of the Institute of Civil engineers from 2008. The publication by Hammond and Jones was the result of research into the embodied carbon of construction materials. While not as inclusive and extensive as the ICE v2.0 database, the resulting values represent the embodied carbon of materials, minus transportation energy, as observed and tested by Hammond and Jones. Their research extends to 14 dwellings varying from standard homes and apartments to energy efficient homes and apartments with results representing the average values of their research. (Hammond & Jones, 2008)

Using the above databases, the embodied carbon of KDOT varied from 9,078 tons to 65,710,504 tons of CO_2 with the last database calculating 23,799 tons. Though these databases were chosen as representative databases, they still show the wide variation that can be obtained based solely on the choice of database and that database's chosen system boundaries.

5.1.4 STEP 4: CALCULATIONS AND CARBON TOTALS

As stated before, database choice makes the single greatest impact on results. In order to analyze database impacts, I have used three databases to evaluate the same data from KDOT. All material quantities, Building Types, and values have remained constant with the database acting as the sole variable in the equation. From Figure 11, one can see that the difference is extreme.

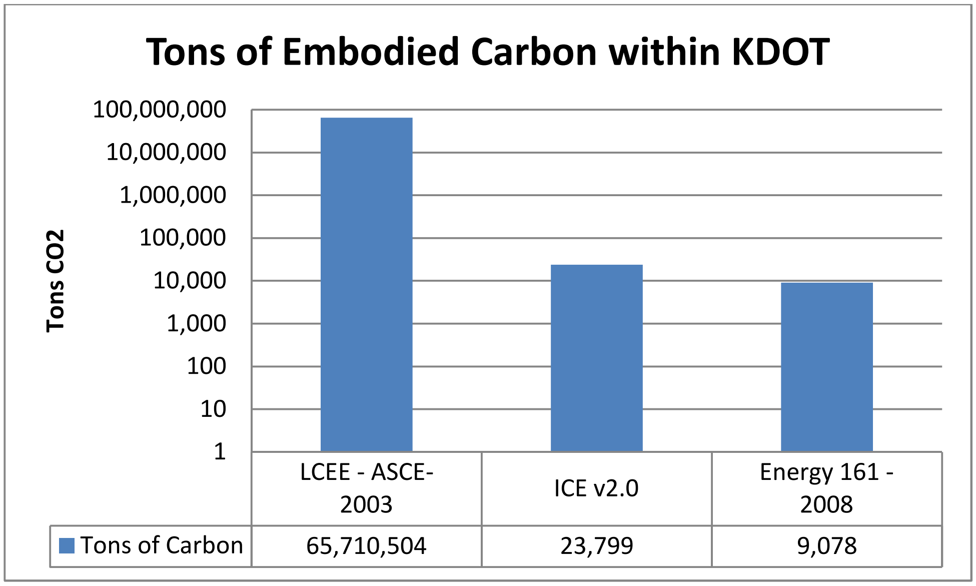


Figure 11: Total Tons of Embodied Carbon within KDOT

With an average value of 21,914,432 tons and a median value of 23,731 tons, the three databases do not return similar or comparable results. ICE and Energy 161 are the closest in value but even ICE is over twice the value of Energy 161.

Reasons behind this drastic discrepancy can be found in the databases' system boundaries. Though the KDOT boundaries were clearly stated, the database boundaries had not been investigated prior to calculations. After further research, it was found that LCEE-2003 sought to determine all carbon emissions associated with a material, including transportation and all manufacturing. The other reason, found within the name of the database is the length of time over which the database drew its carbon values. While ICE and Energy 161 concentrated on the manufacturing and construction carbon, LCEE included the embodied carbon for the life of the material, everything from manufacture and construction to use, renovation, demolition and disposal.

5.1.5 STEP 5: ANALYSIS

Quality analysis

Controlling quality is essential to the viability of LSAA quick audit method. Re-evaluation of analysis using the Pedigree Quality Matrix found in Table 2, allows for a quantitative estimate of the data quality. Using the Pedigree Matrix, Table 6 provides the evaluation for KDOT's embodied carbon analysis.

Table 6: Resulting Method Quality Matrix for Embodied Carbon

LSAA		
Item	Actual Embodied Carbon Analysis	Original Estimate
Method of Acquisition	2.5	2
Independence of Source	2	1
Data Representation	1	1
Time Relevance	1	1
Graphical Representation	2	1
Technological Representation	2	2

The results chart, simply and quickly, shows that the quality was not as high as could have been obtained with ideal data. The Method of Acquisition received a higher score due to the missing blue prints and material data that resulted in assumptions. Similarly, Source Independence is one point high because data was supplied from within the study agency. Finally, a carbon database could not be obtained for the specific Kansas/Midwest region; therefore, a larger geographic area was used resulting in a higher Graphical Representation score. The remaining three evaluation areas performed as expected. Were the KDOT analysis to be repeated with the goal of achieving higher quality, then additional time and human resources would need to be invested in order to obtain the missing data, conduct individual building visits, and contact all employees regarding their buildings.

Category Adjustment

Impact of Individual Buildings Types

To analysis the impact of grouping on the final carbon value, this study manipulated the KDOT building organizational tree from its original state, containing 36 Building Types, into three condensed versions. Each condensed version, named A, B, and C, containing 18, 15, and 10 Building Types respectively, is reorganized and recalculated for new carbon emissions values.

The organizational trees are intended to show how differing categorizations will affect the final carbon results, because each researcher will interpret the buildings differently and will therefore develop slightly different Types within an agency. By developing multiple examples of the same organization with different groupings, readers can determine the wide spread applicability of the LSAA modeling system.

The categorization exemplifies that results of the LSAA method remain relatively consistent with the exception of the database choice. Values vary at most by 15 percent despite intentionally choosing Types outside of the ideal groupings, as per the condensed tree versions. This verifies the initial categories while also proving the need for a nationally recognized database, or, at the very least, a nationally recognized set of system boundaries.

The full organizational tree, that used to calculate the initial carbon emissions values, will represent the baseline values for this portion of the analysis. This chart, as seen in Figure 12, contains 36 total Building Types divided into four main categories. The initial division breaks the buildings into groups based on their energy use, high, low, or medium, and their space conditioning. The next division is building use, followed by a size division. Sizes are broken into a new group at every 2,000 square feet because size differences range from under 2,000 ft^2 to greater than 10,000 ft^2.

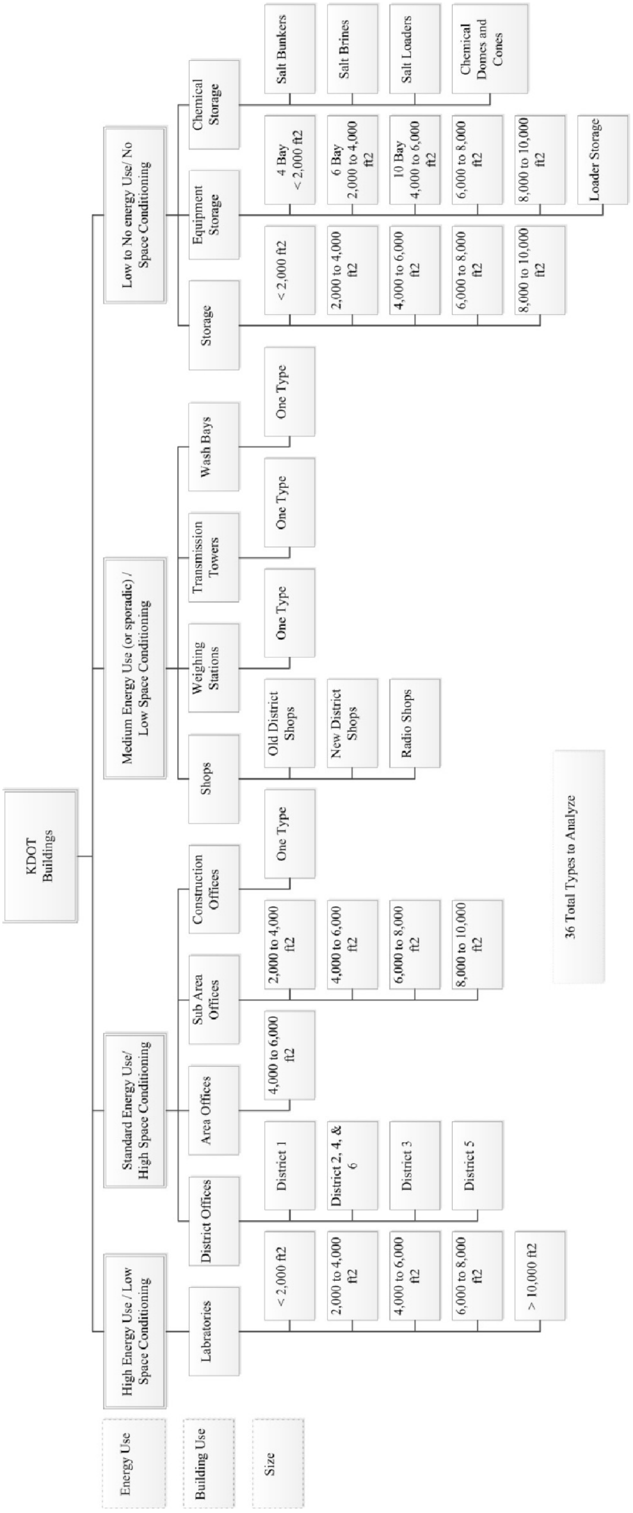


Figure 12: Full Organizational Tree – 36 Types

To condense the Building Types from 36 to 18 Types, many existing categories were combined, as can be seen in Figure 13. This includes the laboratories which changed from four Types broken every 2,000 square feet to two groups broken every 4,000 square feet. The material properties for each previous group were averaged to create the new Type properties. In some cases, all buildings took the properties of the median building of each new type. For example, if the two Types to be combined contained 6 and 31 buildings respectively, then the material properties for the new Type of 37 buildings would take the material values of the second group that originally contained 31 buildings.

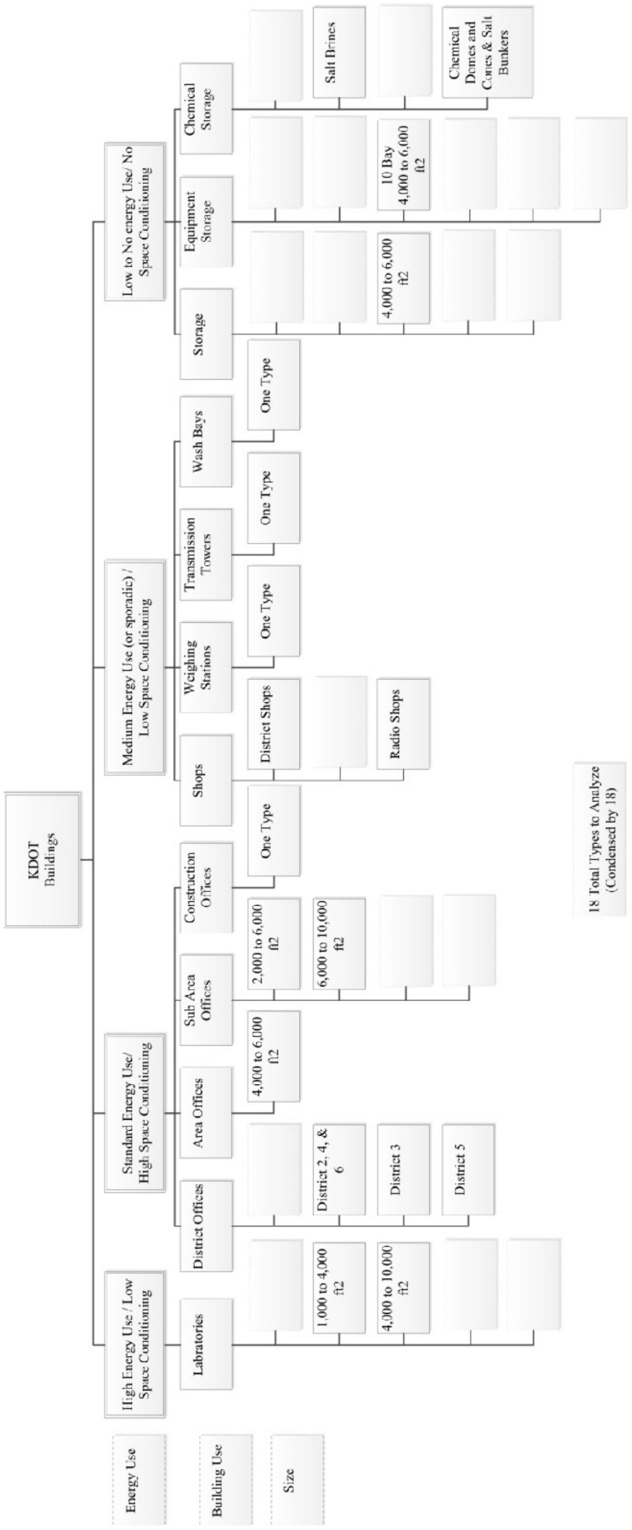


Figure 13: Condensed Organizational Tree A - 18 Types

Figure 13 also displays the fifteen storage Types that were condensed into four Types. As per the earlier discussion, most of the storage buildings use no conditioning and very little electricity if any. For this reason, only the embodied carbon of the materials matters which can be adequately represented by only four groups.

The second condensed organizational tree, shown in Figure 14, reduces the organizational tree further into only 15 Building Types. While the jump from the Condensed A to Condensed B is not as dramatic as the category adjustment from the baseline tree to Condensed Tree A, it is the first time that a larger category, one within the Building Use Division, has been eliminated.

