THROWING SHADE: an analysis of tree shade and energy savings for urban residential homeowners in Baltimore

Final Paper

LEANDRO VIGNA

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WHAT IS THE PROBLEM?

Overview

Concerns about climate change, global warming and the ever-increasing natural catastrophes raised the awareness on the importance of reducing CO2 gas emissions, as it is the main contributor to climate change. Most of the attention in the pursue of this goal is focused on the generation side of the electricity, heavily relying on the replacement of fossil-fuel based (mostly coal) utilities for renewable sources el energy. Even thought this is a necessary step towards decarbonization, less attention is paid to CO2 reductions by savings in efficiency in the built environment.

Buildings are responsible for 32% of total global final energy use, 19% of all global GHG emissions, and approximately one-third of black carbon emission. In order to work towards the Paris agreement's goal of curbing planetary GHG emissions and keeping a temperature raise at well below 2°C, the building sector represents one of the most affordable and effective alternative to reduce emissions[1].

Given the pressing need for a better understanding and widespread action in the field of efficiency in the built environment, the goal of this paper is to explore the potential in operational energy savings from tree shade on buildings.

Tree Shade

When thinking about using trees as a means to save energy in buildings, there are four main reasons why the general public don't fully embrace the whole potential of this idea. Such reasons are mostly related to a lack of knowledge in the following fields:

Fig. 1 – Reasons behind poor tree shade uptake as an energy saving alternative

WHY IS IT IMPORTANT?

Trees bring associated a wide variety of economic, social, aesthetic, and environmental benefits. Focusing on the services that they provide in relation to the built environment, we can mention lower utility costs due to the shade provided by the trees (mostly during summer), and reduced air infiltration (which is a main source of heat loss in leaky buildings), they also serve as a shield against cold winds if planted correctly in the North side of a building; they improve the quality of the surrounding air, bringing along positive health benefits; and they can reduce the median temperature of cities through their evaporating cooling capacity, ameliorating the heat island effect (Fig. 2).

When trying to increase the uptake of tree planting for energy savings purposes, it is important to know all the benefits that they bring associated as those extra reasons may be the triggers that will bring other actors on board. Such extra reasons may include the positive impacts that trees have in communities, the aesthetics and increased property values they can generate, the strengthen of local ecosystems, the potential in water management in cities, etc.

Fig. 2 – Benefits from trees

WHAT ARE THE DESIRED OUTCOMES?

The intention of this paper is to increase the awareness of trees as an energy saving alternative in buildings, exploring the different researches conducted in the field and adding some extra literature by sharing the results of a self-conducted research with geospatial data in Baltimore.

PREVIOUS RESEARCH

Overview

There is a limited amount of research and academic papers that link energy savings in buildings with tree shade. Among these studies, there is a main distinction between simulation-based research and empiric studies. In the following section there is a brief summary with examples of these two types of studies, describing the methodology and main outcomes found by the different authors.

SIMULATION STUDIES

Simulation studies are among the first ones conducted on this topic, and they were the pioneers in the field, which with the increasing power of software and availability of geographic information systems data, evolved into studies containing real-world information.

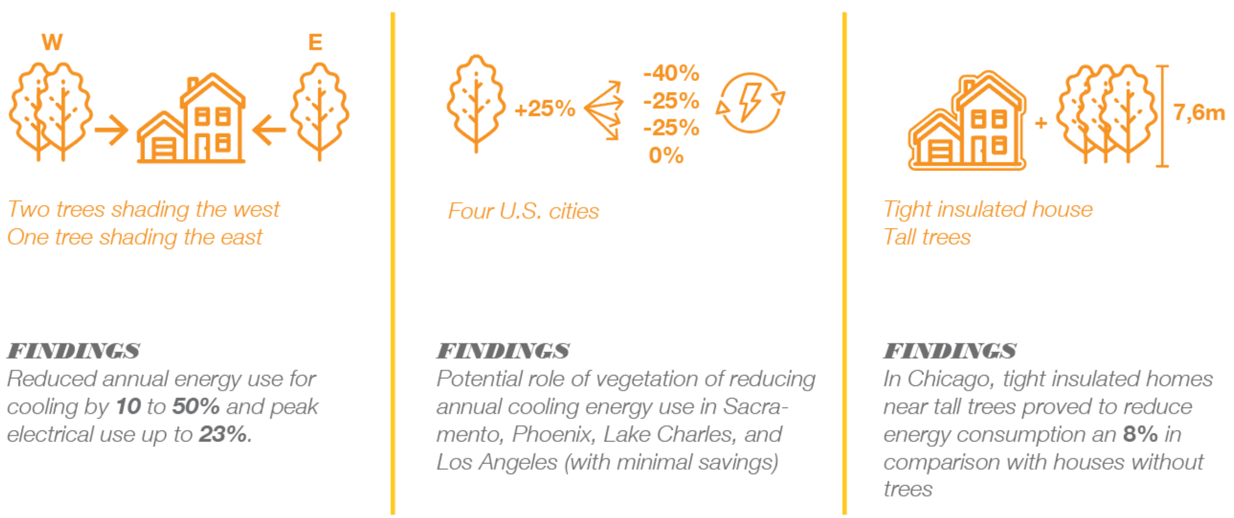


Fig. 3 – Simulation Studies – Main findings

The simulations created by Simpson and McPherson (1996)[2] demonstrated that a building receiving shade from two trees on the west and from one tree on the east can reduce the total energy consumption for cooling by 10-50% (annually) and the peak energy use by 23% (Fig. 3 - Left).

