

Can We Predict Residential Energy Usage with IRS Data?

A Study On 2010 Electric and Gas Usage Across Chicago Zip Codes

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Introduction

Motivation and Goals

Residential energy usage prediction is a complex and highly studied challenge. We do not seek to outperform current methods, rather to present and evaluate a novel method of predicting residential (household) energy usage: using self reported characteristics from the taxpayers within! As energy abatement and efficiency becomes increasingly critical due to climate change, we seek to present taxpayer data as a (potentially) relevant tool policymakers can use for determining residential energy policy. Thus, our goals are:

- *Effectively* model residential energy usage using IRS data.
- Analyze effectiveness of IRS data within our model, and to determine what overall taxpayer qualities, in particular **Residential Energy Credits**, correspond with real energy usage and reduction.

Background

Every April 15, millions of Americans submit their US Individual Income Tax Return Form 1040 [Reference Docs > Fig A] to the Internal Revenue Service (IRS). This is an important administrative and even cultural event within the country, and is also a significant source of demographic and personal finance information. Many taxpayers further include Form 5695, ‘Residential Energy Credits’ [Reference Docs > Fig B]. These tax credits were added to the Internal Revenue Code in 2005 by the Energy Policy Act of 2005 with the goal of rewarding taxpayers for their efforts towards energy efficiency. Therefore a secondary goal of our project is to *contextualize the role of household energy credits* in residential energy prediction using IRS data and to create some framework for further study on the real effect of energy tax credits on abatement.

Methods

Data

Our master data file is contained within our repo in ‘./working_data/chicago_all.csv’. There are 111 rows of 155 variables for 56 unique zip codes.

Our energy usage data which comprises the first 23 variables of `chicago_all` is from “https://data.cityofchicago.org/Environment-Sustainable-Development/Energy-Usage-2010/8yq3-m6wp/about_data”. That data is here: ‘./working_data/prework/final_updated_energy_usage_with_coordinates.csv’, where we have added a `zip` variable along with `Latitude` and `Longitude` variables with python using the ‘uszipcode’ library in python. This novel and detailed data set contains energy usage information from primary providers on commercial and residential housing totals by housing subtype = `single_family`, <7,

and 7+ (multifamily). According to the source, the electricity data (KWH) comprises 68 percent of overall electrical usage in the city while gas data comprises 81 percent of all gas consumption (Therms).

Our IRS 1040 data, beginning with the **STATE** variable, is from “<https://www.irs.gov/statistics/soi-tax-stats-individual-income-tax-statistics-zip-code-data-soi>”. We downloaded the zip data file from 2009. That data is here: ‘./working_data/prework/09zpallagi_stdz.csv’ with minor cleaning performed in python. This data set contains line item totals by zip code and AGI_STUB (class of 1:6 based on Adjusted Gross Income (AGI) levels) as well as line items with zip code return totals and amount totals (in the thousands of dollars, when relevant) for relevant line items from IRS Form 1040 and attached forms. The data set contains data from both IRS 1040 and 1040 EZ returns, when applicable. For documentation information for TY2009 see ‘./artifacts/documentation/09zpdoc’.

To recreate our master data file, please pull our github repository and run ‘./code/data_wrangling.Rmd’. After aggregating each data set by zip code, we create our target variables **THERMS.PER.SQFT** and **KWH.PER.SQFT**. Therms are a measure of natural gas where 1 Therm is equal to 100sqft of natural gas. It is a rather large unit. Kilowatt-hours per square feet is a standard measure of electricity and is smaller, relatively. We standardize each of these using the Chicago data set’s **THERMS.TOTAL.SQFT** and **KWH.TOTAL.SQFT**, which is the square footage associated with the electric and gas energy usage, respectively, in 2010 according to Cook County Assessor Records. We believe this is an accurate measure of how much energy residents of a zip code are using, on average. We further performing averages on the IRS data by weighing each count and amount variables

Approach

Our training and modeling code is all contained in ‘./code/model_prediction.Rmd’. First, we add a partitioned data frame, **chicago_only**, which only contains variables sourced from the Chicago energy data set (https://data.cityofchicago.org/Environment-Sustainable-Development/Energy-Usage-2010/8yq3-m6wp/about_data). We’ll use this feature matrix as a benchmark to determine whether the IRS variables in **chicago_all** are adding any predictive power. Next we filter **chicago_all** and **chicago_only** to only include **BUILDING_SUBTYPE == “All”**, reducing our number of rows to 56. We divide the resulting data frames into training and testing data sets using a 70/30 split, and run a slate of machine learning algorithms (Random Forest, Gradient Boosted Decision Tree (GBDT), and XGBoost) along with a baseline linear model and report using standard performance metrics RMSE (root mean squared error) and MPE (mean percentage error). We then use GBM summary function and XGBoost ‘Gain’ metrics to determine which variables are “important”. Here, we expect variables from the Chicago energy data set to be relevant, but are more interested in the novel information we can gain from the IRS data including residential energy credits.