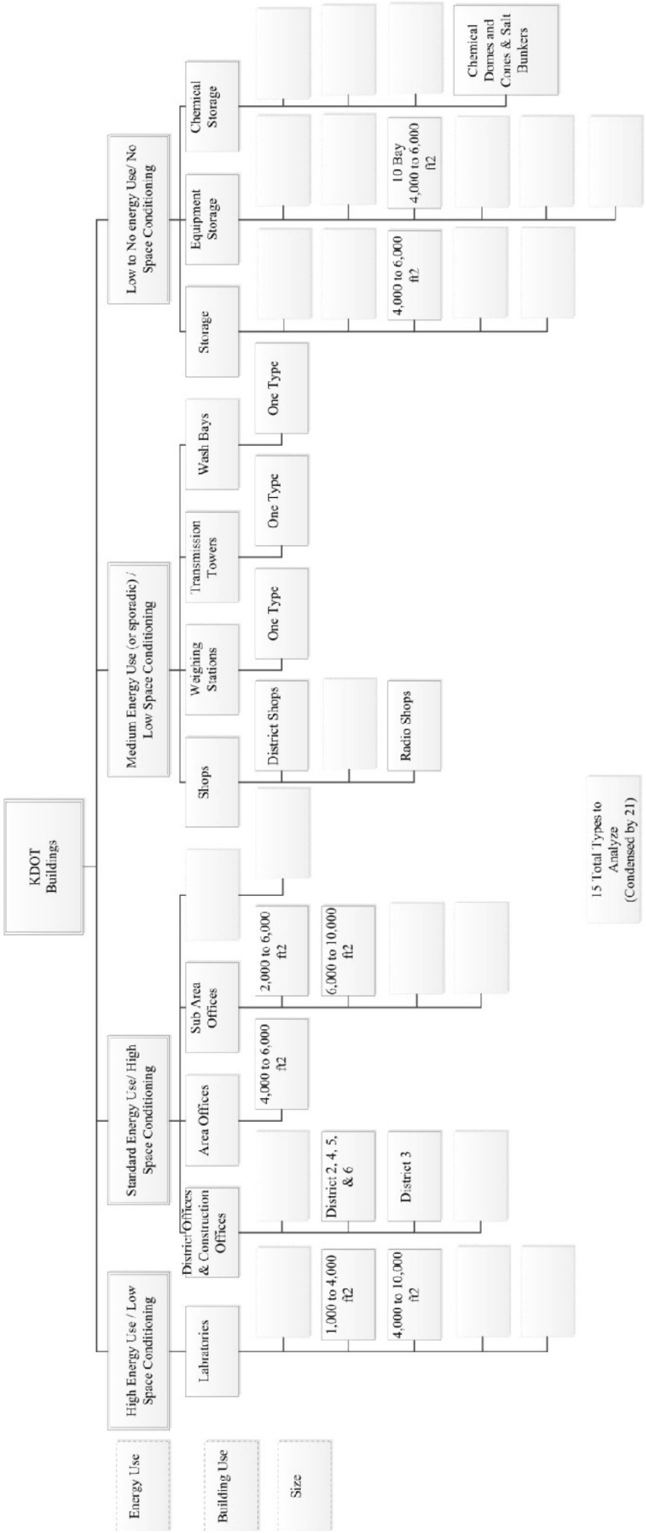


Figure 14: Condensed Organizational Tree B - 15 Types

The final Organizational Tree, seen in Figure 15, is the most condensed. Within this tree, the Types have been narrowed down to a mere ten Building Types. This means twenty six categories have been removed. While the severely condensed trees are not the most accurate in the end, they serve their purpose by showing how differing categorizations will affect the final carbon results. Because each researcher will interpret the buildings differently, he or she will therefore develop slightly different Types within an agency. Through the development of multiple examples of the same organization with different groupings, readers can determine the wide spread application of the modeling system.

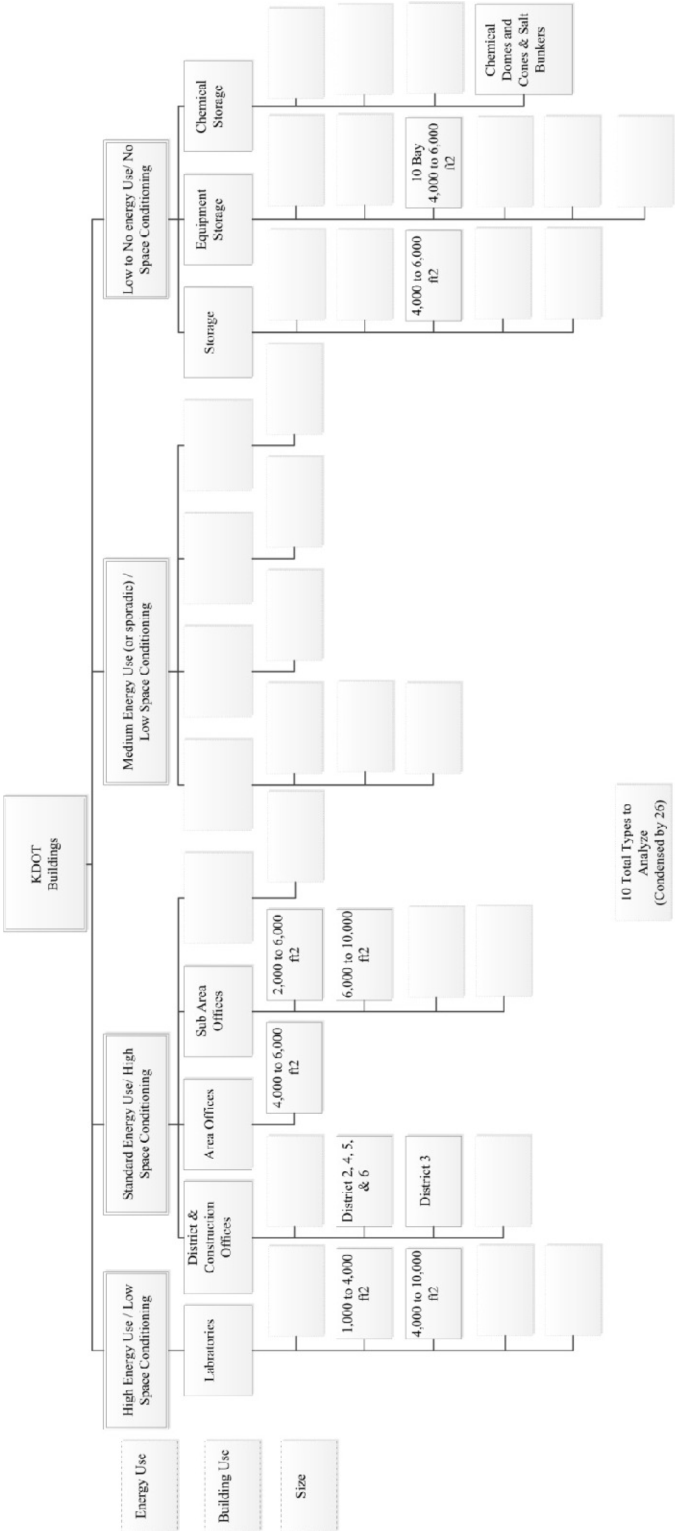


Figure 15: Condensed Organizational Tree C - 10 Types

Altering the Building Types is more than a matter of applying a set equation. It is a collection of small adjustment to the categories until the researcher or engineer is satisfied that the best Building Types have been chosen. Each researcher will possess a different opinion and method of organization that will slightly alter the final outcome. As will be discussed shortly, the consequences of altering or choosing Types will result in different values for baseline carbon.

Results of Categorization Adjustments

All four for the organizational trees, the full tree and the three condensed trees, have been analyzed using the LSAA quick audit method. Each tree was then evaluated using the three previous databases. Table 7 presents the final carbon emission results of the analysis for each Organizational Tree and database.

Table 7: Condensed Categorization Results

	Tons of Carbon			
	Full	A	B	C
LCEE-ASCE 2003	65710504	68611962	68603941	68332429
ICE v2.0	23799	27280	27274	23715
Energy 161 - 2008	9078	10238	10236	8912

In order to visually understand the results, the databases needed to be broken into two groups, one containing LCEE-ASCE and one containing ICE and Energy 161. Because of LCEE’s significantly higher carbon emission values, a representative chart with all three values lessened the magnitude of the changes within ICE and Energy 161 based on Organizational Trees. Results for LCEE database can be found in Figure 16 below. The Organizational Trees are labeled by their abbreviated call names: A for the 18 Building Types, B for the 15 Types, and C for the 10 condensed Building Types.

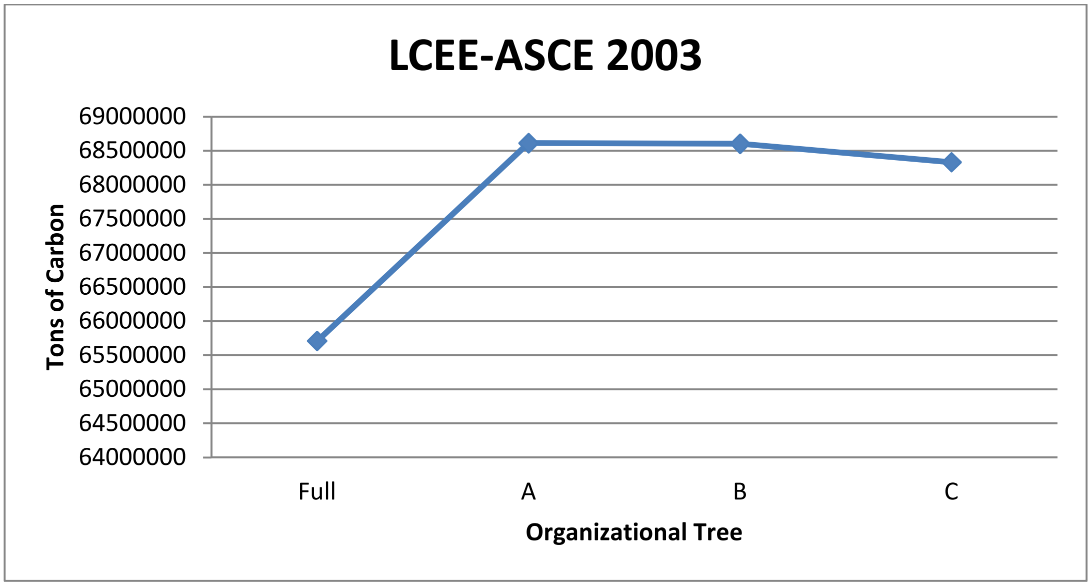


Figure 16: LCEE Carbon Results per Organizational Tree

ICE and Energy 161 database results, being closer in value, can be compared in Figure 17. As seen from the consistent separation distance, the group reordering did not affect the differences derived from the databases. Only the associated material quantities altered as the Building Types were manipulated.

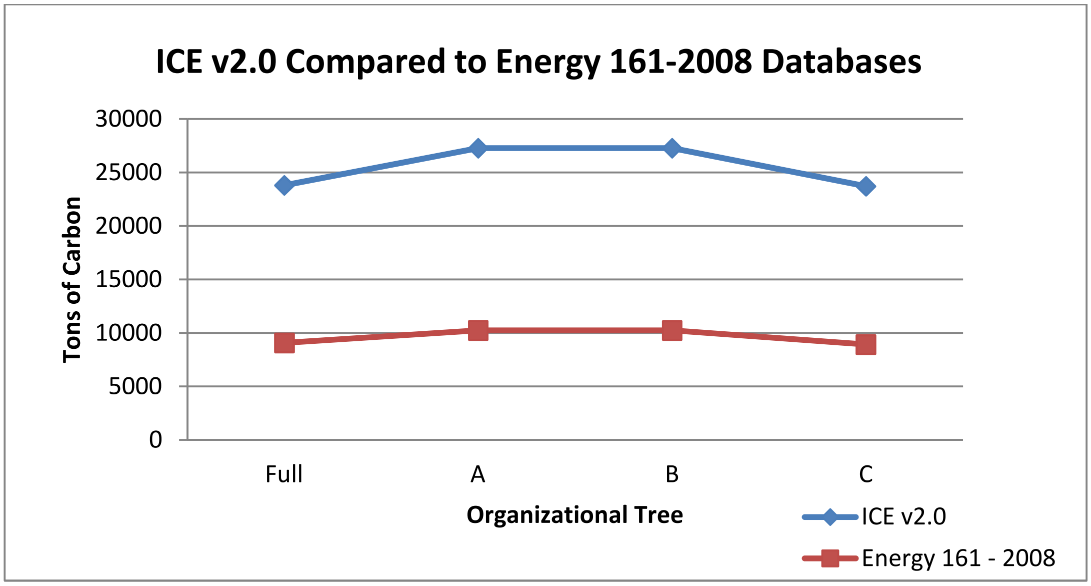


Figure 17: ICE and Energy 161 Results per Organizational Tree

In order to compare all three databases on one chart, the percent change must be calculated per the equation below. All percent changes use the full organizational tree as the baseline, thus all percentages at this point are zero. See Table 8.

$$\left(\frac{\beta-\alpha}{\alpha}\right) * 100 = \Delta$$

Where:

α = Full Organizational Tree Total Carbon Value

β = Variable Total Carbon Value

Δ = Percent Change of Carbon from the Full Organizational Tree Value

Table 8: Percentage of Change from the Original Tree

	Percent Change from Full Tree			
Database	Full	A	B	C
LCEE-ASCE 2003	0%	4%	4%	4%
ICE v2.0	0%	15%	15%	0%
Energy 161 - 2008	0%	13%	13%	-2%

Figure 18 highlights an interesting point. Even though the material quantities remain consistent within an organizational tree, the percentage of change does not retain the same properties between databases. Energy 161 and ICE follow similar trend lines while the final point of LCEE, that corresponding to Condensed Tree C, does not. LCEE maintains a relatively consistent percentage for all of the condensed categories. The three solid lines in Figure 18 represent the actual values, while the dotted line represents what should have been expected, roughly, from LCEE-ASCE 2003 values.