Huang et al. (1987)[3] studied the relation between vegetation increase and cooling energy usage reduction in residential buildings for Sacramento, Phoenix, Lake Charles and Los Angeles. They found that an 25% increase in tree cover reduces cooling energy demand by 40%, 25% and 25% respectively, with minimal impacts in Los Angeles (Fig. 3 – Center).

McPherson et al. (1997)[4] analyzed the role of trees around tightly-insulated new houses in Chicago and found out that buildings with trees demand 8% less energy in cooling and heating costs than those without them (Fig. 3 – Right).

EMPIRIC STUDIES

Empiric studies make use of the latest advances in geospatial software and are able to combine satellite images with highly accurate depictions of tree canopy cover, with map-based data on electricity consumption at the household level. Such crossings of information allow researchers to study the relationship between tree shade and energy use, both in summer and winter.

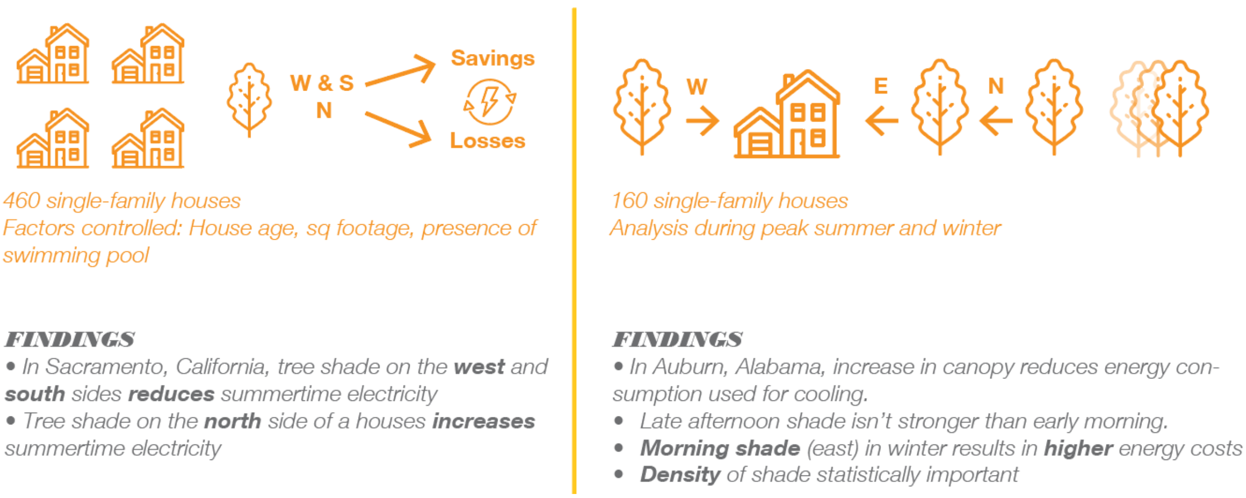


Fig. 4 – Empiric Studies – Main findings

Donovan and Butry (2009)[5] identified that the shade from trees on west and south faces of a house reduce their cooling demand during summer. In addition, they also estimated that shade from trees on the north side of a house increases summertime electricity demand. This research was conducted utilizing data from 460 single-family homes in Sacramento, California, considering parameters such as house age, square footage, and presence of a swimming pool, among others (Fig. 4 – Left).

Pandit and Laband (2010)[6] collected data from 160 single-family homes in Auburn, Alabama, and studied the energy demand of those houses during peak summer and winter, and contemplated the human behavior of their occupants, and the amount of shade casted by the trees on their buildings, as well as the density and timing of that shade. Their findings concluded that there is no relevant difference between the radiation coming from the west and east; that morning shade (blocking radiation coming from the east) in winter results in higher energy costs; and that the density of the shade casted by the trees is statistically important, highlighting the relevance of not only choosing deciduous vs non-deciduous trees, but also considering the type of shade that the trees can provide (Fig. 4 – Right).