Output visualizations and tables are included in Results and Appendix. All code to generate map visualizations is constructed using script: ‘./code/chi_energy_agi_2_legends.R’.

Results

Table 1 [Below]

Model	therm_all_rmse	therm_only_rmse	therm_all_mpe	therm_only_mpe
Linear	0.458	0.063	32.356	3.120
Random Forest	0.074	0.069	1.079	0.209
Gradient Boosting Tree	0.068	0.056	1.159	2.036
XGBoost	0.058	0.070	0.572	0.747

Table2 [Below]

Model	kwh_all_rmse	kwh_only_rmse	kwh_all_mpe	kwh_only_mpe
Linear	9.222	2.819	-1.846	4.405
Random Forest	2.985	2.975	4.479	3.153
Gradient Boosting Tree	2.885	3.000	4.222	4.800
XGBoost	2.964	3.096	1.209	2.991

Residual plot analysis:

Fig1A [Below]:

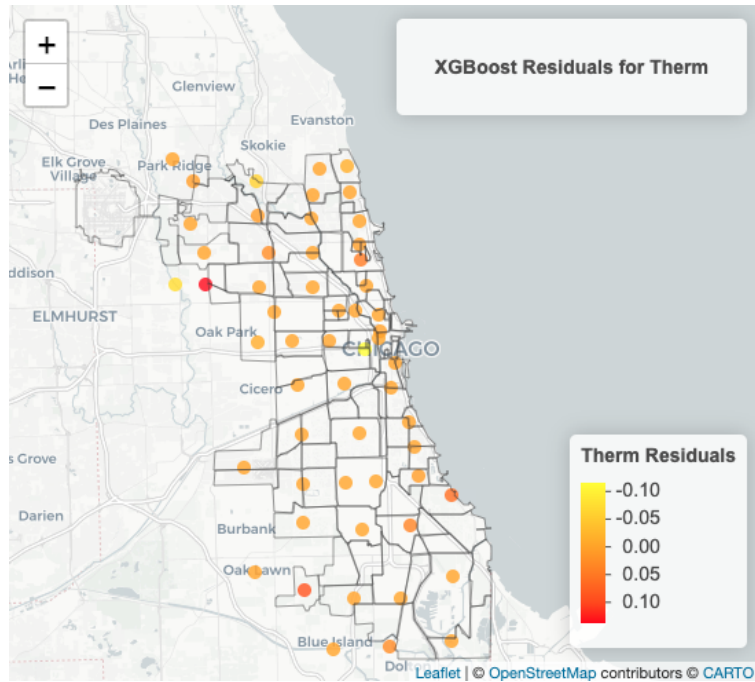
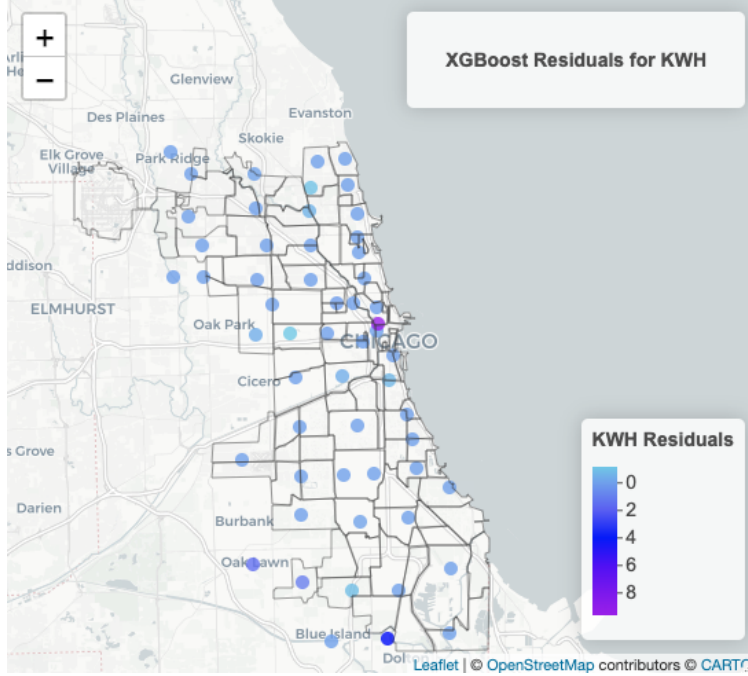


