ESTIMATION OF HEATING ENERGY USE OF EXISTING HOUSES IN A FUTURE CLIMATE: 2050 VS 2007

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ABSTRACT

This paper presents a method for the estimation of potential impact of climate change on the heating energy use of existing houses. The proposed method uses the house energy signature, which is developed from the current heating energy use extracted from the utility bills (e.g., for year 2007) and corresponding climatic conditions. The energy signature, which is an energy-related characteristic of the house, is used along with the outdoor air temperature predicted for 2040-2069 to forecast the heating energy use. The potential impact of climate change is estimated as the percentage of variation of heating energy use in the future compared with the current situation.

INTRODUCTION

Several researchers evaluated the potential impact of climate change, as predicted by the IPCC (2001), on the energy use for heating and cooling in buildings. In all cases, the evaluation was based either on the degree-days method or on detailed computer simulation applied to a reference building.

For instance, Belzer et al. (1995) used the degree-days method to estimate the changes of energy use in commercial buildings due to climate change. Ouranos (2004) used the degree-days method, and estimated the reduction of heating demand in Quebec at 7.7% in 2050 compared with 2001. Gaterell and McEvoy (2005) used the TAS software along with a few scenarios about climate change in the UK by 2050, and predicted the reduction of residential heating energy use between 17% and 72%. Frank (2005) used detailed computer simulation, and estimated at 33-44% the decrease in the annual heating energy demand for Swiss multi-story residential buildings, for the period 2050-2100 compared with 1961-1990. Thatcher (2006) used a linear regression model, and predicted the change in peak regional electric demand in Australia between -2.1% and +4.6% for a simple climate change scenario of 1°C increase in the average outdoor temperature. Christenson et al. (2006) developed a procedure to estimate the heating and cooling degree-days (HDD and CDD) from monthly temperature data based on 41 regional climate change scenarios derived from 35 simulations with 8 global climate models. The HDD and CDD values were used to evaluate the impact of climate warming on Swiss building energy demand. Crawley (2007a) developed typical and extreme weather data for 25 locations in 20 different climate regions, and used the EnergyPlus program to estimate the impact of climate change on a small office building located in the 20 climate regions (Crawley 2007b). The energy use, at locations with predominant heating or balanced heating and cooling needs, is expected to decrease with the climate change scenarios. For instance, if the building is located in Washington, D.C., the energy use is reduced by 5-7%. Isaac and van Vuuren (2009) estimated the impact of climate change on the national energy demand for heating and cooling by using the heating and cooling degree-days method, the structure indicator (floor per capita), the energy use intensity, and the penetration index of air-conditioning systems. In Europe the final energy demand is projected to start decreasing in 2010 by 0.7%.

Another approach for the evaluation of climate change impact on the energy use for heating and cooling consists in the use a large sample of existing buildings, in collaboration with utility companies. The energy signature of each house can be extracted from the utility bills. The potential impact of climate change is evaluated by using the energy signature along with the predicted weather data under given scenarios of climate change. This is an alternative approach to the detailed computer simulation of one or several reference buildings. The time required to collect data from the utility bills and extract the energy signature is incomparable less than the time for developing and calibrating a detailed computer model of each house. Therefore, a much larger sample of existing buildings can be analyzed. Finally, the relationship between the expected variation of heating energy use and other parameters such as type of construction (e.g., detached houses vs townhouses), year of construction, year of last major renovation, and type of heating/cooling system can be developed.

This paper presents such an alternative method that uses the house energy use history extracted from the utility bills.

METHOD

Energy signature

The method uses the house heating energy signature, which is usually defined as the linear relationship between the heating energy use and the outdoor air temperature or heating degree-days (Fels 1986, Deeble et Probert, 1986; Jacobsen, 1985; Lyberg, 1987; Zmeureanu, 1990) (Equation 1). The method is based on the assumption that that every building has its own energy signature that remains unchanged in time, regardless of change in outdoor conditions, provided that no major renovations, change of equipment or change in operating conditions (e.g., thermostat set point) take place. In addition, it is assumed that the usage pattern will not change over time. The energy signature is defined as follows:

$$E_t = a \cdot T_{avge(t)} + b \qquad (1)$$

where E_t is the daily average measured heating energy use, in kWh, calculated from the utility bills of the billing period t; $T_{avge(t)}$ is the daily average measured outdoor air temperature, in ºC, as given by the nearest meteorological station, over the same billing period t. The characteristic coefficients, a and b, are estimated by applying the least squares method to a number of available pair points (E_t, $T_{ext(t)}$).