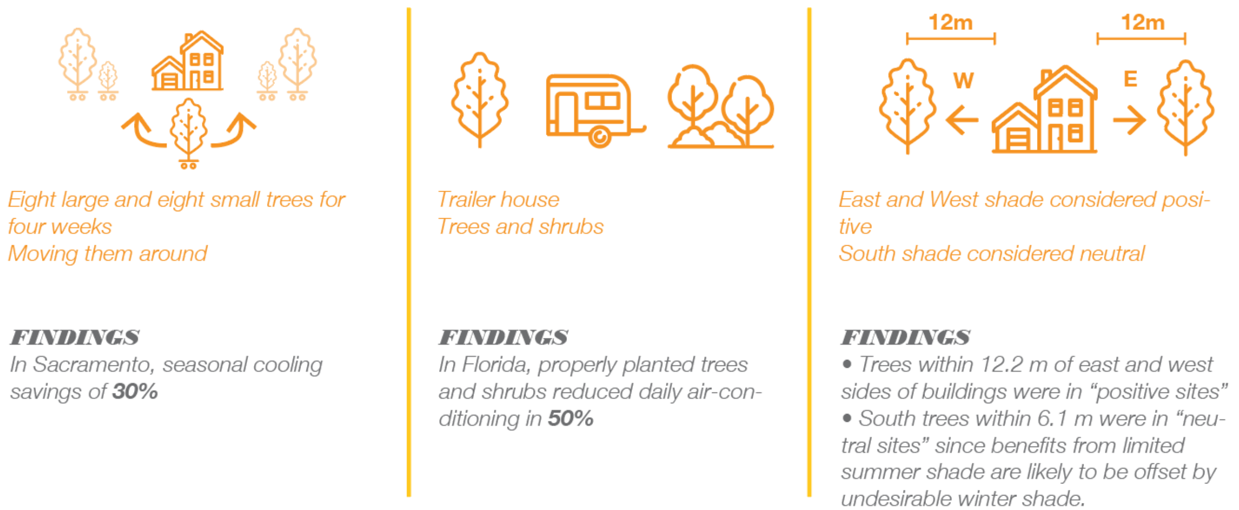


Fig. 5 – Empiric Studies – Main findings

Akbari et al. (1997)[7] studied the impact of tree shade in two homes in Sacramento, California. The experiment consisted in three steps. First, they measured the normal energy consumption of the two houses. Second, they located eight large and small trees in one of the sites, and third, they relocated those trees in the other house. Through this experimentation they found that tree shade can save up to 30% in cooling costs, and save about 0.7kW in peak electricity demand (Fig. 5 – Left).

In Florida, Parker (1981)[8] analyzed the effects that properly located trees and shrubs have in a mobile trailer, and concluded that they can reduce up to 50% of cooling costs in summer (Fig. 5 – Center).

Finally, McPherson and Simpson (2003)[9] studied the tree canopy cover data from aerial photographs and the energy consumption from buildings in California, concluding that tree shade in buildings has the most impact in energy savings for buildings in warm climates, and the least in cold ones. In addition, they estimated that the shade from west-oriented trees results in the greatest net energy benefit, and it is magnified in hot, arid climates. Another conclusion is that the net energy savings are reduced in coastal regions, as the fog reduces the irradiance of the sun. Trees located within 12.2 meters from a house are considered in positive spots, while south-oriented trees are deemed neutral (Fig. 5 – Right).

SUMMARY

Based on the literature review, the following list summarizes the main findings and aspects that influenced my case study and the selection of certain measures and assumptions:

- North orientated trees can prevent cold winds, resulting in energy savings for the winter if the trees are evergreens. However, if the trees are too close to the building, they may reduce the overall performance.
- West and East oriented trees provide the most benefits. One of the studies determined that in hot and arid areas, shade coming from west-oriented trees results in the most efficient net-energy alternative.
- South oriented trees provide no net energetic benefits (benefits from tree shade in summer are offset by greater heating costs in winter).
- Tree shading less efficient in more humid climates