Fig1B [Below]:



Analysis

First we look at the metrics for therms [Table 1] . We fitted our models to only the Chicago energy consumption data (therm_only) and to the data set including IRS data (therm_all). We first compare between these two data sets to see whether the IRS data have significant predictive power on real gas consumption (therms/sqft). We see that, except for the baseline model, RMSE for therm_all is similar in magnitude to RMSE for therm_only. Except the XGBoost model, therm_all has larger RMSE value which we believe is due to over fitting. For the MPE metric, both GBDT and XGBoost perform better for therm_all. But considering the much larger amount of features, we are not sure whether the IRS patterns truly make effect.

Next, lets analyze the metrics for KWH [Table 2]. Except for the baseline model, the RMSE for kwh_all is similar in magnitude to RMSE for kwh_only, and the MPE of GBDT and XGBoost model are weakly better for kwh_all. Considering the larger amount of fitted variables, we are not sure whether the IRS data truly adds predictive power.

Overall the XGBoost model gives us the best prediction for both therm data and KWH data. Fig 1A, 1B [above] shows XGBoost residuals across Chicago zip codes. For context, standard deviations for each metric are 1.620 KWH/sqft and 0.172 therms/sqft. Average absolute values of XGBoost residuals are 0.386 KWH/sqft and .013 therms/sqft. Thus, predictions are quite good for both energy types, and are notably good for therms. For both therms and KWH there are notable outliers in suburb areas, where residential energy usage appears to be mostly underestimated. For KWH only, there is a notable outlier with a residual of ~8KWH in the center of downtown. We believe this must be a data collection error, where electricity usage for large high-rises are being conflated with residential energy usage. Due to our small sample size of 56 as well as the variability of train/test split, this outlier is very harmful to our modeling efforts.

Below [Reference Tables > table B and table C], we list the top 15 most important features from XGBoost and GBDT model for therm and KHW. We first focus on the features which both appear in both the XGBoost and GBDT models. For therms, AVERAGE.HOUSESIZE, AVERAGE.STORIES, Latitude, Longitude - the Chicago features, and A11902_av and N01000_av - the IRS features, all appear twice. For KWH, AVERAGE.STORIES, RATIO.OWNED, AVERAGE.BUILDING.AGE, AVERAGE.HOUSESZIE, Latitude, Longitude - the Chicago features, and A07100_av, N00900_av, N01700_av and A01700_av - the IRS features, all appear twice.

Here are those IRS variables which we deem as most “important” for prediction of residential energy usage, and which offer interesting and valuable avenues for future study:

- A11902: Overpayments refunded amount;
- N01000: Number of returns with net capital gain (less loss);
- A07100: Total tax credits amount;
- N00900: Number of returns with business or professional net income;
- N01700: Number of returns with taxable pensions and annuities;
- A01700: Taxable pensions and annuities amount;

We are also happy to see that N077260_av, ‘average number of returns with residential energy tax credit’, appears in both GBDT models, and A07260_av, ‘average residential energy tax credit amount’, appears in GBDT model for therms. It successfully supports our assumption that the energy tax credit is a decent candidate for the real energy consumption.

Conclusion

Overall, our modeling efforts were pretty good! We saw strong predictive power for residential gas consumption (therms/sqft), and pretty good predictive power for residential electricity consumption (KWH/sqft), with large amounts of noise coming from certain high income areas within the city and from low data collection areas on perimeter (suburbs).

We are also encouraged by multiple instances of N077260_av, ‘average number of energy tax credit forms’ and A07260_av ‘average energy credit amount’ in our tables of important variables. We believe this is significant enough evidence to support a more robust study of energy tax credits. Such a study should have a larger sample size and a more significant geographic link between IRS energy tax credits claimed and residential energy usage- perhaps at household granularity.

Thanks for reading, and we hope you enjoyed.

