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Kansas Department of Transportation's Enterprise Energy and Carbon Accounting and Utility Research Phase 1B: Embodied and Operational Energy and Carbon in Buildings and Vehicles

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The University of Kansas

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While the Kansas State University report (K-TRAN: KSU-11-1) highlights the numbers of carbon emissions for buildings, this report from KU highlights three points: (1) the energy and carbon performance of KDOT buildings are much compared to the rest of the country (using the Energy Information Administration or EIA database), except for those buildings where laboratories are located; (2) the embodied carbon consumed by KDOT can be reduced using the table that this project develops; and (3) the energy and carbon performance from KDOT vehicles are generally acceptable, but the research team sees opportunities to correct the current trend of reliance on diesel (due to regional climate).

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THE KANSAS DEPARTMENT OF TRANSPORTATION
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and

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

NOTICE

DISCLAIMER

Abstract

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Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background

The American Clean Energy Act, President Obama's Energy and Environmental Security proposal, and the Kerry-Lieberman proposal contain many provisions for renewable electricity, carbon emission, energy efficiency, and cap and trade. Under the new bill and proposals, the state of Kansas is required to report, account for, and propose solutions to reduce its carbon emissions. KDOT is one of the the larger state agencies, and therefore must document, account, and reduce the carbon emissions that it generates.

The American Clean Energy and Security Act institutes the future environmental and energy standards for the United States of America. It establishes the standards for renewable electricity, carbon emissions, energy efficiency, and cap and trade. Also, it sets the direction of investments in energy technology, alternative energy, workers' transition, and smart cars and grids. These standards and investments address several critical environmental and energy issues in the United States of America, such as climate change, and energy security, diversity, and technology.

One of the components of the bill is the cap and trade legislation. This will require private companies and public agencies to self-report and reduce greenhouse gases (GHG), toxic particles, sulfur dioxides, and nitrogen oxide emissions, along with sell or buy GHG credits from the market. Private companies that exceed their carbon emissions limits will have to buy carbon credits from the market, while those who have excess emissions will be able to sell the credits back to the market. Even though only private companies may be taxed or required to purchase credits for their carbon emissions, the U.S. Environmental Protection Agency (EPA) will require public agencies to report and reduce their carbon emission levels.

Carbon emissions from large size corporations like the KDOT are generated from: (1) the energy use to run and operate the corporation's assets (like buildings, vehicles, equipment, etc.); (2) the energy and materials used to produce or develop assets and products for the corporation (such as roads, bridges, buildings etc for KDOT); (3) the materials used to operate, maintain and repair the assets and products; and (4) the materials used by assets and/or their occupants. There are two ways to identify energy use and carbon emission: direct and embodied. Energy used and carbon emissions generated by the construction, operation, maintenance, repairing and running of the assets, and to produce and develop assets and products for the corporation is identified as direct energy use and carbon emissions. Embodied energy and carbon is defined as the sum of energy inputs and carbon emissions (fuels/power, materials, human resources, etc.) that was used in the work to make any product, from the point of extraction and refining materials, bringing it to market, and disposal/re-purposing of it. A corporation consuming a product and not responsible to produce it is consuming embodied energy and carbon. A corporation has more control over its direct energy and carbon and able to implement plans to reduce them. On the other hand, a corporation has lesser control over its embodied energy and carbon and could only influence its embodied energy and carbon emissions with their procurement decisions.

Researchers find that energy and carbon footprint of buildings are an effective method to monitor buildings' energy use efficiency and the overall energy efficiency of the whole industry and economy. Energy can be converted into carbon dioxide (CO_2) equivalents and the total may then be compared between similar buildings and the whole industry. According to Matthews et al.,

> Carbon footprints can be used for a variety of purposes…, everything from compliance with government regulation and environmental benefits to economic savings and social popularity… and surely the method used to calculate them should reflect these differing uses (2008).

While some companies and government agencies require only baseline carbon values, others require operational quantities, inter-corporation quantities, or even supply line quantities. The requirements are based on the needs of companies and government agencies.

The construction industry and the operation and maintenance of buildings consume over 40% of all energy consumed in the United States and generate over 35% of all carbon emissions. The transportation sector follows closely behind, consuming 20% of energy and generating over 27% of all carbon emissions. CO_2 is a form of GHG that traps heat from the environment. Too much GHG in the environment will cause the atmosphere to heat up due to the dissipation of heat that is trapped in the GHG. This will lead to change to our climate. Reducing GHG is thus important as it will alleviate the impact on the environment. In addition, growing demand for energy has pushed prices of fuels to new heights and threatens global economy and national security. Energy saving has become more important than in the past as national security has overshadowed the need for just money savings.

Carbon and energy calculation is an important process of determining the energy use and carbon footprint of buildings and vehicles. Various studies suggested that the total energy consumption of buildings has increased over the years even though the energy use per square foot has actually decreased. This suggests that energy use has gone beyond the control of building occupants. Lighting and space cooling are the largest consumers of electricity while space heating consumes the majority of natural gas in the U.S. (Davis 1998).

1.2 GHG: Types, Equivalence and Accounting

GHG include gases like CO_2, methane (CH_4), nitrous oxide (N_2O), water vapor and some Volatile Organic Compounds (VOCs). GHG absorbs more heat energy than other gases (such as oxygen and hydrogen) and thus traps more heat within. As the amount of GHGs increase in the atmosphere, heat from the sun is trapped in the GHG and thus increases the atmospheric temperature. If GHGs are not removed from the atmosphere, and temperate within the GHGs will continue to increase and thus atmospheric temperature will continue to rise at the same time. Temperature rise in the atmosphere may lead to the changing of climate.

The solution to climate change is to remove GHGs from the atmosphere through carbon sequestrating, and to reduce GHGs production. According to the International Panel on Climate Change (IPCC), other non-CO_2 GHGs have to be reported as CO_2-equivalent (IPCC 2001). Non-CO_2 GHGs have to be converted into an equivalent heat retaining value of CO_2, also known as Global Warming Potential (GWP) (WRI 2010). GWP is used as a weighing factor that enables the comparison of global warming effect of GHG and that of a reference gas (i.e. CO_2). The GWP value of 23 for methane highlights that one ton of methane has an equivalent warming effect of 23 tons of CO_2 over a period of 100 years.

CO_2 emission accounting commonly uses weight such as pounds (English unit) and kilograms (International Standard unit) to determine the quantity of emission: the weight of CO_2

per energy consumption in energy units, Joule, kWh, or Btu, is used as the energy factor. These terminologies and factors are widely adopted by various agencies.

1.3 Scope of Project

Estimating energy and carbon footprint of large companies require a different method than what most energy use and carbon emission models provide. The purposes of this project are to first develop a quick and effective method to estimate both the direct and embodied energy and carbon emissions of KDOT (also known as enterprise energy and carbon accounting), and second, estimate a carbon and energy use baseline of KDOT.

The project will develop methods for KDOT to measure its carbon and energy baseline, develop carbon accounting capabilities, and solutions to reduce the agency's carbon emissions. These efforts are extensive and cannot be completed in the time given for this project; thus, it has been divided into three phases. The first phase aims to establish the carbon emission baseline for all KDOT assets [editor's note: this information has been published as K-TRAN: KSU-11-1]. The carbon emission baseline will be developed from existing KDOT assets. The baseline will help KDOT establish the standards to document, measure, and track carbon emission reductions. The second phase will be to develop solutions for potential carbon emission reductions. The final phase will be to develop a complying carbon footprint accounting and reporting system.

The reduction of carbon footprint is important to KDOT for many reasons. First, the reduction of GHG emissions, particularly CO_2, reduces the impact of climate change. Second, the reduction of CO_2 directly contributes to the reduction of energy use. Reducing energy use will ensure that KDOT saves money over time because KDOT's assets consume huge amounts of energy and emit large quantities of GHG. Energy use savings could yield substantial savings for KDOT in the long run. Third, the use of renewable energy sources, such as biofuel, ethanol, and wind and solar energy reduces carbon emissions and creates jobs in the United States. Since most of the alternative fuel sources are produced in the United States, increased use of these fuel sources will create more jobs. The reduction of imported foreign oil and coal can strengthen the resilience of the U.S. economy.

KDOT will be required to reduce its carbon footprint and the earlier it develops this capability, the more financial benefit they will reap. If KDOT takes initiative, they can eliminate the need to take drastic actions to meet the carbon footprint deadline that potential climate change and energy use bill may set. Early alignment on KDOT's goals with these bills will ultimately eradicate any costly inconsistencies. Such alignment will in due course save KDOT millions of dollars. In addition, KDOT will be able to support the development of alternative energy, energy efficient and low-carbon technologies, and smart grids in the state of Kansas, which will lead to long-term economic benefits in Kansas.

The main purpose of this research is thus to calculate and measure the direct and embodied energy use and carbon emissions of the KDOT major assets (buildings, equipment, and vehicles). The secondary purpose is to develop models to measure the direct and embodied energy use and carbon emissions of different KDOT assets. As such, the assets will be divided according to the types and uses (to be discussed later). For example, building types will be separated according their usage and major building materials. Energy use and carbon emissions calculations will be conducted for each asset type and an average will be used to determine a representative value for different asset types.

This research will also establish a method to categorize and evaluate carbon emissions and energy baseline of KDOT assets. The method will aid the development of a dynamic model to calculate embodied carbon and energy calculation. Results of the method will act as guidelines for future design work and decision-making, and will be used in Phase 2.

A series of research questions will also be addressed:

1. Can energy and carbon audits be quickly and accurately determined using the model?
2. How reliable and accurate are the analysis and audit methods?
3. Can the results of the audits be used for design?

As mentioned before, the main purpose of this project is to determine the energy use and CO_2 output of the contribution and operational life cycle of KDOT's assets. The models have to be used by KDOT to estimate their carbon emission footprints annually and to set a baseline for

KDOT assets. An analysis method is developed to quickly and accurately assess the embodied and direct energy use and carbon emissions of KDOT.

Chapter 2: Methodology

Data was collected from KDOT and its utility providers. KDOT supplied data on vehicle types, types of fuels used by vehicles, building blueprints, and campus blueprints. The utility companies supplied data for natural gas, electricity and water used by KDOT. The data is categorized according to the needs of KDOT. Energy use and carbon emissions will then be compared with comparable industry standards from the Energy Information Administration's Commercial Building Energy Consumption Survey (CBECS) database. CBECS is done every four years to gather information on the energy use of commercial buildings in the United States. The survey targets a large number of buildings to better understand the energy use based upon the day-to-day operations of buildings. There are 140 variables that determine the national averages of various building types. CBECS is a very useful way of comparing KDOT buildings with the rest of the buildings in the U.S. It highlights where KDOT stands compared with the rest of the buildings in the country and determine if KDOT needs to improve the efficiency of their buildings. The calculations and comparisons are made for both the direct and embodied energy and carbon emissions. Figure 2.1 summarizes the flow of data collection, analysis and validation.

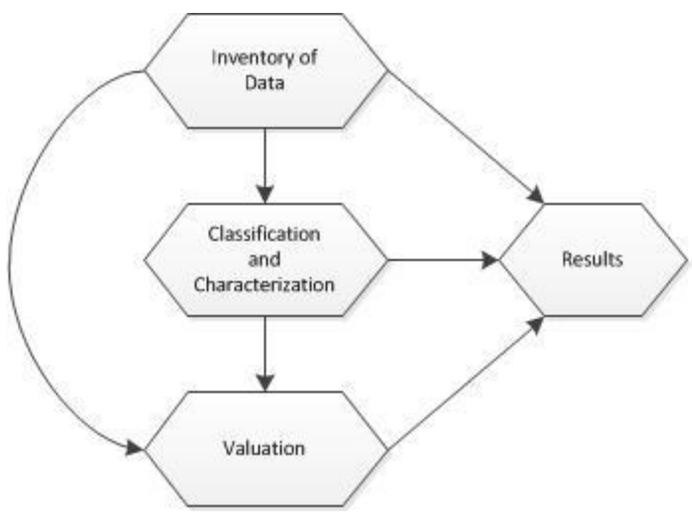


FIGURE 2.1
Method of Analysis

Chapter 3: Transportation-Related CO_2 Emissions

CO_2 is a by-product of fossil fuel combustion when carbon is burned. The fuel that is burned to power KDOT's vehicles and equipment all has carbon present in it and therefore releases CO_2 when combusted. In a theoretically "perfect" combustion process, the oxygen present would react with the hydrogen and carbon in the fuel and convert all the hydrogen to water and the carbon to CO_2, as the equations below show:

Methane: $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

Equation 3.1

Isotane: $C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O$

Equation 3.2

Ethane: $C_2H_6 + 3.5\ O_2 \rightarrow 2\ CO_2 + 3\ H_2O$

Equation 3.3

Thus, any combustion process produces CO_2 emissions, and reductions in these emissions are only possible through reductions in fuel usage. In reality, however, the combustion process is not 100% efficient. As a result, a variety of pollutants are also emitted from fuel combustion, including carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), hydrocarbons (HC), and particulate matter (PM). Carbon monoxide is caused by the incomplete combustion of any carbonaceous fuel where there is an oxygen deficiency. Nitric oxide and nitrogen dioxide are considered nitrogen oxides (NO_x) and are formed whenever any fuel is burned in air. At high temperatures, the nitrogen gas (N_2) and oxygen gas (O_2) already present in the air combine to form nitric oxide and nitrogen dioxide. Nitric oxides react with volatile organic compounds (VOCs), or also called reactive hydrocarbons, in the presence of sunlight to form photochemical oxidants such as the ground-level ozone. Hydrocarbons are formed largely due to incomplete combustion of the fuel or post-oxidation of fuel found in crevices of the combustion chamber. PM forms from the combustion processes emitting small particles of non-combustible ash or incompletely burned soot. Emissions of these pollutants are not addressed in the current work. However, there are emission factors available to allow estimation of emission values for each of these compounds based on total fuel consumption. Data collected for this project on total diesel and gasoline use could therefore be used to provide these estimates at a later date.

CO_2 emissions from vehicle/equipment use will be the measure of KDOT's carbon footprint used for transportation activities in this report. This subdivision of total emissions was chosen over embodied CO_2 emissions and emissions from the construction of roads, bridges, etc. Construction represents a large portion of CO_2 emissions, but is very difficult to obtain data for an accurate determination of construction related emissions, as much of this work is not conducted directly by KDOT. As a result, it was agreed that construction-related CO_2 emissions would not be addressed in this phase of the project. Embodied CO_2 is another relevant measure of emissions, but an accurate accounting using this method would require information on construction and disposal of the vehicles and equipment used, which KDOT has limited control over. Therefore, direct CO_2 emissions from fuel combustion in KDOT vehicles were chosen as the most relevant CO_2 emissions metric for this project.

Two sets of data were obtained from KDOT for use in estimating total fuel usage on an annual basis. This first set of data was purchasing records from fiscal year 2006 to 2010 describing the total yearly amounts of fuel purchased by the agency. (Note that the KDOT fiscal year runs from July to June, so the data discussed here are from July 2005 to June 2010.) These records indicate significant purchases of four different fuels during the study period: unleaded gasoline, standard (#2) diesel, E10 (a 10% blend of ethanol with gasoline) and B5 (a 5% biodiesel blend in #2 diesel). Purchase records were obtained for all four fuel types and aggregated to provide yearly fuel amounts. While there may be some carryover between one fiscal year to another, as fuel purchased in May or June may not be used immediately, this carryover is likely to even out over longer time periods. We therefore assumed for the purposes of our study that all fuel purchased in a given fiscal year was used in that same year.

A second method of determining yearly fuel consumption was carried out through the KDOT vehicle use inventory. This inventory contains monthly records for individual vehicles detailing their used hours, traveled miles, and gallons of fuel added to the vehicle. Vehicle inventory data were obtained from KDOT for fiscal years 2006 to 2010. These data were obtained in the form of an Excel spreadsheet, with each line in the spreadsheet consisting of monthly usage information for a specific KDOT vehicle, including miles traveled and fuel usage. To improve our ability to sort records and obtain fuel usage numbers, we developed a Microsoft Access database for this project. Additional information on this database, which is being further developed as part of the Phase 2 project, is presented in the transportation results section. This database was used to obtain aggregate values for total fuel usage on a yearly basis, and to assess fuel usage by vehicle class. As with the fuel purchasing data, we have assumed that all fuel added in a given month was used in that fiscal year.

Total CO_2 emissions were determined from fuel usage data through application of standard conversion factors. The Code of Federal Regulations and the Intergovernmental Panel of Climate Change (IPCC) list standard carbon contents on a gram carbon per gallon basis for typical gasoline and diesel fuels. A gallon of standard gasoline is assumed to have have 2,421 grams of carbon, and a gallon of standard diesel will have 2,778 grams of carbon (USEPA, 2005). Based on its molecular composition, ethanol will have 76.6% of the carbon content of unleaded gasoline, or 1,854 grams of carbon per gallon. A 10% blend of ethanol with standard gasoline (E10 fuel) will therefore contain 2,364 grams of carbon per gallon. A standard value for biodiesel is more difficult to obtain, as different biodiesel fuels have somewhat different chemical compositions. The major distinguishing factor from standard diesel, however, is the presence of oxygen. For this work, we assumed a typical oxygen composition in pure biodiesel of 10%. The B5 fuel would therefore contain 0.5% oxygen. By assuming the composition is otherwise similar to standard diesel (which makes up 95% of the fuel), we estimated an average carbon content for the B5 fuel of 2764 grams per gallon.

Knowing the carbon content of each fuel allows for calculation of CO_2 emissions due to fuel combustion. The Environmental Protection Agency calculates CO_2 emissions by taking the carbon content of the fuel and multiplying that by the molar weight ratio of CO_2 to carbon, 44/12 (EPA, 2005). A combustion efficiency of 99% is assumed such that 99% of the total carbon in the fuel is assumed to oxidize completely to CO_2. (The remaining 1% will be emitted as carbon monoxide, unburned hydrocarbons, or particulate matter.) This method produces the emission factors listed below for the four major KDOT fuels.

TABLE 3.1
CO_2 Emissions Factors for KDOT Fuels

Fuel	CO_2 Emissions Factor (lb CO_2/gallon)
Unleaded Gasoline	19.4
E10	18.9
Standard Diesel	22.2
B5	22.1

Chapter 4: Carbon Emissions and Energy Use Modeling

There are four carbon emissions and energy use modeling methods: life cycle analysis (LCA), economic input-output (EIO-LCA), process and direct energy assessment path. The types of models to adopt depend on the followings: (1) the types of information available to the research team; (2) time and resource constraints; (3) reliability and accuracy requirements; (4) reporting requirements; and (5) goals and focuses of organization.

4.1 Life Cycle Analysis (LCA)

Life cycle assessment was used by Junnila and Horvath (2003) to estimate the primary energy consumption and GHG emissions of residential buildings. The analysis and models that they developed are comprehensive but the data collection and analysis processes are extremely detailed and time consuming. The results are very reliable, but the effort needed to model hundreds of buildings rendered it less useful for an agency like KDOT. LCA also inherited several limitations as ISO 14040-1997 finds:

1. LCA contains subjective choices such as the data sources and the system's boundaries.
2. Typical LCA assessment models are limited to linear rather than nonlinear models.
3. Local conditions are not adequately described by regional or global values embedded in LCA.
4. Accuracy of results is affected by the accuracy of the data and its availability.
5. Uncertainty is introduced throughout the assessment due to the number of assumptions that are incorporated into the LCA models (Junnila and Horvath 2003).

Boundaries have to be applied to the cutoff regions of LCA. In addition, LCA cannot directly include transportation energy and carbon accounting as transportation cannot be considered as a phase in the life cycle model (MTRI & UAF 2010). Furthermore, LCA is unlikely to cover international boundaries since distances are not part of the development requirement of the models. Goods and services from overseas have to be shipped within the United States and thus energy use and carbon emissions are incurred as a result, but LCA does not allow such information to be separated. Setting the boundaries can be difficult for KDOT as a result. Further ambiguity can be introduced as LCA can only a single type of asset ownership (i.e. rented, lease or own). For example, KDOT leases its headquarters but owns the rest of its building and vehicle assets. KDOT does not have control over who supplies the energy, nor do they have control over any energy saving and efficiency solutions, even though they own the energy use and carbon emissions generated by the spaces they occupy.

Most LCA models can only handle linear analysis. In this study, linear analysis was used to comply with KDOT time requirement. In reality, carbon emission from various sources is non-linear. Weather, location, elevation, surrounding circumstances, and other influencing factors can increase or decrease carbon and energy exponentially.

Carbon databases are available for different geographical locations. The technology used, equipment available, material sources and environmental standards of different geographical locations are different. As a result, carbon emissions of the same product produced in different regions can be different. These databases can only be used in their specified boundaries and regions.

Accuracy of results can be influenced by the accuracy of the data. When data heavily relies on assumptions (as in many cases), the accuracy of the total carbon emissions calculation can be compromised. The accuracy of the models and analyses are influenced by the specifications of the models. Systems must be created to allow more complete data to be collected and categorized. Assumptions have to be double-checked in order to determine their validity. Any dataset that contains invalid assumptions has to be rejected. It is impossible to completely eradicate all uncertainties within the models; however, they can be controlled by monitoring the inputs used in to generate the models outputs. As such, the project team focuses on securing accurate data, developing linear models, integrating the knowledge from past research, and supporting populace in order to enhance the accuracy of the models. The team also eliminates data that contain invalid assumptions and clears out any uncertainties by checking the inputs and outputs from the models. The outputs, most importantly, have to be reasonable.

4.2 Economic Input-Output Life Cycle Analysis (EIO-LCA)

The EIO-LCA method contains similar disadvantages and errors like LCA. However, EIO-LCA has the benefit of relying on the more established government databases that are far more reliable and extensive. EIO-LCA analytical approach is like discovering what is a "black box". Information is used in the analysis and then extracted at the end of the analysis. Government database tends to focus on the macroeconomy and they cannot be broken down easily into microeconomic level data. As such, EIO-LCA cannot be used to propagate accurate energy use and carbon emissions of a company or agency (Treloar 1997).

The input-output (I/O) economic model counts the whole annual economic activity of a country as a lump-sum "revenue" such as gross domestic product (GDP) data, or tax in different industry sectors. The percentages of each activity and sector are measured from the revenue generated by each activity. Applying the percentages to the lump-sum country's emissions, carbon emissions of each activity can be determined. This method was first adopted in Japan by Oka and Michiya in 1993. In the Japanese method, the total amount of domestic, imported, and exported products produced by construction activities, such as steel and concrete, is published by the Research Committee of International Trade and Industry each year using the I/O Table of Japan (Oka et al. 1993).

This method was also adopted in Canada. The Canadians' models are very similar to the Japanese; however, the cost is swapped by a market-based policy instrument, which is a carbon permit system (Dissou 2005). The revenue generated by carbon permit is calculated and then converted into carbon equivalent.

In the United States, economic input-output life cycle assessment (EIO-LCA) method developed by the Green Design Institute at the Carnegie Mellon University also uses a similar input-output method to measure carbon emissions, but they localize it for Pennsylvania and West Virginia. They compose different models for 1992, 1997, and 2002 using the United States Department of Commerce data.

The most important advantage is the easy access of macroeconomic data since most countries have a statistics department to keep track of data such as power and water consumption in different industries. The calculations only require the combinations of different weighting percentages in order to distribute the carbon emissions according to the energy intensity of different production sectors. However, the disadvantage is that macroeconomic data requires a large number of assumptions as these data cannot be broken down further for companies. The assumptions have to be made to address different types of equipment and fuel used and production processes by different sectors. Power lost and other unexpected factors are likely ignored in the IO models, while the process models will count these factors in every step of the calculations (Chong & Hemreck 2010). The assumptions could make the models less accurate.

4.3 Process Models

The process model calculates carbon emissions based on the flow of energy use patterns at the manufacturing and production level. The energy consumption includes building construction, operation and maintenance, material extraction and production, and material transportation. This model is more precise compared to the IO model, and it can effectively be used to estimate the carbon emissions of green building standards. In this modeling method, countries or regions that import most of their construction materials from neighborhood countries, such as Singapore, Hong Kong, and the U.S. may have less carbon emissions on construction materials compared to materials exporting countries such as China. Similarly the raw material carbon emissions of products may not be counted in the supply chain emission accounting with a corporation if it does not generate it. They are normally included as embodied carbon and energy of a company. The process model can be used to calculate carbon emission with diverse variables in the construction and building industry. For green buildings, the variables can be categorized into: general building information, building energy use, domestic water, landscape, transportation, materials, solid waste. These categories will be broken down into sub-categories to determine the contribution of carbon in each activity. For example, for general building information, the number of occupancies is needed to determine the water use and power consumption on escalator, elevator, electrical appliance, HVAC, and lighting (Chong & Hemreck 2010).

4.5 Hybrid Method: Direct Energy Path Assessment Method (DEP)

Due to the proportionally large number of uncertainty variables in LCA and EIO-LCA methods, hybrid analysis methods bridge the gaps between the two methods. The hybrid model is a combination of the economic input-output model and the process model. In this modeling method, EIO-LCA is used to estimate the fuel consumption and carbon emission factors from macro-economy level data, while the process model is used to estimate the carbon emissions factors of criteria like materials and water. Carbon emission factors depend on the level of accuracies needed, the types of information that are available, and the situations of modeling, The Hybrid Model is a very flexible method that often overcomes the disadvantages of either models, but the final model may have the combinations of errors of the two previous models. It contains both the disadvantages of the other two such as lots of assumptions, and boundary justification problems.

