Energy analysis of Texas Metropolitan Areas for climate change mitigation using LiDar

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Abstract

Buildings account for a large share of U.S. energy use making the building sector a prime candidate for efficiency measures. Obtaining accurate information about geometry and occupancy can prove computationally intense. We analyze different neighborhoods in Texas under a new methodology that allows for large scale implementation. This methodology uses PostgreSQL, QGIS, LiDar, Grasshopper and CitySim to generate, analyze and compare energy models under various climate change scenarios. An energy analysis was performed on over 100,000 buildings in Dallas, Texas, evaluating performance in terms of energy efficiency and overheating under several refurbishment scenarios. Neighborhoods in Dallas were analyzed under a modified methodology designed to scale the results of a previous, smaller study by the authors to a broader sample. This study found metropolitan areas performed similarly under various refurbishment scenarios; the more aggressive scenarios showing greater improvements for the same given amount of time. The results of the experiments show consistency between this expanded method and the original. This method must make concessions in terms of detail. While it is possible to achieve a more accurate estimate by taking into account variables such as enclosure composition, building systems and shading surfaces, it becomes difficult for larger simulation, making LiDar an effective alternative.

1. Introduction

We develop a methodology to simulate energy consumption in large metropolitan areas through a multi-step process involving the use of PostgreSQL, QGIS, Python, Grasshopper, and CitySimPro. The methodology increases the flexibility of parametric design in terms of large-scale projects. To test the new methodology, we examine the full refurbishment scenario and analyse neighborhoods in Dallas, Texas, using super computing. In previous work, we used OpenStreetMaps (OSM) to get building footprints [1,2]. The main drawback to this is the lack of availability for many nearby rural areas. Additionally, many OSM building footprints do not include building height which makes it difficult to create 3d models of the buildings. LiDar is a remote sensing technique using light to measure return distances from the earth to the captured sensor. This can and is being used to create elevation maps around Texas. One prominent example of a database using this technology is StratMap. This solves problems that arise from using OSM data, but it is more time consuming, as the LiDar data needs to be processed to be grouped into buildings. However, with no alternative present for some of these smaller neighborhoods, it provides decently accurate data.
Our previous methodology [1,2] uses Intergovernmental Panel on Climate Change (IPCC) projections to model energy demand and building overheating in the West Campus neighborhood. The study found a notable disparity between the performance of Austin buildings based on their use type, and established the basis for a methodology that allows for the parameterization of energy models; a chief concern in the urban energy modelling field with significant contributions from [3, 4]. However, building models used for the predictions were based on a process that involves the scraping of property data records, a time consuming process. Further, more rural governments may not have complete or full repositories for their property records. This paper addresses these concerns and modifies the methodology to make it more suitable for working with large sets of data. This is done through a multi-step process involving the use of PostgreSQL, QGIS, several Python scripts, Grasshopper, and finally CitySimPro. The methodology improves on the previous workflow of the referenced projects and increases the flexibility of the parametric design approach to better suit the needs of large-scale projects. To test the new methodology we examine the full refurbishment scenario outlined in [2] and analyse neighborhoods in Dallas, Texas.

2. Methods

The novelty of the methodology follows the structure outlined in Figure 1. Building geometries are collected either from LiDar Data or a publicly available shapefile resource such as OSM. Building geometries alone provide an insufficient model of energy consumption. In order to create a more accurate model, the footprint is then paired with public property data to estimate building envelope. While some counties keep records of building construction materials, the majority do not. Further, records that do keep construction materials data tend to have widely varying amounts of precision from building to building. In order to keep consistency between different metropolitan areas, the method of estimating building envelope shown in the study [2] was chosen due to its flexibility. This estimate is made using the effective year built date. If an effective year built is not available then construction year was used as a substitute, oftentimes the difference was negligible. In order to pair the building geometry and property data, a spatial tool as well as a relational database is used. This allows us to join large databases quickly and easily. From this database new shapefiles are created with the necessary properties; which in turn are modelled in Rhino with the help of Grasshopper and its accompanying add-ons, Honeybee and Ladybug. Lastly, these energy models are passed into CitySimPro, which then runs daily simulations to generate Heating and Cooling data. The primary strength of the methodology is its flexibility with data inputs. As long as the base components are available publicly, any number of programs can be used to achieve similar results.