Appendix

Figures

Fig1 [Below]

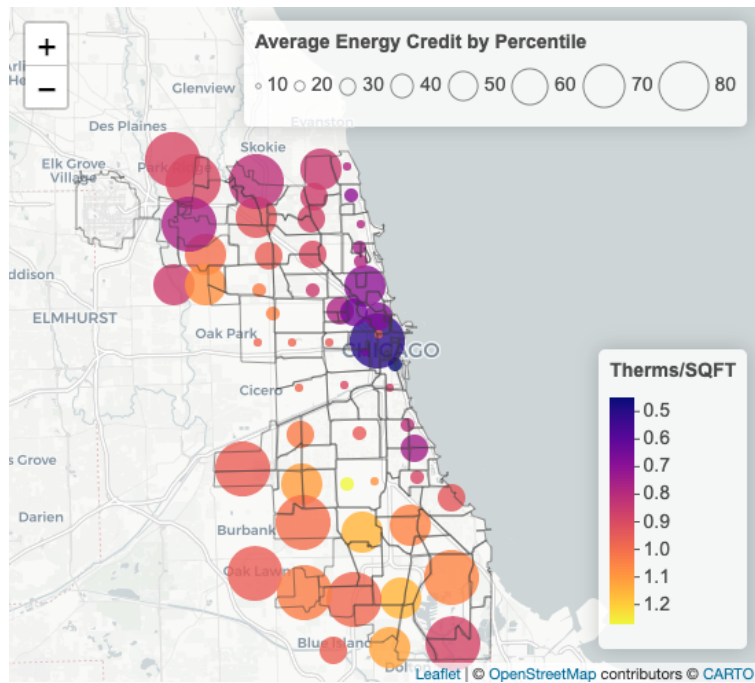


Fig2 [Below]

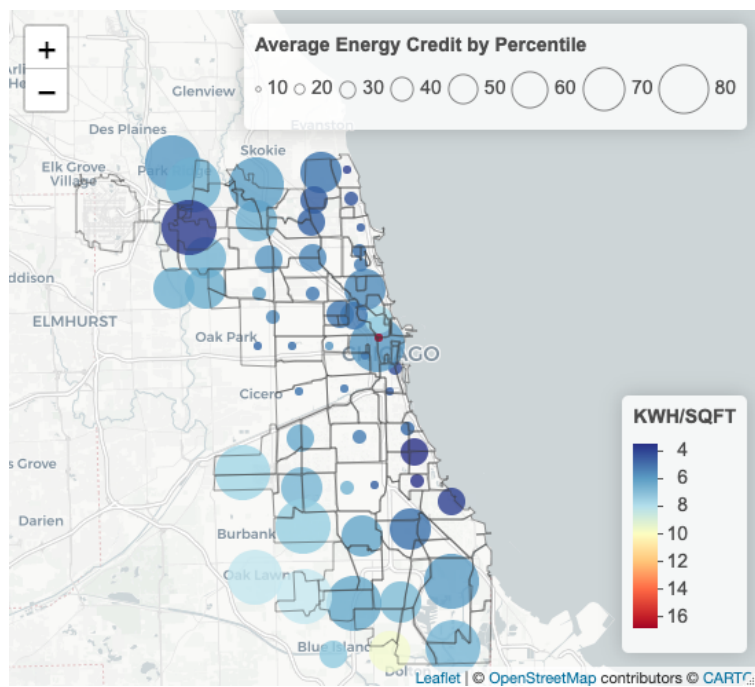


Fig3 [Below]

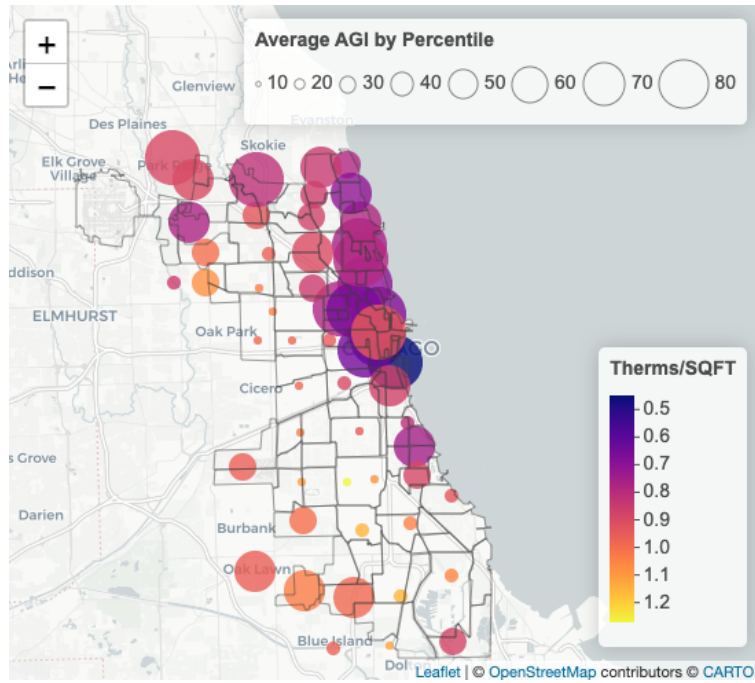


Fig4 [Below]