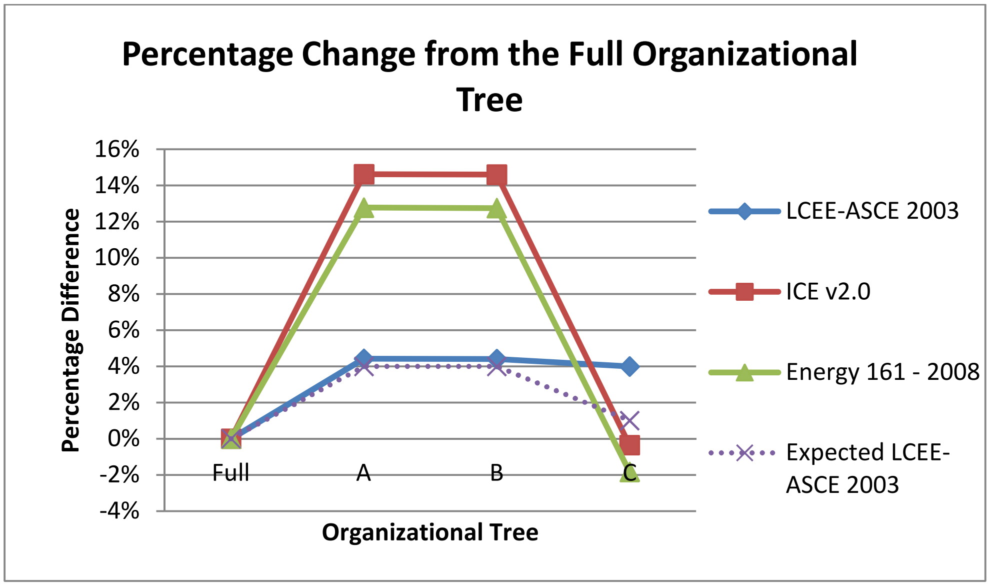


Figure 18: Percentage Change from the Original Building Types

It can be concluded that Building Types alter the final carbon emissions value. While the Building Types can alter the carbon value by up to 15 percent, the difference is far less than to the degree of database change. But, thanks to LCEE, the database has been shown to play a role in the change.

Disregarding the value magnitude differences between the databases, some databases find certain materials to have exponentially greater carbon contents than others. Since the databases show roughly equivalent carbon values per material when only the material's carbon emissions are included, the difference must come from the addition of transportation, construction, and installation.

Certain materials contain a higher percentage of indirect carbon than other materials. Due to category manipulation, that material was present in slightly higher quantities in the condensed tree C than in previous trees, thus causing a spike in LCEE carbon value compared to the other database results.

Flow Chart

To ease future decisions, Figure 20 and Figure 21 provide a design decision chart for KDOT. Figure 20 provides the percentage values of each material within the KDOT study. The total area of each material was divided by the total area of all KDOT materials to obtain the percentage.

Building structure and building exteriors represent the largest percentage of KDOT's material area with 90.6 percent of the total as seen in Figure 19 and Figure 21. Even though much of the concrete block operates as building exterior, the exterior sheathings still represent the largest portion of material area due to roof areas.

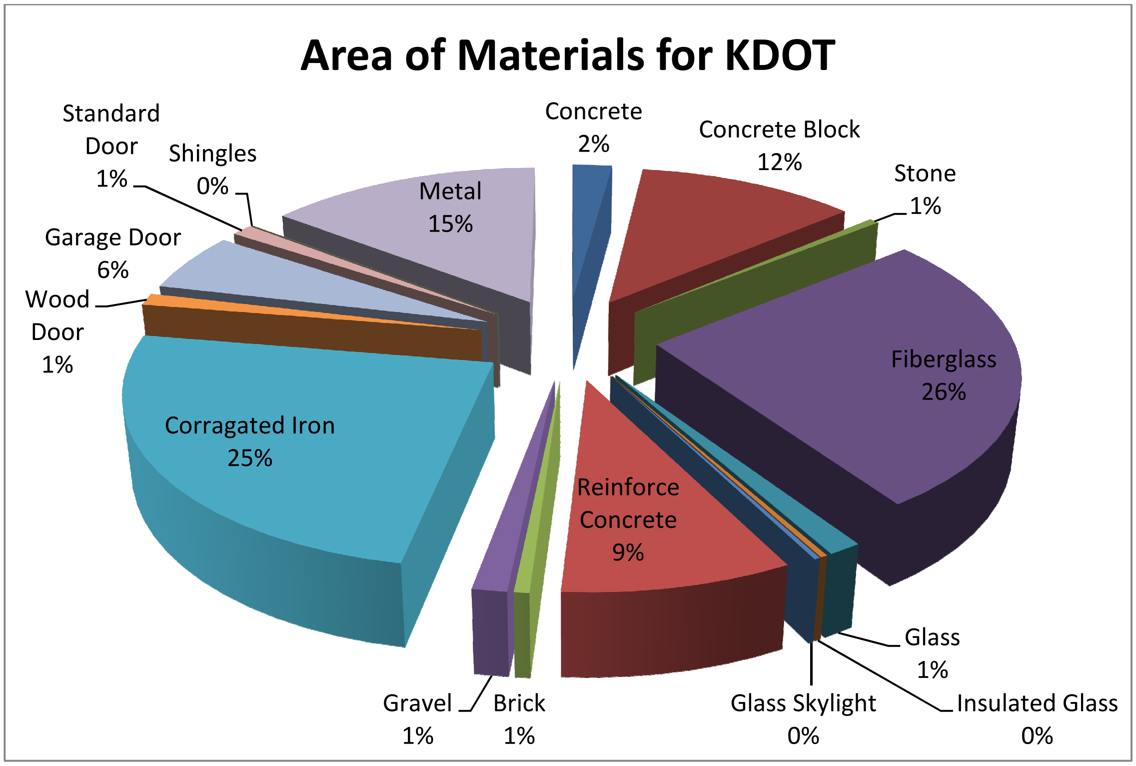


Figure 19: Percentage of Area by Material for KDOT Buildings

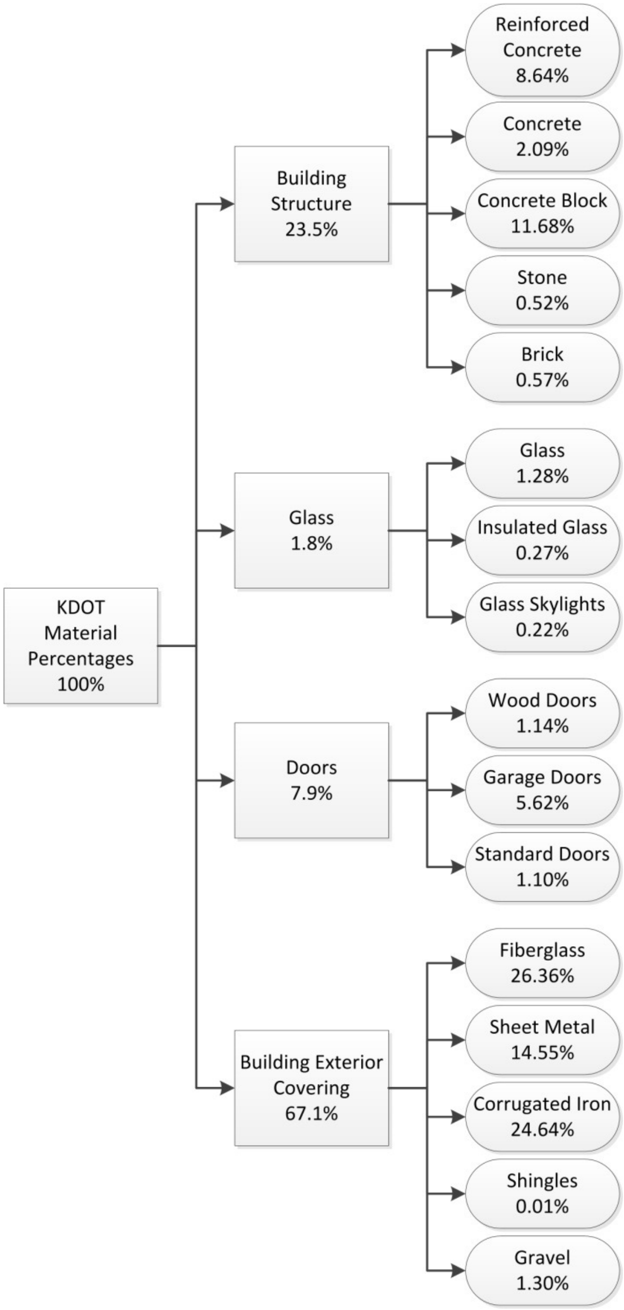
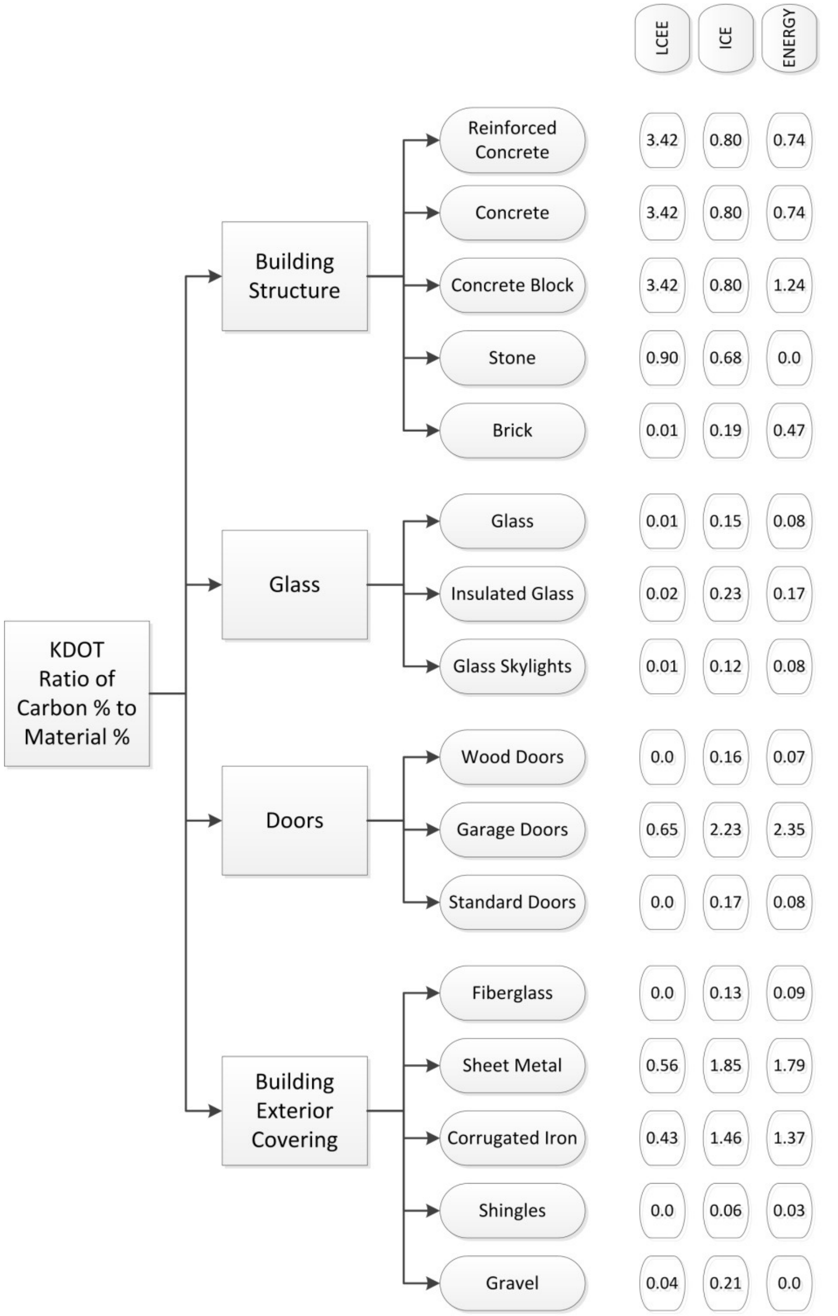


Figure 20: Percentage of Total KDOT Materials by Material Type

Figure 21 represents the carbon emission percentage to material percentage ratio. This figure presents the carbon to material ratio per material per database. All three databases are represented in this figure by the marked columns. Since each value represents a ratio, the values can be sorted. A ratio result of 1.0 means that the percentage of total material area is equal to the percentage of embodied carbon emissions. If the ratio is greater than one, then the embodied carbon percentage per material is higher than the materials percentage of the total material area, thus that material emits higher than average carbon emissions. Materials with higher ratios produce higher levels of carbon emissions. A ratio lower than one represents materials with proportionally lower carbon emissions.



Values represent a ratio of % of Total
Carbon to % of Total Area.

Figure 21: Carbon to Material Ratio Decision Chart

Some materials show a trend in which all databases result in low or high carbon emissions to material area ratios. These materials are easily found by having values higher than one, values lower than one, or a neutral value of roughly one. Other materials are not as conclusive. For example, concrete block is rated differently by all three databases. These results are inconclusive and further study is necessary before a conclusive result can be determined.