The most popular of these hybrids is the direct energy path assessment method (DEP). DEP is a hybrid energy analysis method that examines the decomposition of the energy input-output model into mutually exclusive components. DEP is more time consuming than LCA and EIO-LCA as it requires results to be obtained from a production process (thus DEP is also known as the hybrid process method). Since there are multiple energy paths within a process, an exponential number of paths are usually simulated and combined to attain an average so that the model and variable are more user-friendly. An example documented in Treloar (1998) found that there are 592 direct energy paths existed just for 90% of the total construction energy use to build a residential building (Treloar 1998). When these 90% of energy is further broken down into more categories (energy intensity, direct and indirect), Treloar (1998) found a total of 1,748 paths. It is impossible and unreasonable to calculate all of the energy paths of KDOT energy usage and flow, and a simplified version of DEP will be used instead for this project.

4.6 Enterprise Energy Accounting (EEA) and Enterprise Carbon Accounting (ECA)

EEA and ECA are energy and carbon accounting techniques that large-scale agencies use to measure and account for energy use and carbon. ECA, also called corporate carbon accounting, describes a rapid and cost effective carbon accounting process for large scale organizations to collect, summarize, and report GHG inventories and emissions.

Figure 4.1 presents a partial carbon accounting flow chart showing how ECA “flows” within an organization. As seen in the figure, transportation carbon accounting (TCA) details all vehicles, vehicle miles, and fuel consumption associated with an agency. The occupational carbon accounting (OCA) also forms the backbone of a dynamic carbon model. OCA investigates the equipment, computers, and tools that draw energy within the building as well as the embodied energy that the building consumes. Embodied energy described the indirect energy to produce the materials that are used to build the building.

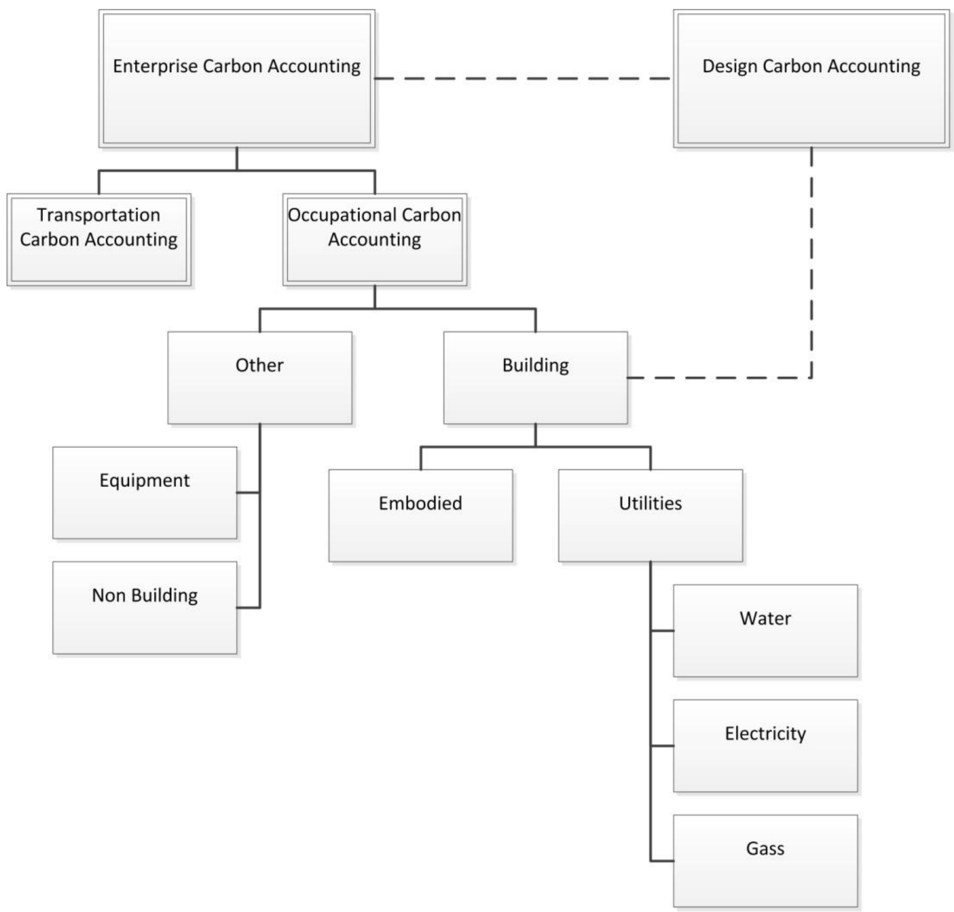


FIGURE 4.1
Enterprise Carbon Accounting

Project stakeholders can improve their control of energy use and carbon emissions generated by buildings if they are able to track and understand how carbon is produced and how energy is used in each of the element shown in the above ECA. The ECA can combine all the carbon emissions and energy use from the elements to calculate the overall carbon and energy use for a building too. Both are what KDOT wants.

Some organizations, such as the Consortium for Research on Renewable Industrial Materials (CCORRIM) claim that certain materials could be produced with less energy and generate lower amount of carbon emissions. Buchanan and Honey (1994) found that wood from Forest Stewardship Certified (FSC) forest is more environmentally friendly and uses less energy and generate less carbon to produce (and thus lower embodied energy). Using materials with lower embodied energy and carbon helps conserve energy and reduce the release of carbon into the atmosphere, and thus creates benefits to the society, economy, and environment.

4.7 Modeling and Analysis Methods

Most energy use and carbon emission accounting methods can only account for either embodied energy and carbon or direct energy and carbon, but not both at the same time. It is more difficult for company and agency to account for the energy use and carbon emission that they have no control over, such as those at the upstream and downstream of a supply chain if the companies do not play a part in producing the product. They will have to rely on information they can find to model these energy use and carbon emissions.

There are three scopes of energy use and carbon emissions that company and agency have to include in their enterprise accounting. Scope 1 encompasses a company's direct energy use and carbon emissions from on-site energy production or industrial activities. Scope 2 accounts for energy that is purchased from off-site (primarily electricity, but also including energy like steam). Scope 3 is much broader and can include anything from employee travel, to "upstream" emissions embedded in products purchased or processed by the firm, to "downstream" emissions associated with transporting and disposing of products sold by the firm. Although Scope 3 is the most difficult to account and measure, it attributes to 75% of an industry sector's carbon footprint. As a result, 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 et al. 2009). Everything from employee travel to trash disposal to use of paper counts toward carbon emissions; however, many of the activities in Scope 3 contribute to insignificant amount of energy use and carbon emissions and are normally excluded in the macro-level models. Thus, only significant energy use and carbon emissions in Scope 3 are included in this project.

The LCA, EIO-LCA, the process, and the hybrid models require justification of what activities should be included. The justification is based on the boundary of direct and indirect carbon emissions. Direct carbon emissions refer to the emissions that are directly emitted from a process, while indirect emissions refer to emissions that are generated by supplementary processes that support the main process. Energy consumed by a cooling system that is used to cool a retail store is a direct carbon emission to the store; however, this energy is an indirect carbon consumed by a consumer who buys something from the store. The definition of carbon emission depends on the established boundary of a product, material or individual. Figure 4.2 shows a simplified manufacturing process of plasterboard that highlights the classification method for carbon emissions. Carbon emissions within the boundary are direct emissions, while those outside the boundary are indirect emissions.

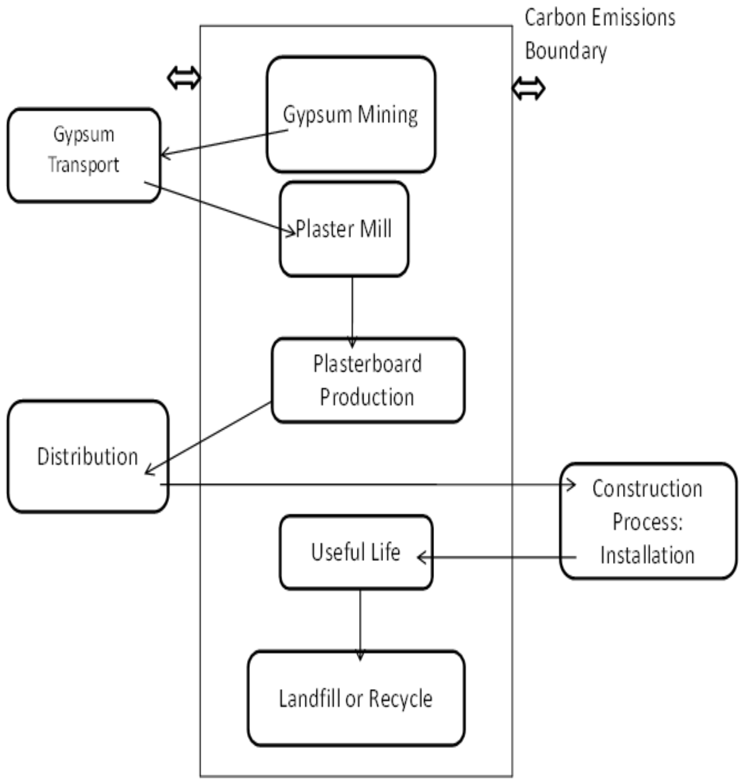


FIGURE 4.2
Direct and Indirect Carbon Emissions of Plasterboard (Lafarge Plasterboard 2010)

4.8 Cost Savings and Carbon Emissions Reduction

Koomey et al. (1998) calculated the energy, carbon, and cost savings of three models: 'business-as-usual' (BAU), 'efficiency' (EFF), and 'high efficiency/low carbon' (HE/LC) buildings. The three models presented strikingly different results. The efficiency model reduces 5.3% energy use and lower 4.4% of carbon emissions than the BAU model in 2010. This represents a saving of $18 billion in annual fuel cost. The HE/LC model generate 12% less energy use and 11% lower carbon emissions than the BAU model. This represented a saving of $33 billion in fuel cost. Even though the HE/LC model spent $13 billion on efficiency improvements and an estimated $1 to $2 billion per year in promotion and policy development costs, the saving was still greater than the EFF program (Koomey et al. 1998). This clearly highlights the cost benefits of targeting efficiency and carbon emissions at the same time.

Before the federal or state government can mandate carbon analysis system or carbon enterprise system, they have to first mandate a standard carbon emissions value system. Of the process-based 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 other three primary methods. Each was developed to ease specific types of modeling analysis, but, as explained before, none were developed with large-scale agencies in mind. All of the above methods are equally time consuming to develop (Treloar et al.2001) and that makes them unsuitable for large-scale analysis.

Chapter 5: Understanding Embodied and Direct Energy and Carbon at Different Life Cycle Stages

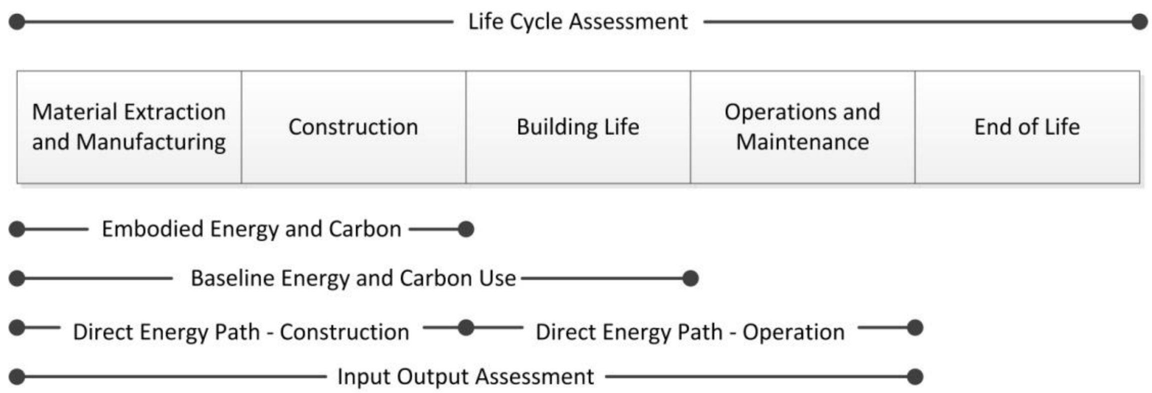


FIGURE 5.1
Life Cycle Breakdown and Analysis Methods

Figure 5.1 depicts the five life cycle stages of energy and carbon usage. The arrows below the stages are the corresponding methods used to calculate the environmental impact (as in this project energy use and carbon emissions) at different life cycle stages. This figure highlights what KDOT will be getting and the types of models the research team will be developing. Both direct energy use and carbon (from vehicles and buildings operation and maintenance) and embodied energy use and carbon (from the materials used to build the buildings) are calculated and modeled through the use of multiple models (LCA, DEP, EIO-LCA and process) due to limitations of time and data types. LCA cannot be used along as its comprehensiveness makes it unsuitable for large agencies and its inherent need for extensive amount of time and extensive and extremely high-quality data. EIO-LCA, though capable of covering building end of life, typically only assesses those areas that are projected into the future. KDOT often operates their utilities locally; it becomes difficult to obtain the same data, utilities, and quantities for every building. This makes the extensive use of EIO-LCA methods impossible, and thus it will only be used to cover the operation stage for energy use. Direct Energy Paths cover the same stages as EIO-LCA, but is subdivided into Construction and Operation stages. Due to DEP's extensive time requirements, it cannot solely be used in this project. Baseline Building Use may be assessed with the first three stages of environmental emissions and is the goal of the new assessment method. The last method listed is an embodied assessment. This is comprised of the first two stages, and is the basis of all other methods since it represents the energy and carbon embodied in the building's structure and materials as it stands. A combination of all of the methods have been adopted to overcome various constraints.

Various methods are combined together to create an Enterprise Carbon Accounting (ECA) for KDOT. ECA is evolving 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. The life cycle of buildings and materials has become more like a circle (i.e. cradle to grave integrating with cradle to cradle) instead of a straight line (end of life without any opportunities for reuse or recycling) as shown in Figure 5.1. As recycling and reuse become more popular, future life cycle diagram will become more circular.

Chapter 6: Categorization of Buildings and Transportation

KDOT's assets (buildings, equipment, and transportation) are categorized according to the types of information available to the research team, and how energy is used and carbon is emitted. As shown in Figure 6.1, the divisions follow the "natural" division of carbon accounting elements and their respective databases. Each division accounts for the specific information that is available to the different assets and the types of assets. They also differentiate the spectrum within each group. In short, they are divided into their asset types, activity types, and information types. Data quality is reviewed to ensure that they are reliable and representative of KDOT assets. The research team adopts a hybrid approach that incorporates elements from EIO-LCA, LCA, process and DEP methods to develop the models and conduct the analyses.

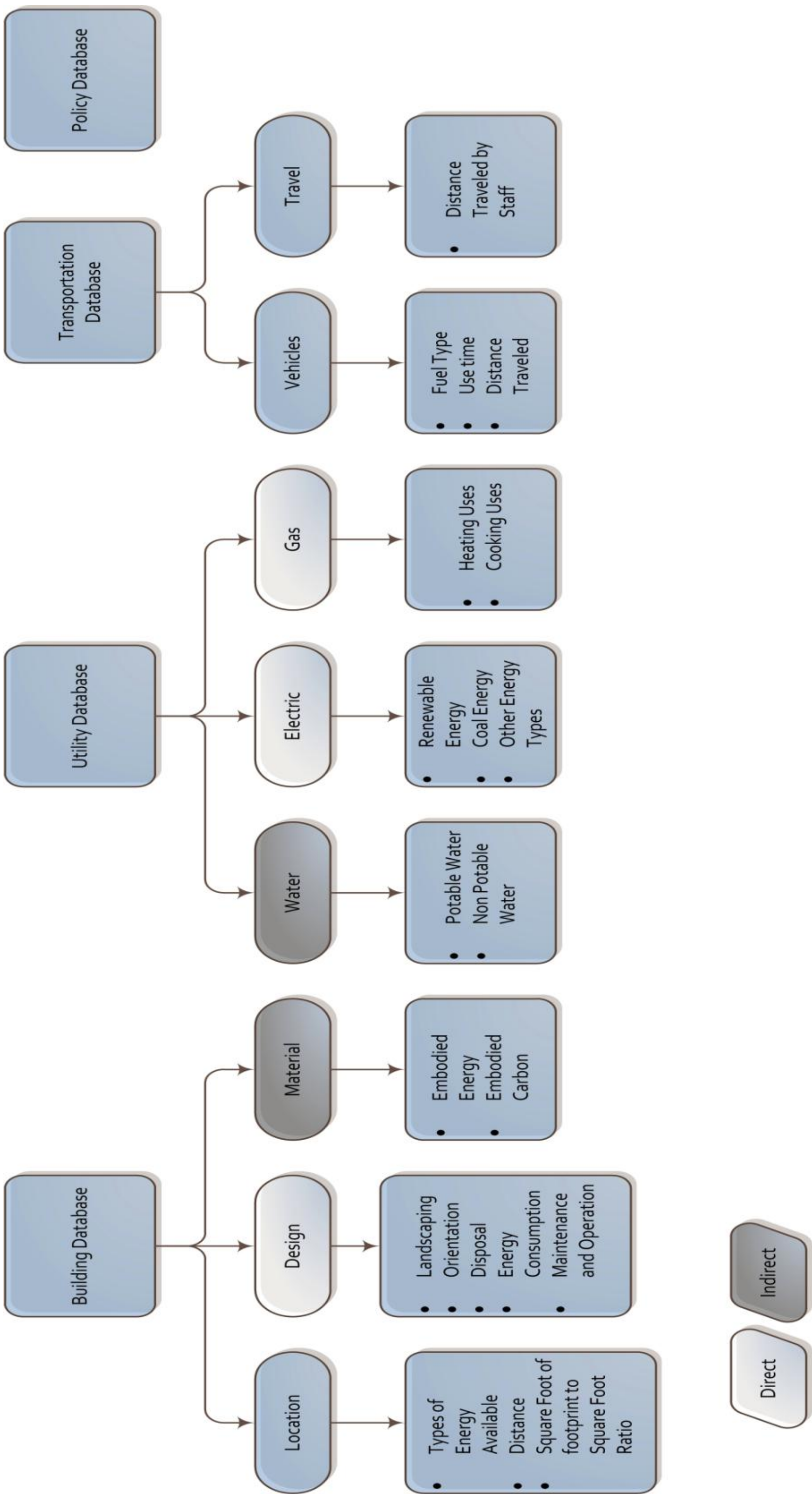


FIGURE 6.1
Components of Carbon Database

6.1 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, the new method will base its data quality from the pedigree matrix developed from a matrix by Weidema and Wesnæs (1996) as seen in Table 6.1.

TABLE 6.1
Pedigree Matrix Used for Data Quality Assessment (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	Less than three years of difference to year of study	Less than five years of difference	Less than 10 years difference	Less 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

Table 6.1 provides the analytical framework on the assessment of the data quality. It is modified into Table 6.2 to better reflect the types of data provided by KDOT and the utility

companies and the types of models that will be adopted by the hybrid model that the research team adopts.

TABLE 6.2
Method Quality Matrix

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

*Using the Example Agency of 941 buildings

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

The method quality matrix allows the research team to evaluate on a per-element basis. The matrix also proves to be adequate for KDOT and this kind of research.

6.2 Data Organization

Buildings are sorted into the five categories: (1) building sizes; (2) types of materials used; (3) occupancy rates; (4) locations; and (5) building usages. These categories reflect the buildings' potential consumption of direct and embodied energy, potential generation of carbon emissions, and the needs of KDOT (thus the model).

6.2.1 Floor Plans and Site Plans

Data are sorted according to these categories. Data for these categories are collected from the KDOT blue prints. While most KDOT blueprints are available to the research team, the older ones are no longer reliable as many of these older buildings have been renovated or modified and information and new blueprints are not available to the research team. As a result, the research team visited representative buildings or called up the occupants to verify the changes made to the older buildings. The research team visited a number of KDOT campuses to obtain a feel for the agency and its buildings and operations. Four additional trips are made to further clarify any discrepancies and confirm any updates.

Phone interviews with KDOT personnel were conducted on the buildings where plans were not available to verify the design and made of those buildings. In addition, Google Maps® was also used to find out the design and make of those buildings. As most KDOT buildings are very similar in designs and made, the research team made reliable assumptions on the design and make too.

6.2.2 Materials

Building blueprints show the dimensions and types of materials of the buildings. Good judgment calls or phone call verifications were made to verify information that cannot be seen clearly on the drawings, e.g., the older or damaged blueprints. Using knowledge and images from four site visits, the unknown materials are easily identifiable. The research team found many similarly designed buildings and thus made reliable assumptions base on several buildings that they visited. Phone call verifications allowed the research team to confirm their results.

6.2.3 Building Usage

Buildings are categorized according to the actual use of the building rather than the intended or planned use. This field, "Building Usage", separates buildings based on their energy usage and space conditioning requirements. For example, office spaces require energy mainly to conditioned spaces for the occupants while workshops spent most of their energy on running equipment. KDOT representatives were interviewed to see if the building plans portray accurate building usage.

6.2.4 Occupancy

Even though some KDOT buildings are designed to deliver conditioned air for several occupants, these buildings are not frequently occupied during their operating hours. Most of the occupants spent their time on the roads. Phone calls are made with those who actually occupied the buildings to determine if the above is accurate. Full-time and part-time occupants are also separated in the analysis in order to determine how many actual occupants are occupying the buildings full time. Full-time occupants contribute to greater energy use in those buildings than part time occupants.

6.2.5 Building Age

"Building age" is also used to separate the building types. It is an important field as the quality and type of materials used for the buildings and the energy needed to run the buildings tend to be very similar among buildings with the same age. Older buildings may often use higher quality materials and are better constructed but may not be as well insulated as the newer buildings. Materials also deteriorate with age due to wear and tear from weather and damages inflicted by occupants and animals.

KDOT buildings are regularly renovated and maintained to ensure that they keep up with current energy efficiency technologies and building standards. Thus a 50-year old office building will likely be outfitted with 5-year-old windows. Any alterations made to an older building can drastically change the energy efficiency and performance of the building. They will behave "younger" and thus may be more energy efficient and perform better. Thus, other than categorizing the buildings base on age, they are also categorized based on when they were last renovated.

6.2.6 Maintenance and Operation

Maintenance and Operations is divided into two categories: maintenance of the facilities, and daily operations. Maintenance includes the maintenance and repair state of equipment and materials of the buildings. Such information includes whether burners on a furnace are still functioning, the numbers of burnt out light bulbs, whether windows sealants are cracked, or if filters are dirty. All of these maintenance issues affect building performance.

Operations include activities that are repeated on a regular basis on a building, like the running of cooling system and general cleaning. Some buildings at KDOT are used for multiple purposes. A building can be used for truck storage even though it has a garage to store laboratory equipment. Building use determine what kinds of operations are needed on a regular basis. Such information is obtained through phone interviews with the building occupants.

6.2.7 Buildings Policy and Practices

State policies and agency practices are also collected to understand how they impact energy consumption of various buildings. Space conditioning is the single greatest energy consumer. For this reason it is important to determine if occupants alter their interior temperatures based on the exterior temperatures. While a shop worker might be expected to wear gloves during winter and expect heat during the summer, an office workers' tolerance towards fluctuations in temperature tend to be lower than a shop worker. Cultural differences may also impact expectations and requirements.

Policies and practices, and employees' behaviors may vary from district to district. Some regions employ a "lights out" policy that requires that lights be turned off when no one is in a room. Some offices turn off lights on hot summer days in order to save energy, and some area offices may utilize windows rather than the thermostat to control indoor temperature.

6.2.8 Utility Data

The utility data from KDOT shows how energy use may vary more drastically than what they normally assume. For example, a furnace exploded in an office basement and their employees had to work without heating in the building for several weeks. 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 outside conditions. Many employees complimented the comfort level of the improvised method over the previous furnace that produced uneven and spotty heating. The energy use during that period actually came down significantly. Such information may be difficult to come by since phone calls have to be made to the right persons who remember such incident. With the great help from our Kansas State University colleagues, extensive utility data are gathered and they are used to measure the energy and carbon footprints of all KDOT buildings.

6.3 Assumptions for Building Dimensions and Specifications

Assumptions have to be made on most of the data and analysis. Only reasonable and verified assumptions are used in the models and analyses. As many KDOT blueprints and records were either missing or grossly out of date, the following table of assumptions was used to reduce the impacts due to missing and out of date information.