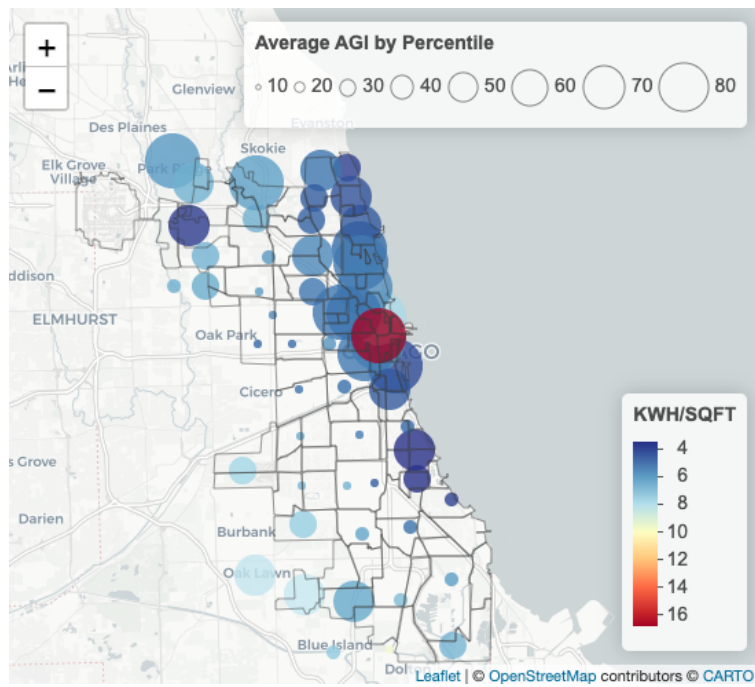


Fig5 [Below]

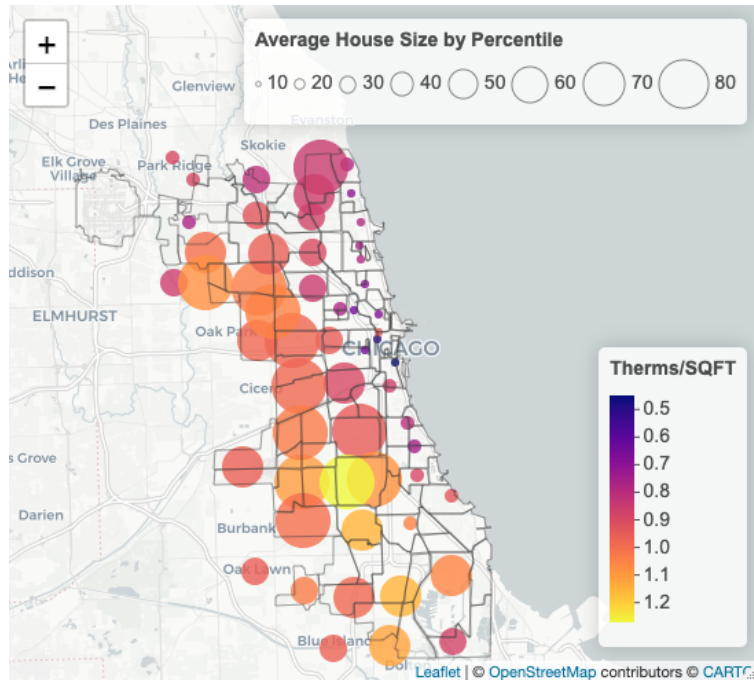
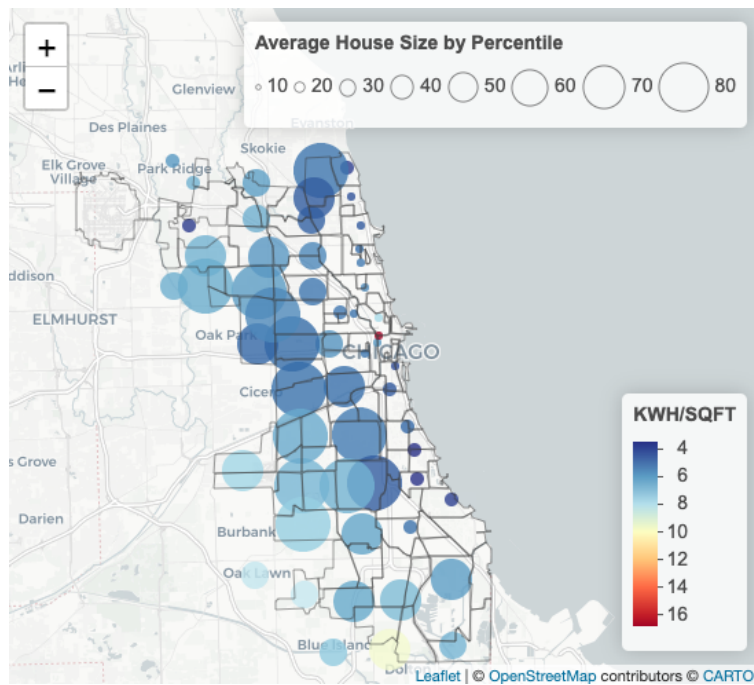