The Design Decision Chart is intended to allow designers to visually determine which materials have proportionally lower carbon emissions for the amount of area they cover. While standard emission charts represent the amount of carbon in one kg of the material, it is often difficult for designers to draw an accurate conclusion between a material's weight and its coverage area (e.g. concrete vs. sheet metal). Concrete weighs less than sheet metal per volume, but more weight is contained in one square foot of concrete wall than in one square foot of sheet metal wall because a concrete wall is eight inches deep while a sheet metal wall is only a millimeters thick.

The single stage of a building's life that can most impact the final embodied carbon of the building is the design phase. If engineers can influence designers to make more thoughtful decisions regarding carbon emissions, then the total carbon emissions of an agency can be reduced significantly. Systems such as the decision chart will improve efforts. One step beyond the decision chart is to attach the carbon values directly to the products. One paper by Rendall and Chong (2009) suggested the use of an eco-label to "*…convey the information of building design and product* *eco-efficiency accurately to the designers so that they could reduce the impact of their designs on the environment*." This eliminates the research and comparison step so designers can design with minimal interruption.

Alterations to make the design flow chart a stronger aid would be to produce a formal chart in the Construction Specifications Institute (CSI) Format so that each material would fall under its corresponding Division number.

5.2 OPERATIONAL CARBON

5.2.1 STEP 1: DATA COLLECTION

Initial research was placed in the utility providers themselves. For example, "*Kansas requires utilities to sell a certain percentage of electricity from renewable sources. The state's renewable portfolio standard requires utilities to provide twenty percent of peak demand capacity based on the average demand from the previous three years from renewables by 2020 and beyond. Also, in 2007 Gov. Sebelius's administration became the first state government to reject a permit for a coal-fired power plant because of carbon dioxide emissions*." (Institute for Energy Research, 2011) This shows that a certain level of carbon dioxide monitoring is in effect across the state of Kansas. Knowledge of this allows analyzers to determine if peak energy use or energy carbon production is a result of the utility's inefficiency or the agency conducting the study.

Utility information

In the case of KDOT, a span from 2007 to 2010 was desired. Due to availability, most KDOT accounts have roughly three and a half years of data since many accounts no longer had access to the spring of 2007 while other utilities would or could not release late 2010 data. To add to the confusion, all meters were not consistent over the four year span. As can be seen from Table 10, some locations have erratic utility draws while others, Table 9, remain relatively consistent throughout the years.

Table 9: Utility Results for 2646 Calhoun Bluff Rd. for the Years 2007 thru 2010

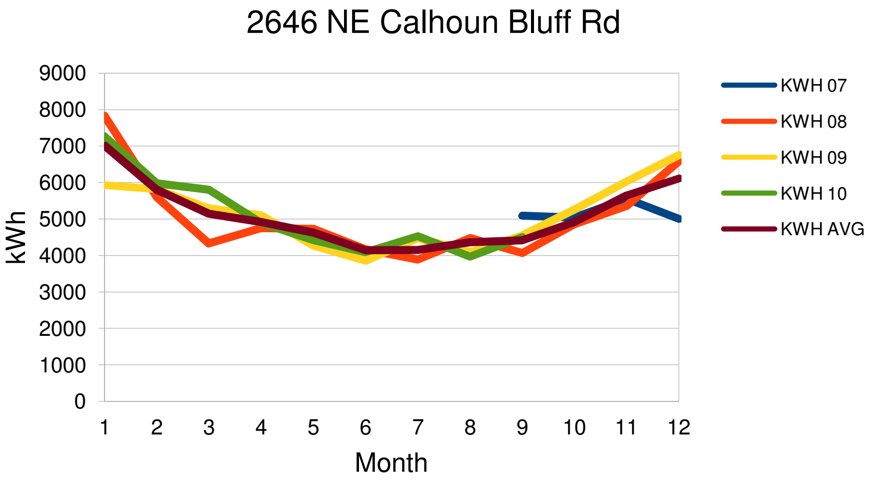
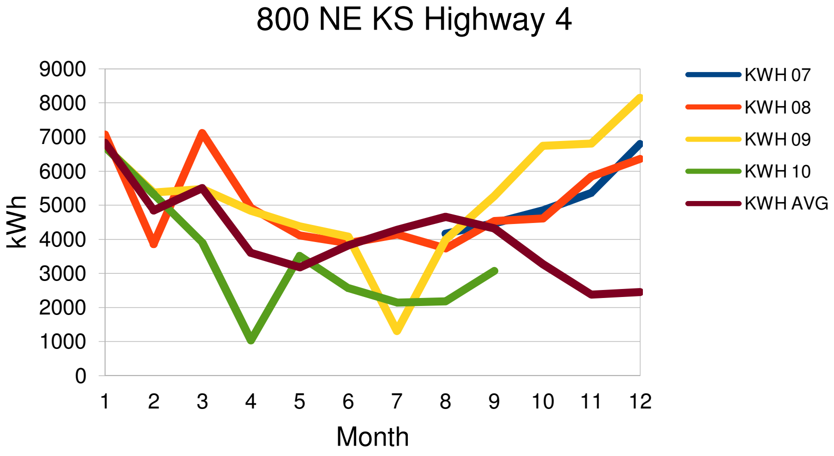


Table 10: Utility Results for 800 NE KS Highway 4 for the Years 2007 thru 2010



An unforeseen problem arose with the KDOT campus accounts. Due to utility provider's grouping of meters, it was impossible to separate security lights (highway lights, road lights, and campus yard lights) from building utility draw. After speaking with the utilities it was found that in many cases, coverage for these lights is on a set-fee basis rather than a wattage-usage basis. Further confusion was added when individual meters represented multiple buildings.

Because of the discrepancies, buildings were grouped into campuses. KDOT proved to be the perfect candidate for this method since its campuses are repeated throughout the state in roughly the same form. For example, a standard sub area campus generally contains a chemical dome, a wash bay, a salt bunker, a sub area office, and a storage/equipment building. By grouping accounts and meters into campuses, meter allocation problems were avoided.

Origin of Energy

The state of Kansas derives 69.9 percent of its electricity from coal, 19.0 percent from nuclear, 5.7 percent from natural gas, and 5.2 percent from wind power. (Institute for Energy Research, 2011)

Occupancy

Building occupancy within KDOT was intended to be transitional. Because KDOT built for the intended occupation, knowing the habits of DOT employees, the building built occupancy and actual occupancy agree.

Maintenance and Operations

Due to the time constraints, full O&M records were not collected. Based on the analysis results and design criteria, KDOT is able to determine some outlying buildings.

Prior to a full reduction listing, basic maintenance changes must be made. During tours, KDOT employees stated knowledge of these maintenance issues and pledged that the issues were listed. Notes of these problem areas were taken during site tours for record.

Building Usage

KDOT is a prime example of how intended use is not always actual use. An example comes from one garage in Salina. Only in deep winter is the garage used for vehicles. The rest of the year, the space is repurposed as an extension of the laboratory with the corresponding space conditioning.

Because of this story and others, observations were made during site visits to ascertain exact use of spaces. Fortunately, regardless of actual use, the space conditioning remained roughly consistent.

Building Types

An additional grouping method has been introduced for this portion of the analysis. Due to the utility provider's meter accounting methods, many buildings needed to be regrouped based on their campuses. For the following energy analysis, campus Types will be used to track the energy and carbon values of KDOT rather than the Building Types associated with the EC portion.

Policies and Practices

Policies and practices can greatly impact the way a building is categorized and its carbon is calculated. One KDOT example, though extreme, notes how energy use can vary drastically from what is on paper. One winter a furnace exploded in an office basement. The employees, without heating for the building for some time, became inventive. Computers, lights, electronics, and laboratory equipment were left running throughout the day and into the night. The resulting heat was enough to maintain building temperature despite the wintery conditions outside. Many employees complimented the comfort level of the 'new method' over the previous furnace which produced notoriously uneven heating.

Assumptions and Omissions

Within KDOT, despite the helpfulness of those involved, some data points were never resolved: meters could not be attached to their corresponding buildings, utility companies were unable to provide the full four years' worth of data, or exact campus compositions were blurred.

All of these omissions result in the need for assumptions. Meters were placed in their corresponding accounts and the resulting building grouping was converted to a campus Type, utility data from three and a half years was averaged, and phone calls and aerial views were used to identify unknown buildings. These solutions introduced points of possible error, and because of the possible error, assumptions were tracked through the analysis and monitored for overall deviations to results.

Because of these problems, assorted omissions were also necessary. Street lighting was not included within the analysis. But the single largest omissions were due to a lack of utility data from the utility providers. Of the six districts within KDOT, District 3 and District 6, those located on the far western boarder of Kansas, utility companies either could not be reached or did not possess the required data. Therefore, results are not included for Districts 3 and 6. These omissions will be noted in final results.

Many assumptions were based on the presence of unknown and time constrained data. Natural gas and propane gas were omitted. Few KDOT facilities use natural gas in their buildings and the few that do, mostly for old heating units, use an insignificant amount compared to the quantities of electricity used. Propane gas, due to its portable nature was also not included. It was found that the propane was not inventoried or noted in most areas and was impossible to track given the available resources. Similar reasons excluded oxygen, acetylene, and other gases from this study.

The rest areas along highways were also excluded from this analysis. Though under control of KDOT, these facilities are usually unstaffed restrooms and vending machines along the major interstate highways. It is acknowledged that they do represent an energy draw from the system, however, due to time limitations and available resources, including them within the energy analysis was not considered.

5.2.2 STEP 2: CATEGORY DEVELOPMENT

Category development for LSAA OC is mostly determined by the previous EC categories and the categories developed from utility data. Changes could be made to the categories based on desired results, however, for KDOT Building Types, campus Types, and districts proved adequate for this analysis.

5.2.3 STEP 3 & 4: DATABASE AND CONVERSION CALCULATIONS

KDOT only utilized the grid electricity component of the Energy Forms chart provided by Carbon Trust in Table 4. While other forms of energy do exist, their relative scarcity left them as minor sources of error compared to the lack of some grid electricity account data.

To determine the impact of conversion database choice, three widely accepted standards, Carbon Trust, EPA, and CO_2 Benchmark, were used. Though all three values are represented in Table 12, only the EPA eGRID 2006 v 2, the state specific value were used for final evaluations. To convert from kWh’s into tons of carbon, the energy value of KDOT for one year must be multiplied by the conversion factor found in Table 11.

Table 11: Conversion from kWh of Energy to Tones of Carbon

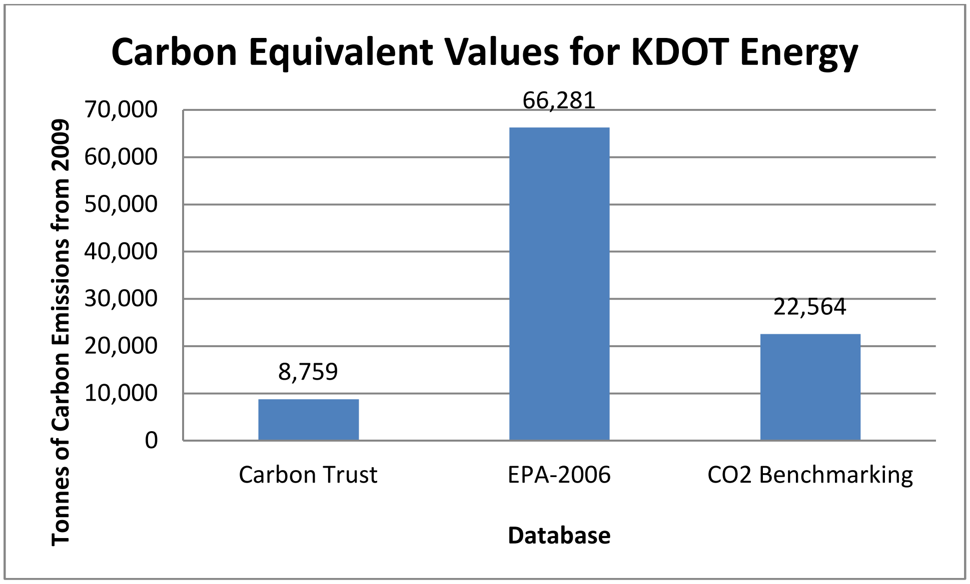
Units	kg CO_2E per unit	Tons CO_2E per unit	Source	Notes
kWh	0.55	0.0006	Carbon Trust	UK specific
kWh	4.13	0.0041	EPA eGRID2006 version 2.1	KS specific
kWh	1.40	0.0014	CO_2 Benchmark	via eGRID 2005 US National Average Emissions

Convert Energy into Carbon

To convert the energy into carbon emissions, this study will use an EPA publication. The US Environmental Protection Agency (EPA) published an example calculation sheet to demonstrate how energy calculations should be conducted. Their section on Electricity Reductions (kWh) provides an emissions factor of $6.8956*10^{-4}$ metric tons of CO_2 per kWh. (EPA, 2011) The EPA strives to provide examples of all energy calculations on their webpage including disposal energy, equivalent carbon emissions, and energy source (coal plant, wind power, solar, etc,) carbon emissions.

Resulting carbon emission equivalent values can be found in Table 12. The total tonnage of carbon varies from 8.8 thousand tones to 66.3 thousand tons per year with an average of 32.5 thousand tons. Once again, the need for a single national database is demonstrated. Though the national database does not need to present a single conversion value for the entire nation, the database must provide a consistent calculation base and boundary system for any and all conversion factors.