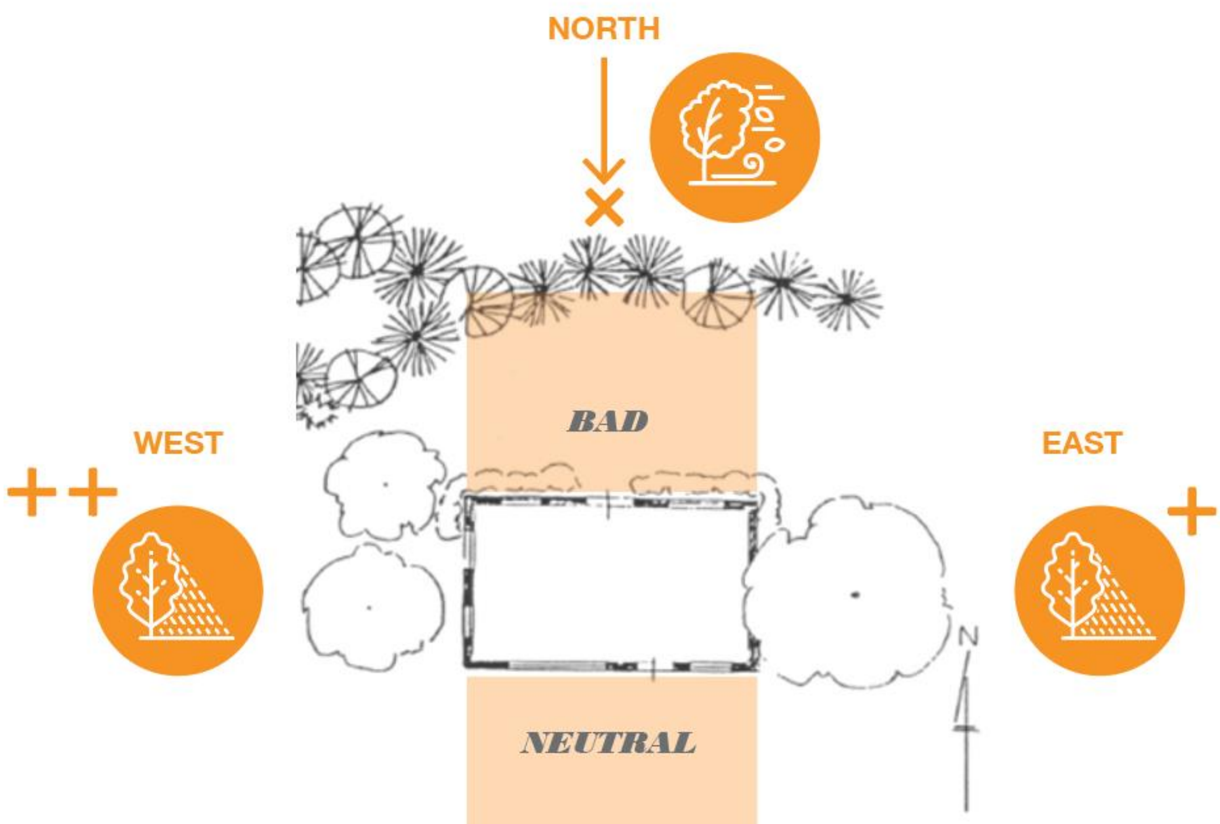
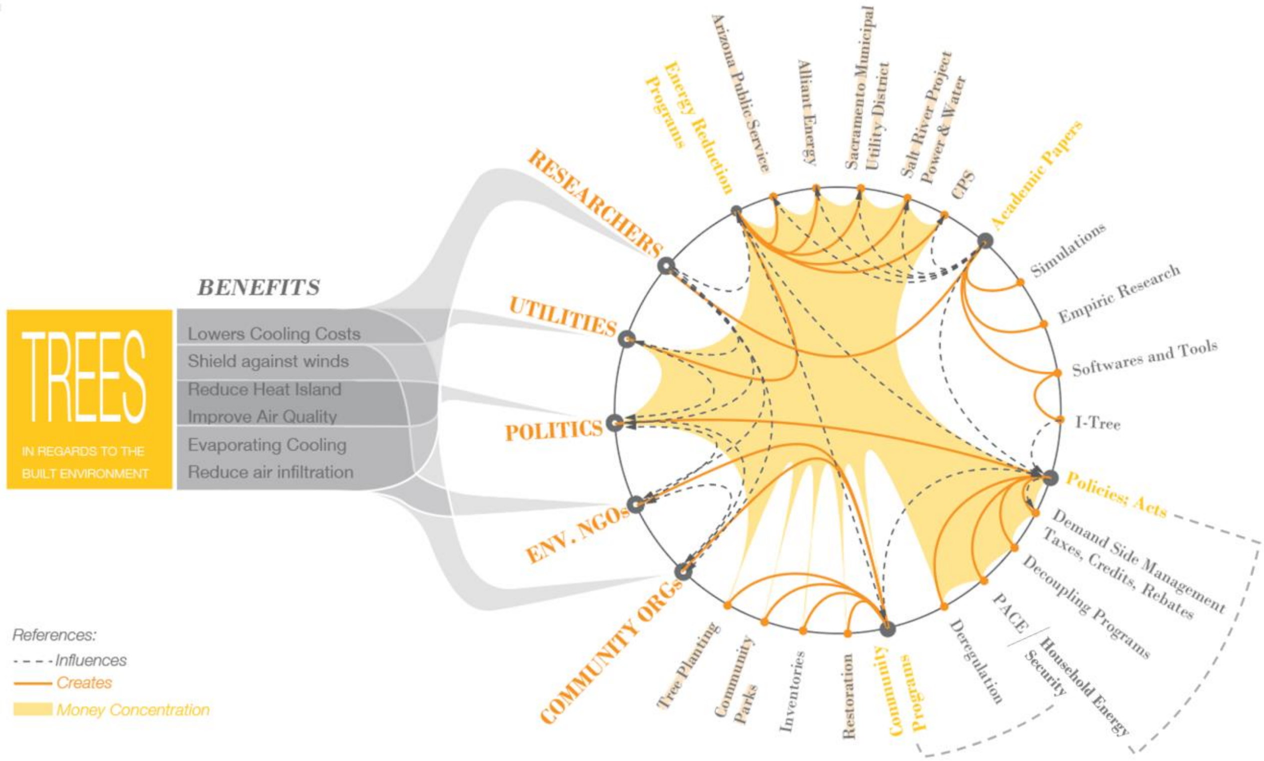


Fig. 6 – Summary of tree orientation and energy savings

PARSING - DIAGRAM



Narrative

This parsing was creating with the underlying intention that it should be useful for those trying to implement a tree planting program in any context, with the ultimate goal of providing savings in energy for buildings. Thus, it focuses on the main actors behind tree planting programs and research on trees and energy savings. These actors are linked between them and the products that they create depending on the network of influences and **self-interests** that each of them has. If trying to use this parsing to become more persuasive in a local context, the main takeaway is to go back and forth in the products and the creations, and find out what each actor is interested in, and who else shares the same interest, in order to leverage the power and tailor pitches according to the agendas of each actor.

Trees, as they relate to savings in energy and operational costs in buildings, provide six major benefits: Lowering cooling costs, shield against winds, reduce heat island effect, improve air quality, provide evaporating cooling, and reduce air infiltration. Each of these benefits are in the interests of different actors, with some overlaps and exclusions.