Fig6 [Below]:



Reference Tables

[Table A] *IRS Codebook*

Variable	Description
STATE	The State associated with the ZIP code
YEAR	Tax year of origin for published data

Variable	Description
N1	Number of returns
MARS2	Number of joint returns
PREP	Number of returns with paid preparer's signature
N2	Number of individuals
A00100	Adjust gross income (AGI)
N00200	Number of returns with salaries and wages
A00200	Salaries and wages amount
N00300	Number of returns with taxable interest
A00300	Taxable interest amount
N00600	Number of returns with ordinary dividends
A00600	Ordinary dividends amount
N00650	Number of returns with qualified dividends
A00650	Qualified dividends amount
N00900	Number of returns with business or professional net income (less loss)
A00900	Business or professional net income (less loss) amount
N01000	Number of returns with net capital gain (less loss)
A01000	Net capital gain (less loss) amount
N01400	Number of returns with taxable individual retirement arrangements distributions
A01400	Taxable individual retirement arrangements distributions amount
N01700	Number of returns with taxable pensions and annuities
A01700	Taxable pensions and annuities amount
SCHF	Number of farm returns
N02300	Number of returns with unemployment compensation
A02300	Unemployment compensation amount
N02500	Number of returns with taxable Social Security benefits
A02500	Taxable Social Security benefits amount
N03300	Number of returns with Self-employed (Keogh) retirement plans
A03300	Self-employed (Keogh) retirement plans amount
N04470	Number of returns with itemized deductions
A04470	Total itemized deductions amount
N18425	Number of returns with State and local income taxes
A18425	State and local income taxes amount
N18450	Number of returns with State and local general sales tax
A18450	State and local general sales tax amount
N18500	Number of returns with real estate taxes
A18500	Real estate taxes amount
N18300	Number of returns with Total taxes paid
A18300	Total taxes paid amount
N19300	Number of returns with Home mortgage interest paid
A19300	Home mortgage interest paid amount
N19700	Number of returns with Total charitable contributions
A19700	Total charitable contributions amount
N04800	Number of returns with taxable income
A04800	Taxable income amount
N09600	Number of returns with alternative minimum tax
A09600	Alternative minimum tax amount
N07100	Number of returns with total tax credits
A07100	Total tax credits amount
N07180	Number of returns with child and dependent care credit
A07180	Child and dependent care credit amount
N07260	Number of returns with residential energy tax credit
A07260	Residential energy tax credit amount

Variable	Description
N59660	Number of returns with earned income credit
A59660	Earned income credit amount
N59720	Number of returns with excess earned income credit
A59720	Excess earned income credit (refundable) amount
N11070	Number of returns with refundable child tax credit or additional child tax credit
A11070	Refundable child tax credit or additional child tax credit amount
N06500	Number of returns with income tax after credits
A06500	Income tax after credits amount
N10300	Number of returns with tax liability
A10300	Total tax liability amount
N11901	Number of returns with tax due at time of filing
A11901	Tax due at time of filing amount
N11902	Number of returns with overpayments refunded
A11902	Overpayments refunded amount
NUMDEP	Number of dependents [variable unavailable after '17]

[Table B] *Therm Feature Importance Rank*

XGBoost.Therm.Feature	XGBoost.Therm.Importance	GBDT.Therm.Feature	GBDT.Therm.Importance
AVERAGE.HOUSESIZE	0.218	AVERAGE.HOUSESIZE	12.327
AVERAGE.STORIES	0.117	N01400_av	7.718
OCCUPIED.HOUSING.UNITS	0.056	Latitude	7.205
AVERAGE.BUILDING.AGE	0.052	AVERAGE.STORIES	6.522
Latitude	0.048	N00200_av	5.231
A11902_av	0.042	A00600_av	4.738
RATIO.OWNED	0.040	A07260_av	4.159
N11070_av	0.036	N02300_av	3.873
A00100_av	0.029	N07260_av	3.673
N01000_av	0.028	Longitude	3.408
Longitude	0.024	N01000_av	3.208
N09600_av	0.022	N00900_av	2.654
A01400_av	0.021	A01000_av	2.542
N00200_av	0.021	N01700_av	2.514
N1	0.020	A11902_av	2.194