Table 12: Results of Energy Conversion into Carbon Emissions



5.2.4 STEP 5: ANALYSIS

Initial analysis took place on the Building Types. Each building, based on its occupation, energy levels, and use was assigned an expected energy value in KWh. The value was then normalized by dividing by the total area of the building. This value, the EIA value, is presented in Table 13 below.

Table 13: Building Types Used for Analysis with EIA Average Benchmarks

Building Type	Description	EIA Average (KWh/Ft^2/Year)	
A-1	Chemical Storage	1.75	
B-4	Wash Bays	6.28	
C-5	Equipment Storage ≤ 2,000 ft^2	1.33	
D-6	Equipment Storage 2,000 ft^2 ≤ 4,000 ft^2	1.33	
E-7	Equipment Storage 4,000 ft^2 ≤6,000 ft^2	0.683	
F-8	Equipment Storage 6,000 ft^2 ≤ 8,000 ft^2	0.683	
G-9	Equipment Storage 8,000 ft^2 ≤ 10,000 ft^2	0.683	
H-10	Area Office 2,000 ft^2 ≤ 4,000 ft^2	67.1	
I-11	Area Office 4,000 ft^2 ≤ 6,000 ft^2	67.1	
J-12	Area Office 6,000 ft^2 ≤ 8,000 ft^2	67.1	

K-13	Area Office 8,000 ft^2 ≤ 10,000 ft^2	67.1	
14	Salt Bunker	0.296	
15	Salt Loader	0.296	
L-17	Sub Area Office 2,000 ft^2 ≤ 4,000 ft^2	14.33	
M-18	Sub Area Office 4,000 ft^2 ≤ 6,000 ft^2 Storage	3.04	
N-18	Sub Area Office 4,000 ft^2 ≤ 6,000 ft^2 Office	48.6	
O-19	Sub Area Office 6,000 ft^2 ≤ 8,000 ft^2 Storage	3.04	
P-19	Sub Area Office 6,000 ft^2 ≤ 8,000 ft^2 Office	48.6	
20	Sub Area Office 8,000 ft^2 ≤ 10,000 ft^2	17.9	
Q-21	Transmission Tower	1.80	
R-22	Storage ≤ 2,000 ft^2	0.482	
S-23	Storage 2,000 ft^2 ≤ 4,000 ft^2	0.482	
T-24	Storage 4,000 ft^2 ≤ 6,000 ft^2	0.382	
U-25	Storage 6,000 ft^2 ≤ 8,000 ft^2	0.382	
26	Storage 8,000 ft^2 ≤ 10,000 ft^2	45.5	
V-27	Weighing Station	13.42	
28	Loader Storage	39.3	
W-29	‘Old’ District Shop	39.5	
X-30	‘New’ District Shop	27.1	
Y-31	Laboratory ≤ 2,000 ft^2	19.6	
Z-32	Laboratory 2,000 ft^2 ≤ 4,000 ft^2	21.1	
2A-33	Laboratory 4,000 ft^2 ≤ 6,000 ft^2	15.5	
2B-34	Laboratory 6,000 ft^2 ≤ 8,000 ft^2 Storage	15.5	
2C-34	Laboratory 6,000 ft^2 ≤ 8,000 ft^2	30.2	
2D-36	Laboratory ≥ 10,000 ft^2	30.2	
2E-37	District Office 3	42.9	
2F-38	District Office 1	33.5	
2G-39	Construction Office, District 1	39.3	
40	Salt Brine Storage	0.296	
2H-41	Radio Shop	0.296	
2I-42	District 2 and 4 Office	41.9	
2J-43	District 5 Office	42.9	
2K-44	District 6 Office	41.9	
50	HDQ Material Laboratory, Dis. 1	21.5	
51	Geology/Planning Office, Dis. 1	16.0	

For KDOT’s analysis, further steps were taken to determine energy use per district as well as the average EUI across the district. Table 14 provides a summation of the information per district.

Table 14: Resulting Energy draw based on KDOT District

Area	Total Annual Use kWh (2009)	Total Area in ft^2	Average Energy Intensity ($KWh/Ft^2/Year$)	Total Area in m^2	Average Energy Intensity ($KWh/Ft^2/Year$)
District 1	8,180,000	686,561	11.91	63784	128.2
District 2	1,220,000	373,614	3.27	34710	35.1
District 4	517,000	414,760	1.25	38532	13.4
District 5	6,140,000	449,848	13.65	41792	146.9
Total	16,057,000	1924783	8.34	178818	89.8

Many hypotheses exist, but without further study, cannot be definitively stated. It is important to note that while the first group of Districts, 1 and 5, contained almost all of their utility data, Districts 2 and 4 were missing some utility data. This means that only a portion of the total energy use was applied to the entirety of the District's building area. While the omissions account for up to half of the discrepancy, the remaining intensity differences must still be accounted for.

In order to identify the remaining discrepancies, it is important to know the activities within each district, most notably, where large laboratories are located. District 1 in particular contains the state's main testing and evaluation laboratory. This lab has an extremely high energy draw with a proportionally low floor area.

The remaining two districts, District 2 and District 4 are not office head districts nor headquarter districts. These district campuses are purposed for road workers and equipment more so than office workers and computers. Since equipment and storage buildings, large areas with little to no energy draw, are included in calculations for these districts, the expected energy intensities will be lower than other districts.

Knowledge of the usage and occupancy of the districts proved a vital insight into energy intensity values.

Based on known operations and use of buildings in Districts 3 and 6, a conservative estimate would place the AEI values between the resulting averages of Districts 2 and 4. This averages to 2.25 KWh/ft^2 per year.

Based on the total values, KDOT appears to use less energy than EIA expected, but due to its close correlation with roads and the outdoors, the expected draw would be arguably lower than a standard office based agency.

Quality Verification

Utilizing the Quality Matrix and the available data, this study finds the operational carbon results to be the most accurate section within LSAA. All ratings, with the exception of the technological representation are ranked as 1's, the highest score possible. The exception, technology, is rated at a 1.5, border line between 1 and 2, because half of the materials under study were from within the study while the other half was from similar materials outside of KDOT. Table 15 displays the quality results beside the original, ideal estimate. It is important to note that this rating does not include the unavailable districts.

Table 15: Resulting Method Quality Matrix for Operational Carbon

LSAA		
Item	Actual Operational Carbon Analysis	Original Estimate
Method of Acquisition	1	1
Independence of Source	1	1
Data Representation	1	1
Time Relevance	1	1
Graphical Representation	1	1
Technological Representation	1.5	1

Life Time Comparison

KDOT buildings have outstanding lifetimes. Unlike standard office buildings which are often occupied for only a few decades, KDOT buildings remain in activity for almost a century. Many of the original buildings built in the 1930's are still in use today. While this does not necessarily bode well for the state of insulation, the buildings themselves remain useful for their entire life cycle.

Using the life span equation, Figure 22 and Figure 23 are the resulting embodied and operational carbon emissions quantities. The baseline year, year 0, represents 2009. Correspondingly, year 5 is 2014, year 10 is 2019, and year 20 is 2029.

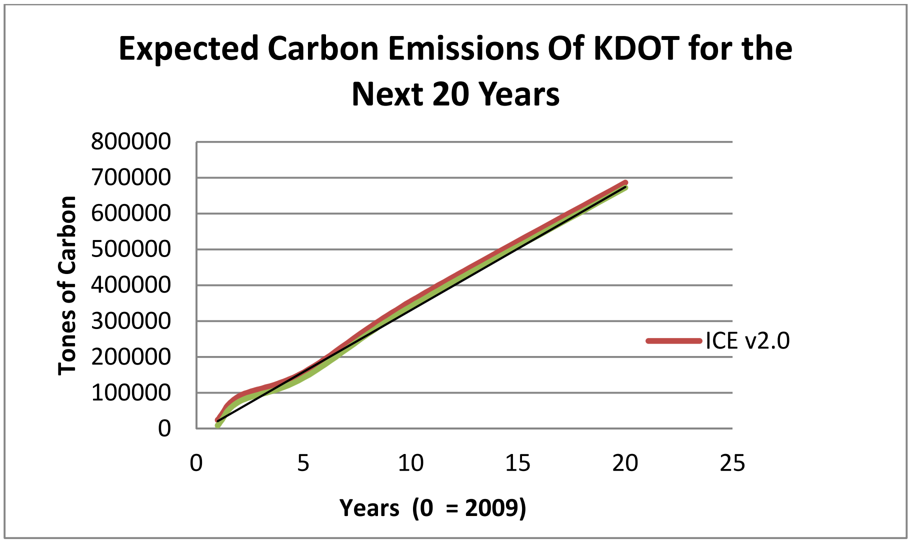


Figure 22: Future Estimates Based on ICE and Energy 161

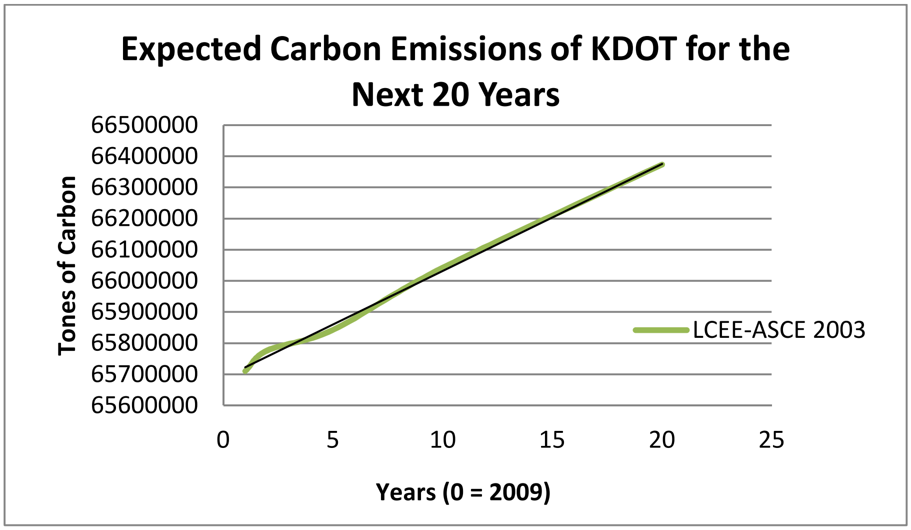


Figure 23: Future Estimates Based on LCEE

Through Figure 22, it becomes apparent that the operational energy is the dominating factor over the lifetime of the buildings. While embodied carbon represents an initially high value, it is the day to day energy use that emits the most carbon dioxide into the atmosphere. "*Generally, the contributions from the construction phase have been found to be on the order of 0.4-12 percent due to the* *overwhelming impacts from the lengthy phase use*." (Guggemos & Horvath, 2006) Based on a 20 year study, embodied carbon for KDOT represents roughly 14 percent of the total carbon. When the time span is increased to the full 40 or 100 years, the embodied carbon becomes even less of a component.

Figure 23 presents a different result. Because of the exponentially large embodied carbon value, regardless of the building's age, the operational carbon will be the main emissions contributor. However this comparison is unfair. The embodied carbon database used a broadly defined system boundary, while the Kansas operational carbon database was a narrower system boundary. It is important that if the two databases do not come paired through a national or regional standard that, at least, the two databases observe similar system boundaries.

CHAPTER 6: ADDITIONS TO ANALYSIS METHOD

Future uses for carbon analysis are only limited by the researcher's own mind and programming skills.

"*The potential of Information and Communication Technologies (ICT) based innovations goes beyond incremental improvements in the efficiency of existing products and services. The ICT revolution is making the tools and services we depend upon smarter… They will drastically transform how services are provided, requiring new business models to replace traditional ways of doing things. Homes, offices, and cities can make different and smarter use of energy*." (Johnston, 2009) Johnston's ideas are not based on wishful thinking since the ICT sector is already "*more than three times more energy efficient than the economy as a whole*" (Johnston, 2009).

6.1 BIM WITH CARBON

One goal for near future carbon analysis comes from computer based modeling systems. Building information modeling systems (BIM) model structures in three dimensions with each element of the design as its own entity. This means that each representational wall has certain properties attributed to it, such as height, length, width, material, total cost, average cost per square foot, and construction details. It does not take much imagination to add an additional category to the property list. This one addition would create a building modeling system that, as well as calculating the wall area, volume, cost, and perimeter, would also calculate the embodied carbon of the materials.

Carbon additions to building information modeling systems would simplify design decisions because the carbon emissions and embodied carbon values would immediately be calculated for each design element. This reduces the required time for calculations as well as provides instantaneous feedback. A designer would have the option to compare multiple materials and configurations and within a few minutes and design to optimize the desired values, whether they are cost, carbon, or material.

BIM could be programmed to output the embodied carbon values for newly modeled buildings into a final spread sheet for environmental considerations. This allows owners to self-evaluate the carbon emissions of a building without adding additional time to the design phase of construction. A BIM carbon database would speed the evaluation of carbon emissions and simplify compliance with local, regional, or national carbon emissions regulations.

6.2 CLOUD COMPUTING

The problem with a system such as BIM is the vast amount of data, supplied by a representative database, that would be necessary to furnish a single licensure of the modeling program with all of the materials, regions, and suppliers needed for a full and accurate carbon analysis. The answer is simple. Rather than requiring each licensure to maintain a multiple gigabyte or more file, a single server would provide and update the file for all licensures.

