The Impact of Tree Shade on Residential Electricity Consumption in Auburn, Alabama

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Introduction

- Trees affect the well-being of humans in a variety of ways:
  - Source of energy for heating/cooking
  - Building material (houses, fences, furniture, etc.)
  - Aesthetics
  - Food source
  - Habitat for wild animals that humans value
  - Forage for domesticated animals
  - Medicines
  - **Provide shade that lowers temperature**
Energy consumption

- Hot (summer) conditions -- tree shade has offsetting effects:
  - lowers ambient temperatures, reducing energy used for cooling -- trees as natural air conditioning systems
  - reduces the amount of light reaching a building, increasing energy used for lighting.
Energy consumption

Southeastern U.S. : long, **HOT** summers
**Not much wind**

Houses (pre-air conditioning):

Multi-level - - kitchen below, bedrooms upper
Built on rises and hilltops
Windows at cross-angles

*Large shade trees all around the house*
Introduction

• Common sense tells us that tree shade keeps us cooler in the summer and thus lowers utility bills. But by how much?

• When you cut those mature trees near your house so the next hurricane (cyclone) does not blow them on your roof, what will this cost you in terms of higher electric bills?

• There is little scientific guidance — mostly simulation work, almost no hard estimates using real data from households.
Should residential real estate developers cut down all the trees before planting houses?

Depends in part on how valuable the trees are to prospective home buyers.

Clear cut areas for housing development

House under construction
Methods and Data

Hedonic Analysis

• Statistical (multivariate regression) estimation of the impact of different factors on monthly electricity consumption

• Size of family, gender, age distribution, loads of laundry per week, square footage of dwelling, age of dwelling, exterior construction material, swimming pool, multiple freezers, cook/heat with electricity versus natural gas, thermostat setting in summer (winter), *shade conditions*
Methods and Data

• Letters explaining purpose and soliciting study participants distributed randomly to 2,000 Auburn residences in June 2007.

• Participants would provide information about electricity usage monthly for 12 months

• Participants would complete initial survey, providing information about family size, dwelling, etc.

• 160 residential households in Auburn, AL (8% response)
Information collected – dependent variable

**Kilowatt hours of electricity** used during the billing cycle

Period of the billing cycle

Permits us to calculate kwh / day usage
Information collected – explanatory variables

**Dwelling information**

- Living area (square feet)
- Age of structure
- # of levels
- Cooking – electric vs natural gas
- Heating – electric vs natural gas
- Water heater – electric vs natural gas
- Additional freezer
- Swimming pool
Information collected – explanatory variables

Family information

- # females
- # males
- <= 18 years
- 19 – 25 years
- 26 – 60 years
- > 60 years
- # loads of laundry per week
- Daytime thermostat setting – winter/summer
- Nighttime thermostat setting – winter/summer
Information collected – explanatory variables

**Exogenous factors**

- Average daily high temperature – monthly
- Average daily temperature – monthly
  Used to calculate difference between thermostat setting and actual temperature (intensity of cooling effort)
- Average atmospheric humidity – monthly
- Data from Auburn National Weather Service station
Information collected – explanatory variables

Shade conditions

• % shade: mid-a.m., early p.m., late p.m. 0, 1-10%, 11-20%, 21-30, etc.

• Shade intensity: light, moderate, heavy

• Field data collected once per month, mid-month
Sample houses

House with no shade

House with shade
Shade conditions

Late a. m. shade

Early p.m. shade
Sample houses (contd.)

Shading either on morning or evening

Shading through out the day
Seasonality on shade conditions

Summer

Winter
Temperature variations and seasonal electricity usage

Electricity usage and temperature variations for summer months 2007/08

Electricity usage and temperature variations for winter months 2007/08
Temperature variations and seasonal electricity usage 2
## Sample statistics - households