![Urban energy simulation workflow](image-url)
2.1 Property Data and Building Footprints

In order to study options for refurbishment in multiple cities, a core goal was to create a framework that was reliant on information available in both rural and urban centers. This makes property data an easy selection for building envelope information. Property records give insight to the year of construction of a building, which in turn can be used to infer material properties. In this study buildings are grouped into two bins - constructed before 1999 and constructed after 2000. Geometry files can prove a more difficult input to obtain. A large discrepancy exists in the quality of building geometry data, varying widely from county to county. For this project a combination of OSM and Public County Data was used to generate building footprints for the neighborhoods examined. LiDar was also explored as an alternative [Section 2.6], but the results of the simulation use a combination of OSM and Property Data to achieve a greater level of accuracy.

2.2 PostgreSQL and PostGIS

PostgreSQL and PostGIS, are open Source Relational Database tools. By storing information in PostgreSQL it allows us to parse large amounts of data quickly. PostGIS further allows the data to be kept in geometry formats with locations still attached, making for easy transfer between programs. These tools improve the scalability, making it possible to use this methodology on entire cities given the processing power and data.

2.3 QGIS

QGIS serves two purposes, import building footprints through the QuickQSM add-on, and bind the spatial data to the tabulated property records. Information in more rural counties remains unavailable due to sourcing from public records. Alternatively, one could use ArcGIS to parse the geometry data.

2.4 LiDar as an Alternative

LiDar is a remote sensing technique that uses light to measure return distances from the earth to the captured sensor. Using this process we can generate elevation maps of buildings. This solves the problems that arise from using OSM data, but it is more time consuming due to the need to establish building boundaries to create energy models. However, it can provide accurate data. Figure 2 shows a comparison between LiDar and OSM data for a neighborhood in Collin County. While some differences exist, the heating and cooling data medians approximate each other extremely closely.

2.5 Grasshopper Input

Grasshopper filters out building geometry that is either incomplete or too complex to run through our energy simulation software, CitySimPro. First we remove sheds and other small buildings sometimes incorporated into QuickOSM data. This is done through filtering by square footage. CSObjects, ground surface, climate, and occupancy schedules, need to be created and added to the simulation. The ground surface is created based on the corner edges of the farthest reaching buildings, to minimize run-time the smallest surface is selected. Next, we generate a CLI file; this file is used to generate the climate of our scenario according to geographic location and also allows us to mimic different climate change scenarios. Additionally, we generate occupancy schedules and occupant numbers that match our buildings. Currently these numbers are created based on the assumption that all buildings are residential. This holds true for this study as the neighborhoods were intentionally selected to be predominately residential areas. Occupant schedules are selected to match ASHRAE Standards. Finally the program
converts regular geometry surfaces to energy modelling surfaces through the Honeybee extensions. Honeybee surfaces are geometry surfaces that have material properties attached to their XML file in order to create a more accurate simulation. The materials for our wall construction are based off our residential detail files and the year of construction. This information was previously attached to our geometries in the previous section and informs which LEED standard to assign a given building. In the case of refurbishment a special set of parameters are used.

![Image]

**Figure 2:** Cooling savings (left) (-MWh) and Heating demand (kWh) (right) for Collin County Neighborhood under IPCC climate A1b

2.6 Simulation

CitySimPro, a Graphical User Interface built on top of the CitySim Solver, handles energy simulations after the buildings have been modelled. In order to evaluate the effectiveness of refurbishment, energy consumption is looked at as a primary value. Energy consumption is measured in terms of heating and cooling values.