"*At the core of cloud computing is a simple concept: software as a service, or SaaS. Whether the underlying software is an application, application component,* *platform, framework, environment, or some other soft infrastructure for composing applications to be delivered as a service on the Web, it's all software in the end. But the simplicity ends there. Just a step away from that core, a complex concoction of paradigms, concepts, and technologies envelop cloud computing.*" (Hakan, 2009)

Cloud computing acts like a server to other servers. Figure 24 presents a simplified model of how a cloud system works. Unlike a standard server to computer system where the personal computer borrows data from the server, a cloud platform allows software to be shared between computers via the internet. Cloud computing perfectly solves the database dilemma. It provides a storage location for the huge carbon database needed and it allows for frequent updates without bothering the user for installation permission.

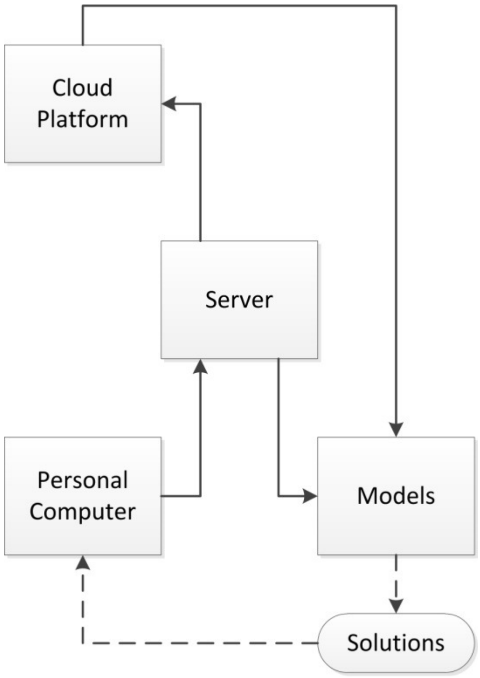


Figure 24: Cloud Computing Flow Chart

With the cloud system, the BIM program would send info to server. The server then accesses the cloud platform to perform the calculations. The cloud platform uses the supplied information from the network of servers it is connected to so that it can compute the carbon value. The platform returns the value to the personal computer and then the computer supplies the BIM program with the desired values.

If questions arise as to the efficiency of cloud platforms, one must only consult Google and Amazon to determine the value of cloud computing. Google released their Crome OS a few years ago; it does everything in the cloud. For instance, instead of using Microsoft Word, Google Documents supplies a software package from the cloud platform for users to access and use. Amazon Cloud Storage operates in the same way. Instead of using a personal hard drive it access the cloud platform. Many games use the platform too. Rather than updating personal computers, On-Live Games use the cloud. On-Live computes the gaming calculations and visuals in the cloud and sends the image to the player's personal computer. The player controls the game. On-Live benefits the player because the computer's system does not need to be equipped to handle a large game. Only a strong internet connection is needed. Even Amazon allows users to rent individual server times (CPU time) via cloud platforms. Google and Amazon both operate cloud platform music players where users do not require local players or music storage. They just browse music on the server and borrow software from the cloud. The list is endless.

If only a portion of the vast cloud resources were to be devoted to carbon equivalent modeling in BIM programs, then the design realm could drastically change the speed at which carbon is emitted.

6.2.1 UPDATING CAPABILITIES

Another benefit to cloud platforms for BIM modeling comes in the form of updates. If databases were stored on individual computers, mass updates would be needed throughout the life of the license. With a cloud database, the carbon values can be constantly updated without disturbing the users. A change of data in server or a change of calculation and manipulations in cloud could take place at any time so the database and software would always be up-to-date. To avoid calculation reproducibility problems, a time stamp could be added to all computer-based calculations to identify which set of values were used.

"*Service-oriented computing and cloud computing have a reciprocal relationship — one provides computing of services and the other provides services of computing. Although service-oriented computing in cloud computing environments presents a new set of research challenges, the authors believe the combination also provides potentially transformative opportunities*." (Wei & Blake, 2010) The capabilities of such a system would transform the way BIM impacts builders and designers.

6.2.2 PROS AND CONS

The benefits of cloud platforms can be found on each and every personal computer that accesses the platform; less computer storage. Because additional software and data are kept on the platform, personal computers are not required to maintain large memory, databases, or RAM abilities. Because less processing is done locally, less local hard drive is needed. While this means an increased space conditioning need in the server park, the increased draw is less than the cumulative draw from the hundreds of personal computers operating independently with full hardware and software loads.

Additional carbon emissions savings are created through the wide spread use of cloud computing. By centralizing the software and hard drives, IT resources can be shared among organizations, individuals, and general users. "*The carbon emissions reducing potential of cloud computing is a thrilling breakthrough. … The results show that by 2020, large U.S. companies that use cloud computing can achieve annual energy savings of $12.2 billion and annual carbon reductions equivalent to 200 million barrels of oil – enough to power 5.7 million cars for one year*."
(Verdantix, 2011)

Not only can cloud computing help engineers and designers to design with the goal of lower carbon emissions in mind, but the method of achieving the goal helps lower carbon emissions.

The only downfall to a cloud system is latency. In order for BIM to function with the carbon emissions capabilities, the computer would require an internet connection. The data lag that would occur without a solid connection would render the carbon program mote until a connection could be established.

6.3 DYNAMIC MODELS

To accompany the LSAA method, this study emphasizes the need for a dynamic carbon modeling system to accurately assess carbon emissions of individual buildings and large-scale agencies.

The Systems Analysis, Modeling, and Prediction Group (SAMP) at the University of Oxford, already "*studies the modeling, development and application of data … for complex dynamical systems where the underlying dynamics vary from the simple (periodic/single-component) to the complex (chaotic and/or multi-component). Thus these methods are applicable to a wide class of real-world problem domains, for example…, renewable energy, operations research and social science*." (Systems Analysis, Modeling, and Prediction Group (SAMP), 2008) While SAMP acknowledges the usefulness of dynamic systems in energy analysis, they as well as other researchers, have not yet applied a dynamic model to large-scale carbon emissions calculations.

6.3.1 PROBLEMS WITH LINEAR METHOD

Some researchers believe carbon analysis to be static, but those who have undergone in-depth research realize that nothing about carbon emissions is static; however, they disregard this knowledge to continue modeling with linear, static models for the speed and simplicity it offers.

In a linear model system, it is possible to use one database for a building on one side of town that sits facing south in a wooded area in a high rainfall zone and then use the same database for another building on the other side of town that faces north on the edge of an exposed plain in a low rainfall zone. Though both buildings fall within one town, their circumstances are drastically different. By not taking into account the details, researchers are able to flatten the mathematics and create a linear system. As all of the details and variables are added, the model becomes more dynamic.

"*The researchers found that community GHG inventories are most often reported by broad energy-use sectors – such as residential or commercial buildings – which are too open-ended to plan for effective GHG mitigation*." (Anscombe, 2011) They also found that uncertainty was introduced from the weather impacts on the buildings, variability of vehicles from their factory standards, and fuel source tracing.

"*Calculating GHG [including carbon dioxide] inventories involves more than just accounting. … Most of the cities we studied used climate action-planning guidance and a software tool developed by the International Council for Local Environmental Initiatives (ICLEI). This software is too simplistic and there is considerable room for improvement by, for example, modeling the impact of the weather and including some simple quality-assurance factors in the software*." (Blackhurst, Matthews, Sharrard, & Hendrickson, 2011)

Blackhurst recommended that a short term solution, temporary patch to the linear model, be instated into carbon modeling. "*Inventories could be supplemented with annual or seasonal heating and cooling degree day data or use existing regression studies to adjust for weather*." (Blackhurst, Matthews, Sharrard, &

Hendrickson, 2011) Long term, Blackhurst proposes that all sources of uncertainty and variability are accounted for within calculations. This would include elements such as electricity consumption and its resulting operational carbon emissions.

While Blackhurst concedes the need for a new modeling system, his proposal only goes as far as to adjust the linear system rather than overhauling it to create a dynamic model. Carbon emissions are not static. They cannot be accurately modeled with a static, linear model. To accurately model the carbon emissions of a building or an agency, a dynamic, multi-leveled model must be developed.

6.3.2 DYNAMIC MODEL DATABASE

In order to achieve a functioning and widely applicable database for dynamic modeling, an overseeing third party, outside the calculating engineer and the building owners/occupants, must develop a standard set of values. For carbon, either a national or international organization, such as the IPCC, would be a good choice for third party developers.

The resulting database would not be a listing of carbon quantities per material quantity. Rather, the database would provide factors. A strong example of the theory can be found in the organization of the ASHRAE Handbook. Rather than providing a single, all-inclusive chart to display air flow results, ASHRAE breaks each variable into a chart or data listing. Material emissivities, heat generation, resistance, and permeability are each listed in a separate chart based on set, known values. (ASHRAE Research, 2005) To obtain a desired value, users draw variables from the required charts based on the problem’s properties, materials, orientation, etc., and calculate the final value via the variables.

For carbon emissions, each variable would be based on origin and earlier variables. Calculations would then be based off the charted variables. Similar to ASHRAE, the carbon database would result in a robust text that provided charts and values corresponding to the variables listed below. Variables listed under Material Information will help assess the embodied carbon values while the Building, Equipment, and Energy Information variables will assess the operational carbon values

Material Information

- Method of Extraction
    - Recycled
    - Virgin
- Method of Manufacture
    - Machinery
    - Chemicals
    - Location
    - Method
- Shipping Materials
    - Boxed / Bagged
    - Wrapped / Padded
- Transportation Distance
- Shipping Method
    - Truck, Boat, Train, Airplane, etc

- Installation Method
- Operation
    - Policies
    - Practices
- Maintenance
- Demolition Method
- Disposal
    - Recycled
        - Facility
        - Location
        - Percentages
    - Trashed

Building Information

- Location
    - Latitude and Longitude
    - Elevation
- Climate / Weather
    - Temperatures
    - Winds
    - Moisture/Humidity
    - Extremes
- Orientation
    - North, South, East, West
    - Angles
- Surroundings
    - Shaded, Exposed, Enclosed

    - Rural, Urban, Suburban

Equipment Information

- Make and Model
- Efficiency
    - Expected vs. Actual
- Operation
    - Conditions
        - Temperatures
        - Space Enclosure
        - Ventilation
    - Times
- Maintenance/ Condition
    - State of Repair
    - Operating hours before a repair occurs

Energy Information

- Energy
    - Electricity
    - Natural Gas
    - Oil
    - Coal
    - Wood
- Energy Source
    - Coal, Hydro Electric, Nuclear, Solar, Wind
    - Extracted Energy

    - On or Off Grid
- Source Method
    - Fracking
    - Sustainable drilling
    - Strip Cutting
    - Others
- Energy Use
    - Season
    - Time

The number of variables used will depend on the level of calculations users conduct. A dynamic quick audit would utilize slightly fewer variables than a full audit. A detailed audit could add additional variables. The provided list is not restrictive or all inclusive.

6.3.3 PROPOSED DYNAMIC MODEL

This study proposes a Comprehensive Dynamic Carbon Analysis (CDCA) method that utilizes known variables into a complex mathematical model to obtain an accurate carbon value for the given building. The dynamic model will determine carbon values, not based on a blanket statement database, but will be calculated based on all of the variables effecting the final emissions. This method is a Dynamical Mathematical Method, also known as a dynamic or non-linear system.

"Non-linear systems are systems that cannot be mathematically described as the sum of their components. While certain assumptions can be made for linear systems that often make the mathematical modeling of such systems easy,

mathematical modeling of non-linear systems is often very difficult or impossible." (University of Monash, 2007)

While CDCA will not be so mathematically complex as to become impossible, it will be a more time consuming method than the linear models. One benefit of the CDCA model is its easy assimilation into computer analysis. Computers, the fastest and simplest method of solving large matrixes, is perfectly suited to contain and calculate dynamic carbon emissions values based on given databases. With the addition of a cloud platform, CDCA becomes rapid and easily available to designers, engineers, owners, and the general public.

The dynamical model, depending on complexity can be based on one of the following two dynamical systems. The first system is an affine transformation. Though most often used for computer graphics, due to its repetition of element sets, affine transformations utilizes linear transformations. (Gray, 1997) & (Croft, Falconer, & Guy, 1991) These transformations are applicable to changes in location, scale, and quantities found in carbon emissions calculations. (Weisstein, 2011) Structural Matrix Analysis also uses a form of this equation to evaluate repeating bay, steel and concrete structures. (Nilson, Darwin, & Dolan, 2004) & (Kassimali, 1999)

$$\Phi(\chi) = A\chi + b$$

Where:

A = a matrix of values (database)

b = a vector of numbers (constant values)

χ = a position vector (material vector)

Φ = resulting value matrix

The second model, a more complex mathematical model than the first system, is based on eigenvectors and eigenvalues. This model is "*the key to understanding the long term behavior or evolution of a dynamical system described by a difference equation* $\chi_{(k+1)} = A\chi_k$ *… The vectors* χk*, give information about the system as time (denoted by k) passes*" (Lay, 2003).

$$\chi_{(k+1)} = A\chi_k$$

Where:

A = a matrix of values (database)

k = variable (generally time)

χ = a position vector

The second equation has a unique feature to it. When the eigenvector and eigenvalue equations are decoupled, the resulting equation resembles an affine transformation. Decoupling occurs when "*A is a diagonal matrix.*" (Lay, 2003) In CDCA, a diagonal matrix would result when only the relevant data values remain in the matrix and all other values are zeroed. The equation below is very simplified, but it displays how matrix analysis will simplify current carbon emissions calculations. The database matrix has been zeroed to leave only the pertinent data values, resulting in a diagonal matrix. A, B, and C represent material quantities. Though this example only shows three variables, an infinite number of materials could be calculated at a time, limited only on the computer's capabilities. The variables X, Y, and Z are the resulting carbon dioxide emission values. Admittedly more complex steps, larger databases, and more detailed equations will be needed, but in the end, they can trace their basis back to this simplified example.

$$\begin{vmatrix} \# & 0 & 0 \\ 0 & \# & 0 \\ 0 & 0 & \# \end{vmatrix} * \begin{vmatrix} A \\ B \\ C \end{vmatrix} = \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}$$

These equations are uniquely suited for CDCA because they allow for easy computer analysis via the matrixes. Each matrix represents the variables, materials, or quantities present in the building so that the resulting value matrix, Φ, is the carbon within the system. Because "*a vector is a collection of mathematical objects that obey the same laws of addition*" (Boyce & DiPrima, 2005), one vector can represent all the quantities or materials included in analysis.