<table>
<thead>
<tr>
<th>Feature</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living area (ft sq)</td>
<td>2,691.47</td>
<td>858.97</td>
<td>1,170</td>
<td>6,100</td>
</tr>
<tr>
<td>(m sq)</td>
<td>250.05</td>
<td>79.80</td>
<td>108.7</td>
<td>566.71</td>
</tr>
<tr>
<td>Age</td>
<td>14.34</td>
<td>12.49</td>
<td>1</td>
<td>57</td>
</tr>
<tr>
<td># floors</td>
<td>1.53</td>
<td>0.51</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Elec. Cooking</td>
<td>Yes</td>
<td>No</td>
<td>129</td>
<td>31</td>
</tr>
<tr>
<td>Elec. Heating</td>
<td>Yes</td>
<td>No</td>
<td>107</td>
<td>53</td>
</tr>
<tr>
<td>Elec. H2O heater</td>
<td>Yes</td>
<td>No</td>
<td>84</td>
<td>76</td>
</tr>
<tr>
<td>Additional freezer</td>
<td>Yes</td>
<td>No</td>
<td>83</td>
<td>77</td>
</tr>
<tr>
<td>Swimming pool</td>
<td>Yes</td>
<td>No</td>
<td>12</td>
<td>148</td>
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</table>
## Sample statistics – summer

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min.</th>
<th>Max.</th>
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</thead>
<tbody>
<tr>
<td>Kwh/day</td>
<td>73.71</td>
<td>29.67</td>
<td>17.53</td>
<td>192.97</td>
</tr>
<tr>
<td>Inside temp – day (s)</td>
<td>76.31(24.62)</td>
<td>2.75</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>Inside temp – night (s)</td>
<td>75.64(24.24)</td>
<td>3.17</td>
<td>65</td>
<td>85</td>
</tr>
<tr>
<td>Outside high temp (s)</td>
<td>92.73(33.74)</td>
<td>1.88</td>
<td>88.16</td>
<td>96.21</td>
</tr>
<tr>
<td>Outside mean temp (s)</td>
<td>82.48(28.04)</td>
<td>1.33</td>
<td>79.19</td>
<td>84.94</td>
</tr>
<tr>
<td>Outside min temp (s)</td>
<td>72.35(22.42)</td>
<td>0.53</td>
<td>70.94</td>
<td>73.23</td>
</tr>
<tr>
<td>Average humidity (%)</td>
<td>66.87</td>
<td>4.50</td>
<td>61.14</td>
<td>73.00</td>
</tr>
<tr>
<td>Daytime temp diff (mean)</td>
<td>6.17(10.28)</td>
<td>3.00</td>
<td>-3.59</td>
<td>14.86</td>
</tr>
<tr>
<td>Nighttime temp diff (mean)</td>
<td>6.84(11.40)</td>
<td>3.41</td>
<td>-2.81</td>
<td>18.43</td>
</tr>
</tbody>
</table>
### Shade conditions - summer