TABLE 6.3
Material Assumptions (Legacy Formwork 2011)

Material	Thickness	Weight per area (lb/ft^2)	Other Notes
Plaster	5/8" thick	2.76	
Glass	1/8" thick	1.677	Single pane
	2 1/8" thick	3.354	Double pane with ⅛" to ¼" air gap
Gravel	4" deep	35	
Common Red Brick	Standard	40	4" × 2 2/3" x 8"
Cast Iron	1/4" thick	9.375	
Rolled Steel	3/8" thick	15.469	
Wood doors	2" thick	2.75	Solid doors
Sandstone	8" deep	96.7	Value used
	12" deep	145	Not standard assumption
Concrete Wall	6" deep	74	Not standard assumption
	8" deep	98.7	Value used
	12" deep	148	Not standard assumption
Fiberglass		1	Assumption
Shingles		1	Assume soft wood
Siding		1	Assume heavy duty plastic siding

6.4 Adjustments of Building Dimensions and Specifications

Data gathered from KDOT building blueprints and from the utility companies are adjusted to reduce the amount of errors from some of the incomplete blueprints and unclear utility bills. Three trips were made to verify the locations of some of the meters. The adjustments are also made due to limited time that the research team faces, and are based on the best of knowledge of the research team and time allowed to verify the data. Highway rest stops are excluded from the study due to time and resource constraints. As there are massive number of street lightings and highways in the state, they are excluded from the research but will probably be included in future projects.

6.4.1 Utility Data

The first and most time consuming task within the energy analysis is obtaining the utility data. Kansas State University has been on the frontline to collect these data and spent a huge amount of time doing so. The utility data is analyzed by the two project teams (KU and KSU). The utility information for all accounts within the agency must be amassed from each of the supplying utility companies. Large buildings and campuses are contained under a single account number or can be broken into several accounts. Each account can consist of multiple meters. A few large-scale utility providers hold many of the agency's accounts, in which case obtaining the account information en masse will proceed quickly. Other agencies may use small, local utility providers, in which case many phone calls will be necessary to obtain the data. The report from Kansas State University (K-TRAN: KSU-11-1) will describe these processes in detail.

When contacting providers, four key pieces of information are required:

1. Years
2. Locations
3. Value 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 were required, seeking utility records from the past decade would prove beneficial. Newer buildings may not have ten years' worth of data, but obtaining records from the present billing period to the first billing will be adequate. For current energy analysis, a span of three to five years will provide a strong average value for the analysis. In the case of KDOT, a span from 2007 to 2010 was desired. Due to availability, most accounts contain roughly three and one-half years of data since many accounts no longer had access to data before the spring of 2007.

Each account number is 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.

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 companies 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 small 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 being able to group accounts and meters into campuses, meter allocation problems were avoided.

6.4.2 Utilities-Origin of Energy

Energy source data represents the sources from which power is drawn. Electrical energy (or electricity) can be generated from coal, nuclear, hydroelectric, wind, and solar power may be combined to make up the total power provided by the utility company. Oil and gas may be locally mined or traded internationally. In addition, natural gas is often used as backup power generator when excess electricity is in demand. Depending on the region in the United States, different sources of fossil (coal, oil and natural gas) and non-fossil (nuclear) fuels, and renewable energy sources (solar, wind, or hydroelectric power) are combined to generate electricity in different proportion before distribution to consumers. The efficiency rates of converting various fossil and non-fossil fuels and renewable energies to electricity varies significantly from 28% from solely coal fire power plant to over 80% for natural gas, and thus the amount of carbon emissions from these energy sources differ significantly. In addition, the efficiencies of different energy sources are also affected by the technology applied (e.g., fourth generation solar panels versus third generation), quality of fuel sources (e.g., different classification of crude oil), and the distribution networks and distances of different fuel sources. All the aforementioned factors influence the rate of carbon emissions of different electricity supplies.

6.4.3 Organization of Building Utilities Data and Analysis

Utility data and analysis are grouped into "Building Types" and "Campus Types". "Building Types" describes the uses and sizes of the buildings (as shown in the table below) while "Campus Types" describes a group of buildings that are located in one specific area (e.g. regional office). As the utility companies install one meter for each campus rather than for each building, the utility data are grouped by campuses first and then grouped by buildings (whenever possible). The building types are described in Table 6.4. The table also highlights some energy use averages for different building types base on the Department of Energy's Energy Information Agency's averages for the building types. With the buildings in the set categories, each building type was given an ideal version of the type based upon the majority of the buildings. These ideal buildings were used to get a uniform set of variables that would work for the building type. These variables included items such as building material, government/non-government owned, geographic location, number of workers, hours of operation, type of lights used, hours lit, etc. This ideal building was used to make the EIA benchmark that would be used for the analysis of the building type by kWh per ft^2 per year, as shown in Table 6.4. This was then compared to the meter data supplied for each building, showing if the building is performing above or below the national average for that type of building.

TABLE 6.4
Building Types Used for Analysis with EIA Average Benchmarks

Building Type	Description	EIA Average (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

6.4.4 Utilities Base on Occupancy

"Occupancy rates" is also used to group the KDOT buildings for analysis, these rates are the same as mentioned above.

6.4.5 Utilities Vary With Building Age

Building energy system efficiency deteriorates with age unless it is overhauled, replaced or repaired. Building energy efficiency is thus tied to building age and its maintenance status. The older a building system gets the more energy use it uses and carbon emissions it generates. Thus, the age of building system is somehow correlated to with the energy efficiency of building, and can be used to project and estimate building energy use.

Energy analysis can be used to estimate asset energy use of companies. The analysis is generally conducted on the buildings, machinery, campuses, or any items that consume significant amount of energy. Energy analysis can be used to benchmark energy use of companies and compare with industry, regional and international standards.

6.4.6 Utilities Vary With Building Usage

A literature review found that the types of building affect utility use of a building. The Energy Information Agency's (EIA) Commercial Buildings Energy Consumption Survey (CBECS) collect and analyze commercial building data across the United States. CBECS estimates an average energy use per square foot of building for different building types. For example, an office building has an energy intensity of 93,000 Btu per square foot while a warehouse of similar size would require half the amount of energy to run per square foot. Thus buildings have to be grouped similarly to CBECS categories in order to make the comparison useful. Buildings within each category have to be further separated. Office buildings that offer more amenities, located at a high end area and owned by the owners may have lower energy intensity than the other normal office buildings. Installing and using increasing number of energy intensive equipment in the building occupants will also increase building energy intensity. Occupants' behavior in the buildings is assumed to be constant for all of the buildings. The project team chose the CBECS Consumption and Energy Intensity by Building Activity chart as a benchmark as this is the latest version (2010) of the series of EIA CBECS publications. CBECS also publishes representative energy intensities for many types of buildings. These values are used as benchmarks to compare KDOT buildings with the rest of the country.

6.5 Utility Data Assumptions

The campus utility data were further separated for individual buildings. Phone calls were made to various KDOT building operators and Google Maps were used to determine the building types, sizes, uses and occupancy rates. Information from the CBECS database was used to calculate the energy intensity distribution of various building types, sizes, uses, and occupancy rates. The CBECS information improves the reliability of the assumptions made by the research team; however, the utility analysis for individual buildings can still contain some errors from the assumptions.

Natural gas was omitted from the utility data as few KDOT facilities use natural gas to run their buildings. Even among those that do, natural gas is only used to run old heating units, and it is such a trivial amount compared to the quantities of electricity used. As mentioned before, the resting areas along highways were excluded from this analysis.

The average carbon emission generated by the production of electricity is calculated from the types of fuels used to produce electricity in Kansas. The fuel sources to generate electricity in Kansas come from coal (69.9%) coal, nuclear (19.0%), natural gas (5.7%), and wind (5.2%) (Institute for Energy Research 2010). Together, they generate 1.871 lbs. of power per kWh (MiloSlick Scientific 2007). The research assumes that all regions in Kansas use the same types and quantity of fuels, and uses the same technologies to convert the fuels into electricity. Fossil fuel power stations (except for the magnetohydrodynamic generators) have some kind of rotating machinery to convert the heat energy of combustion into mechanical energy, which then operate an electrical generator. The prime mover may be a steam turbine, a gas turbine or, in small isolated plants, a reciprocating internal combustion engine. All plants use the drop between the high pressure and temperature of the steam or combusting fuel and the lower pressure of the atmosphere or condensing vapor in the steam turbine. Byproducts of power thermal plant operation need to be considered in both the design and operation. Waste heat due to the finite efficiency of the power cycle must be released to the atmosphere, using a cooling tower, or river or lake water as a cooling medium. The flue gas from combustion of the fossil fuels is discharged to the air; this contains CO_2 and water vapor, as well as other substances such asnitrogen, nitrogen oxides, sulfur oxides, and (in the case of coal-fired plants) fly ash, mercury and traces of other metals. Solid waste ash from coal-fired boilers must also be removed. Some coal ash can be recycled for building materials.

Fossil fueled power stations are major emitters of CO_2, a GHG which according to a consensus of scientific organizations is a contributor to global warming observed over the last 100 years. Brown coal emits three times as much CO_2 as natural gas; black coal emits twice as much CO_2 per unit of electric energy. Carbon capture and storage of emissions are not expected to be available on a commercial economically viable basis until 2025.

The efficiency of various technologies of different fossil fuel power plants and the types of fossil fuels they used affect the amount of GHG they emit per kWh of electricity they produce. The efficiency of wind power is affected by the types of engines they use and the locations in which they are grounded, while the efficiencies of other forms of fuels are also affected by different factors such as technologies used, locations, weather, etc. As a result, the carbon emissions of various energies can only be estimated and averaged unless one wishes to go through the details to estimate the actual carbon footprints. The most cost effective approach is to rely on the data that utility companies and the Environmental Protection Agency provides, though the research team would recommend direct measurement of various power generating sources to obtain more accurate estimates.

6.6 Units Used for Utilities and the Analysis

Energy use per square foot of building area (kWh/ft^2) is a unit commonly used for energy calculation and simulation such as for ASHRAE 90.1 energy simulation. Energy use per square foot is also known as Energy Use Intensity (EUI) (Eto et al. 1990).

> EUI's is 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 2004).

Btu per square foot is also a commonly used unit (especially the Department of Energy or DOE). DOE favors this unit as many English speaking countries (former British colonies) adopt Btu per square foot as their standard unit. Conversion between these units is extremely easy (Btu to kWh for example only requires a conversion factor) and thus the choice is simply a formality and preference.

The utility data is separated into districts, building, campus, and depots for the analysis. The "building types" category is based on the Energy Information Administration's (EIA) the CBECS standard (EIA 2011). The eight buildings types the research team uses to categorize KDOT buildings are as follows:

- Education
- Office
- Public Assembly
- Public Order and Safety
- Service
- Warehouse and Storage
- Other
- Vacant

This key focuses of this research are to: (1) determine the districts that have the highest energy intensity (consume most energy per area); and (2) the top 10 high-energy consuming buildings or campuses in KDOT. These analyses will then be compared to similar buildings from the EIA CBECS database. The energy data will then be converted into equivalent carbon emissions in order to determine the total carbon footprint of KDOT for its utilities.

The following organization tree exhibits how various buildings are categorized in this research initially. The organizational tree begins 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 are to differentiate the buildings by their types. The organizational tree branched out into three main stalks: one for high energy/high conditioned spaces, one for medium energy/low conditioned spaces, and one for low energy/low conditioned spaces. An additional branch is also created for specialized laboratories which consume huge amount of energy.

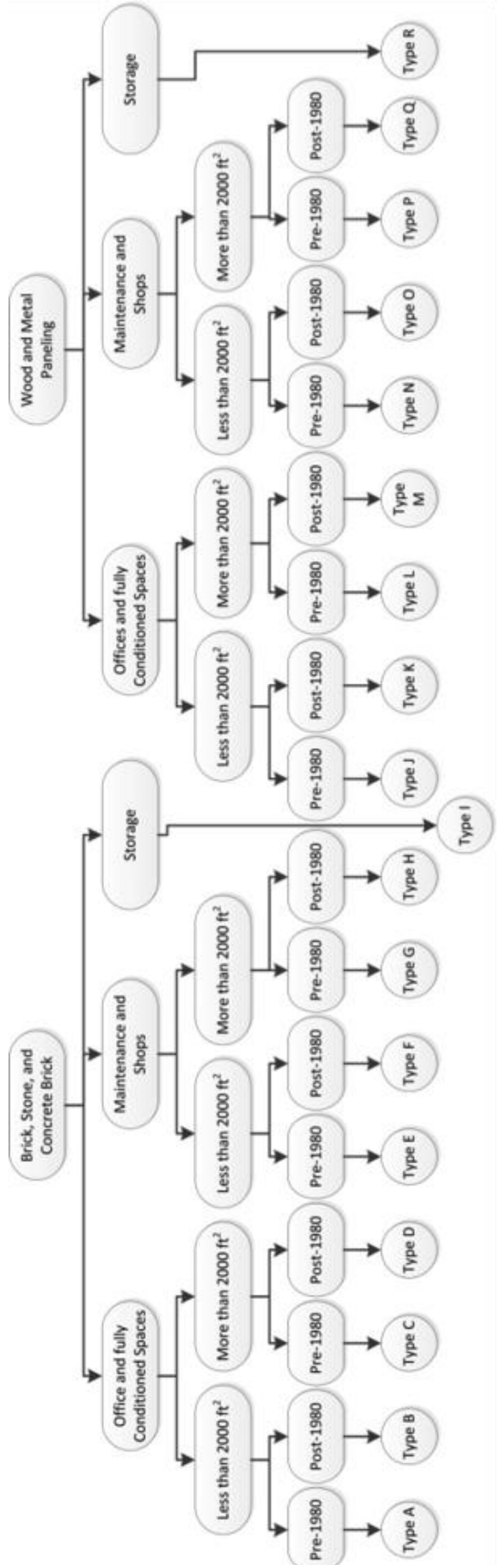


FIGURE 6.2
Basic Organizational Tree

6.7 Properties Type

Table 6.7 provides information for type A-1 buildings, the KDOT wash bays. Each material has a section for its area values, and at the bottom is the total number of buildings that fall within a given type.

TABLE 6.5
Material Quantity in ft^2 for Example Type: Wash Bays

TYPE A-1	Wash bays						
Material	Concrete	Reinforced Concrete	Concrete Block	Metal	Glass - Skylight	Doors Standard	Doors Garage
Wall 1 N	156	0	0	364	0	0	0
Wall 2 E	270	0	0	708	0	42	0
Wall 3 S	72	0	0	252	0	0	196
Wall 4 W	306	0	0	714	0	0	0
Roof	0	0	0	1270	96	0	0
Total	804	0	0	3308	96	42	196
89	Buildings of Type A-1						

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

6.8 Building Categorization

The KDOT building organizational tree is reorganized from its original state, containing 36 building types, into three condensed versions. Each condensed version, containing 18, 15, and 10 building types respectively, is reordered and recalculated for new carbon emissions values. The categorization is the basis of the LSAA model. Demonstrating the effects of the categorization is part of the method's proof.

For KDOT's purposes, 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% (and that is after intentionally choosing types outside of the ideal groupings). This acts to verify information for KDOT while also proving the need for a reliable database, or, at the very least, a nationally recognized set of system boundaries.

The original outline for a basic organizational tree may be seen below in Figure 6.2. It is divided into two main categories that are further branched to achieve each building type. After the first break, that of the building's material type, the buildings are divided by the use, followed by size, greater than or less than 2,000 ft^2, then the age. Finally, each type is labeled by a letter of the alphabet for ease of reference.

However, the initial grouping was not the ideal grouping for KDOT's final analysis. Due to additional building types and multiple variations on similar buildings, the final organizational scheme was different from the one shown above.

Much of the reorganizing 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 buildings 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 stored.

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 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 the following table, contains 36 total building types divided into four main categories. The initial categories break 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 of size differences that range from under 2,000 ft^2 to greater than 10,000 ft^2.

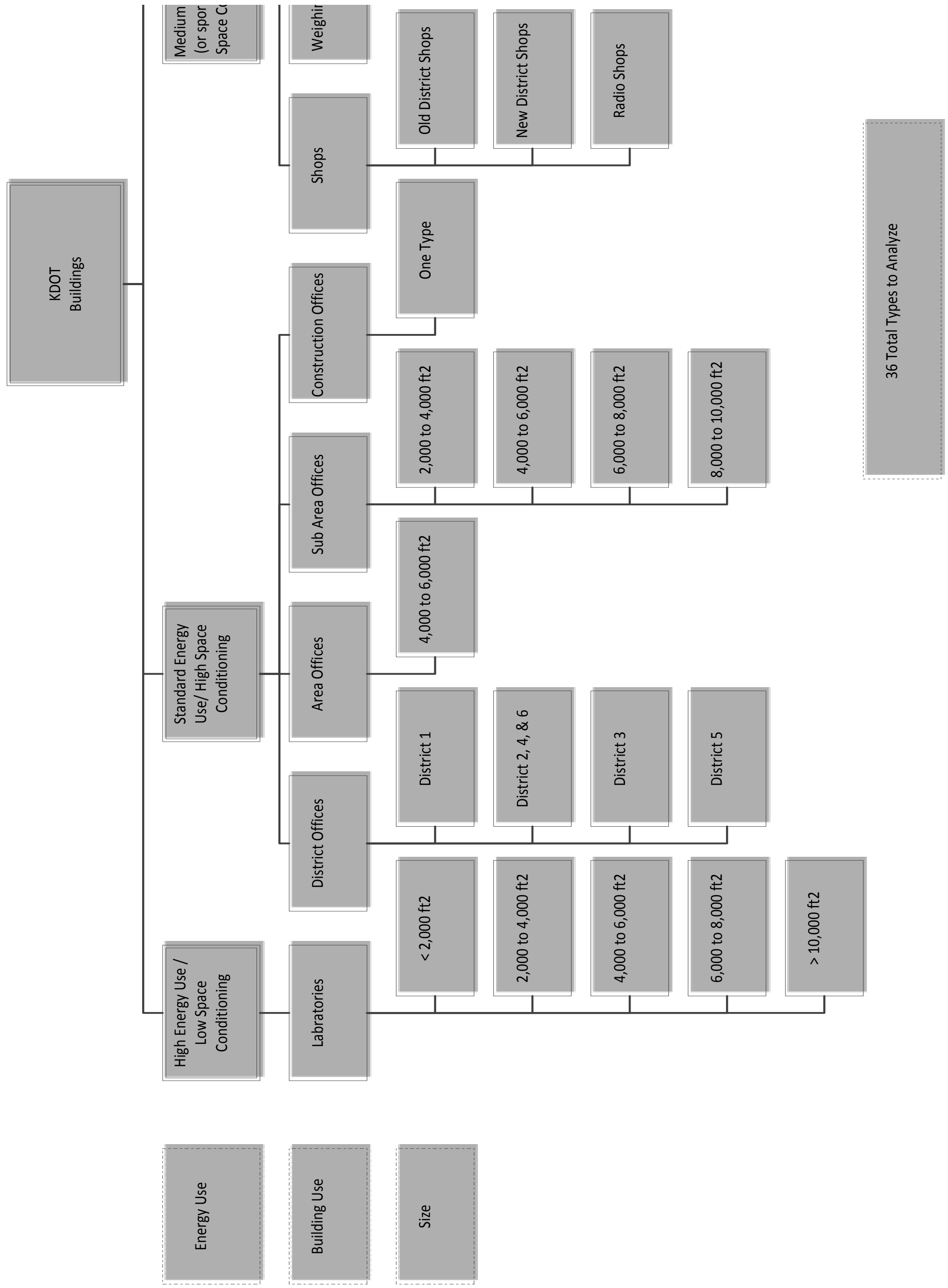


FIGURE 6.3
Full Organizational Tree—36 Types (Front Portion)

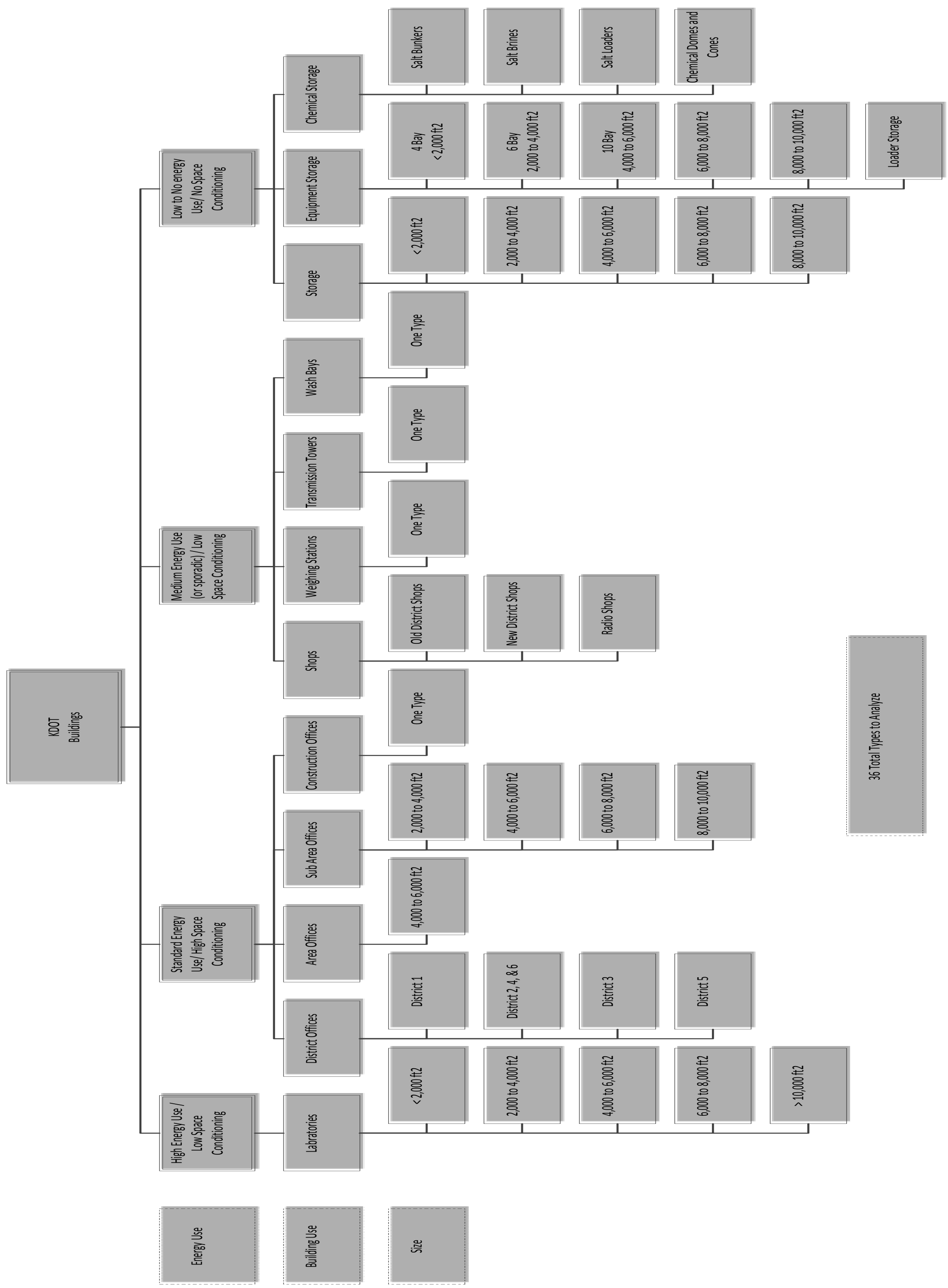


FIGURE 6.4
Full Organizational Tree—36 Types (End Portion)

The building types are later condensed from 36 to 18 types after the data analysis as either some of the categories are not used or there are too few buildings that belong to these types. For example, there were initially four types of laboratories but are consolidated into two groups of “below 4,000 square feet” and “over 4,000 square feet” after the analysis. The final groupings are organized as shown in Figures 6.5 to 6.9.

Figure 6.5 also shows how the fifteen storage types were condensed into four. Since most of the storage buildings use no conditioning and very little electricity, only the embodied carbon of the materials matters, which can be adequately represented by the four groups were analyzed. The final condensed organizational tree, shown in Figure 6.8, 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 form the baseline tree to Condensed Tree A, it is the first time that a larger category, one within the Building Use, has been eliminated.