Dynamical modeling is considered difficult and time consuming because of the uncertainty and unknowns commonly associated with the models. In order to avoid these unknowns, the database must address all variable elements. In some instances, calculation can continue without a value by basing the missing value on other known values. In general though, it is the carbon calculator's role to obtain all known data about the buildings he or she is conducting the model for.

Full CDCA databases and equations are outside the scope of this study, but the need for them has been established and exemplified throughout this study.

6.4 INTEGRATED DESIGN

Informed choices make good choices. The importance of good choices in the design phase is crucial to reducing carbon emissions over the life of the building. Certain materials contain higher levels of embodied carbon while other materials cause higher operational carbon to be needed over the building's life time. There is *"… a growing awareness that in the choice of building materials, the designer must consider not only the requirements of the building owner and occupier, but also the resource base and the effects of extraction, manufacture and processing of building materials on the social and natural environment of this planet*" (Buchanan & Honey, 1994)

As was discussed under the embodied carbon method, design decisions impact all levels of carbon emissions. Though, Design Carbon Accounting (DCA) is an area of design lacking in general notoriety, awareness and practice of DCA would allow for more accurate ECA for building occupants and owners. "*More works need to be done in this area to allow engineers to better understand and acknowledge the real energy and resource consumptions of their designs*." (Hermreck & Chong, 2009)

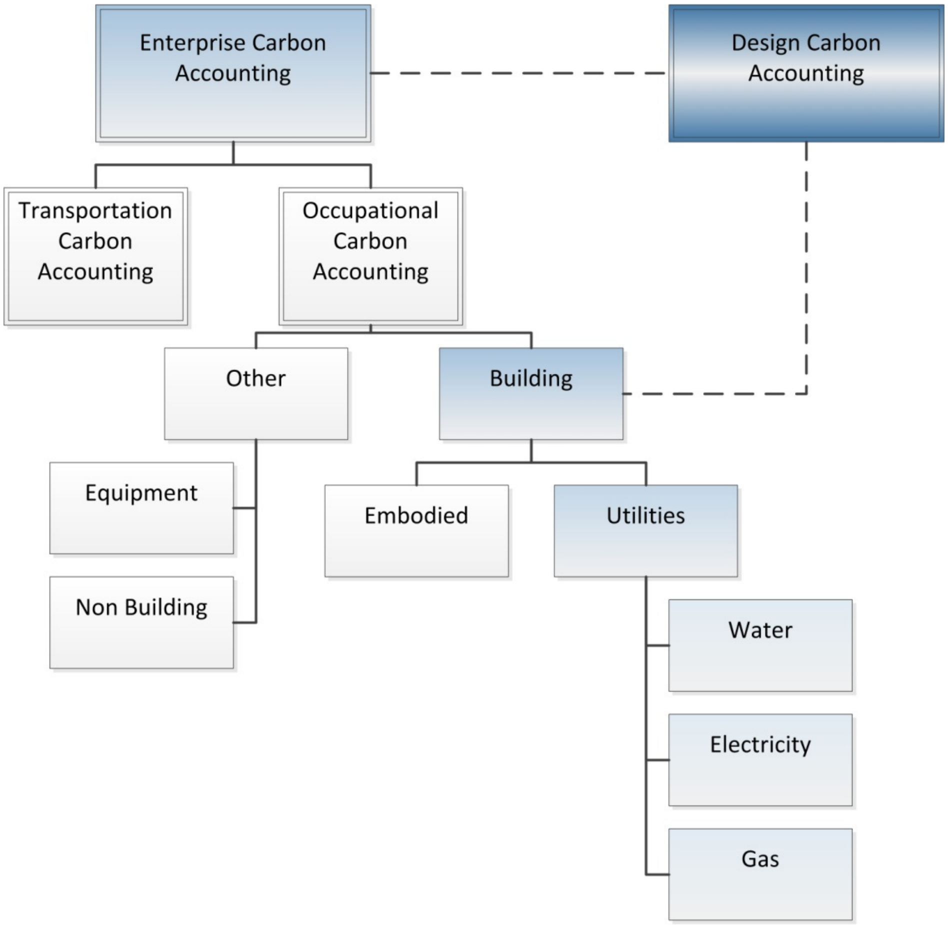


Figure 25: Carbon Accounting Design

Figure 25 draws the connection between design, ECA, and the built building. DCA acts as a shortcut between building carbon emissions and ECA carbon emissions. It would be foolish for designers not to make use of this shortcut to achieve a beneficial goal for all parties involved.

CHAPTER 7: RESEARCH SUMMATION

Conclusions are a method of drawing together the important factors of a study. Large-Scale Agency Analysis is a method of establishing a quick audit carbon system over a large number of buildings. Using the LSAA quick audit method established in this thesis, KDOT arrived with a baseline estimate of their carbon emissions. It also provided them with basic knowledge of areas that are in need of improvement if further studies are to be conducted. These improvements include, but are not limited to the collection of full building documentation for all KDOT buildings, utility data for all campuses, and up-to-date renovation and operational information. The basic carbon calculation sheets, designed for their agency will allow for future additions and alterations of the agency buildings as well entry locations for new databases.

Table 16 provides a summation of the three existing methods alongside the newly proposed LSAA method. Differences in approach can be easily seen utilizing this side-by-side comparison. LSAA offers the best mix of time and accuracy for large-scale analysis.

Table 16: Method Comparison

Item	LCA	EIO-LCA	DEP	LSAA	Modifications
Method Basis	Product and process based	Process based	LCA and EIO-LCA hybrid	LCA and EIO-LCA hybrid	-
Level of Analysis	Primary Consumption	Primary Consumption	Primary, Secondary, and Subsequent	Primary Consumption	Primary and Secondary
Life Cycle Coverage	Cradle to Grave	Construction and Life	Construction and Occupation	Construction and Life (optional End of Life)	
Databases	Choice of multiple databases - unregulated	National standards (US)	Independent research	Choice of databases	Approved standard - nat. or internat.
System Boundaries	Varies	Nationally established per sector	Varies	Varies	Approved standard - nat. or internat.
Time Involved	Moderate to high	Moderate	High	Moderate to low	-
Accuracy	Moderate to high	Moderate	High	Moderate to High	-
Transfer-ability	Building specific	Sector building specific	Building specific	Type Specific	-
Mathemat-ical Model	Linear	Linear	Linear	Linear	Dynamic
Misc.	Diminished regional differences	Black Box Analysis - Comparable Results - Difficult to apply to large, multi-functional buildings	Time and labor intensive		

LSAA also provided the best quality score of the examined methods as can been seen in Table 17.

Table 17: Quality Assessment based on a Large –Scale Agency with Ideal Data

	Method							
	LSAA		LCA		EIO-LCA		DEP	
Item	EC	OC	EC	OC	EC	OC	EC	OC
Method of Acquisition	2	1	2	2	2	2	2	2
Independence of Source	1	1	1	1	1	1	1	1
Data Representation	1	1	1	1	1	1	2	1
Time Relevance	1	1	2	1	2	1	1	1
Graphical Representation	1	1	2	1	2	1	2	1
Technological Representation	2	1	2	1	2	1	2	1

* Using the example agency of 941 buildings

** All values come from the information each method would utilize from the same sources

EC = Embodied Carbon OC = Occupational Carbon

Databases proved to be the leading cause of discrepancies throughout this study. Since all databases contain varying quantities and system boundaries, the results per database were incomparable to buildings that used a different database. A national standard database must be created before a large-scale carbon emissions reduction system can be instated. Without a consistent system, no carbon emissions values resulting from database calculations can be used as a comparison. While the auditing system may prove reliable, the accuracy cannot be determined until the database discrepancies have been corrected.

The basis of this study was the creation of a method to quickly assess the carbon emissions of large agencies with a relative accuracy. Up until this point, all carbon emission methods were only capable of assessing individual buildings. This paper explored a large agency method to calculate emissions for many buildings at once using the similarities of buildings within a large agency to the advantage of the researcher.

The LSAA method can be described as a quick audit system to achieve carbon emissions values. As previously discussed, the quick audits are only as accurate as the database used, but given future advances and standardization of databases, the quick audit system can only improve its accuracy. Using the simplified method flow charts presented in Figure 26 and Figure 27, a comprehensive and rapid evaluation of large agencies' carbon emissions values can be calculated.