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>S.D.</th>
<th>Min</th>
<th>Max</th>
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</thead>
<tbody>
<tr>
<td>Percentage of house area under tree shade</td>
<td>17.45</td>
<td>19.45</td>
<td>0.00</td>
<td>88.00</td>
</tr>
<tr>
<td>Late a.m. (9-11 a.m.) percent house area under tree shade</td>
<td>20.94</td>
<td>25.32</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Early p.m. (12-2 p.m.) percent house area under tree shade</td>
<td>10.25</td>
<td>14.93</td>
<td>0.00</td>
<td>90.00</td>
</tr>
<tr>
<td>Late p.m. (3-5 p.m.) percent house area under tree shade</td>
<td>29.82</td>
<td>31.19</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Variable</td>
<td>Coefficient</td>
<td>Standard Error</td>
<td>t-value</td>
<td>Significance</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------</td>
<td>----------------</td>
<td>---------</td>
<td>--------------</td>
</tr>
<tr>
<td>Intercept</td>
<td>17.780</td>
<td>8.070</td>
<td>2.20**</td>
<td></td>
</tr>
<tr>
<td>Family size</td>
<td>3.369</td>
<td>0.468</td>
<td>7.20***</td>
<td></td>
</tr>
<tr>
<td>Living area</td>
<td>0.013</td>
<td>0.001</td>
<td>20.17***</td>
<td></td>
</tr>
<tr>
<td>House age</td>
<td>0.112</td>
<td>0.046</td>
<td>2.45***</td>
<td></td>
</tr>
<tr>
<td># floors</td>
<td>1.950</td>
<td>1.051</td>
<td>1.86*</td>
<td></td>
</tr>
<tr>
<td>Elec. Cooking</td>
<td>-1.472</td>
<td>1.265</td>
<td>-1.164</td>
<td></td>
</tr>
<tr>
<td>Elec. H2O Heat</td>
<td>4.473</td>
<td>0.965</td>
<td>4.64***</td>
<td></td>
</tr>
<tr>
<td>Window AC</td>
<td>4.436</td>
<td>2.688</td>
<td>1.65*</td>
<td></td>
</tr>
<tr>
<td>Laundry loads/wk</td>
<td>1.078</td>
<td>0.166</td>
<td>6.481***</td>
<td></td>
</tr>
<tr>
<td>2nd Freezer</td>
<td>2.418</td>
<td>0.946</td>
<td>2.56**</td>
<td></td>
</tr>
<tr>
<td>Swimming pool</td>
<td>21.035</td>
<td>1.733</td>
<td>12.14***</td>
<td></td>
</tr>
<tr>
<td>Average humidity</td>
<td>-0.243</td>
<td>0.110</td>
<td>-2.22**</td>
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<tr>
<td>Daytime temp. diff. (mean)</td>
<td>2.396</td>
<td>0.077</td>
<td>30.97***</td>
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<tr>
<td>Percent shade</td>
<td>-0.158</td>
<td>0.029</td>
<td>-5.39***</td>
<td></td>
</tr>
</tbody>
</table>

R-sq = .6054

F-statistic: 178.6
We have hair!

<table>
<thead>
<tr>
<th>Feature</th>
<th>Intercept</th>
<th>Females</th>
<th>Males</th>
<th>Living area</th>
<th>House age</th>
<th># floors</th>
<th>Elec. Cooking</th>
<th>Elec. H2O Heat</th>
<th>Window AC</th>
<th>Laundry loads/wk</th>
<th>2\textsuperscript{nd} Freezer</th>
<th>Swimming pool</th>
<th>Average humidity</th>
<th>Daytime temp. diff. (mean)</th>
<th>Percent shade</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>16.574</td>
<td>5.159</td>
<td>2.398</td>
<td>0.013</td>
<td>0.117</td>
<td>2.214</td>
<td>-1.711</td>
<td>4.488</td>
<td>4.588</td>
<td>1.087</td>
<td>2.754</td>
<td>20.873</td>
<td>-0.250</td>
<td>2.388</td>
<td>-0.161</td>
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<tr>
<td></td>
<td>8.052</td>
<td>0.775</td>
<td>0.600</td>
<td>0.001</td>
<td>0.046</td>
<td>1.049</td>
<td>1.262</td>
<td>0.962</td>
<td>2.678</td>
<td>0.166</td>
<td>0.947</td>
<td>1.730</td>
<td>0.109</td>
<td>0.077</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td>2.06**</td>
<td>6.66***</td>
<td>4.00***</td>
<td>20.32***</td>
<td>2.56***</td>
<td>2.11**</td>
<td>-1.36</td>
<td>4.67***</td>
<td>1.71*</td>
<td>6.54***</td>
<td>2.91***</td>
<td>12.06***</td>
<td>-2.28**</td>
<td>30.95***</td>
<td>-5.51***</td>
</tr>
</tbody>
</table>
By age of family members

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Count</th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 and under</td>
<td>4.017</td>
<td>0.607</td>
<td>6.62***</td>
</tr>
<tr>
<td>13 – 24</td>
<td>0.720</td>
<td>1.064</td>
<td>0.68</td>
</tr>
<tr>
<td>25 – 60</td>
<td>1.730</td>
<td>1.144</td>
<td>1.51</td>
</tr>
<tr>
<td>Over 60</td>
<td>0.764</td>
<td>1.184</td>
<td>0.65</td>
</tr>
</tbody>
</table>
## By shade characteristics