![Image]

**Figure 3:** Refurbishment schedule scenarios applied to a given neighborhood

To evaluate the effectiveness of refurbishment, three scenarios were selected. In Scenario 1 refurbishment occurs rapidly with 50 percent refurbishment by 2050 and 100 percent by 2100. In scenario two refurbishment occurs at a medium pace with 25 percent refurbishment at 2050, 50 percent at 2070 and 100 percent at 2100. Finally in Scenario 3 refurbishment occurs slowly with 25 percent refurbishment by 2050 and 50 percent refurbishment by 2100.
3. Results

In the simulation two outputs were analyzed, cooling demands and heating demands. These two outputs were used as a standard for comparison in understanding the risks in overheating and energy consumption as a result of climate change. Two scenarios were examined for each of the neighborhoods, a refurbishment scenario and a non-refurbishment scenario. Dallas showed considerably lower cooling and heating demands with future refurbishments. The results of the experiments show consistency between the expanded method and the original. Figure 4 shows Heating and Cooling levels based on different refurbishment scenarios (from which we derive percentage of building stock refurbished vs. percentage of cooling and heating demand reduced).

Figure 4: Cooling savings (-MWh) and Heating demand (kWh) for Dallas under A1b (Blue: Base Case, Red: Scenario 3, Yellow: Scenario 2, Green: Scenario 1)

In Figure 4 we see Dallas shows significant improvement in terms of heating and cooling. There is a clear change between full refurbishment and no refurbishment. The large-scale test of the Dallas area demonstrates this new methodology’s ability to handle large sets of data. The section of the Dallas metropolitan that was analyzed contains over 100,000 buildings.

The simulations focus on the IPCC A1b Climate scenario and the efficacy of the various refurbishment policies. Refurbishment proved effective both in terms of Heating and Cooling demands with more aggressive efforts resulting in sizable reductions in cooling demands. All Scenarios showed improvement by 2050 with Median Cooling values in Dallas dropping from the base case value of 265 MWh to 242 MWh in Scenarios 3 and 2, a nine percent decrease. Similarly
Dallas saw a drop from 265 MWh to 146 MWh, a 45 percent decrease. Our results show that the methodology is able to generate reasonable predictions. It demonstrates a significant decrease in computation allowing for more complex models to be examined. Looking at the results of the simulation itself, Scenario 1 showed the highest performance in terms of mitigation, while Scenario 3 showed the lowest. This is consistent with the previous Scenarios as Scenario 1 was the most aggressive approach to refurbishment while Scenario 3 demonstrates a slower approach.

4. Conclusion
Due to the large scale, this method must make concessions in terms of detail. While it is possible to achieve a more accurate estimate by taking into account variables such as enclosure composition, building systems and shading surfaces, it becomes difficult for larger simulations. Material properties are assigned to a template to process a larger number of buildings. This makes the simulation less representative of the actual building stock of the city as it only takes into account the age of the building. Occupancy and use types are heavily simplified in the model due to having varying levels of information for different neighborhoods. Another large limiting factor is processing power. A larger simulation was tested where a selection of 6000 buildings were selected from a neighborhood in the Dallas metropolitan area. The simulation required the use of the TACC supercomputer in order to run and still required anywhere from four to eight hours per simulation to compute. While the ability to run large scale simulations is useful, the scale greatly hampers the accessibility of the method. Finally, an extension used to create the Honeybee surfaces was shown to have difficulties running with more complex geometry involving a high frequency of angles. This problem can generally be avoided with geometry simplification tools, but there is a loss in detail of the building footprint. Additionally, some geometries are too complex to run and must be culled from the simulation resulting in a smaller available sample size to choose from. Overall, this is a more flexible methodology for analysis of refurbishment scenarios throughout decades. The results show consistency with previous studies in Dallas, where more aggressive refurbishment seemed to provide better accounts in terms of energy consumption.

5. References
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