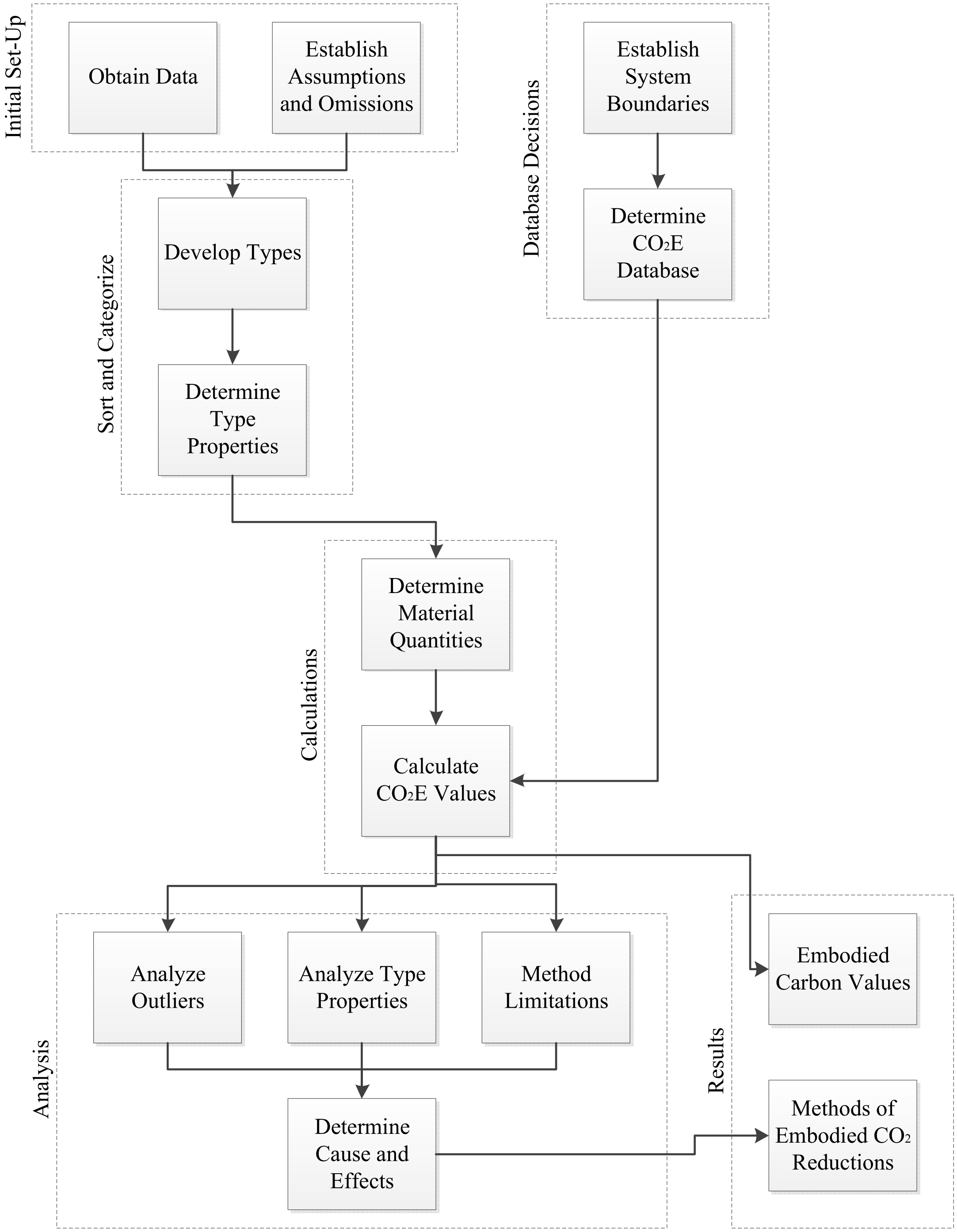


Figure 26: Embodied Carbon Method Flow Chart

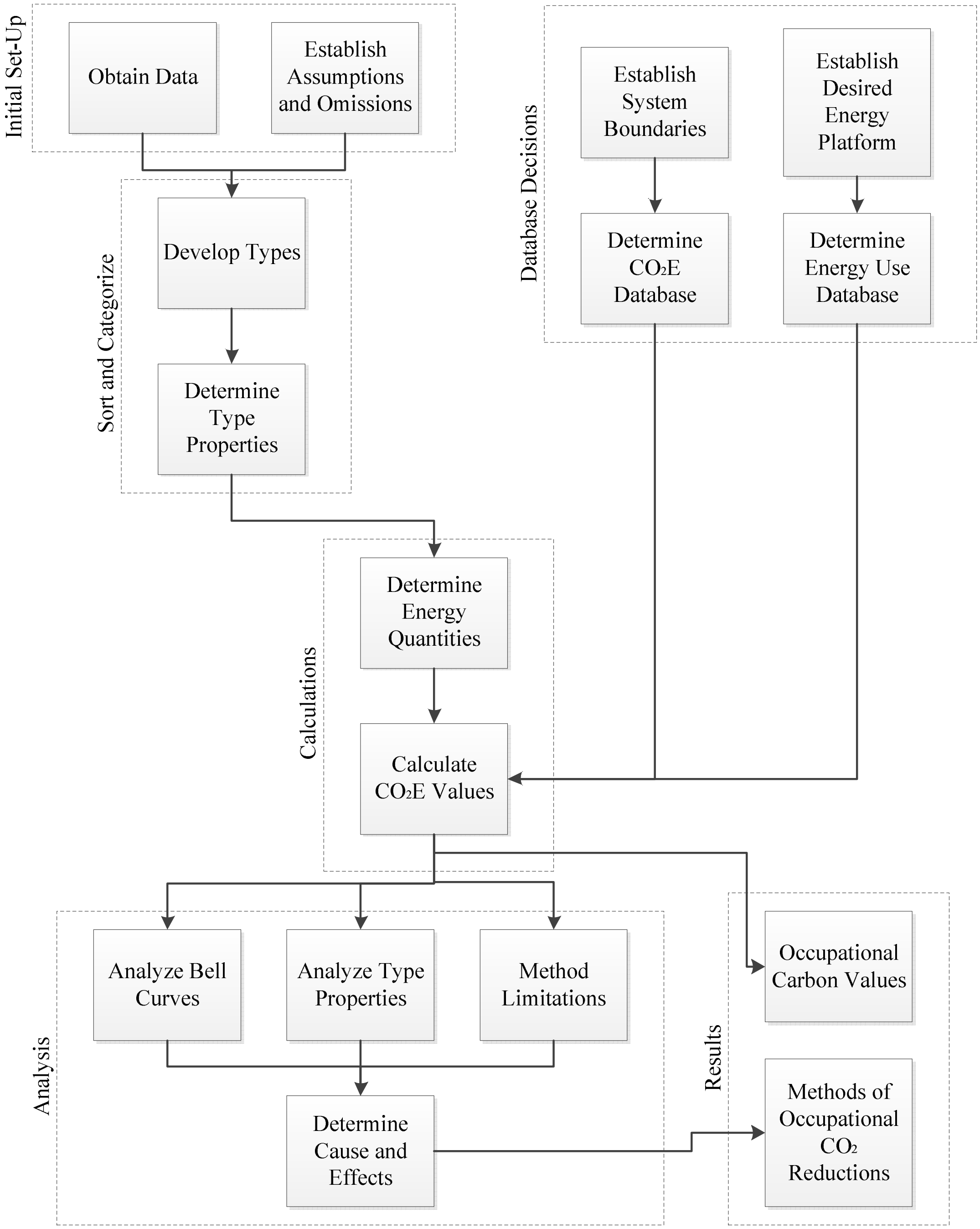


Figure 27: Operational Carbon Method Flow Chart

Successes of the LSAA method were dulled by the commonly used linear analysis system for carbon emissions. Based on the study results, research, and previous mathematical models from other scientific areas, this thesis proposes the creation and adoption of a Comprehensive Dynamic Carbon Analysis system. The CDCA method will reduce the inaccuracies of carbon emissions with the given data, take advantage of recent computing powers and advances in technology, and open carbon emissions to the general public's knowledge. This method will help turn carbon emissions from a best estimate model to an exact scientific method.

Engineers, as a rule, are cautious of new models and quick audits systems. The presented methods however, provide a quick audit system that utilizes the engineer's knowledge of building materials, carbon emissions, and utilities to maximize the engineer's time. A comprehensive mathematical model aids in establishing exact carbon dioxide emission values. The systems pull knowledge from outside sources and databases rather than reinventing the wheel. This approach satisfies the engineer and the building owners as well as any political or social entities with an invested interest in the agency. While engineers might still hold reservations for CDCA and the quick audit system, LSAA, political and social decision-makers will view the rapid calculation systems as helpful guides towards reducing carbon emissions.

Today, one of the greatest goals in the environmental conservation and construction efforts is that of drawing awareness to the importance of carbon emissions and their effects on our environment. By making carbon more accessible to more people, it becomes a familiar element that can be more easily manipulated, controlled, and reduced. The LSAA quick audit system and the CDCA calculation method presented within this study provide a bridge between carbon emissions, carbon awareness, and carbon reductions for everyone involved in building design, construction, and occupation.

“*That being said, relying entirely on one indicator can sometimes be misleading; therefore, one should remain conscious of oversimplification*.” (Weidema et al, 2008)

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APPENDIX

TABLE 18: KDOT BUILDING AND CATEGORIZATION NUMBERS

Categorization Number	Description	Number of Building Types
TYPE A-1	Chemical Domes - Standard, Dome, and Cone	209
TYPE B-4	Wash bays	89
TYPE C-5	Equipment Storage - 4 Bay - less than 2000 ft^2	9
TYPE D-6	Equipment Storage - 6 Bay - 2000 to 4000 ft^2	13
TYPE E-7	Equipment Storage - 10 Bay - 4000 to 6000 ft^2 - Open Sided	43
TYPE F-8	Equipment Storage - 6000 to 8000 ft^2	55
TYPE G-9	Equipment Storage - 8000 to 10000 ft^2 - Open sided	8
TYPE H-10	Area Office - 2000 to 4000 ft^2 (none in existence)	0
TYPE I -11	Area Office - 4000 to 6000 ft^2	18
TYPE J-12	Area Office - 6000 to 8000 ft^2 - No info	3
TYPE K -13	Area Office - 8000 to 10000 ft^2 - No info	1
TYPE 14	Storage - Salt Bunker	111
TYPE 15	Storage - Salt Loader	79
TYPE L-17	Sub Area - 2000 to 4000 ft^2	69
TYPE M-18	Sub Area - 4000 to 6000 ft^2 - Garage portion	31
TYPE N-18	Sub Area - 4000 to 6000 ft^2	31
TYPE O-19	Sub Area - 6000 to 8000 ft^2 - Garage	6
TYPE P-19	Sub Area - 6000 to 8000 ft^2	6
TYPE 20	Sub Area - 8000 to 10000 ft^2	8
TYPE Q-21	Transmission Tower	1
TYPE R-22	Storage - less than 2000 ft^2	83
TYPE S-23	Storage - 2000 to 4000 ft^2	10
TYPE T-24	Storage - 4000 to 6000 f^2	4
TYPE U-25	Storage - 6000 to 8000 ft^2	3
TYPE 26	Storage - 8000 to 10000 ft^2	1
TYPE V-27	Weighing Station	5
TYPE 28	Loader Storage	11
TYPE W-29	Old District Shop	3

TYPE X-30	New District Shop	3
TYPE Y-31	Laboratory - less than 2000 ft^2	6
TYPE Z-32	Laboratory - 2000 to 4000 ft^2	4
TYPE 2A-33	Laboratory - 4000 to 6000 ft^2	2
TYPE 2B-34	Laboratory - 6000 to 8000 ft^2 - Garage	1
TYPE 2C-34	Laboratory - 6000 to 8000 ft^2	1
TYPE 2D-36	Laboratory - Larger than 10000 ft^2	2
TYPE 2E-37	District Office - District 3	1
TYPE 2F-38	District Office - District 1	1
TYPE 40	Salt Brine	2
TYPE 2H-41	Radio Shop	3
TYPE 2I-42	District Office - District 2	1
TYPE 2J-43	District Office - District 5	1
TYPE 2K-44	District Office - District 6 (similar to 2 and 4)	2

TABLE 19: TYPE RESULTS OF EMBODIED CARBON WITHIN KDOT AS OF 2010

Results per Type of Embodied Carbon Emissions				
		LCEE	ICE	Energy 160
	Number of Buildings	tons CO_2	Tons CO_2	tons CO_2
TYPE A-1	Chemical Domes - Standard, Dome, and Cone			
For One Building	1	84722	11	4
For Building Type	209	17706963	2330	746
TYPE B-4	Wash bays			
For One Building	1	80370	49	18
For Building Type	89	7152899	4323	1621
TYPE C-5	Equipment Storage - 4 Bay - less than 2000 ft^2			
For One Building	1	109614	19	8
For Building Type	9	986525	170	75
TYPE D-6	Equipment Storage - 6 Bay - 2000 to 4000 ft^2			
For One Building	1	141458	26	9
For Building Type	13	1838951	342	112
TYPE E-7	Equipment Storage - 10 Bay - 4000 to 6000 ft^2 - Open Sided			

For One Building	1	70607	88	31
For Building Type	43	3036091	3763	1351
TYPE F-8	Equipment Storage - 6000 to 8000 ft^2			
For One Building	1	77481	96	35
For Building Type	55	4261459	5278	1946
TYPE G-9	Equipment Storage - 8000 to 10000 ft^2 - Open sided			
For One Building	1	87573	111	39
For Building Type	8	700585	887	314
TYPE H-10	Area Office - 2000 to 4000 ft^2 (no plans in existence)			
For One Building	1	0	0	0
For Building Type	4	0	0	0
TYPE I -11	Area Office - 4000 to 6000 ft^2			
For One Building	1	337880	40	21
For Building Type	18	6081842	715	380
TYPE J-12	Area Office - 6000 to 8000 ft^2 - No info			
For One Building	1	0	0	0
For Building Type	3	0	0	0
TYPE K -13	Area Office - 8000 to 10000 ft^2 - No info			
For One Building	1	0	0	0
For Building Type	1	0	0	0
TYPE L-17	Sub Area - 2000 to 4000 ft^2			
For One Building	1	132086	19	9
For Building Type	69	9113923	1288	654
TYPE M-18	Sub Area - 4000 to 6000 ft^2 - Garage portion			
For One Building	1	124746	21	10
For Building Type	31	3867134	664	324
TYPE N-18	Sub Area - 4000 to 6000 ft^2			
For One Building	1	188741	16	10
For Building Type	31	5850963	505	295
TYPE O-19	Sub Area - 6000 to 8000 ft^2 - Garage			
For One Building	1	68627	20	9
For Building Type	6	411763	121	54
TYPE P-19	Sub Area - 6000 to 8000 ft^2			
For One Building	1	74350	7	4
For Building Type	6	446100	39	23
TYPE Q-21	Transmission Tower			
For One Building	1	3531	3	1

For Building Type	1	3531	3	1
TYPE R-22	Storage - less than 2000 ft^2			
For One Building	1	19449	24	9
For Building Type	83	1614279	2000	722
TYPE S-23	Storage - 2000 to 4000 ft^2			
For One Building	1	44785	56	20
For Building Type	10	447855	555	199
TYPE T-24	Storage - 4000 to 6000 f^2			
For One Building	1	51530	64	23
For Building Type	4	206120	256	92
TYPE U-25	Storage - 6000 to 8000 ft^2			
For One Building	1	45515	56	21
For Building Type	3	136546	169	62
Type V-27	Weighing Station			
For One Building	1	23	1	0
For Building Type	5	114	5	0
TYPE W-29	Old District Shop			
For One Building	1	109209	37	3
For Building Type	3	327627	111	10
TYPE X-30	New District Shop			
For One Building	1	457	4	1
For Building Type	3	1372	11	2
TYPE Y-31	Laboratory - less than 2000 ft^2			
For One Building	1	152246	13	5
For Building Type	6	913477	80	28
TYPE Z-32	Laboratory - 2000 to 4000 ft^2			
For One Building	1	11803	9	2
For Building Type	4	47211	36	9
TYPE 2A-33	Laboratory - 4000 to 6000 ft^2			
For One Building	1	199109	28	14
For Building Type	2	398219	56	28
TYPE 2B-34	Laboratory - 6000 to 8000 ft^2 - Garage			
For One Building	1	158956	28	14
For Building Type	1	158956	28	14
TYPE 2C-34	Laboratory - 6000 to 8000 ft^2			
For One Building	1	74350	7	4
For Building Type	0	0	0	0

TYPE 2D-36	Laboratory - Larger than 10000 ft^2			
For One Building	1	162771	16	6
For Building Type	0	0	0	0
TYPE 2E-37	District Office - District 3			
For One Building	1	200	1	0
For Building Type	1	200	1	0
TYPE 2F-38	District Office - District 1			
For One Building	1	0	0	0
For Building Type	1	0	0	0
TYPE 2I-42	District Office - District 2			
For One Building	1	17512	13	3
For Building Type	1	17512	13	3
TYPE 2J-43	District Office - District 5			
For One Building	1	31632	24	6
For Building Type	1	31632	24	6
TYPE 2K-44	District Office - District 6 (similar to 4)			
For One Building	1	20562	15	4
For Building Type	2	41124	31	8

TABLE 20: SUMMATION OF OPERATIONAL CARBON PER DISTRICT

Area	Total Annual Energy Use (kWh 2009)	CO$_2$E - EPA (.0006895) tons/kWh	CO$_2$E - Carbon Trust (0.54522) kg/kWh	CO$_2$E - EPA 2006 (4.1256) kg/kWh	CO$_2$E - CO$_2$ Benchmark (1.4045) kg/kWh)
District 1	8177974	5639	4458795	33739050	11485964
District 2	1225434	845	668131	5055651	1721122
District 4	517483	357	282142	2134928	726805
District 5	6144828	4237	3350283	25351102	8630411
Total for KDOT	16065719 kWh	11,077 Tons	8,759 Tons	66,281 Tons	22,564 Tons
		11077313 kg	8759351 kg	66280730 kg	22564302 kg