<table>
<thead>
<tr>
<th>Shade Characteristic</th>
<th>Percent Shade</th>
<th>Density – Heavy</th>
<th>Density – Moderate</th>
<th>Density – Light</th>
<th>Late a.m. shade %</th>
<th>Early p.m. shade %</th>
<th>Late p.m. shade %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.158***</td>
<td>-9.416**</td>
<td>-0.610</td>
<td>-0.002</td>
<td>-7.84E-03</td>
<td>2.76E-02</td>
<td>-1.38E-01***</td>
</tr>
<tr>
<td></td>
<td>(0.029)</td>
<td>(1.331)</td>
<td>(1.269)</td>
<td>(1.406)</td>
<td>(2.80E-02)</td>
<td>(4.73E-02)</td>
<td>(2.17E-02)</td>
</tr>
<tr>
<td></td>
<td>-0.081***</td>
<td>-7.334***</td>
<td>0.630</td>
<td>0.950</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.036)</td>
<td>(1.620)</td>
<td>(1.432)</td>
<td>(1.444)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Spending on electric power

Alabama Power Co. rate - - $0.1152/kwh
Tallapoosa Electric rate - - $0.1229/kwh

Average household in our sample used 73.71 kwh per day in the summer (May-September)

$259.84/month at AL Power rate
$277.20/month at Tallapoosa Electric rate
Mean daily usage 0.00% shade: 76.47 kwh/day
Mean daily usage 17.45% shade: 73.71 kwh/day

Estimated Kwh reduction at ‘typical’ residence:

$$17.45 \times -0.158 = -2.757 \text{kwh/day} (-3.6\%)$$

savings on AL Power bill - - $9.73/mo.
savings on Tallapoosa Electric bill - - $10.37/mo.
More shady savings

Mean daily usage 0.00% shade: 76.47 kwh/day
Mean shade coverage: 50.00 percent
Estimated impact of shade: -.158 per shade percent

Estimated Kwh reduction at residence with 50 percent shade:

\[50.00 \times -0.158 = -7.9 \text{ kwh/day} \quad (-10.3\%)

savings on AL Power bill - - $27.85/mo.
savings on Tallapoosa Electric bill - - $29.71/mo.
Even shadier savings

Not all shade is created equal, *dense* shade is better than light shade

Mean daily usage 0.00% shade: 76.47 kwh/day
Mean shade coverage: 17.45 percent
Estimated impact of shade: -.081 per shade percent
Additional impact of having *dense* shade: -7.334 kwh/day

Estimated Kwh reduction at ‘typical’ residence with *dense* shade:

\[
17.45 \times -0.081 = -1.413 \text{ kwh/day} + -7.334 \text{ kwh/day} = -8.747 \text{ kwh/day} (-11.4\%)
\]

savings on AL Power bill - - $30.83/mo.
savings on Tallapoosa Electric bill - - $32.90/mo.
Mean daily usage 0.00% shade: 76.47 kwh/day
Mean shade coverage – late p.m.: 29.82 percent
Estimated impact of shade: -.138 per shade percent

Estimated Kwh reduction at ‘typical’ residence w/ late p.m. shade

29.82 x -0.138 = -4.115 kwh/day (-5.4%)

savings on AL Power bill - - $14.50/mo.
savings on Tallapoosa Electric bill - - $15.48/mo.
More shady savings

Mean daily usage 0.00% shade: 76.47 kwh/day
Mean shade coverage: 50.00 percent
Estimated impact of shade: -.158 per shade percent

Estimated Kwh reduction at residence with 50 percent shade:

\[ 50.00 \times -0.158 = -7.9 \text{ kwh/day} \quad (-10.3\%) \]

savings on AL Power bill - - $27.85/mo.
savings on Tallapoosa Electric bill - - $29.71/mo.
shady savings and thermostat setting

Mean daily usage 17.45% shade: 73.71 kWh/day
Daytime temp diff (mean) 6.17
Inside temp – day (s) 76.31

Daytime temp. diff. - - regression coefficient 2.396

Estimated savings by raising thermostat ONE degree at ‘typical’ residence:

2.396 kWh/day (-3.3%)

savings on AL Power bill - - $8.45/mo.
savings on Tallapoosa Electric bill - - $9.01/mo.
Acknowledgements

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