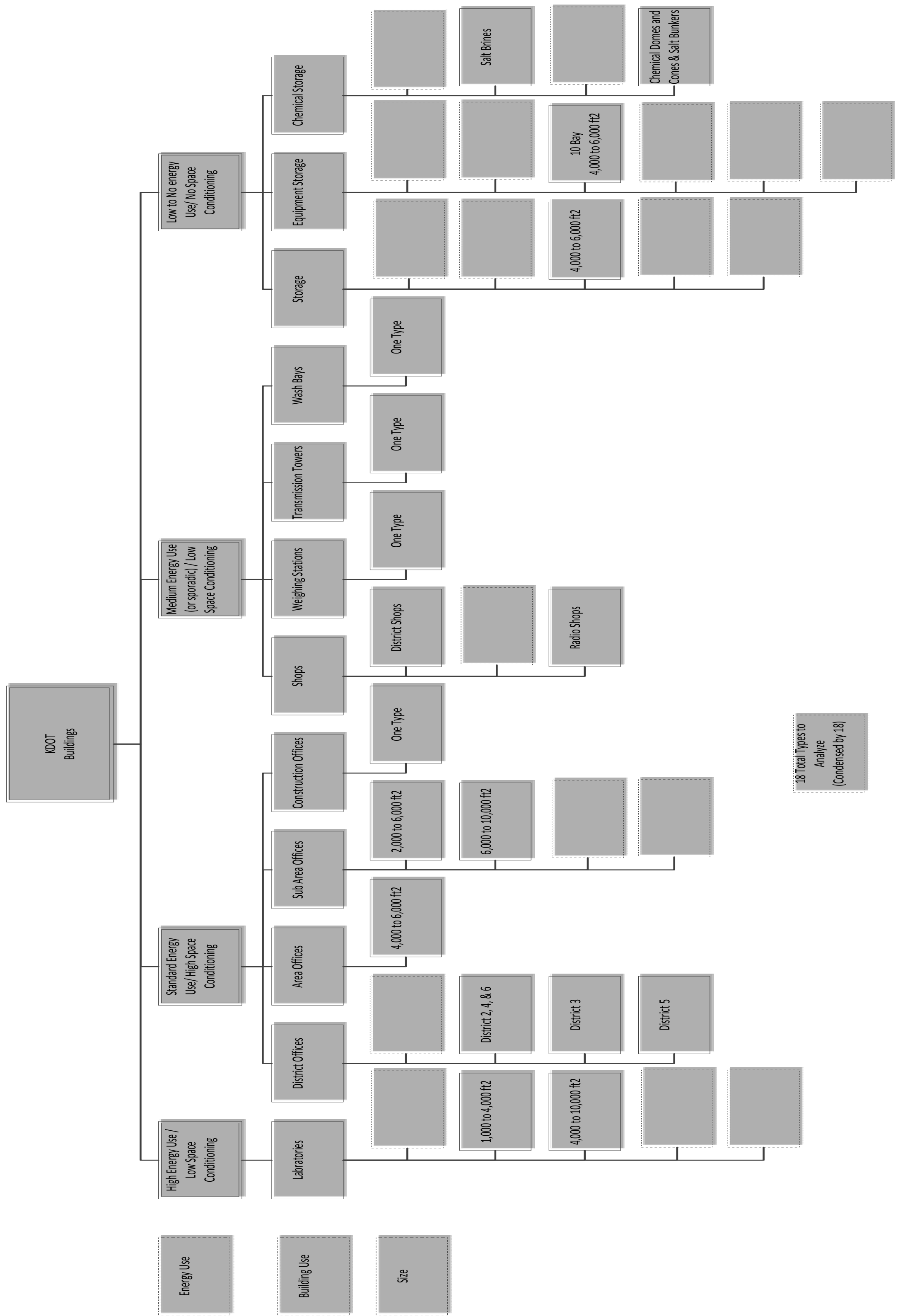


FIGURE 6.5
Condensed Organizational Tree A—18 Types

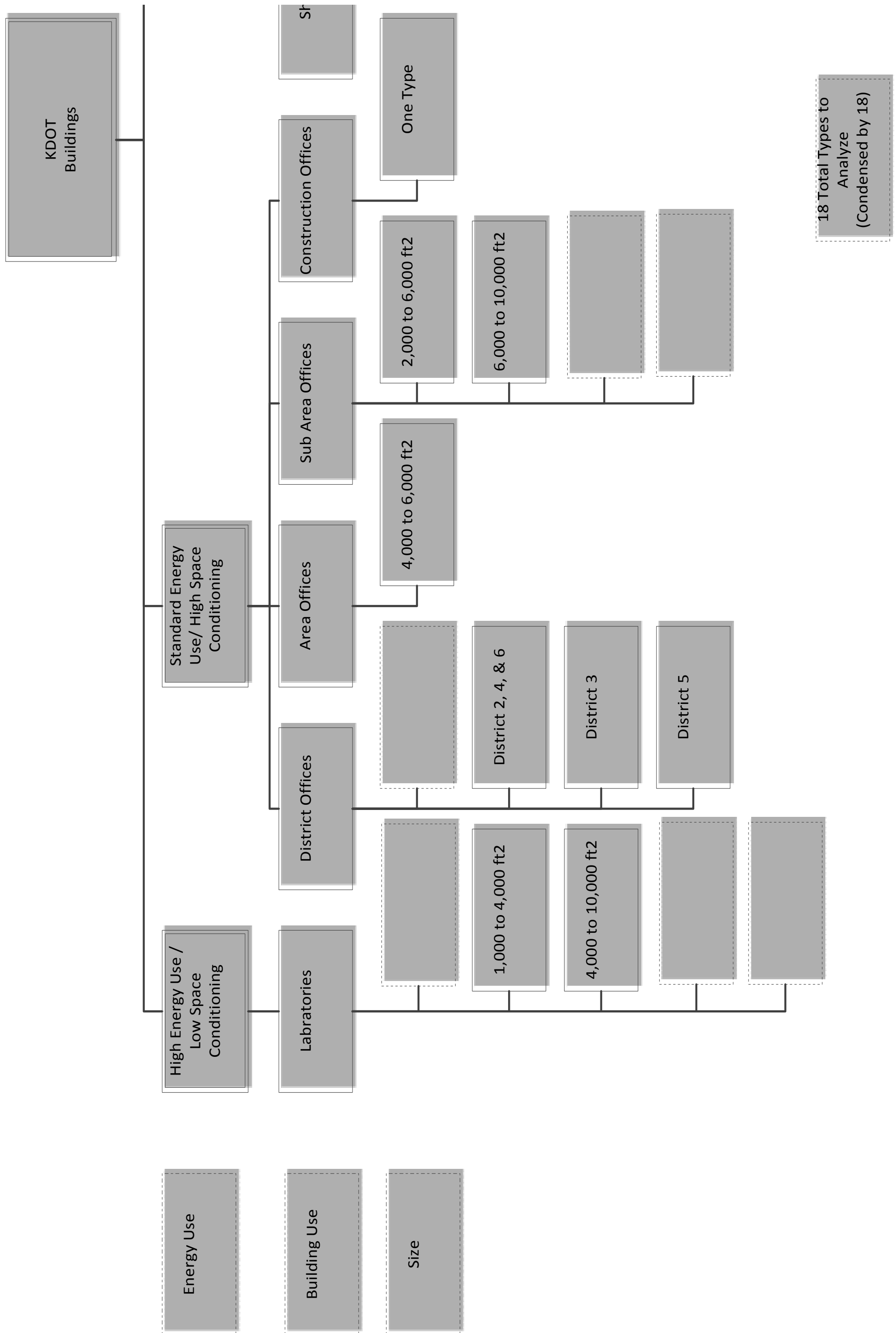


FIGURE 6.6
Condensed Organizational Tree A—18 Types (Front Portion)

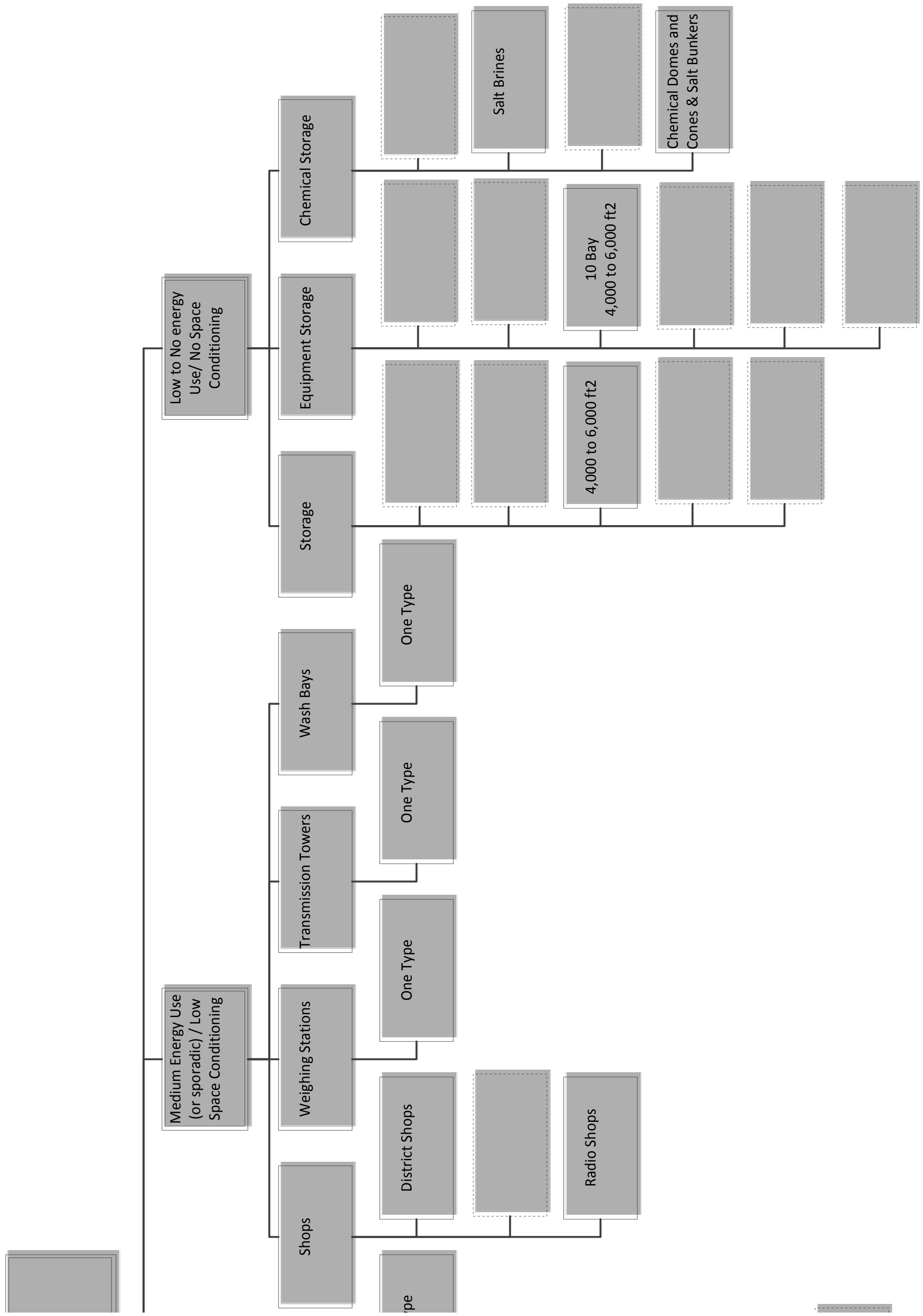


FIGURE 6.7
Condensed Organizational Tree A—18 Types (End Portion)

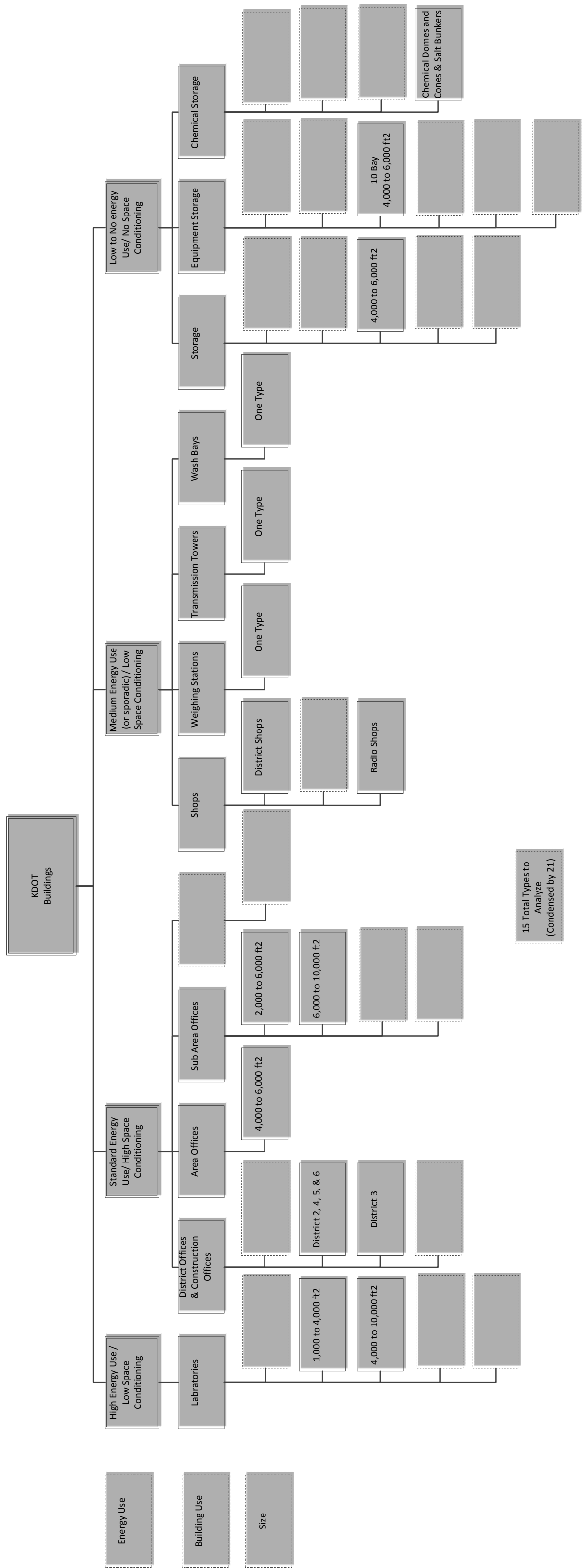


FIGURE 6.8
Condensed Organizational Tree B—15 Types

The final Organizational Tree, seen in Figure 6.9, is the most condensed. Within this tree, the types have been whittled down to a mere 10 building types. This means 26 total categories have been removed. While this method may not prove the most accurate in the end, it is good for evaluating the impact of categorization changes.

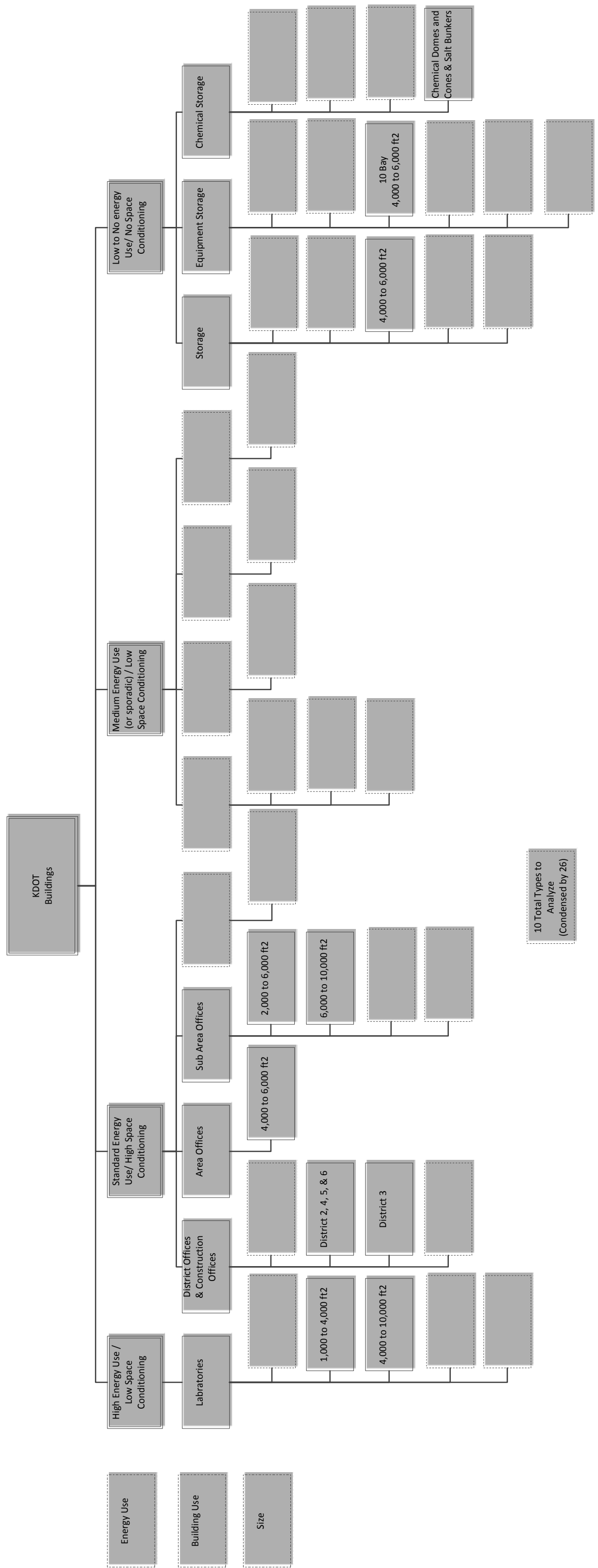


FIGURE 6.9
Condensed Organizational Tree C - 10 Types

Altering the building types is more than a matter of playing with chart graphics while altering types will result in different values for baseline carbon. Thus, the purpose of adopting multiple categorizations is to understand how categorization affects the outputs from the analyses. The research team can then adopt the best categorization approach to measure the best categorization approach for the project.

Chapter 7: Embodied Carbon Emissions Databases and Calculations

The most important decision for the carbon analysis process is the choice of carbon database. The values in the database directly influence the outputs of the calculator. There are several databases available for embodied carbon and energy calculation for materials. The values of the data are influenced by the LCA boundaries set for the models and the locations where the data are gathered from.

Boundaries may create greater differences than even locations can produce. While some databases only calculate the embodied energy in manufacturing a material, other databases include the manufacturing, transportation, installation, and construction energies. By expanding the given boundaries, the material values may drastically vary from one database to another.

Many organizations including the EPA and ICE have developed CO_2 emission equivalent databases. In this analysis, the research team utilized three reputable carbon databases, the LCEE-ASCE 2003, ICE v. 2.0, and Energy 161-2008. As seen in Figure 7.1, the differences seem to be obvious. These dataset passes the quality matrix test shown in Tables 3.1 and 6.1.

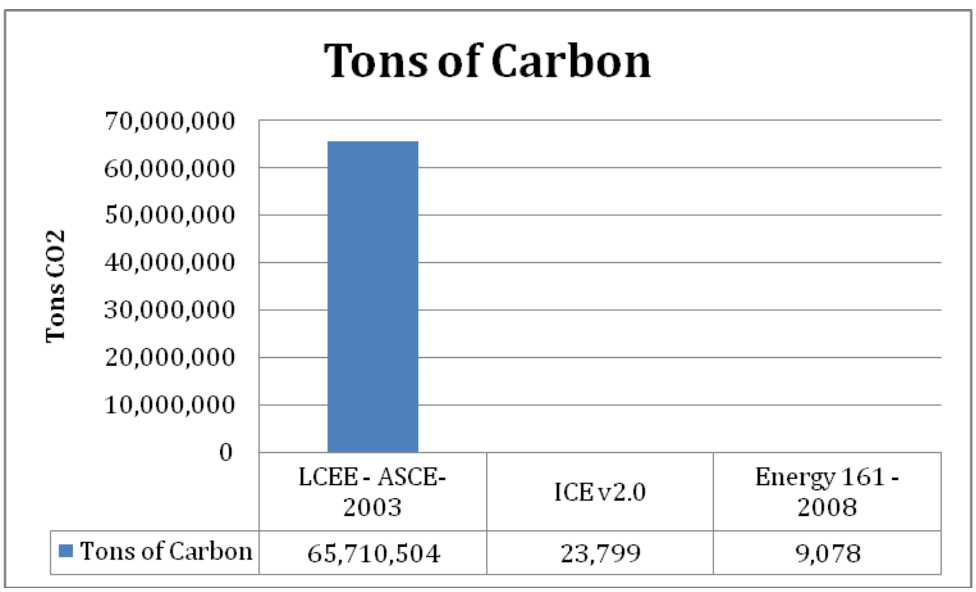


FIGURE 7.1
Total Tons of Embodied Carbon Within KDOT

The three databases generate different results as shown in the figure above. ICE and Energy 161 exclude energy use from material extraction and transportation and thus their data are lower than LCEE-ASCE-2003 which include both.

7.1 Embodied Carbon Emissions from Different Building Categories: Do Categorization Affect the End Results?

An analysis was conducted to study the impact of different categorization on the overall carbon footprints of the buildings. The study was conducted on all the four organizational trees: the comprehensive tree and the three condensed trees. Each tree was evaluated using the three previous databases. Table 7.1 presents the final carbon values of the analysis per organizational tree and database. “Full” depicts the organization tree that separates the buildings into 36 categories, while “A” depicts the “A” organization tree and so forth. 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 widespread applicability of the modeling system.

Values between trees vary because of the groupings. In some instances two groups of buildings we combined and, because of median values, all buildings within the type were assigned to the larger of the two groups’ representative building. In some instances this over estimated the building sizes, and in other instances it underestimated them.

TABLE 7.1
Condensed Categorization Results

	Carbon (Tons)			
	Full	A	B	C
LCEE-ASCE 2003	65,710,504	68,611,962	68,603,941	68,332,429
ICE v2.0	23,799	27,280	27,274	23,715
Energy 161 - 2008	9,078	10,238	10,236	8,912

The study reflects large variations between the three sets of data. The LCEE data reflects significantly higher carbon emission than the ICE and Energy 161. Thus the LCEE analysis is separately presented in the following figure. The organizational trees are labeled by their abbreviated call name: A for the 18 building types, B for the 15 types, and C for the 10 condensed building types.

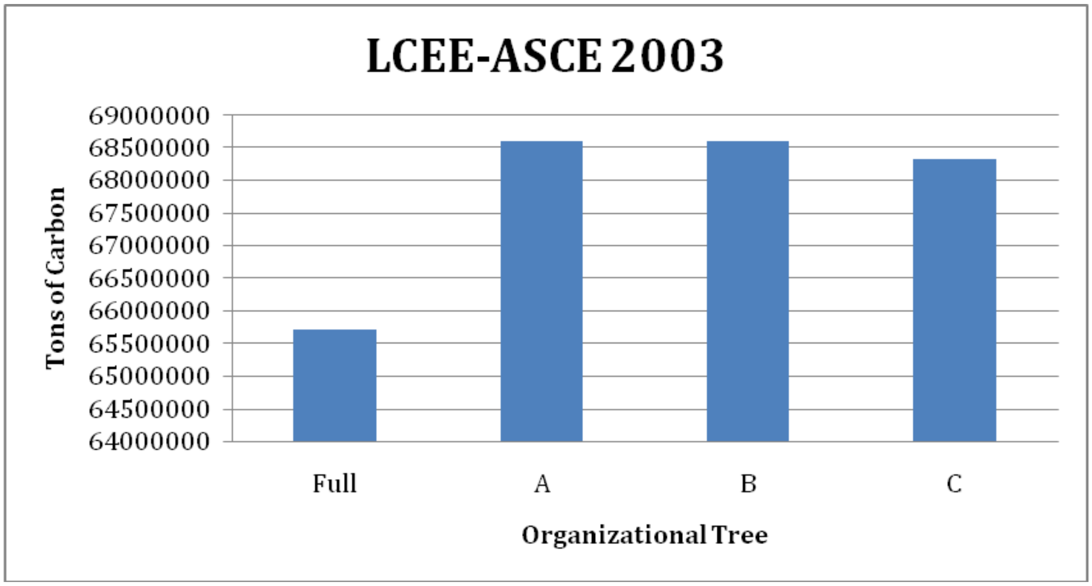


FIGURE 7.2
LCEE Carbon Results per Organizational Tree

ICE and Energy 161 database results are compared in the following figure. As can be seen from the constant 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.

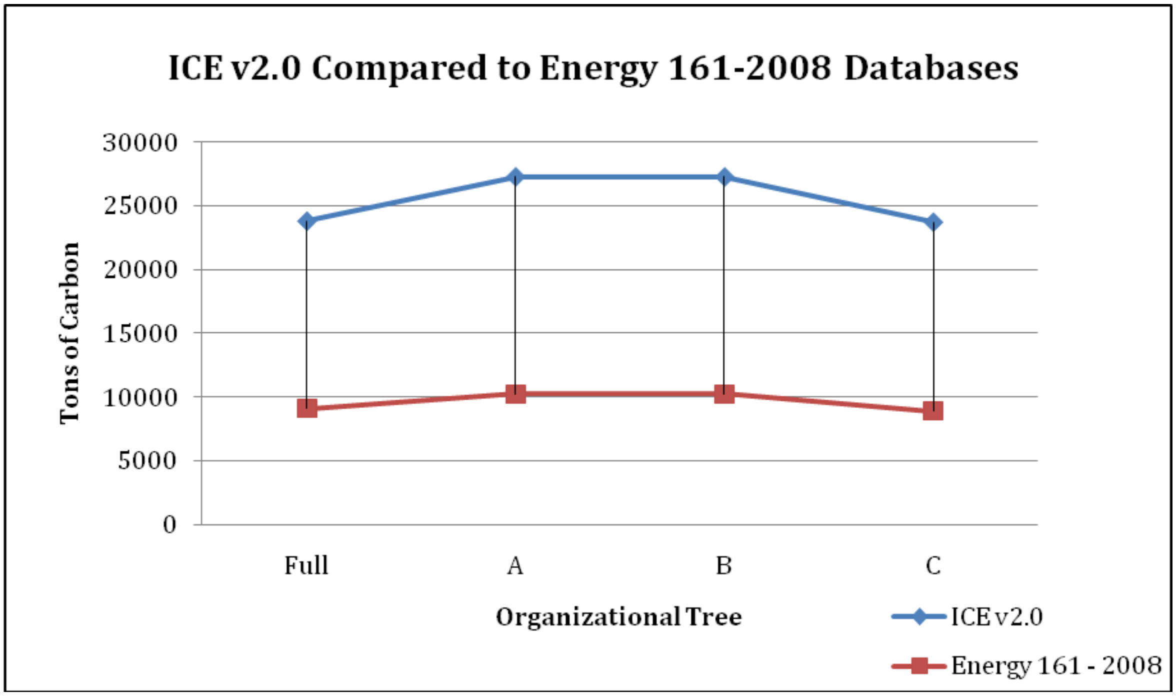


FIGURE 7.3
ICE and Energy 161 Results per Organizational Tree

In order to compare all three databases at once, the percent change must be used. The percentages are derived using the following equation:

Tree × Carbon Value - Full Tree Carbon Value)/ Full Tree Carbon Value

Equation 7.1

All percent changes use the full organizational tree as the baseline, thus all percentages at this point are zero (see Table 7.2). The categorization is the basis of the LSAA model. Demonstrating the effects of the categorization is part of the method's proof. For KDOT's purposes, 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% (and that is after intentionally choosing types outside of the ideal groupings). This acts to verify information for KDOT while also proving the need for a nationally accepted database, or, at the very least, a nationally recognized set of system boundaries.