[Table C] *KWH Feature Importance Rank*

XGBoost.KWH.Feature	XGBoost.KWH.Importance	GBDT.KWH.Feature	GBDT.KWH.Importance
AVERAGE.STORIES	0.289	AVERAGE.STORIES	26.032
A07100_av	0.144	RATIO.OWNED	16.856
RATIO.OWNED	0.139	A07100_av	9.614
N07260_av	0.097	AVERAGE.BUILDING.AGE	4.365
AVERAGE.BUILDING.AGE	0.062	N00900_av	4.031
AVERAGE.HOUSESIZE	0.054	AVERAGE.HOUSESIZE	3.948
SCHF_av	0.052	N02500_av	2.767
Latitude	0.027	N01700_av	2.734
Longitude	0.022	A11902_av	2.461
N07180_av	0.018	Longitude	2.459
N00900_av	0.015	A07260_av	2.320

XGBoost.KWH.Feature	XGBoost.KWH.Importance	GBDT.KWH.Feature	GBDT.KWH.Importance
N01700_av	0.009	A01700_av	2.270
A01700_av	0.009	Latitude	1.732
OCCUPIED.HOUSING.UNITS	0.007	PREP	1.718
A00900_av	0.007	N1	1.651

Reference Docs

[Fig A] Below: *IRS Form 1040*

Form 1040 (See instructions on page 14.) Use the IRS label. Otherwise, please print or type.	Department of the Treasury—Internal Revenue Service U.S. Individual Income Tax Return 2009 (99) IRS Use Only—Do not write or staple in this space.	OMB No. 1545-0074																																																						
Label (See instructions on page 14.) Use the IRS label. Otherwise, please print or type.	For the year Jan. 1–Dec. 31, 2009, or other tax year beginning _____, 2009, ending _____, 20 Your first name and initial _____ Last name _____ If a joint return, spouse's first name and initial _____ Last name _____ Home address (number and street). If you have a P.O. box, see page 14. _____ Apt. no. _____ City, town or post office, state, and ZIP code. If you have a foreign address, see page 14. _____	Your social security number _____ Spouse's social security number _____ You must enter your SSN(s) above.																																																						
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Filing Status Check only one box. 1 <input type="checkbox"/> Single 2 <input type="checkbox"/> Married filing jointly (even if only one had income) 3 <input type="checkbox"/> Married filing separately. Enter spouse's SSN above and full name here. _____ 4 <input type="checkbox"/> Head of household (with qualifying person). (See page 15.) If the qualifying person is a child but not your dependent, enter this child's name here. _____ 5 <input type="checkbox"/> Qualifying widow(er) with dependent child (see page 16)																																																								
Exemptions 6a <input type="checkbox"/> Yourself. If someone can claim you as a dependent, do not check box 6a. b <input type="checkbox"/> Spouse c Dependents: <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>(1) First name</th> <th>Last name</th> <th>(2) Dependent's social security number</th> <th>(3) Dependent's relationship to you</th> <th>(4) <input checked="" type="checkbox"/> If qualifying child for child tax credit (see page 17)</th> </tr> </thead> <tbody> <tr><td> </td><td> </td><td> </td><td> </td><td><input type="checkbox"/></td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td><input type="checkbox"/></td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td><input type="checkbox"/></td></tr> <tr><td> </td><td> </td><td> </td><td> </td><td><input type="checkbox"/></td></tr> </tbody> </table> If more than four dependents, see page 17 and check here <input type="checkbox"/> d Total number of exemptions claimed _____			(1) First name	Last name	(2) Dependent's social security number	(3) Dependent's relationship to you	(4) <input checked="" type="checkbox"/> If qualifying child for child tax credit (see page 17)					<input type="checkbox"/>					<input type="checkbox"/>					<input type="checkbox"/>					<input type="checkbox"/>																													
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Adjusted Gross Income <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%;">23 Educator expenses (see page 29)</td> <td style="width: 10%;">23</td> <td style="width: 30%;"></td> </tr> <tr> <td>24 Certain business expenses of reservists, performing artists, and fee-basis government officials. Attach Form 2106 or 2106-EZ</td> <td>24</td> <td></td> </tr> <tr> <td>25 Health savings account deduction. Attach Form 8889</td> <td>25</td> <td></td> </tr> <tr> <td>26 Moving expenses. Attach Form 3903</td> <td>26</td> <td></td> </tr> <tr> <td>27 One-half of self-employment tax. Attach Schedule SE</td> <td>27</td> <td></td> </tr> <tr> <td>28 Self-employed SEP, SIMPLE, and qualified plans</td> <td>28</td> <td></td> </tr> <tr> <td>29 Self-employed health insurance deduction (see page 30)</td> <td>29</td> <td></td> </tr> <tr> <td>30 Penalty on early withdrawal of savings</td> <td>30</td> <td></td> </tr> <tr> <td>31a Alimony paid b Recipient's SSN</td> <td>31a</td> <td></td> </tr> <tr> <td>32 IRA deduction (see page 31)</td> <td>32</td> <td></td> </tr> <tr> <td>33 Student loan interest deduction (see page 34)</td> <td>33</td> <td></td> </tr> <tr> <td>34 Tuition and fees deduction. Attach Form 8917</td> <td>34</td> <td></td> </tr> <tr> <td>35 Domestic production activities deduction. Attach Form 8903</td> <td>35</td> <td></td> </tr> <tr> <td>36 Add lines 23 through 31a and 32 through 35</td> <td>36</td> <td></td> </tr> <tr> <td>37 Subtract line 36 from line 22. This is your adjusted gross income</td> <td>37</td> <td></td> </tr> </table>			23 Educator expenses (see page 29)	23		24 Certain business expenses of reservists, performing artists, and fee-basis government officials. Attach Form 2106 or 2106-EZ	24		25 Health savings account deduction. Attach Form 8889	25		26 Moving expenses. Attach Form 3903	26		27 One-half of self-employment tax. Attach Schedule SE	27		28 Self-employed SEP, SIMPLE, and qualified plans	28		29 Self-employed health insurance deduction (see page 30)	29		30 Penalty on early withdrawal of savings	30		31a Alimony paid b Recipient's SSN	31a		32 IRA deduction (see page 31)	32		33 Student loan interest deduction (see page 34)	33		34 Tuition and fees deduction. Attach Form 8917	34		35 Domestic production activities deduction. Attach Form 8903	35		36 Add lines 23 through 31a and 32 through 35	36		37 Subtract line 36 from line 22. This is your adjusted gross income	37										
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[Fig B] Below: IRS Form 5695: Residential Energy Tax Credit