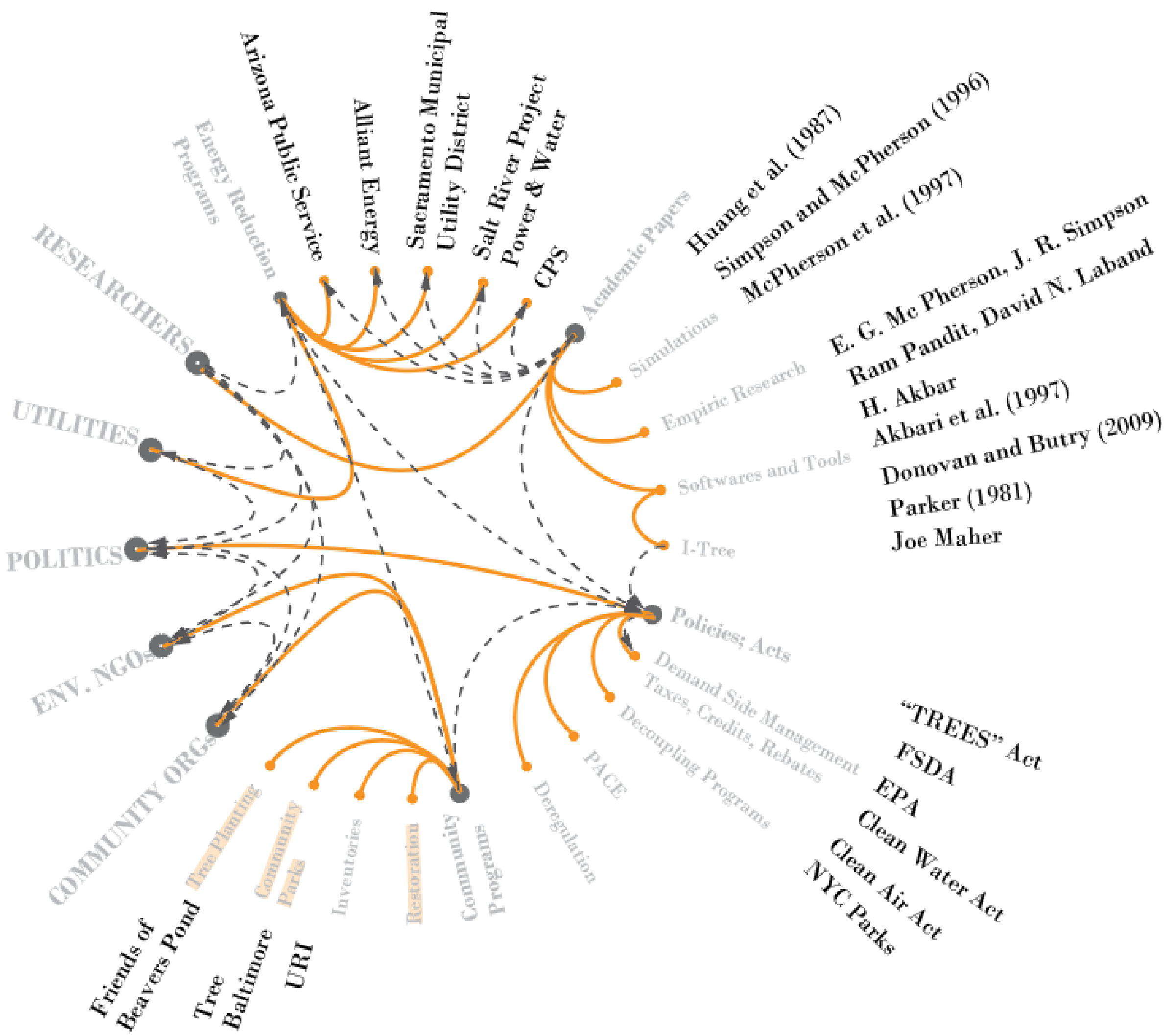
Once we know what each actor is interested in, we can see the network of influences (dashed gray line) that each actor exerts on the other ones. Researchers are the main influencers, as they come out with new findings in this topic that are in the interests of more actors. Politics, as expected, receive influence from all the other actors and are pushed to create programs related to tree planting and energy savings.

Each of the actors have their own specific creations (orange line) that may or may not come in response of the pressures and influences received. Researchers create academic papers that pushes the horizons of what we currently know in terms of energy savings and provide scientific reasons to pursue tree planting programs. These academic papers are divided into simulations and empiric studies, as well as the creation of software.

Certain utility companies create energy reduction programs that provide trees to consumers as a means to reduce their overall energy demand. NGOs and community groups create organizations and community programs that include tree planting initiatives, street trees inventories, community parks creations and/or restorations, etc. Politics and policy makers have a huge leverage in the promotion of tree planting and energy efficiency incentives, and thus they can create tax rebates, credits, decoupling programs, PACE, or simply deregulate certain aspects from outdated energy market.

Once we know the connections and creations of each actor, we can see in the yellow area the representation of money concentration, which gives an idea of what sectors have greater shares of money, and thus, power to create impact. Creations highlighted in orange represent specific programs that involve tree planting on the ground.

ORGANIZATIONAL NETWORK – DIAGRAM



Narrative

Based on the parsing, I included the different actors that are involved within the various creations I considered. Given that this paper is mostly concerned with an academic review and theoretical research, most of the actors included here are either authors of my literature review, organizations that they referred to, or tree planting NGOs that I came to know through the Urban Ecology class.

CASE STUDY DESCRIPTION

Main question

"Is there a correlation between ***ENERGY CONSUMPTION*** *and* ***BUILDINGS SHADED*** *by trees in Baltimore?"*

Methodology

For this real-world data analysis, I combined the geospatial information from Baltimore, Maryland, of three main layers (Fig. 7).