TABLE 7.2
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 7.4 shows unexpected results. 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 consistent percentage for all of the condensed categories.

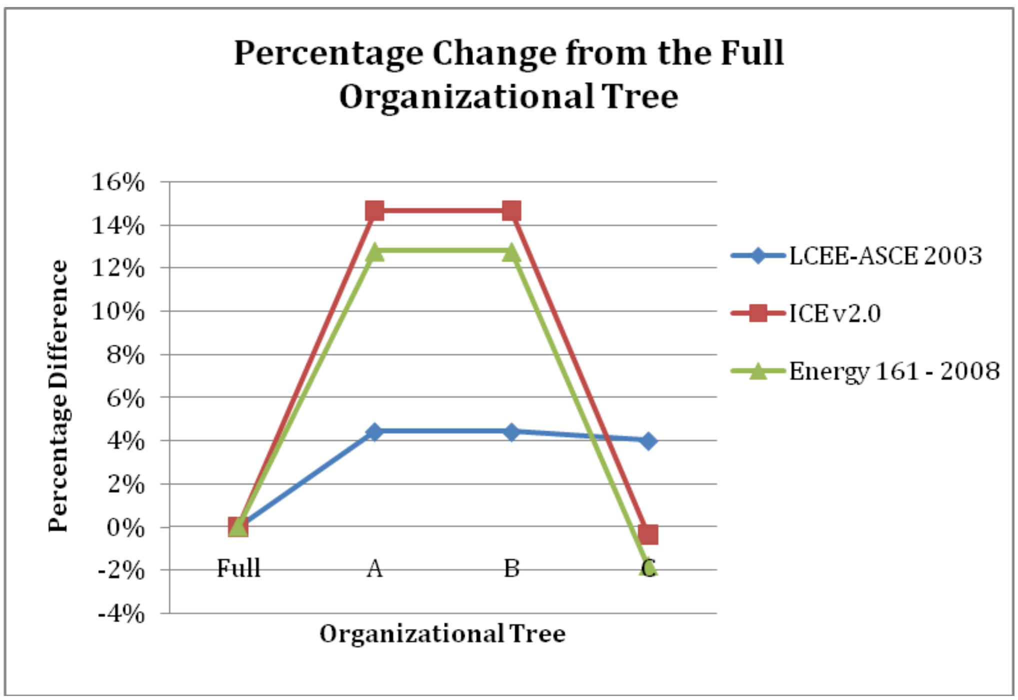


FIGURE 7.4
Percentage Change from the Original Building Types

It may be concluded that building categorization can significantly alter the final carbon emissions value. However, LCEE is determined that the database plays a role in the change. Disregarding the value 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, high carbon emissions materials were present in slightly higher quantities in the condensed tree C than in previous trees, thus causing a spike in carbon value compared to the other databases. Figure 7.5 shows the percentage breakdown of embodied carbon emissions of different building materials. The result shows that concrete has higher carbon emission percentage using the carbon emission factors from different databases in KDOT buildings. Sheet metals and iron also have high embodied carbon emission percentages in KDOT buildings using ICE and Energy 161 databases.

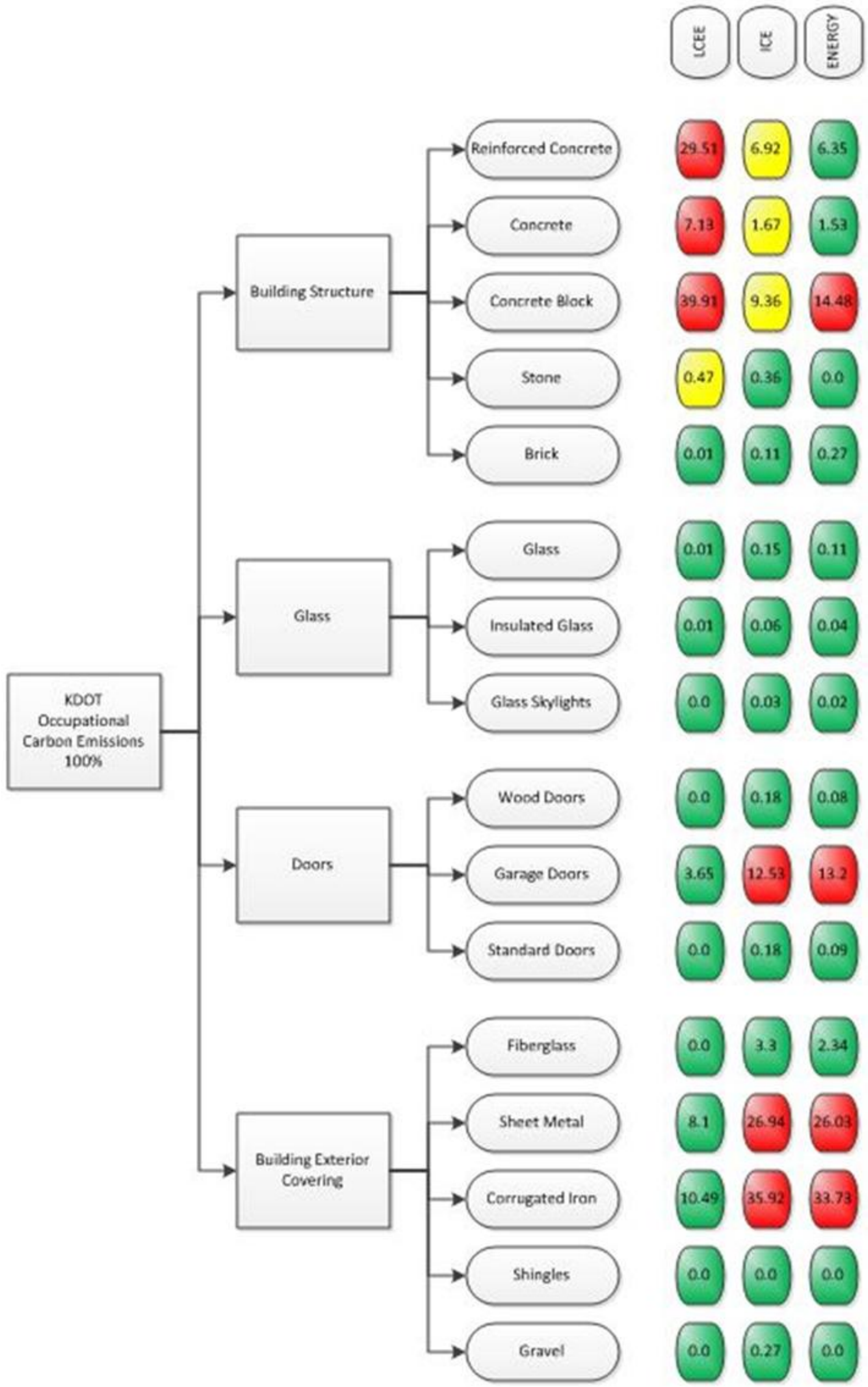


FIGURE 7.5
Embodied Carbon Emissions Percentage of Building Materials at KDOT

The following tables contain the embodied carbon of all types of KDOT buildings. The tables also present the total embodied carbon of a sample of the building type and the total footprints for all the buildings in the particular type.

TABLE 7.3
Embodied Carbon of Buildings Type A-1 to Type H-10

		LCEE	ICE	Energy 160
	Number of Buildings	CO_2 (Tons)	CO_2 (Tons)	CO_2 (Tons)
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

TABLE 7.4
Embodied Carbon of Buildings Type I-11 to Type R-22

		LCEE	ICE	Energy 160
	Number of Buildings	CO^2 (Tons)	CO^2 (Tons)	CO^2 (Tons)
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

TABLE 7.5
Embodied Carbon of Buildings Type S-23 to 2C-34

		LCEE	ICE	Energy 160
	Number of Buildings	CO^2 (Tons)	CO^2 (Tons)	CO^2 (Tons)
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 ft^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

TABLE 7.6
Embodied Carbon of Buildings Type 2D-36 to Type 2K-44

		LCEE	ICE	Energy 160
	Number of Buildings	CO_2 (Tons)	CO_2 (Tons)	CO_2 (Tons)
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

The KDOT buildings are initially organized into 36 types according to the type of uses, size (less than or larger than 2000 square feet), and age (pre- or post-1980). Due to the large number of types of buildings with minor variations, organizing this classification will not be feasible for KDOT. The categorization is condensed into tree A, B, and C with 18 types, 15 types, and 10 types, respectively. The organization trees show similar carbon emissions of KDOT. ICE v2.0 has the highest carbon emissions number out of two different carbon factor sources. The following tables show the intensity ranking of various KDOT buildings.

TABLE 7.7
Embodied Carbon of Buildings Type I-11 to Type X-30

Type	Description	LCEE	ICE	Energy 160
		CO2 (Tons)		
TYPE I -11	Area Office - 4000 to 6000 ft^2	337880	40	21
TYPE 2A-33	Laboratory - 4000 to 6000 ft^2	199109	28	14
TYPE N-18	Sub Area - 4000 to 6000 ft^2	188741	16	10
TYPE 2D-36	Laboratory - Larger than 10000 ft^2	162771	16	6
TYPE 2B-34	Laboratory - 6000 to 8000 ft^2 - Garage	158956	28	14
TYPE Y-31	Laboratory - less than 2000 ft^2	152246	13	5
TYPE D-6	Equipment Storage - 6 Bay - 2000 to 4000 ft^2	141458	26	9
TYPE L-17	Sub Area - 2000 to 4000 ft^2	132086	19	9
TYPE M-18	Sub Area - 4000 to 6000 ft^2 - Garage portion	124746	21	10
TYPE C-5	Equipment Storage - 4 Bay - less than 2000 ft^2	109614	19	8
TYPE W-29	Old District Shop	109209	37	3
TYPE G-9	Equipment Storage - 8000 to 10000 ft^2 - Open sided	87573	111	39
TYPE A-1	Chemical Domes - Standard, Dome, and Cone	84722	11	4
TYPE B-4	Wash bays	80370	49	18
TYPE F-8	Equipment Storage - 6000 to 8000 ft^2	77481	96	35
TYPE P-19	Sub Area - 6000 to 8000 ft^2	74350	7	4
TYPE 2C-34	Laboratory - 6000 to 8000 ft^2	74350	7	4
TYPE E-7	Equipment Storage - 10 Bay - 4000 to 6000 ft^2 - Open Sided	70607	88	31
TYPE O-19	Sub Area - 6000 to 8000 ft^2 - Garage	68627	20	9
TYPE T-24	Storage - 4000 to 6000 f^2	51530	64	23
TYPE U-25	Storage - 6000 to 8000 ft^2	45515	56	21
TYPE S-23	Storage - 2000 to 4000 ft^2	44785	56	20
TYPE 2J-43	District Office - District 5	31632	24	6
TYPE 2K-44	District Office - District 6 (similar to 4)	20562	15	4
TYPE R-22	Storage - less than 2000 ft^2	19449	24	9
TYPE 2I-42	District Office - District 2	17512	13	3
TYPE Z-32	Laboratory - 2000 to 4000 ft^2	11803	9	2
TYPE Q-21	Transmission Tower	3531	3	1
TYPE X-30	New District Shop	457	4	1

TABLE 7.8
Embodied Carbon of Buildings Type A-1 to Type V-27

Type	Description	Total Buildings	LCEE	ICE	Energy 160
			CO2 (Tons)		
TYPE A-1	Chemical Domes - Standard, Dome, and Cone	209	17706963	2330	746
TYPE L-17	Sub Area - 2000 to 4000 ft^2	69	9113923	1288	654
TYPE B-4	Wash bays	89	7152899	4323	1621
TYPE I -11	Area Office - 4000 to 6000 ft^2	18	6081842	715	380
TYPE N-18	Sub Area - 4000 to 6000 ft^2	31	5850963	505	295
TYPE F-8	Equipment Storage - 6000 to 8000 ft^2	55	4261459	5278	1946
TYPE M-18	Sub Area - 4000 to 6000 ft^2 - Garage portion	31	3867134	664	324
TYPE E-7	Equipment Storage - 10 Bay - 4000 to 6000 ft2 - Open Sided	43	3036091	3763	1351
TYPE D-6	Equipment Storage - 6 Bay - 2000 to 4000 ft^2	13	1838951	342	112
TYPE R-22	Storage - less than 2000 ft^2	83	1614279	2000	722
TYPE C-5	Equipment Storage - 4 Bay - less than 2000 ft^2	9	986525	170	75
TYPE Y-31	Laboratory - less than 2000 ft^2	6	913477	80	28
TYPE G-9	Equipment Storage - 8000 to 10000 ft^2 - Open sided	8	700585	887	314
TYPE S-23	Storage - 2000 to 4000 ft^2	10	447855	555	199
TYPE P-19	Sub Area - 6000 to 8000 ft^2	6	446100	39	23
TYPE O-19	Sub Area - 6000 to 8000 ft^2 - Garage	6	411763	121	54
TYPE 2A-33	Laboratory - 4000 to 6000 ft^2	2	398219	56	28
TYPE W-29	Old District Shop	3	327627	111	10
TYPE T-24	Storage - 4000 to 6000 f^2	4	206120	256	92
TYPE 2B-34	Laboratory - 6000 to 8000 ft^2 - Garage	1	158956	28	14
TYPE U-25	Storage - 6000 to 8000 ft^2	3	136546	169	62
TYPE Z-32	Laboratory - 2000 to 4000 ft^2	4	47211	36	9
TYPE 2K-44	District Office - District 6 (similar to 4)	2	41124	31	8
TYPE 2J-43	District Office - District 5	1	31632	24	6
TYPE 2I-42	District Office - District 2	1	17512	13	3
TYPE Q-21	Transmission Tower	1	3531	3	1
TYPE X-30	New District Shop	3	1372	11	2
TYPE 2E-37	District Office - District 3	1	200	1	0
TYPE V-27	Weighing Station	5	114	5	0

The above tables suggest that using LCEE data, type I-11 (Area Office—4,000 to 6,000 ft^2) contains the highest embodied energy. However, if the ICE and Energy 161 data are used, type G-9 (Equipment Storage—8,000 to 10,000 sq ft) contains the highest embodied energy.

Type I-11 does not even rank in the top five if ICE and Energy 161 data are used, while the embodied carbon of type G-9 is less significant if LCEE data is used. Such disparities exist in all of the calculations.

The boundaries set for all three database are different, while LCEE boundaries are larger than ICE and Energy 161. LCEE includes carbon generated by extraction and production. However, the large differences render the result inconclusive and thus more research needs to be done to confirm the key

Chapter 8: Analysis of Direct Energy Use from Utilities

The analysis of direct energy use (utility) is divided into KDOT districts and is shown in Table 8.1. District 1 consumes the highest amount of electricity, and this result is expected because District 1 covers the major metropolitan areas of Kansas such as Greater Kansas City, Topeka, Lawrence, and Manhattan. In addition, its energy intensity is also the highest.

TABLE 8.1
Total Electricity Consumption in Relation to Square Footage

Area	Total Annual Use kWh (2008)	Total Annual Use kWh (2009)	Total Area (ft^2)
District 1	8,241,006	8,177,974	686,561
District 2	1,131,044	1,225,434	373,614
District 4	545,350	517,483	414,760
District 5	6,043,107	6,144,828	449,848
Total	15,960,507	16,065,719	1,924,783

The Energy Information Administration (EIA) average per district is shown in Table 8.2, with the top 10 depots by power consumption are shown in Table 8.2. Table 8.2 exhibits the top 10 power consuming locations in various KDOT districts. Most of these buildings are located in Topeka. The electricity use of the main campus consumed the most power and its average per kWh per ft^2 is higher than similar buildings across the United States. On the other hand, most of the other top 10 energy intensive KDOT locations have lower average per kWh per square foot than similar buildings across the United States. Districts 1, 4 and 5 total annual electricity use is higher than the baseline of the EIA CBECS. On the other hand, the overall total annual use in 2009 is lower than the EIA average.

TABLE 8.2
Total Power Use Compared to EIA Average

Area	Total Annual Use kWh (2008)	Total Annual Use kWh (2009)	Total EIA Average kWh
District 1	8,241,006	8,177,974	7,825,825
District 2	1,131,044	1,225,434	4,154,812
District 4	545,350	517,483	3,709,672
District 5	6,043,107	6,144,828	5,518,733
Total	15,960,507	16,065,719	21,209,042

Table 8.4 shows the top 10 power consuming locations of KDOT. The majority of the buildings are located in the state capital Topeka and the electricity use in the main campus is a lot higher than the EIA Average kWh.

Most of the top 10 locations have power consumption lower than EIA average. The total CO_2 produced by the power generation is shown in Table 8.3. The carbon factor used in the conversion is 1.871 pound per kWh (USEPA 2007). Since District 1 has the highest power consumption, it has the highest carbon emissions on utilities in KDOT. The total KDOT utility carbon production in 2009 is 15,028 tons. The top 10 carbon producing buildings are the same as the top 10 power consuming buildings. Table 8.4 shows that 2300 Van Buren, Topeka (KDOT's Materials and Research Center) contribute 17.8% of the carbon production of KDOT. The other locations are around or less than 5% of the total carbon production.

TABLE 8.3
Total Amount CO^2 Emissions from Utilities by District

Area	Total Annual Use kWh (2009)	Total Annual CO_2 Production (2009) (Tons)
District 1	8,177,974	7,650
District 2	1,225,434	1,146
District 4	517,483	484
District 5	6,144,828	5,748
Total	16,065,719	15,028

TABLE 8.4
Power Consumption Depots

Rank	Location	Types	Quantity	Electricity Use kWh (2009)	EIA Average kWh
1	2300 Van Buren, Topeka	T-24	1	2,858,580	1,296,533
		50	1		
2	101 Gage, Topeka	A-1	3	826,783	1,115,991
		B-4	1		
		C-5	1		
		F-8	2		
		G-9	1		
		K-13	1		
		M-18	1		
		N-18	1		
		O-19	1		
		P-19	1		
		Q-21	1		
		R-22	4		
		T-24	1		
		Z-32	2		
		2H-41	1		
		51	1		
3	3200 45th, Wichita	A-1	1	631,937	662,121
		B-4	1		
		C-5	1		
		E-7	2		
		H-10	1		
		14	1		
		M-18	2		
		N-18	2		
		R-22	2		
		S-23	1		
		40	1		
		2H-41	1		
4	121 21st, Topeka	2F-38	1	363,240	1,372,504
5	500 Hendricks, Hutchinson	F-8	1	281,599	1,160,247
		S-23	2		
		W-29	1		
		X-30	1		
		2J-43	1		
6	650 K-7 HWY, Bonner Springs	E-7	1	273,880	368,880
		14	1		
		20	1		
7	1041 3rd, Salina	2I-42	1	234,480	337,061
8	1112 3rd, Salina	L-17	1	179,080	41,995
		R-22	1		
9	1812 4th, Pittsburg	A-1	2	102,875	420,659
		B-4	1		
		I-11	1		
		L-17	1		
		R-22	2		
10	1220 4th, Hutchinson	2D-36	1	102,160	413,045

TABLE 8.5
Top 10 Buildings in Carbon Emissions

Rank	Location	Types	Quantity	Electricity Use kWh (2009)	Percent
1	2300 Van Buren, Topeka	T-24	1	2,858,580	17.8%
		50	1		
2	101 Gage, Topeka	A-1	3	826,783	5.15%
		B-4	1		
		C-5	1		
		F-8	2		
		G-9	1		
		K-13	1		
		M-18	1		
		N-18	1		
		O-19	1		
		P-19	1		
		Q-21	1		
		R-22	4		
		T-24	1		
		Z-32	2		
		2H-41	1		
		51	1		
3	3200 45th, Wichita	A-1	1	631,937	3.93%
		B-4	1		
		C-5	1		
		E-7	2		
		H-10	1		
		14	1		
		M-18	2		
		N-18	2		
		R-22	2		
		S-23	1		
		40	1		
		2H-41	1		
4	121 21st, Topeka	2F-38	1	363,240	2.26%
5	500 Hendricks, Hutchinson	F-8	1	281,599	1.75%
		S-23	2		
		W-29	1		
		X-30	1		
		2J-43	1		
6	650 K-7 HWY, Bonner Springs	E-7	1	273,880	1.70%
		14	1		
		20	1		
7	1041 3rd, Salina	2I-42	1	234,480	1.46%
8	1112 3rd, Salina	L-17	1	179,080	1.11%
		R-22	1		
9	1812 4th, Pittsburg	A-1	2	102,875	0.640%
		B-4	1		
		I-11	1		
		L-17	1		
		R-22	2		
10	1220 4th, Hutchinson	2D-36	1	102,160	0.636%

The Materials and Research Center in Topeka consumes a significantly larger amount of power than the average buildings in the EIA database. This is due, in large part, to the specialized laboratory equipment. EIA data does not take into account all types of equipment possible that could be installed.

8.1 Carbon Emissions of Vehicle Assets of KDOT

8.1.1 Fuel Purchasing and Consumption Results

Tables 8.6 and 8.7, below, summarizes the fuel purchasing data obtained for the 2006–2010 fiscal years for gasoline and diesel based fuels, respectively. In total, KDOT purchased 5.5 million gallons of gasoline fuels (unleaded gasoline + E10) and 13.9 million gallons of diesel fuels (#2 diesel plus B5) during the five-year period examined. In all years, diesel fuels represented 67% of more of total fuel purchases, emphasizing KDOT's reliance on diesel-powered vehicles. Purchases of both gasoline and diesel fuels are relatively consistent from year to year for both sets of fuels, with no significant long-term trends over the five-year period. The maximum year for gasoline fuels purchase was 2009, while diesel fuel purchases peaked in 2008. There is a weakly negative correlation between diesel and gasoline fuel purchases for a given year, but the small sample size means that it is difficult to establish if this correlation is significant.

Figures 8.6 and 8.7 show the distribution of total fuel purchases between the four major fuels over the study period. Both major fuel categories contain two fuels, one of which can be described as a blend of renewable and petroleum based fuel (E10 and B5 for gasoline and diesel fuels, respectively). The results show that ethanol blended fuel usage is neutral to increasing over the study period. E10 fuel purchases were typically 60 to 70% of the total gasoline fuels purchased by KDOT throughout the period, with an increase to 81% of all gasoline purchases in 2010. Diesel fuel purchasing number, by contrast, show a consistent decline in the purchase of B5 and a corresponding increase in #2 diesel purchases from 2005 to 2010. This is likely due to fluctuations in the availability and cost of biodiesel fuels over this period.