Residential Energy Credits

► See instructions.
► Attach to Form 1040 or Form 1040NR.

OMB No. 1545-0074

2009

Attachment
Sequence No. **158**

Your social security number

Before You Begin Part I: Figure the amount of any credit for the elderly or the disabled you are claiming.

Part I Nonbusiness Energy Property Credit (See instructions before completing this part.)

1	Were the qualified energy efficiency improvements or residential energy property costs for your main home located in the United States? (see instructions)	1	<input type="checkbox"/> Yes <input type="checkbox"/> No
Caution: If you checked the "No" box, you cannot claim the nonbusiness energy property credit. Do not complete Part I.			
2	Qualified energy efficiency improvements (see instructions).		
a	Insulation material or system specifically and primarily designed to reduce the heat loss or gain of your home	2a	
b	Exterior windows (including certain storm windows) and skylights	2b	
c	Exterior doors (including certain storm doors)	2c	
d	Metal roof with appropriate pigmented coatings, or asphalt roof with appropriate cooling granules, that are specifically and primarily designed to reduce the heat gain of your home, and the roof meets or exceeds the Energy Star program requirements in effect at the time of purchase or installation	2d	
3	Residential energy property costs (see instructions).		
a	Energy-efficient building property	3a	
b	Qualified natural gas, propane, or oil furnace or hot water boiler	3b	
c	Advanced main air circulating fan used in a natural gas, propane, or oil furnace	3c	
4	Add lines 2a through 3c	4	
5	Multiply line 4 by 30% (.30)	5	
6	Maximum credit amount. (If you jointly occupied the home, see instructions)	6	\$1,500
7	Enter the smaller amount of line 5 or line 6	7	
8	Enter the amount from Form 1040, line 46, or Form 1040NR, line 43	8	
9	Enter the total, if any, of your credits from Form 1040, lines 47 through 50, and Schedule R, line 24; or Form 1040NR, lines 44 through 46	9	
10	Subtract line 9 from line 8. If zero or less, stop . You cannot take the nonbusiness energy property credit	10	
11	Nonbusiness energy property credit. Enter the smaller of line 7 or line 10	11	

For Paperwork Reduction Act Notice, see instructions.

Cat. No. 13540P

Form **5695** (2009)