- **Energy consumption**: Provided at the group block level, using the electricity usage index or residential houses only, which is a measurement that compares average energy consumption per block with national averages, providing numbers that ranges above or below 100, which represents the national average.
- **Tree Canopy cover**: A complete map with the boundaries of every single tree in the city of Baltimore.
- **Buildings:** The footprints of every single building in the city of Baltimore.

These three layers were obtained from online open sources (trees and buildings), and the energy consumption corresponds to the year 2013 and was obtained from the Environmental Systems Research Institute (ESRI).

Fig. 7 – Baltimore maps – Three main layers

Fig. 8 – Snapshot of the three layers overlaid

Once I had the data, I needed to process every layer to adapt it to my specific interests for the research. In order to do so, I followed the steps detailed below:

Energy data provided at the Group Block level
- *Only* **residential** *average consumption*

Not all trees qualify for my study
- *Filter by* **size**
- *Incorporate* **tree shade**

Footprint of all buildings in Baltimore (more than 300,000)
- *Filter by* **residential type**
- *Filter by considering* **only the buildings** *that are touched by the* **tree shade**

1- **Tree filtering**: For the trees, I needed to adopt certain assumptions and criteria before utilizing the raw data. Thus, I first assumed that all the trees in my study were "Red Maples". This assumption came from "The Baltimore Tree Inventory" (Fig. 9. – Left) which has census data of trees in Baltimore, and clearly shows that the Red Maples is the most commonly planted tree in the city.
Considering Red Maples as the studied trees, I needed to filter only the conopy that was producing meaningful shade to the buildings. Based on research on mature Red Maples

measurements, I filtered those canopies/boundaries that had less than 6,2ft (1,9m) in diameter.

Once I had the trees filtered, I wanted to include the effects of their east and west shade. Since I was considering mature Red Maple trees with at least 6,2ft in diameter, the shade that these trees provide is at least of 39ft (12m) long. So, I offset their areas and extended their boundaries to accommodate this new shape.

2- **Building filtering**: I filtered the building footprints to only considered those that that are for residential use only. After this, I filtered the buildings once again to only consider those buildings that are being touched by the new boundary of tree canopy that I constructed in the step 1.

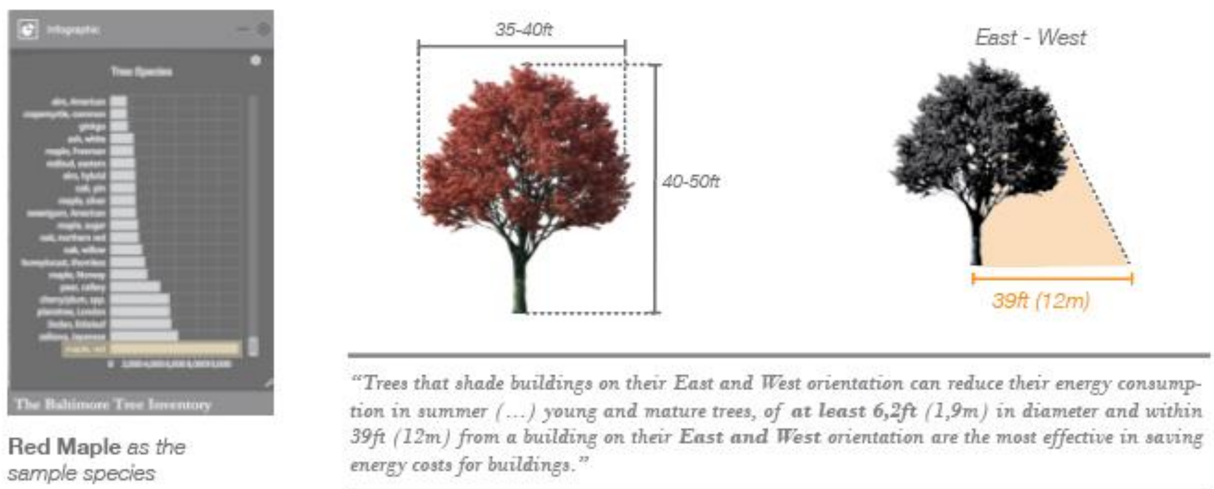


Fig. 9 – Baltimore Tree Inventory and measurements of a Red Maple

Calculations

Once I knew how many buildings were touched by tree shades, I wanted to cross this information with the electricity consumption of each block to see if there was any relation.

First, I calculated the percentage of buildings touched by trees per group block, and compared it with the electricity consumption index per group block. I did this by counting the amount of residential buildings touched by trees per group block, and dividing them by the total number of residential buildings per group block, and alter on comparing it with the electricity consumption of each block. The results of this comparison are shown in Fig. 10.

According to the resulting graph, the distribution of dots suggests that there is a greater concentration of buildings with a lower average consumption when the percentage of buildings shaded by trees increases.