TABLE 8.6
Gasoline Based Fuel Purchases 2006–2010 (All Values in Gallons)

Year	Unleaded	E10	**Total Gasoline Fuels**
2006	455,532	710,601	**1,166,133**
2007	363,365	759,659	**1,123,024**
2008	287,001	764,716	**1,051,717**
2009	289,107	875,970	**1,165,077**
2010	191,427	818,767	**1,010,194**

TABLE 8.7
Diesel Based Fuel Purchases 2006–2010 (All Values in Gallons)

Year	Diesel	B5	**Total Diesel Fuels**
2006	964,297	1,802,344	**2,766,641**
2007	1,045,357	1,944,916	**2,990,273**
2008	1,641,915	1,455,029	**3,096,944**
2009	1,432,265	979,646	**2,411,911**
2010	1,817,772	809,867	**2,627,639**

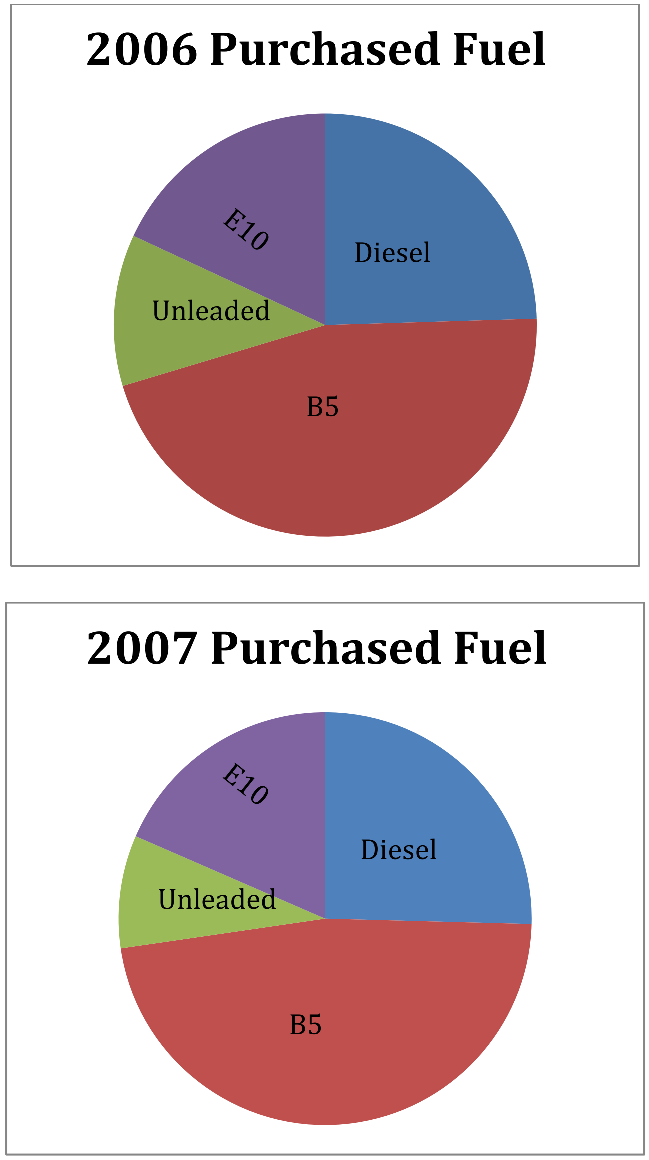


FIGURE 8.1
Fuel Purchases for 2006 and 2007 Fiscal Years by Fuel Type

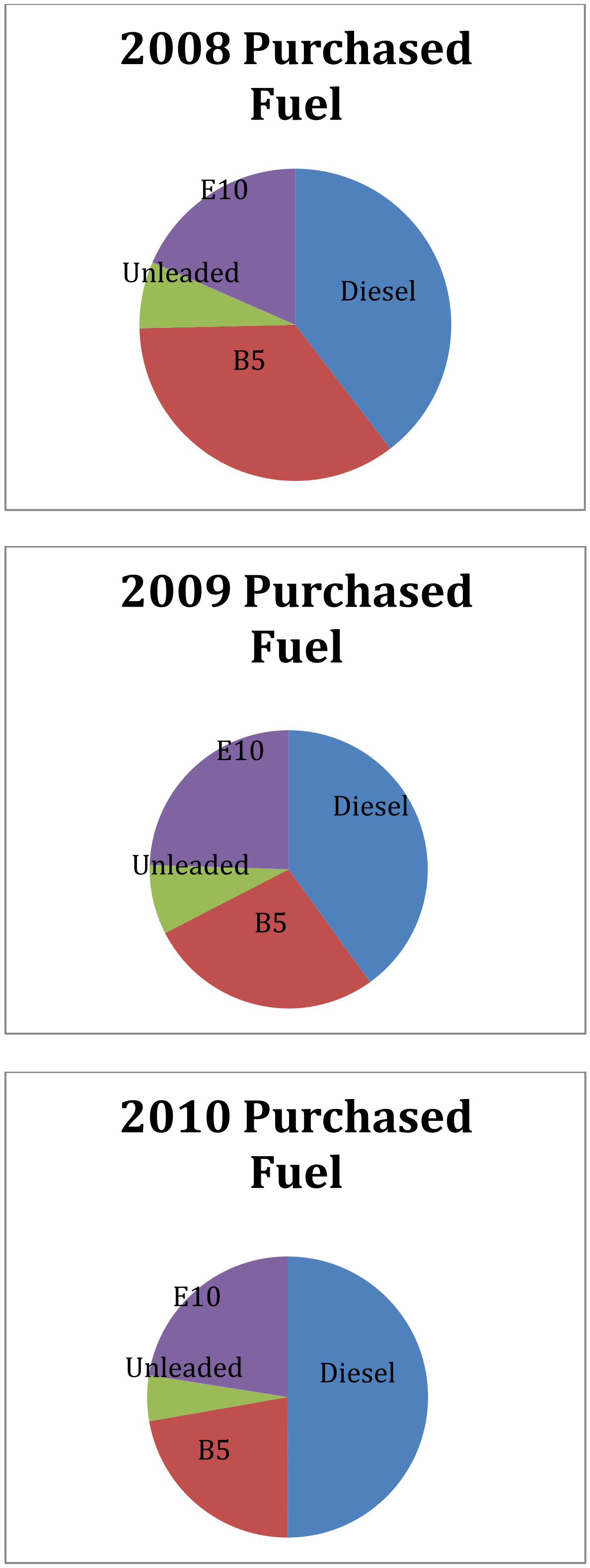


FIGURE 8.2
Fuel Purchases for 2008–2010 Fiscal Years by Fuel Type

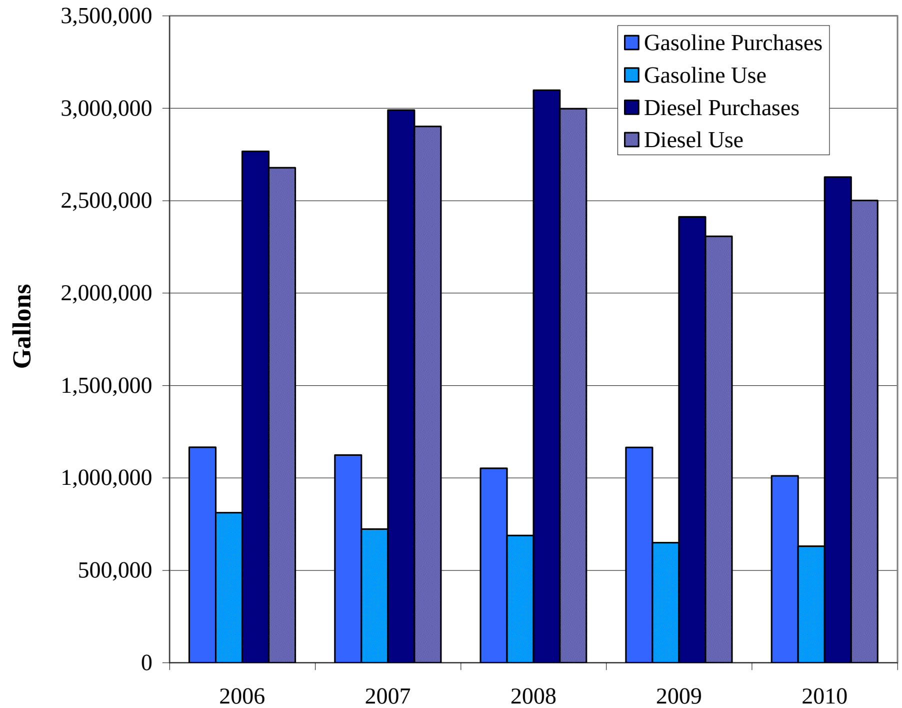
Fuel usage data for 2006 to 2010 based on the KDOT vehicle inventory are contained in Table 8.8. Several features stand out from these tables. First, the vehicle use inventory contains only three fuel categories: gasoline, diesel and ethanol. The third category, ethanol, refers to a small number of vehicles that are specially equipped to use an 85% ethanol in gasoline blend (E85) as their primary fuel source. While there is no corresponding purchase data for E85 blends, the total amount of fuel used by these vehicles is small, with a total consumption of 9,000 gallons of E85 over the entire five year period. Thus, any effect on overall fuel calculations will be minimal. More broadly, however, these fuel usage numbers do not distinguish between unleaded gasoline and E10, or between #2 diesel and B5.

TABLE 8.8
KDOT Vehicle Fuel Usage 2006–2010 (All Values in Gallons)

Year	Gasoline	Diesel	Ethanol (E85)
2006	811,050	2,678,019	1,119
2007	723,308	2,901,216	757
2008	688,719	2,997,315	924
2009	649,081	2,307,474	1,702
2010	629,773	2,501,403	4,496

Comparison of the fuel purchasing and usage data also revealed a difference is estimates of total KDOT fuel use (Figure 8.7). For diesel fuels the yearly aggregated usage values obtained from the vehicle inventory database are 95 to 98% of yearly total diesel purchases (#2 diesel + B5). For gasoline fuels, however, there is a significant discrepancy between the two numbers. The total gasoline used by inventoried vehicles ranged from 56 to 70% of the purchased fuel numbers for the same year. As this discrepancy occurred for five consecutive years, it is unlikely that it is due to timing mismatches between fuel purchase and use dates. The vehicle inventory does not include small motorized equipment used at the various KDOT facilities. Our initial assumption had been that these items would not consume a substantial amount of fuel compared to the larger inventoried vehicles and equipment. However, the fuel use results here suggest that they were significant consumers of fuel. In further phases, therefore, an attempt should be made to inventory and categorize these items.

FIGURE 8.3
Purchased and Used Fuel Volumes, 2006–2010



8.1.2 CO_2 Emissions

Because of the discrepancy between purchased and consumed gasoline fuels described above, the purchased fuel data was considered to be a more reliable estimate for yearly KDOT fuel usage. These purchased fuel data were used to generate a value for total CO_2 generated from gasoline and diesel powered vehicles and equipment using the emission factors in Table 3.1. The results of this calculation are presented in Table 8.9. Overall CO_2 emissions from vehicles and equipment peaked in 2008 at 44,346 tons, and have been lowest in the most recent two years for which data were available.

TABLE 8.9
CO_2 Emissions from Fuel Combustion (Tons)

	Diesel Fuels		Gasoline Fuels		
Year	**#2 Diesel**	**B5**	**Unleaded**	**E10**	**Total CO_2 Emitted (tons)**
2006	10,716	19,929	4,412	6,721	41,778
2007	11,617	21,505	3,519	7,185	43,826
2008	18,246	16,088	2,779	7,233	44,346
2009	15,916	10,832	2,800	8,285	37,833
2010	20,200	8,955	1,854	7,744	38,753
Total	**76,695**	**77,309**	**15364**	**37,168**	**206,536**

While these emissions calculations take into account the difference in CO_2 emission levels for the four fuels used by KDOT, they do not account for differences in carbon sources between petroleum based and renewable fuels. Renewable fuels such as ethanol and biodiesel should contribute less net CO_2 to the atmosphere than petroleum based fuels, since their carbon comes from recently-grown plants that have themselves sequestered CO_2 from the atmosphere as part of their growth process. This contrasts with petroleum-based gasoline and diesel fuels, which have been isolated from the atmosphere in subsurface deposits. It may therefore be appropriate to consider the different sources of carbon in the different fuels in calculating an overall carbon footprint for KDOT fuel combustion.

There are several approaches that can be used to estimate the difference in net atmospheric CO_2 emissions that result from KDOT's use of renewable fuel blends. One relatively simple approach used to estimate the impact of renewable fuels is that used by the U.S. Energy Information Agency Voluntary Reporting of Greenhouse Gas Program, also known as the 1605b program. Emission coefficients for unleaded gasoline, #2 diesel, B5 and E10 are available through this program on a net CO_2 emission basis (Energy Information Agency, 2011). Under this calculation method, fully renewable fuels such as ethanol and 100% biodiesel have net CO_2 emissions of 0 lb/gallon. Blends such as B5 and E10 therefore have somewhat lower emission coefficients than those used in our total emissions calculations. Using these emission factors, a recalculation was performed to determine net CO_2 emissions from KDOT fuel combustion for each of the five years in our study. Using this approach, net CO_2 emissions for KDOT were 2% lower than total CO_2 emissions over the entire study period.

A more comprehensive approach to estimating net CO_2 emissions due to the use of alternative fuels would be a full life cycle analysis that includes not only direct CO_2 emissions, but also the embodied energy required to produce a gallon of fuel. Life cycle analysis for biofuels is a complicated calculation, and there is significant debate over where to draw the boundaries for analysis. In particular, the secondary effects of crop replacement and land use changes, which can have a substantial effect on the embodied CO_2 for both ethanol and biodiesel are strongly debated. Given the wide variety of existing estimates for embodied CO_2emissions, we do not recommend that significant effort be invested in this calculation until a more standardized method is developed.

Chapter 9: Databases

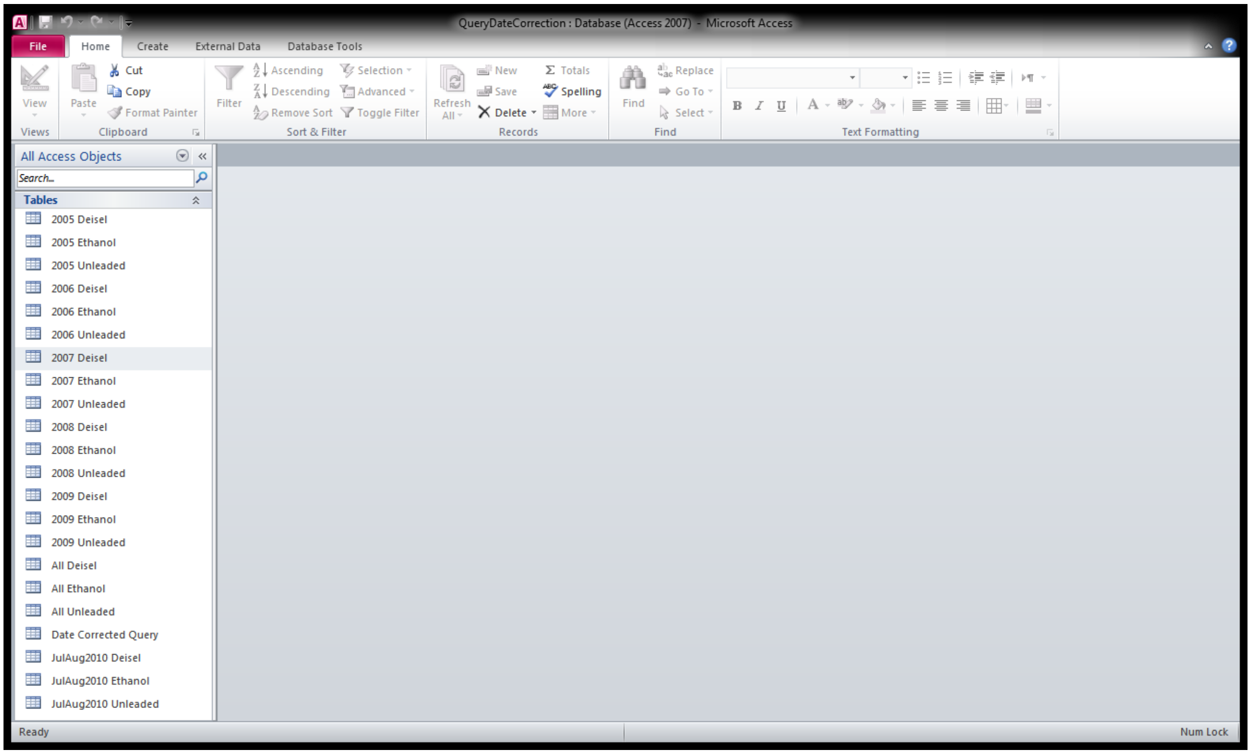
Three databases were developed for KDOT from this research: Vehicle Usage, Embodied Energy for Buildings, and Enterprise Operational Energy (Utilities) for Buildings. The databases are described below.

9.1 The Vehicle Usage Database

The information provided by KDOT on vehicle usage and fuel consumption from fiscal years 2006 to 2010 consisted of almost 226,000 entries, with each entry representing the monthly information on mileage, fuel use and hours of operation for an individual vehicle. The sheer volume of entries made it difficult to effectively work with the file to extract information. Our solution to this issue was to develop a Microsoft Access database to house this information. This database serves as a search tool for aggregating and examining fuel usage patterns as a function of multiple parameters, including time, vehicle type, and vehicle age or operating hours. In its current form, the database can be used for information gathering, but requires additional work during Phase II of this project to make it user-friendly. The following paragraphs provide a brief introduction to the database in its current form.

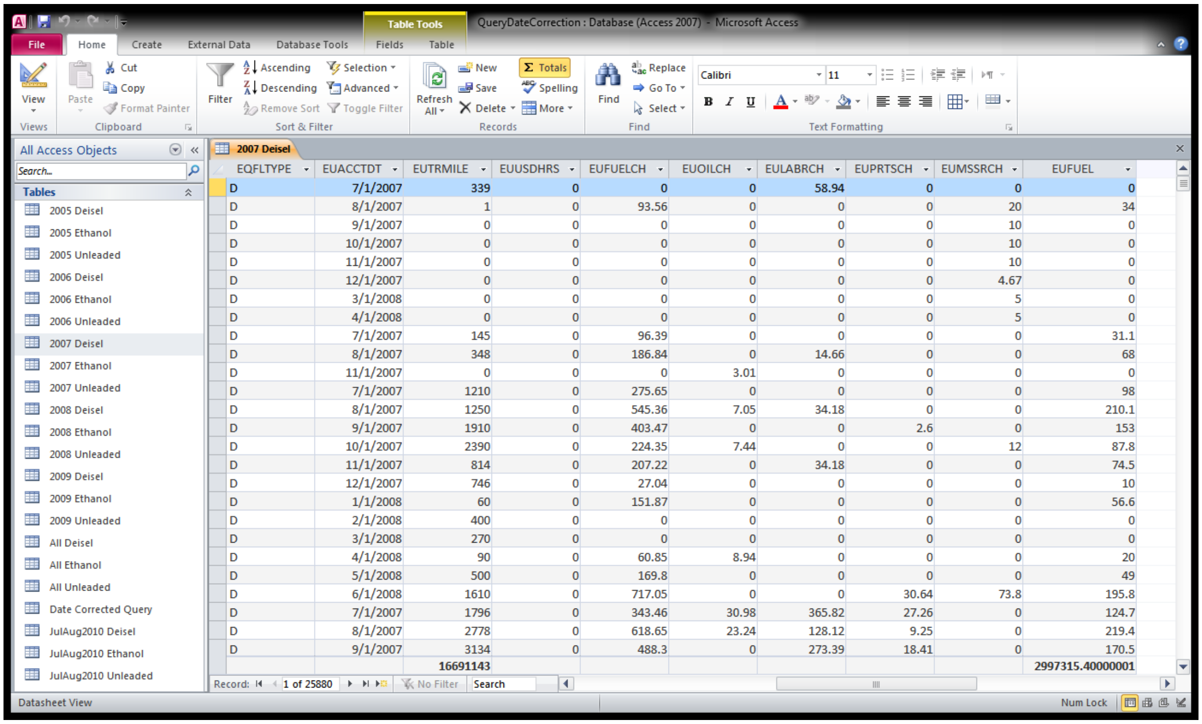
As seen below, the user may view the entire five-year database and all its entries or the user may be interested in a specific year and/or fuel type thereby selecting the corresponding table for viewing.

FIGURE 9.1
Main Database Screen



For example, if a user was interested in how much diesel was used in 2007 they would open the 2007 Diesel table and scroll to the EUFUEL row and find a total of 2,997,315.4 gallons of diesel used for the 2007 fiscal year. From this screen (Figure 9.1) the user can also find that the vehicles that used diesel in 2007 traveled a total distance of 16,691,143 miles.

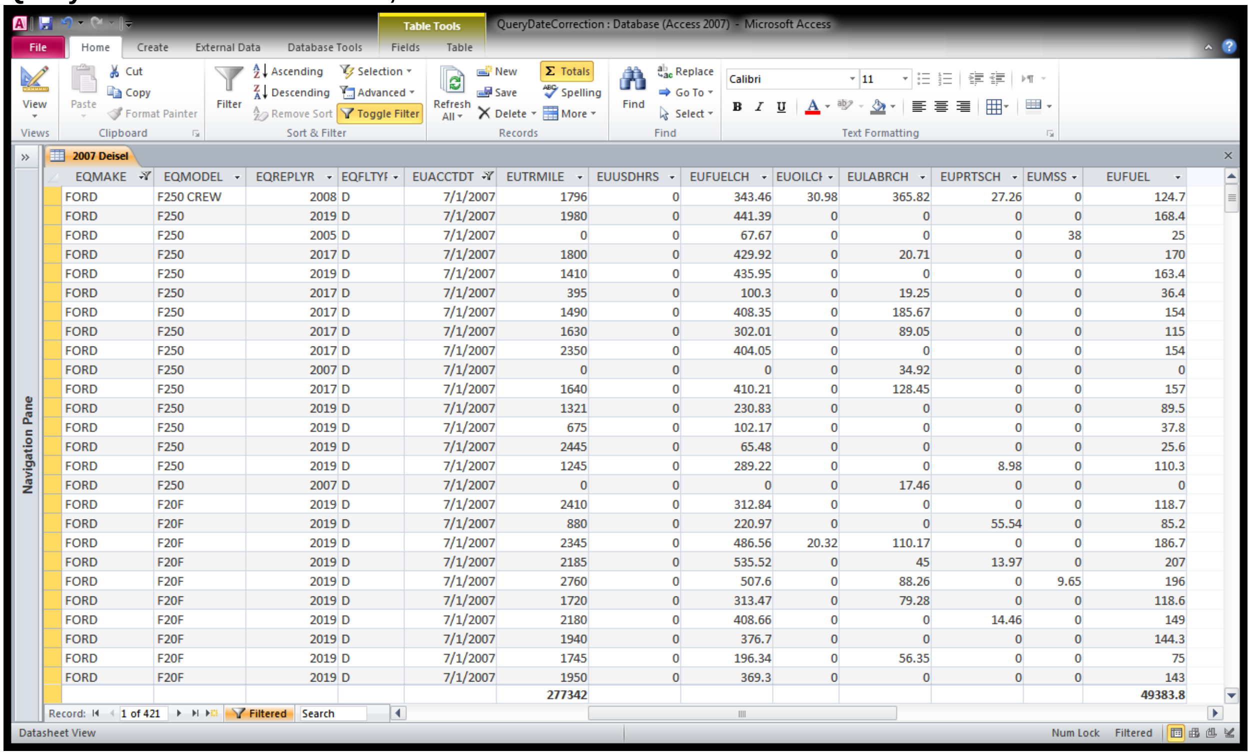
FIGURE 9.2
Fiscal Year 2007 Diesel Information Table



EQFLTYPE	EUACCTDT	EUTRMILE	EUUSDHRS	EUFUELCH	EUOILCH	EULABRCH	EUPRTSCH	EUMSSRCH	EUFUEL
D	7/1/2007	339	0	0	0	58.94	0	0	0
D	8/1/2007	1	0	93.56	0	0	0	20	34
D	9/1/2007	0	0	0	0	0	0	10	0
D	10/1/2007	0	0	0	0	0	0	10	0
D	11/1/2007	0	0	0	0	0	0	10	0
D	12/1/2007	0	0	0	0	0	0	4.67	0
D	3/1/2008	0	0	0	0	0	0	5	0
D	4/1/2008	0	0	0	0	0	0	5	0
D	7/1/2007	145	0	96.39	0	0	0	0	31.1
D	8/1/2007	348	0	186.84	0	14.66	0	0	68
D	11/1/2007	0	0	0	3.01	0	0	0	0
D	7/1/2007	1210	0	275.65	0	0	0	0	98
D	8/1/2007	1250	0	545.36	7.05	34.18	0	0	210.1
D	9/1/2007	1910	0	403.47	0	0	2.6	0	153
D	10/1/2007	2390	0	224.35	7.44	0	0	12	87.8
D	11/1/2007	814	0	207.22	0	34.18	0	0	74.5
D	12/1/2007	746	0	27.04	0	0	0	0	10
D	1/1/2008	60	0	151.87	0	0	0	0	56.6
D	2/1/2008	400	0	0	0	0	0	0	0
D	3/1/2008	270	0	0	0	0	0	0	0
D	4/1/2008	90	0	60.85	8.94	0	0	0	20
D	5/1/2008	500	0	169.8	0	0	0	0	49
D	6/1/2008	1610	0	717.05	0	0	30.64	73.8	195.8
D	7/1/2007	1796	0	343.46	30.98	365.82	27.26	0	124.7
D	8/1/2007	2778	0	618.65	23.24	128.12	9.25	0	219.4
D	9/1/2007	3134	0	488.3	0	273.39	18.41	0	170.5
		16691143							2997315.40000001

The design of these tables allows any user to be as specific as he/she wants to be with a couple of easy filtering steps. If a user was interested in how many gallons of diesel were used to fuel Ford trucks in June 2007, then he/she would only need to filter the EQMAKE for FORD and filter the EUACCTDT for 7/1/2007 (Figure 9.2). This allows a user to find that 49,383.8 gallons of diesel were used to fuel Ford vehicles in June 2007. Also, from here one could further filter by manufacturer make, model, or year for more in-depth information.

FIGURE 9.3
Query Results for Ford Trucks, June 2007 Data



EQMAKE	EQMODEL	EQREPLYR	EQFLTYI	EUACCTDT	EUTRMILE	EUUSDHRS	EUFUELCH	EUOILCI	EULABRCH	EUPRTSCH	EUMSS	EUFUEL
FORD	F250 CREW	2008	D	7/1/2007	1796	0	343.46	30.98	365.82	27.26	0	124.7
FORD	F250	2019	D	7/1/2007	1980	0	441.39	0	0	0	0	168.4
FORD	F250	2005	D	7/1/2007	0	0	67.67	0	0	0	38	25
FORD	F250	2017	D	7/1/2007	1800	0	429.92	0	20.71	0	0	170
FORD	F250	2019	D	7/1/2007	1410	0	435.95	0	0	0	0	163.4
FORD	F250	2017	D	7/1/2007	395	0	100.3	0	19.25	0	0	36.4
FORD	F250	2017	D	7/1/2007	1490	0	408.35	0	185.67	0	0	154
FORD	F250	2017	D	7/1/2007	1630	0	302.01	0	89.05	0	0	115
FORD	F250	2017	D	7/1/2007	2350	0	404.05	0	0	0	0	154
FORD	F250	2007	D	7/1/2007	0	0	0	0	34.92	0	0	0
FORD	F250	2017	D	7/1/2007	1640	0	410.21	0	128.45	0	0	157
FORD	F250	2019	D	7/1/2007	1321	0	230.83	0	0	0	0	89.5
FORD	F250	2019	D	7/1/2007	675	0	102.17	0	0	0	0	37.8
FORD	F250	2019	D	7/1/2007	2445	0	65.48	0	0	0	0	25.6
FORD	F250	2019	D	7/1/2007	1245	0	289.22	0	0	8.98	0	110.3
FORD	F250	2007	D	7/1/2007	0	0	0	0	17.46	0	0	0
FORD	F20F	2019	D	7/1/2007	2410	0	312.84	0	0	0	0	118.7
FORD	F20F	2019	D	7/1/2007	880	0	220.97	0	0	55.54	0	85.2
FORD	F20F	2019	D	7/1/2007	2345	0	486.56	20.32	110.17	0	0	186.7
FORD	F20F	2019	D	7/1/2007	2185	0	535.52	0	45	13.97	0	207
FORD	F20F	2019	D	7/1/2007	2760	0	507.6	0	88.26	0	9.65	196
FORD	F20F	2019	D	7/1/2007	1720	0	313.47	0	79.28	0	0	118.6
FORD	F20F	2019	D	7/1/2007	2180	0	408.66	0	0	14.46	0	149
FORD	F20F	2019	D	7/1/2007	1940	0	376.7	0	0	0	0	144.3
FORD	F20F	2019	D	7/1/2007	1745	0	196.34	0	56.35	0	0	75
FORD	F20F	2019	D	7/1/2007	1950	0	369.3	0	0	0	0	143
					277342							**49383.8**

By designing the database in this way, any user can find information as specific or general as they desire. The bottom right corner of every table in the database has the total gallons of fuel for that table. This provides a means for determining the total fuel and fuel types used each year. These tables were used to compile the fuel usage data in Table 8.2. At present, the database includes only data from 2006 to 2010, although adding data from fiscal year 2011 will be one of the tasks for Phase 2.

In the second phase of this project, we will use the database to assess KDOT diesel and gasoline use across different vehicle classes, function (construction, maintenance, passenger travel, etc.) and operational hours. These data will be used to identify areas for potential fuel consumption and CO_2 emissions reductions and cost savings. As one example of this functionality, we have identified the top vehicle classes for gasoline and diesel fuel use over the 2006 to 2010 period (Tables 9.1 and 9.2).

TABLE 9.1
Top Diesel Consumers by Vehicle Class

Class	Description	Diesel Use (gal)	% of Total Diesel Use
TK	Truck	10,188,628	74
TC	Tractor	1,203,558	8.7
LR	Loader	875,530	6.3
MG	Motor Grader	596,635	4.3
DT	Distributor	244,513	1.8

TABLE 9.2
Top Gasoline Consumers by Vehicle Class

Class	Description	Gasoline Use (gal)	% of Total Gas Use
TK	Truck	2,700,659	74
AU	Automobile	494,155	14
VN	Van	324,311	8.9
SW	Sweeper	22,072	0.6
EQ	Other Equipment	20,506	0.6

9.2 Embodied Energy for Building Database

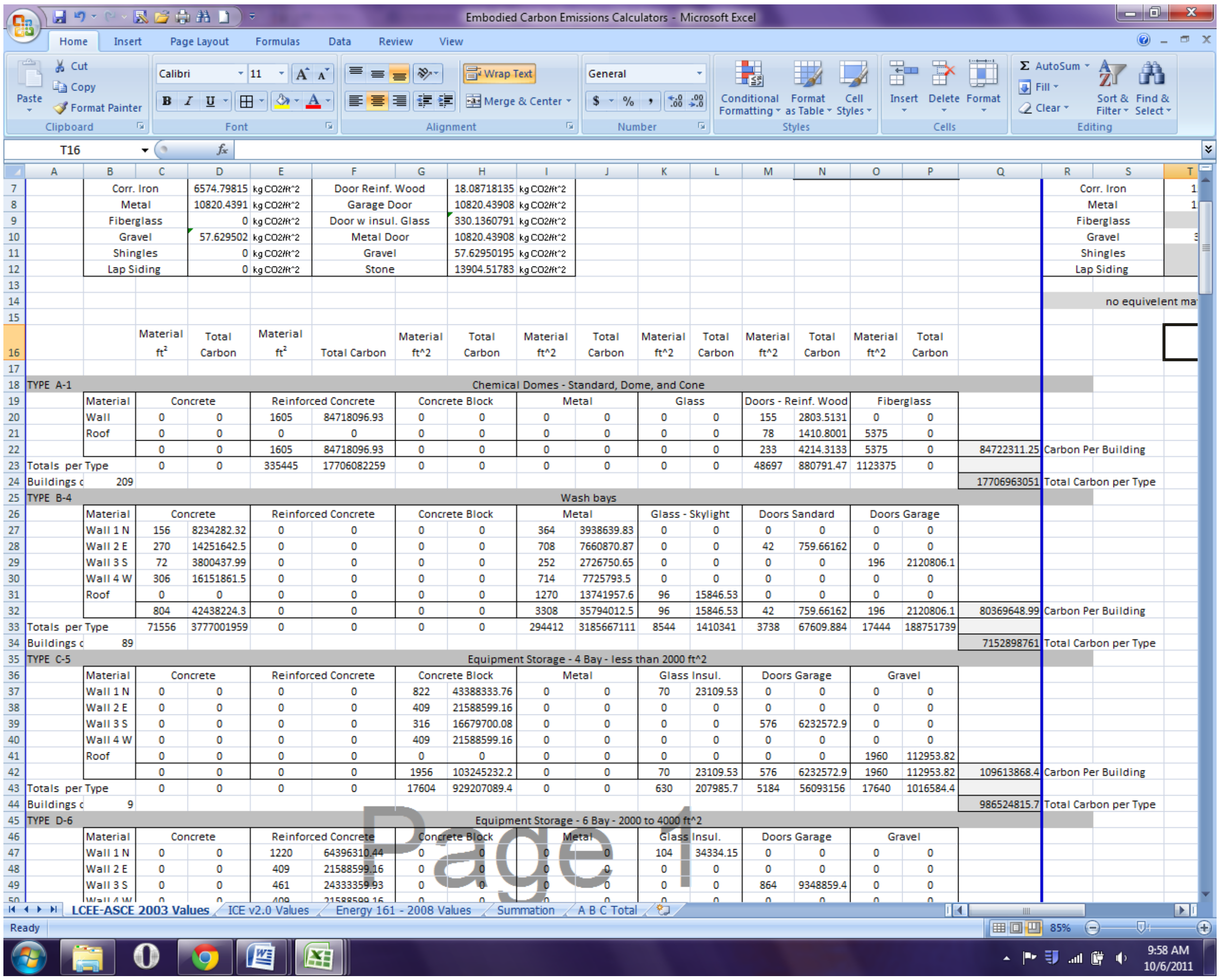


FIGURE 9.4
Embodied Carbon Database and Worksheet

As seen on Figure 9.4, the embodied carbon database categorizes buildings into different types. The building types are listed in Table 6.4, and the detailed descriptions can be found in the database. The database allows users to input quantities of materials into different building types to generate a summary figure for embodied energy of different types of buildings. It calculates the embodied carbon for over 10 types of materials (namely, Concrete, Reinforced Concrete, Concrete Block, Corrugated Iron, Brick, Metal, Glass, Fiberglass, Gravel, Shingles, Lap Sidings, Windows, Doors –Standard, and Doors-Garage) and combine them to generate a figure on embodied energy. These items are found to consume the most carbon during their production stage and thus are singled out for the database. The embodied carbon of the other less significant items are added to the database as an embodied carbon base on the building square footage.

16			Material ft^2	Total Carbon	Material ft^2	Total Carbon	Material ft^2	Total Carbon	Material ft^2	Total Carbon	Material ft^2	Total Carbon	Material ft^2	Total Carbon	Material ft^2	Total Carbon		
17																		
18	TYPE A-1		Chemical Domes - Standard, Dome, and Cone															
19		Material	Concrete		Reinforced Concrete		Concrete Block		Metal		Glass		Doors - Reinf. Wood		Fiberglass			
20		Wall	0	0	1605	84718096.93	0	0	0	0	0	0	155	2803.5131	0	0		
21		Roof	0	0	0	0	0	0	0	0	0	0	78	1410.8001	5375	0		
22			0	0	1605	84718096.93	0	0	0	0	0	0	233	4214.3133	5375	0	84722311.25	Carbon Per Building
23	Totals per Type		0	0	335445	17706082259	0	0	0	0	0	0	48697	880791.47	1123375	0		
24	Buildings c	209															17706963051	Total Carbon per Type

FIGURE 9.5
Embodied Carbon Interpretation

The top row shown Figure 9.5 highlights the types of information that are input into the column. The square footage of the materials is input into the column. The square footages are then multiplied by the equivalent carbon (shown on the top right hand corner of Figure 9.4) to calculate total carbon. The quantities of materials are calculated from the blueprints that KDOT provide the research team. The calculations are divided into types of building components (as seen in Figure 9.5, Wall and Roof), and wall orientations (as seen in Figure 9.4 for Type B-4).

The results are then presented in the folder “Summation” in the Excel spreadsheet as seen in the following figure.

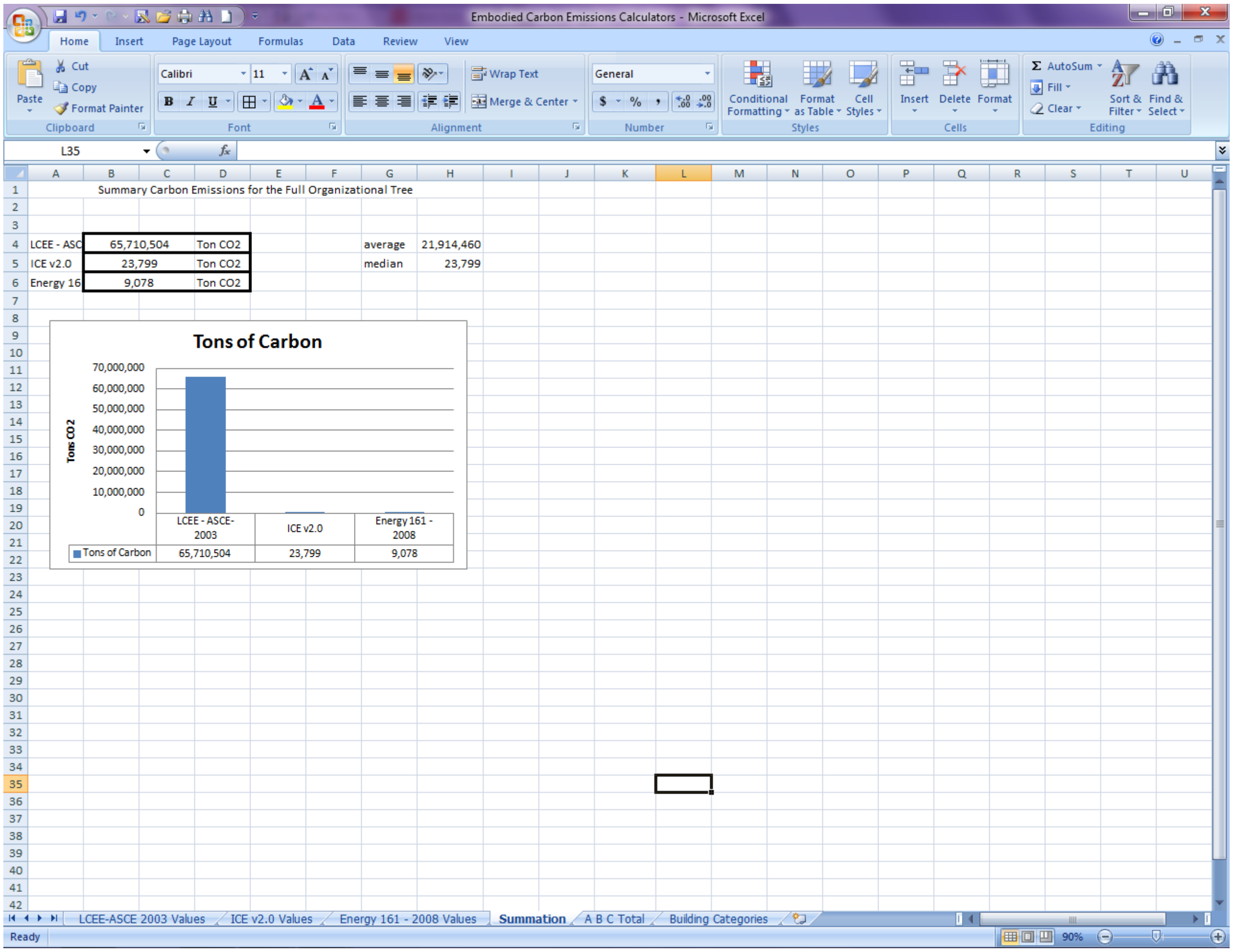


FIGURE 9.6
Embodied Carbon Outputs

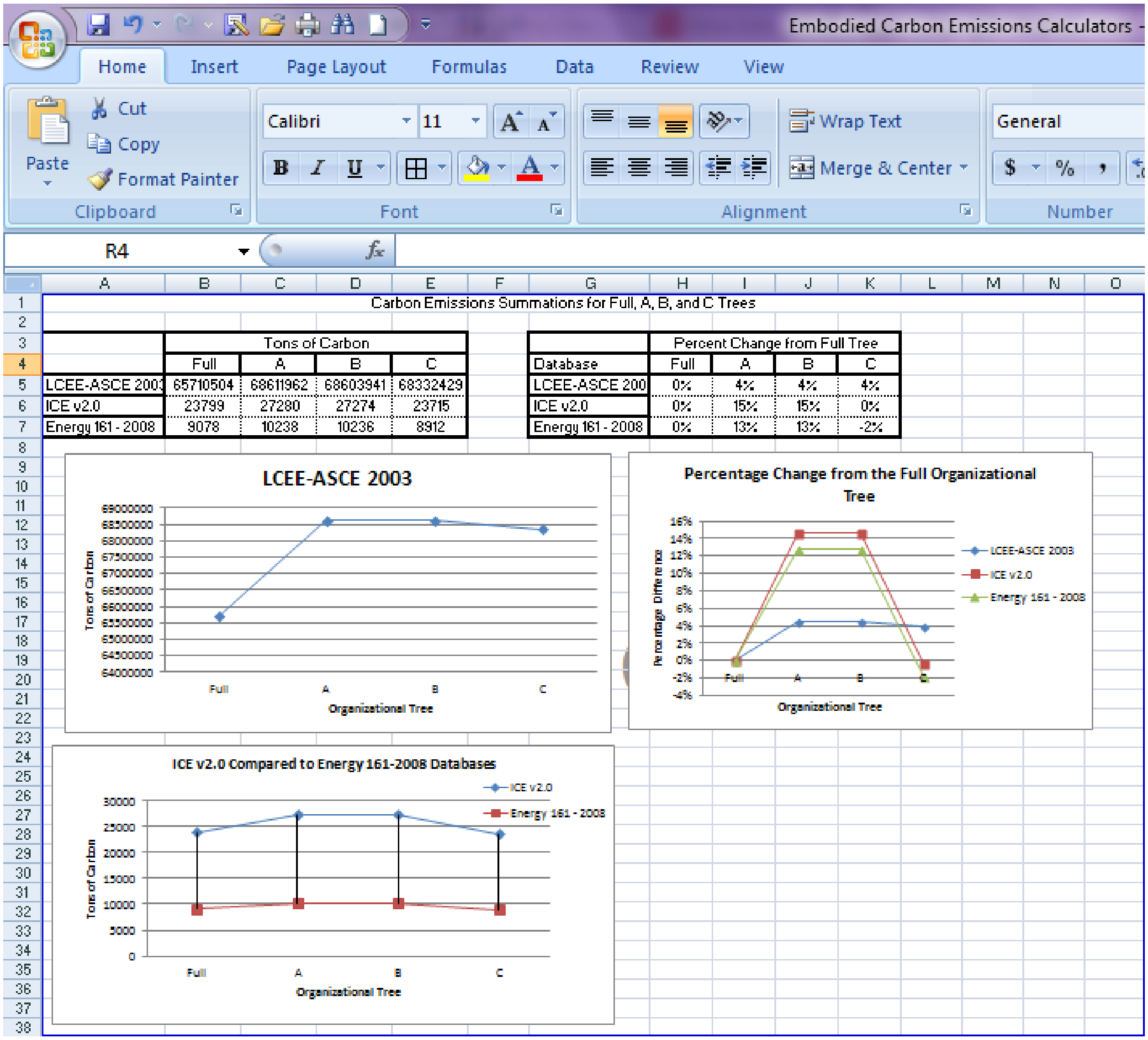
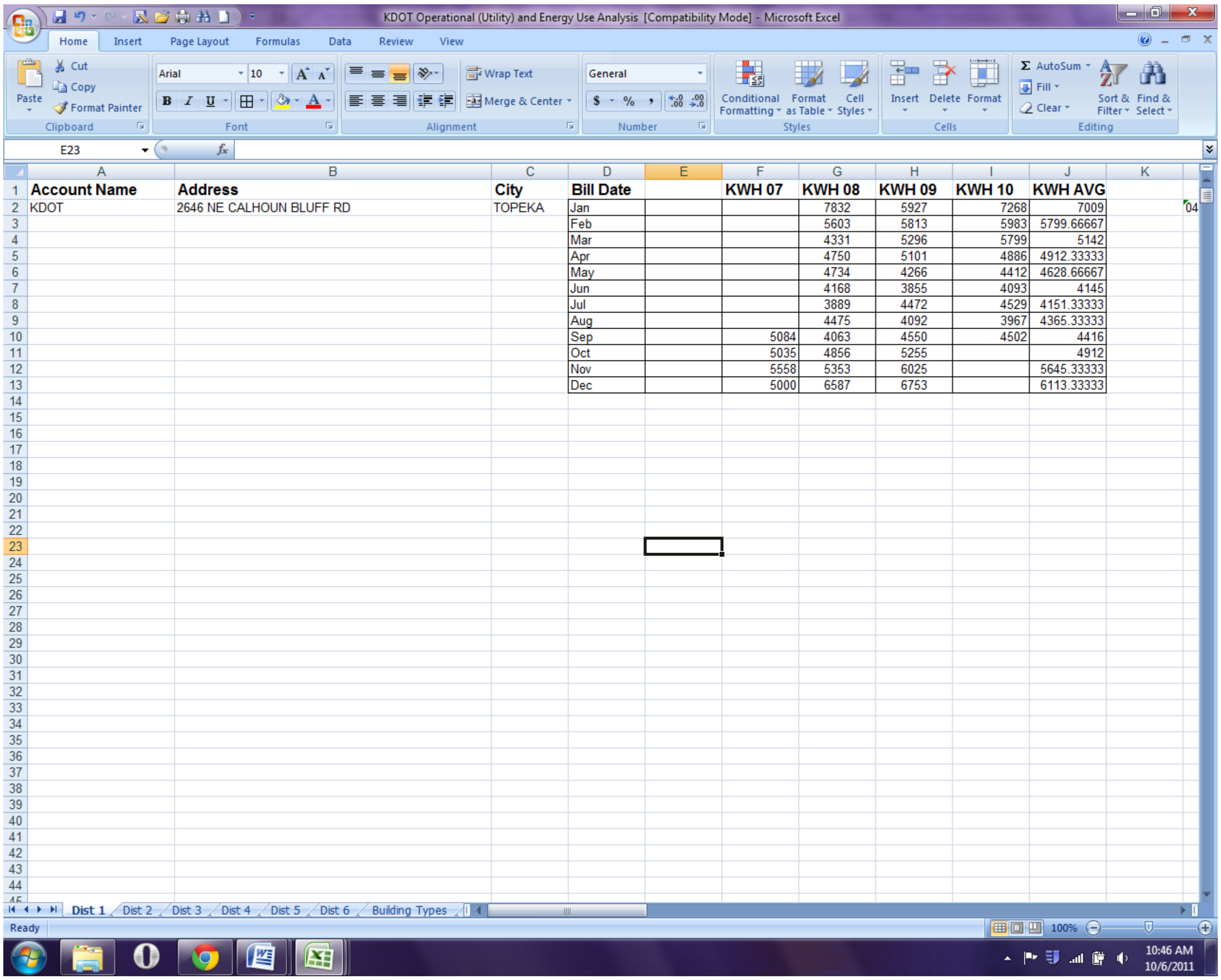


FIGURE 9.7
Output from Three Different Embodied Carbon Database

The database also provided calculations from the three embodied carbon databases as shown in the above Figure 9.7. The calculator is designed to calculate the embodied carbon from the LCEE, ICE and Energy 161 database (three of the most recognized database).

9.3 Operational Energy for Building Database

The operational energy for building database is designed to let KDOT personnel model energy use from their utilities for different types of buildings and for different districts.



Account Name	Address	City	Bill Date		KWH 07	KWH 08	KWH 09	KWH 10	KWH AVG
KDOT	2646 NE CALHOUN BLUFF RD	TOPEKA	Jan			7832	5927	7268	7009
			Feb			5603	5813	5983	5799.66667
			Mar			4331	5296	5799	5142
			Apr			4750	5101	4886	4912.33333
			May			4734	4266	4412	4628.66667
			Jun			4168	3855	4093	4145
			Jul			3889	4472	4529	4151.33333
			Aug			4475	4092	3967	4365.33333
			Sep		5084	4063	4550	4502	4416
			Oct		5035	4856	5255		4912
			Nov		5558	5353	6025		5645.33333
			Dec		5000	6587	6753		6113.33333

FIGURE 9.8
Operational Energy from Utilities for Building Database

As seen in Figure 9.8, the energy bill is generated for a particular campus at Topeka. The utility bills from 2007 to 2010 are input into the "KWH" columns to calculate the overall KWH and the average KWH. The calculator then generates a total kWh for the campus. The "KWH" column can be modified and expanded to calculate energy use beyond 2010, and thus is useful to continuously track the energy generated from utilities.