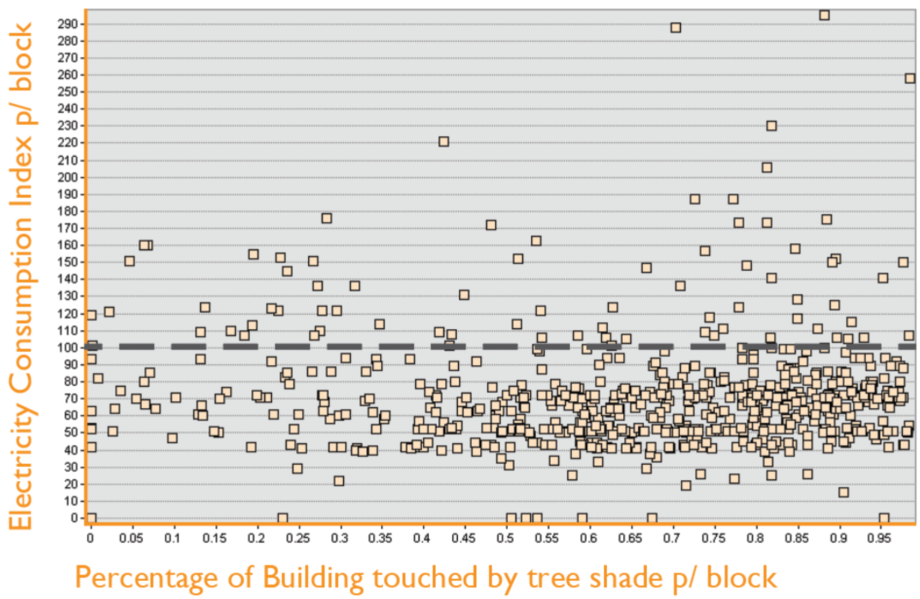


Fig. 10 – Electricity consumption vs buildings touched by trees

Second, I calculated the percentage of canopy cover per group block and compared it to the average energy consumption per group block. The idea of this analysis is to have it as a control study to contrast the previous comparison. The results can be seen in the Fig. 11.

By looking at the graph, it is counterintuitive to see that there is no positive correlation between a greater canopy cover and lower energy consumption, but rather the opposite. These results can also indicate that there is a very inequal distribution of trees within the blocks, meaning that despite having many trees in a block, many buildings do not get shaded by them.

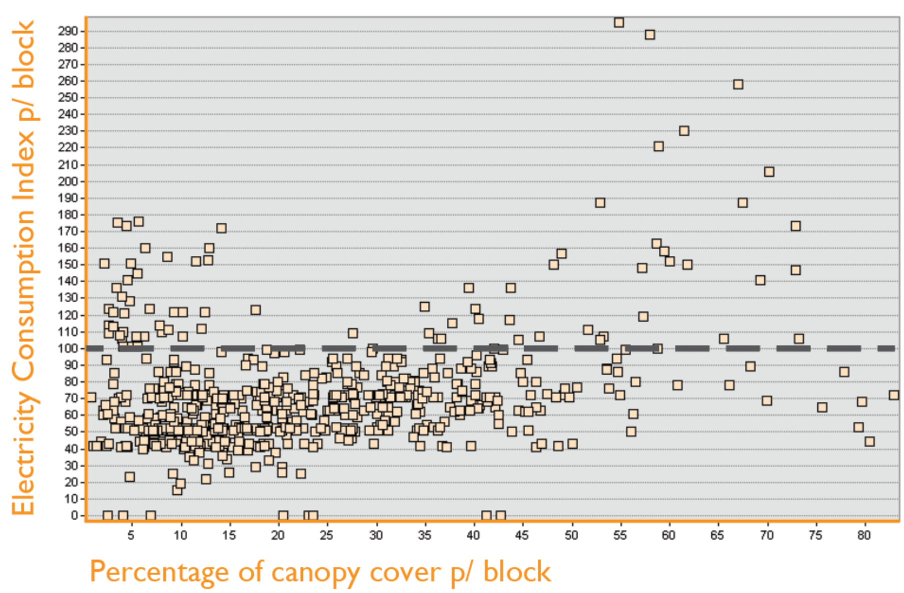


Fig. 11 – Electricity consumption vs canopy cover percentage

DIANGOSIS

CONCULSIONS

- Based on the results from my analysis, no direct conclusions on a positive relation between tree canopy and energy consumption can be drawn
- The graphs show a slight tendency of a greater share of buildings shaded by trees to consume less electricity
- Reductions in energy consumption from tree shade is very specific to the house level, and thus using energy measurements form the block level leave too many variables out of the scope.
- Empirical studies from literature review is very useful, though there's a lack of information on tree shade energy savings in more humid, semi-tropical and tropical climates.
- Empirical studies demonstrate the need for not only house-level energy information, but also the hourly distribution to better distinguish the effects from tree shade during the day.

DIANGOSIS

SHORTCOMINGS

- Even the empirical studies with house-level energy information failed to recognize the related effects in energy savings derived from the efficiency of the building construction.
- Empirical studies also fail to account for human behavior in buildings, which can count up to 50% of the efficiency from a home.
- Empirical studies from literature review is very useful, though there's a lack of information on tree shade energy savings in more humid, semi-tropical and tropical climates.

- Empirical studies demonstrate the need for not only house-level energy information, but also the hourly distribution to better distinguish the effects from tree shade during the day
- Co-benefits from trees are hard to monetarize, and they are very local and context dependent.