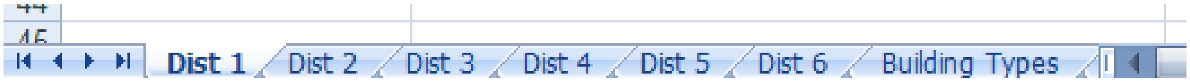
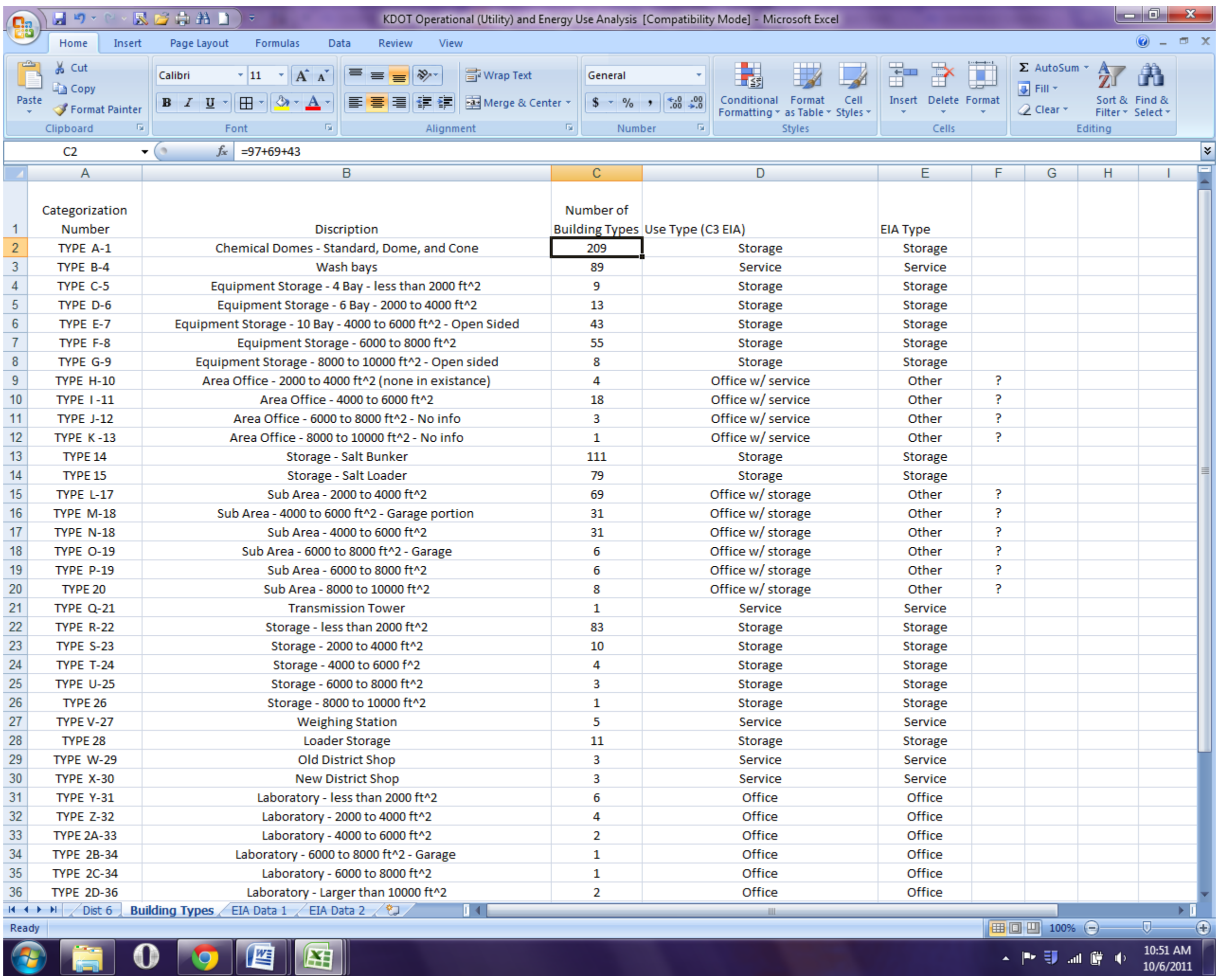


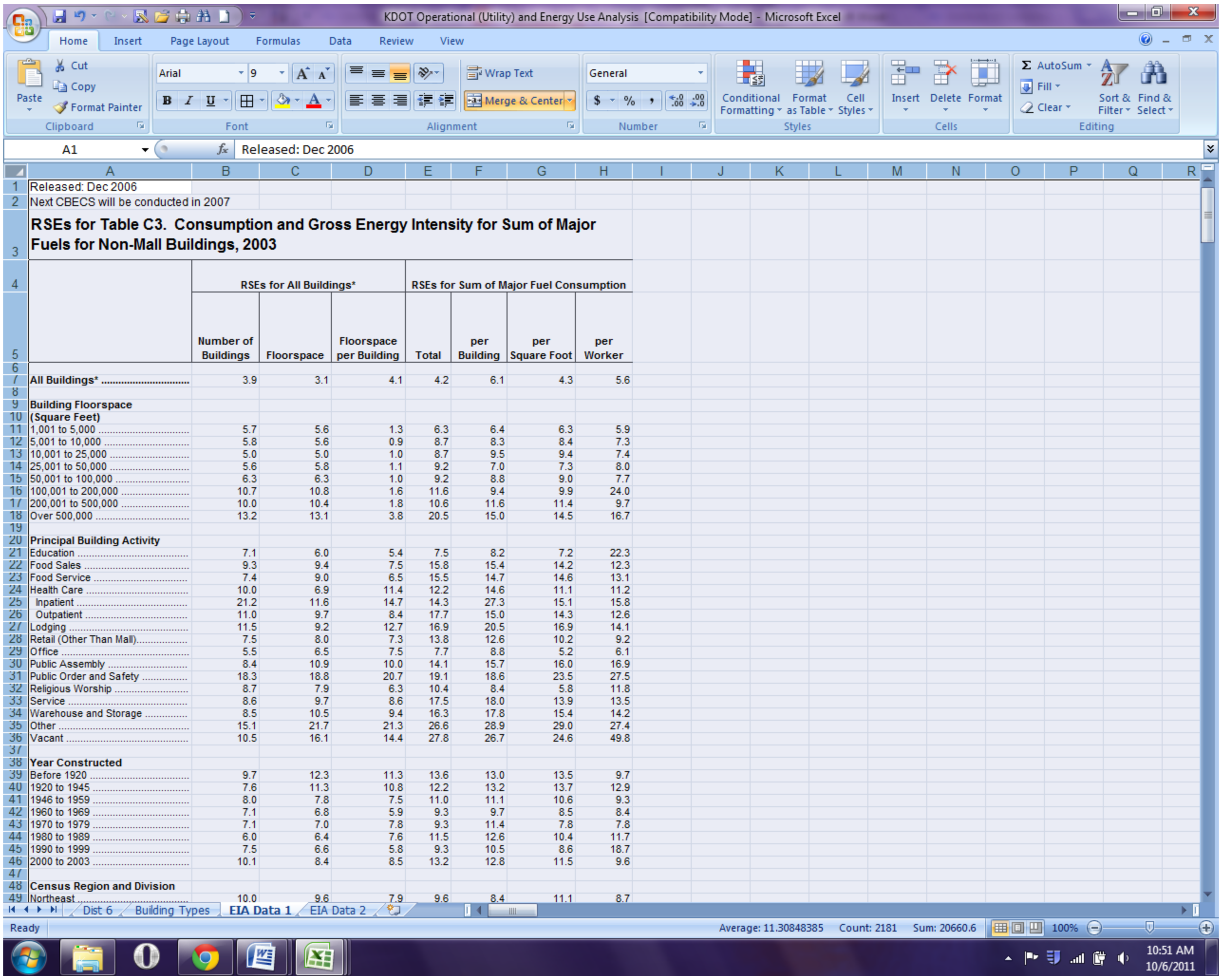
FIGURE 9.9
Operational Energy from Utilities for Building Database for Different Districts

The calculations are separated into different buildings types as shown in Figure 9.8 and by districts (seen in Figure 9.9). The database also contains different building types used in the database and calculator.



Categorization Number	Discription	Number of Building Types	Use Type (C3 EIA)	EIA Type	
TYPE A-1	Chemical Domes - Standard, Dome, and Cone	209	Storage	Storage	
TYPE B-4	Wash bays	89	Service	Service	
TYPE C-5	Equipment Storage - 4 Bay - less than 2000 ft^2	9	Storage	Storage	
TYPE D-6	Equipment Storage - 6 Bay - 2000 to 4000 ft^2	13	Storage	Storage	
TYPE E-7	Equipment Storage - 10 Bay - 4000 to 6000 ft^2 - Open Sided	43	Storage	Storage	
TYPE F-8	Equipment Storage - 6000 to 8000 ft^2	55	Storage	Storage	
TYPE G-9	Equipment Storage - 8000 to 10000 ft^2 - Open sided	8	Storage	Storage	
TYPE H-10	Area Office - 2000 to 4000 ft^2 (none in existance)	4	Office w/ service	Other	?
TYPE I-11	Area Office - 4000 to 6000 ft^2	18	Office w/ service	Other	?
TYPE J-12	Area Office - 6000 to 8000 ft^2 - No info	3	Office w/ service	Other	?
TYPE K-13	Area Office - 8000 to 10000 ft^2 - No info	1	Office w/ service	Other	?
TYPE 14	Storage - Salt Bunker	111	Storage	Storage	
TYPE 15	Storage - Salt Loader	79	Storage	Storage	
TYPE L-17	Sub Area - 2000 to 4000 ft^2	69	Office w/ storage	Other	?
TYPE M-18	Sub Area - 4000 to 6000 ft^2 - Garage portion	31	Office w/ storage	Other	?
TYPE N-18	Sub Area - 4000 to 6000 ft^2	31	Office w/ storage	Other	?
TYPE O-19	Sub Area - 6000 to 8000 ft^2 - Garage	6	Office w/ storage	Other	?
TYPE P-19	Sub Area - 6000 to 8000 ft^2	6	Office w/ storage	Other	?
TYPE 20	Sub Area - 8000 to 10000 ft^2	8	Office w/ storage	Other	?
TYPE Q-21	Transmission Tower	1	Service	Service	
TYPE R-22	Storage - less than 2000 ft^2	83	Storage	Storage	
TYPE S-23	Storage - 2000 to 4000 ft^2	10	Storage	Storage	
TYPE T-24	Storage - 4000 to 6000 f^2	4	Storage	Storage	
TYPE U-25	Storage - 6000 to 8000 ft^2	3	Storage	Storage	
TYPE 26	Storage - 8000 to 10000 ft^2	1	Storage	Storage	
TYPE V-27	Weighing Station	5	Service	Service	
TYPE 28	Loader Storage	11	Storage	Storage	
TYPE W-29	Old District Shop	3	Service	Service	
TYPE X-30	New District Shop	3	Service	Service	
TYPE Y-31	Laboratory - less than 2000 ft^2	6	Office	Office	
TYPE Z-32	Laboratory - 2000 to 4000 ft^2	4	Office	Office	
TYPE 2A-33	Laboratory - 4000 to 6000 ft^2	2	Office	Office	
TYPE 2B-34	Laboratory - 6000 to 8000 ft^2 - Garage	1	Office	Office	
TYPE 2C-34	Laboratory - 6000 to 8000 ft^2	1	Office	Office	
TYPE 2D-36	Laboratory - Larger than 10000 ft^2	2	Office	Office	

FIGURE 9.10
Building Types in Database



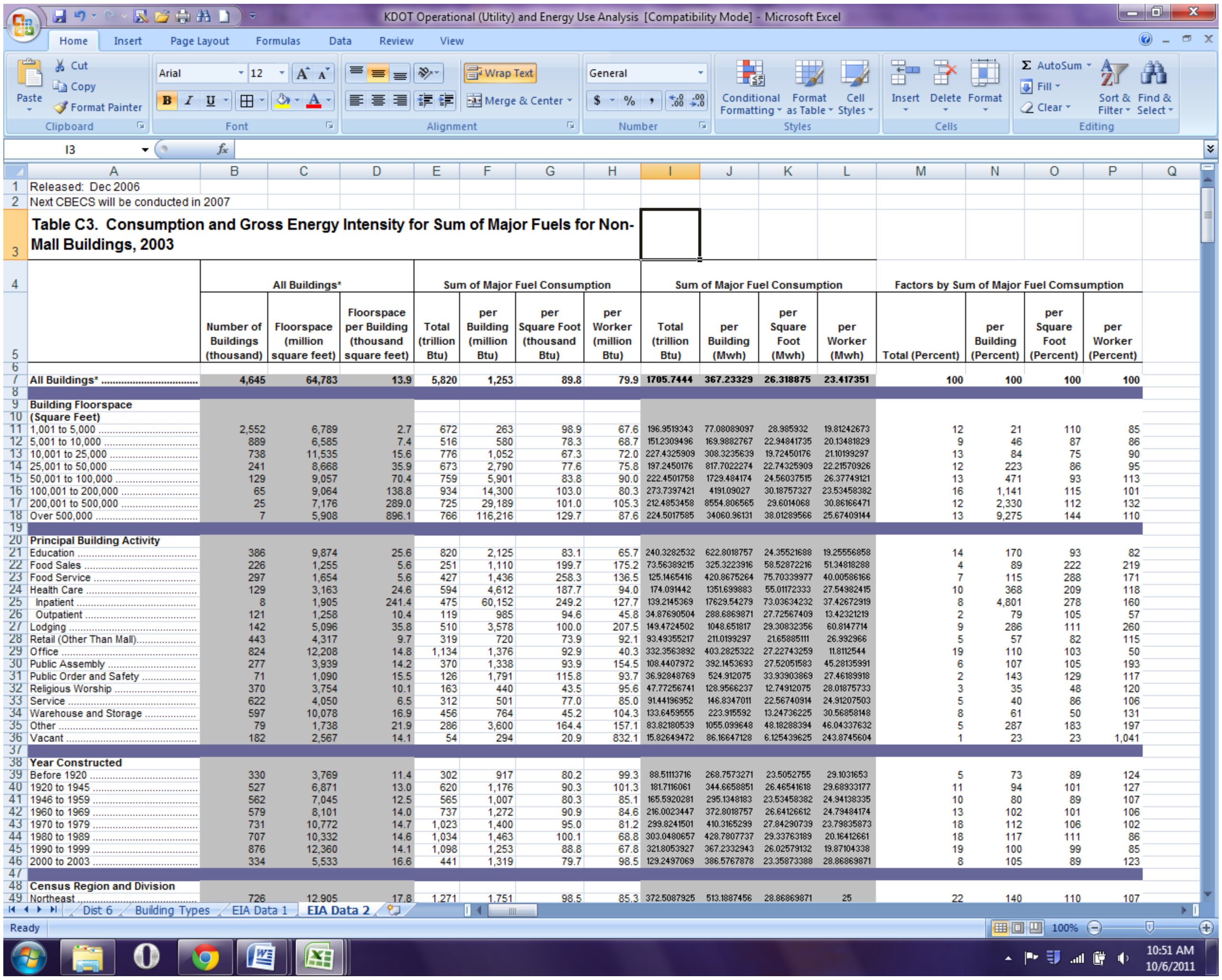
Released: Dec 2006

Next CBECS will be conducted in 2007

RSEs for Table C3. Consumption and Gross Energy Intensity for Sum of Major Fuels for Non-Mall Buildings, 2003

	RSEs for All Buildings*			RSEs for Sum of Major Fuel Consumption			
	Number of Buildings	Floorspace	Floorspace per Building	Total	per Building	per Square Foot	per Worker
All Buildings*	3.9	3.1	4.1	4.2	6.1	4.3	5.6
Building Floorspace (Square Feet)							
1,001 to 5,000	5.7	5.6	1.3	6.3	6.4	6.3	5.9
5,001 to 10,000	5.8	5.6	0.9	8.7	8.3	8.4	7.3
10,001 to 25,000	5.0	5.0	1.0	8.7	9.5	9.4	7.4
25,001 to 50,000	5.6	5.8	1.1	9.2	7.0	7.3	8.0
50,001 to 100,000	6.3	6.3	1.0	9.2	8.8	9.0	7.7
100,001 to 200,000	10.7	10.8	1.6	11.6	9.4	9.9	24.0
200,001 to 500,000	10.0	10.4	1.8	10.6	11.6	11.4	9.7
Over 500,000	13.2	13.1	3.8	20.5	15.0	14.5	16.7
Principal Building Activity							
Education	7.1	6.0	5.4	7.5	8.2	7.2	22.3
Food Sales	9.3	9.4	7.5	15.8	15.4	14.2	12.3
Food Service	7.4	9.0	6.5	15.5	14.7	14.6	13.1
Health Care	10.0	6.9	11.4	12.2	14.6	11.1	11.2
Inpatient	21.2	11.6	14.7	14.3	27.3	15.1	15.8
Outpatient	11.0	9.7	8.4	17.7	15.0	14.3	12.6
Lodging	11.5	9.2	12.7	16.9	20.5	16.9	14.1
Retail (Other Than Mall)	7.5	8.0	7.3	13.8	12.6	10.2	9.2
Office	5.5	6.5	7.5	7.7	8.8	5.2	6.1
Public Assembly	8.4	10.9	10.0	14.1	15.7	16.0	16.9
Public Order and Safety	18.3	18.8	20.7	19.1	18.6	23.5	27.5
Religious Worship	8.7	7.9	6.3	10.4	8.4	5.8	11.8
Service	8.6	9.7	8.6	17.5	18.0	13.9	13.5
Warehouse and Storage	8.5	10.5	9.4	16.3	17.8	15.4	14.2
Other	15.1	21.7	21.3	26.6	28.9	29.0	27.4
Vacant	10.5	16.1	14.4	27.8	26.7	24.6	49.8
Year Constructed							
Before 1920	9.7	12.3	11.3	13.6	13.0	13.5	9.7
1920 to 1945	7.6	11.3	10.8	12.2	13.2	13.7	12.9
1946 to 1959	8.0	7.8	7.5	11.0	11.1	10.6	9.3
1960 to 1969	7.1	6.8	5.9	9.3	9.7	8.5	8.4
1970 to 1979	7.1	7.0	7.8	9.3	11.4	7.8	7.8
1980 to 1989	6.0	6.4	7.6	11.5	12.6	10.4	11.7
1990 to 1999	7.5	6.6	5.8	9.3	10.5	8.6	18.7
2000 to 2003	10.1	8.4	8.5	13.2	12.8	11.5	9.6
Census Region and Division							
Northeast	10.0	9.6	7.9	9.6	8.4	11.1	8.7

FIGURE 9.11
Building Types in Database



Released: Dec 2006
Next CBECS will be conducted in 2007

Table C3. Consumption and Gross Energy Intensity for Sum of Major Fuels for Non-Mall Buildings, 2003

	All Buildings*			Sum of Major Fuel Consumption				Sum of Major Fuel Consumption				Factors by Sum of Major Fuel Comsumption			
	Number of Buildings (thousand)	Floorspace (million square feet)	Floorspace per Building (thousand square feet)	Total (trillion Btu)	per Building (million Btu)	per Square Foot (thousand Btu)	per Worker (million Btu)	Total (trillion Btu)	per Building (Mwh)	per Square Foot (Mwh)	per Worker (Mwh)	Total (Percent)	per Building (Percent)	per Square Foot (Percent)	per Worker (Percent)
All Buildings*	**4,645**	**64,783**	**13.9**	**5,820**	**1,253**	**89.8**	**79.9**	**1705.7444**	**367.23329**	**26.318875**	**23.417351**	**100**	**100**	**100**	**100**
Building Floorspace (Square Feet)															
1,001 to 5,000	2,552	6,789	2.7	672	263	98.9	67.6	196.9519343	77.08089097	28.985932	19.81242673	12	21	110	85
5,001 to 10,000	889	6,585	7.4	516	580	78.3	68.7	151.2309496	169.9882767	22.94841735	20.13481829	9	46	87	86
10,001 to 25,000	738	11,535	15.6	776	1,052	67.3	72.0	227.4325909	308.3235639	19.72450176	21.10199297	13	84	75	90
25,001 to 50,000	241	8,668	35.9	673	2,790	77.6	75.8	197.2450176	817.7022274	22.74325909	22.21570926	12	223	86	95
50,001 to 100,000	129	9,057	70.4	759	5,901	83.8	90.0	222.4501758	1729.484174	24.56037515	26.37749121	13	471	93	113
100,001 to 200,000	65	9,064	138.8	934	14,300	103.0	80.3	273.7397421	4191.09027	30.18757327	23.53458382	16	1,141	115	101
200,001 to 500,000	25	7,176	289.0	725	29,189	101.0	105.3	212.4853458	8554.806565	29.6014068	30.86166471	12	2,330	112	132
Over 500,000	7	5,908	896.1	766	116,216	129.7	87.6	224.5017585	34060.96131	38.01289566	25.67409144	13	9,275	144	110
Principal Building Activity															
Education	386	9,874	25.6	820	2,125	83.1	65.7	240.3282532	622.8018757	24.35521688	19.25556858	14	170	93	82
Food Sales	226	1,255	5.6	251	1,110	199.7	175.2	73.56389215	325.3223916	58.52872216	51.34818288	4	89	222	219
Food Service	297	1,654	5.6	427	1,436	258.3	136.5	125.1465416	420.8675264	75.70339977	40.00586166	7	115	288	171
Health Care	129	3,163	24.6	594	4,612	187.7	94.0	174.091442	1351.699883	55.01172333	27.54982415	10	368	209	118
Inpatient	8	1,905	241.4	475	60,152	249.2	127.7	139.2145369	17629.54279	73.03634232	37.42672919	8	4,801	278	160
Outpatient	121	1,258	10.4	119	985	94.6	45.8	34.87690504	288.6869871	27.72567409	13.42321219	2	79	105	57
Lodging	142	5,096	35.8	510	3,578	100.0	207.5	149.4724502	1048.651817	29.30832356	60.8147714	9	286	111	260
Retail (Other Than Mall)	443	4,317	9.7	319	720	73.9	92.1	93.49355217	211.0199297	21.6588511	26.992966	5	57	82	115
Office	824	12,208	14.8	1,134	1,376	92.9	40.3	332.3563892	403.2825322	27.22743259	11.8112544	19	110	103	50
Public Assembly	277	3,939	14.2	370	1,338	93.9	154.5	108.4407972	392.1453693	27.52051583	45.28135991	6	107	105	193
Public Order and Safety	71	1,090	15.5	126	1,791	115.8	93.7	36.92848769	524.912075	33.93903869	27.46189918	2	143	129	117
Religious Worship	370	3,754	10.1	163	440	43.5	95.6	47.77256741	128.9566237	12.74912075	28.01875733	3	35	48	120
Service	622	4,050	6.5	312	501	77.0	85.0	91.44196952	146.8347011	22.56740914	24.91207503	5	40	86	106
Warehouse and Storage	597	10,078	16.9	456	764	45.2	104.3	133.6459555	223.915592	13.24736225	30.56858148	8	61	50	131
Other	79	1,738	21.9	286	3,600	164.4	157.1	83.82180539	1055.099648	48.18288394	46.04337632	5	287	183	197
Vacant	182	2,567	14.1	54	294	20.9	832.1	15.82649472	86.16647128	6.125439625	243.8745604	1	23	23	1,041
Year Constructed															
Before 1920	330	3,769	11.4	302	917	80.2	99.3	88.51113716	268.7573271	23.5052755	29.1031653	5	73	89	124
1920 to 1945	527	6,871	13.0	620	1,176	90.3	101.3	181.7116061	344.6658851	26.46541618	29.68933177	11	94	101	127
1946 to 1959	562	7,045	12.5	565	1,007	80.3	85.1	165.5920281	295.1348183	23.53458382	24.94138335	10	80	89	107
1960 to 1969	579	8,101	14.0	737	1,272	90.9	84.6	216.0023447	372.8018757	26.64126612	24.79484174	13	102	101	106
1970 to 1979	731	10,772	14.7	1,023	1,400	95.0	81.2	299.8241501	410.3165299	27.84290739	23.79835873	18	112	106	102
1980 to 1989	707	10,332	14.6	1,034	1,463	100.1	68.8	303.0480657	428.7807737	29.33763189	20.16412661	18	117	111	86
1990 to 1999	876	12,360	14.1	1,098	1,253	88.8	67.8	321.8053927	367.2332943	26.02579132	19.87104338	19	100	99	85
2000 to 2003	334	5,533	16.6	441	1,319	79.7	98.5	129.2497069	386.5767878	23.35873388	28.86869871	8	105	89	123
Census Region and Division															
Northeast	726	12,905	17.8	1,271	1,751	98.5	85.3	372.5087925	513.1887456	28.86869871	25	22	140	110	107

FIGURE 9.12
Building Types in Database

Figures 9.11 and 9.12 show the EIA information that are used to compare KDOT energy use with the national averages. This database will be documented in the database so that KDOT can compare their future numbers with these EIA information.

Chapter 10: Research Summary

The key findings are:

1. Embodied Carbon: The database use to calculate the total amount of embodied energy consumed by and carbon emitted by KDOT affect the calculated outputs. There is no way to draw conclusive evidence to benchmark KDOT embodied energy and carbon and compare them with the national average. Thus, the project team develops Figure 7.5 to assist KDOT in reducing the amount of embodied energy and carbon in their building designs.

2. Operational Energy: Most buildings that KDOT operates consume significantly lesser than other similar buildings in the country, except for those that contain large amount of laboratory equipment. This suggests that KDOT footprint is significantly smaller than other states.

3. Vehicular Energy: The study shows that KDOT has increased its diesel consumption and reduced its bio-diesel consumption. This may reflect the potential problem of bio-diesel use in KDOT vehicles during the winter months.

Chapter 11: Future Work

Further work on this project is already planned. Phase 2 of this project will involve analyzing the data gathered to find potential reductions and savings along with the development of a carbon calculator. Phase 3 of this project will involve highways and highway construction equipments in Kansas. These steps will allow KDOT personal to keep an accurate and up-to-date inventory of their CO_2 emissions. Along with these steps, more accurate CO_2 emissions can be calculated by separating vehicular classes into similar fuel efficiency categories. Then, by using emission standards for each class and knowing travelled miles, a more accurate carbon footprint could be obtained.

11.1 Discussion

Accuracy of data is crucial to establishing an accepted carbon emissions value. A number of methods may be employed to work towards proving legitimacy but may 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 carbon results are higher or lower than should be expected. This method of crosschecking 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.

Testing values against known values presents another solution. Energy Benchmarking of Buildings and Industries suggests using “peer groups”, similar to building types. 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 place one’s own evaluation.

The utility data shows that 17.8% of the power consumption and carbon emissions of KDOT facilities came from the Materials and Research Laboratory in Topeka. This is due, in large part, to the specialized laboratory equipment and tests that are run daily. The laboratory is part of a complex of buildings that also house offices and occupied by employees during office hours. Their power consumption is higher than the baseline suggested by Energy Information Administration. Future phases of this research should focus on lowering the power consumption in these locations. The next phases are, but are not limited to:

- Determine ways to lower power consumption in office spaces.
- Determine organizational methods to lower carbon emissions from fossil fuel-consuming equipment.
- Compose a cost-effective, power-efficient policy to monitor the carbon emissions of KDOT.
- Perform a case study of enterprise carbon accounting at KDOT.
- Determine opportunities for reduced fuel consumption in KDOT vehicle fleet.
- Assess the potential for increased renewable fuel use by KDOT vehicles.

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