DIANGOSIS

RECOMMENDATIONS

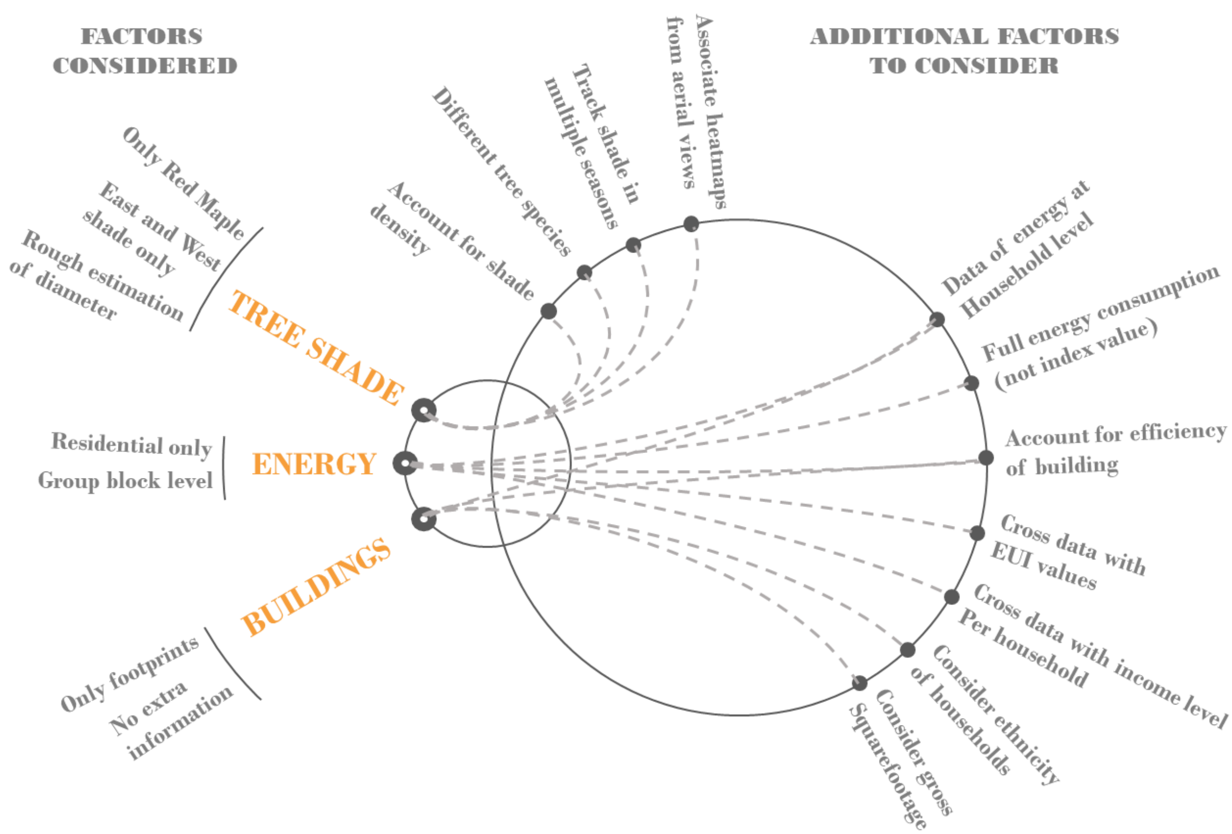


Fig. 12 – Parsing on factors considered and additional factors for future research

- It is very important to make home owners and builders aware of the monetary savings in electricity consumption that they can incur by having well located buildings - Preserving existing trees, and promoting the plantation of new ones.

- Future studies on savings in energy through tree shade should consider the efficiency of the buildings. One good way of taking this into account could be by accessing data from the EnergyStar Portfolio and indexing the Energy Unit Intensity (EUI) to have a better idea of how the savings in energy from tree shade affect those buildings differently.
- Future studies should also focus on humid climates, where savings from tree shade might be reduced, but nonetheless trees can provide several other performance benefits to the built environment (Fig. 12).
- It would be interesting to overlay the income levels of each block group and the majoritarian ethnicities to see if there is a correlation between these two factors and the percentage of buildings shaded by trees, plus the energy consumption levels. Aka., it would be worth exploring evidence about vulnerable populations having less access to tree shade in their homes (Fig. 12).

REFERENCES

BIBLIOGRAPHY

1. IPCC, *IPCC Fourth Assessment Report: Climate Change 2007*, in *4.3 Mitigation options*. 2007.
2. Simpson, J.R. and E.G. McPherson, *Simulation of tree shade impacts on residential energy use for space conditioning in Sacramento.* Atmospheric Environment, 1998. **32**(1): p. 69-74.
3. Akbari, H., et al., *Cooling our communities: A guidebook on tree planting and light-colored surfacing*. 1992.
4. Mcpherson, E.G., et al., *Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project.* Urban Ecosystems. **1**(49-61).
5. Donovan, G. and D. Butry, *The value of shade: Estimating the effect of urban trees on summertime electricity use*. Vol. 41. 2009. 662-668.
6. Pandit, R. and D. Laband, *Energy savings from tree shade*. Vol. 69. 2010. 1324-1329.
7. Akbari, H., et al., *Peak power and cooling energy savings of shade trees.* Energy and Buildings, 1997. **25**(2): p. 139-148.

8. Parker, J.H., *Use of Landscaping for Energy Conservation.* Department of Physical Sciences, 1981(Florida International University).

9. McPherson, E.G. and J.R. Simpson, *Potential energy savings in buildings by an urban tree planting programme in California.* Urban Forestry & Urban Greening, 2003. **2**(2): p. 73-86.