Although the linear relationship with only one independent variable, $T_{avge(t)}$, (Equation 1) is simple, it has the advantage of using information easily available from past periods: (1) the utility bills from the utility company or from the homeowner's file, and (2) the outdoor air temperature from the closest meteorological station. The lack of easily available measured data for other independent variables prevents the use of multi-linear or non-linear relationships or even more detailed methods such dynamic computer simulation or Artificial Neural Networks.

Estimation of annual energy use for heating

Once the a and b coefficients are known, the annual energy use for heating, E_H in kWh, is calculated as follows:

$$E_H = \sum_j n_{month,j} \cdot (a \cdot T_{avge,j} + b) \qquad (2)$$

where $n_{month,j}$ is the number of days of month j; $T_{avge,j}$ is the average outdoor temperature of month j; the summation is made over 12 months, j=1 to 12.

The annual energy use $E_{H,present}$ for heating the house during the reference year is estimated by using Equation (2) along with the weather data of 2007. The annual energy use $E_{H,future}$ for heating the house during the period 2040-2069 (here indicated as year 2050) is estimated by using Equation 2 along with the predicted weather data based on climate change scenarios.

The predicted change ΔE_H, in %, of the annual heating energy use of the house due to climate change is calculated as follows:

$$\Delta E_H = (E_{H,future} - E_{H,present}) \cdot 100 / E_{H,present} \qquad (3)$$

The potential impact of social, technological and economic factors, beyond those changes considered by the climate changes scenarios, is not included.

EXAMPLE OF EVALUATION

The first case study presented in this section covers the heating energy use of a house in cold climate (Montreal, Canada) that complies with the Quebec energy-related regulations. The second case study covers a house in warmer environment (Lyon, France) that complies with the French regulation RT (2005).

The detailed computer simulation with TRNSYS program (TRNSYS 2006) of these two houses gave the energy use data, which is used as synthetic data to develop the energy signature. Finally, this section ends with the comparison of results from the proposed method for the year 2050 with those from TRNSYS.

Weather data

The monthly average data for Montreal is extracted from the web site of Canadian Institute for Climate Studies (CICS 2007). The current climate conditions are indicated as the year 2007. The future climate conditions are indicated as the year 2050 (2040-2069), and the values presented in Table 1 are calculated as the average of five scenarios: CGCM2 B2x; HadCM3 A2x; ECHAM4 A21 and ECHAM4 B21.

The monthly average weather data for Lyon is extracted from the web site of 'Science and vie' (2008) magazine, developed by Sciama (2008). The future climate conditions (year 2050) are extracted for the A2 and B2 scenarios. Table 1 shows only the values corresponding to the B2 scenario.

The monthly average outdoor air temperature is predicted to increase in Montreal during the winter months by 2.4-5.1°C, while in Lyon the increase is only of 0.9-2.1°C. The monthly average solar radiation is expected to decrease by 3.5-5.4% (December to February) in Montreal, while in Lyon a greater change in solar radiation is expected: a decrease by about 9% in December, and an increase by 39% and 4.5% in January and February, respectively.

The monthly values presented in Table 1 for each analysis period are used as input to the pre-processor of weather data, called Type 54, which is a component available in the TRNSYS environment coverts. This module converts the monthly average values into hourly values required by the computer simulation with TRNSYS (TRNSYS 2006; Knight et al. 1991) to generate the synthetic data of energy use.

Table 1

Monthly average weather data 2007 and 2050 for Montreal and Lyon

Month	Montreal		Lyon	
	T_{ext} °C	Solar W/m²	T_{ext} °C	Solar W/m²
	2007			
Jan	-11.6	48.0	1.69	35.9
Feb	-10.8	74.4	3.31	67.0
Mar	-5.8	119.2	5.31	112.9
Apr	0.8	171.8	8.42	159.7
May	8.0	210.4	12.37	194.7
Jun	14.6	226.6	16.26	212.8
Jul	17.8	214.0	19.35	220.6
Aug	17.8	193.0	19.83	199.0
Sep	13.8	153.0	16.03	142.8
Oct	6.2	95.8	9.86	78.6
Nov	-0.4	52.8	5.32	39.7
Dec	-5.2	39.8	2.29	20.4
	2050		**Scenario B2**	
Jan	-6.5	45.4	4.54	49.9
Feb	-7.4	71.8	4.22	70.0
Mar	-3.0	118.4	7.01	109.7
Apr	3.3	173.2	10.26	176.7
May	10.8	212.8	15.32	218.8
Jun	17.3	229.8	16.09	207.7
Jul	20.8	216.0	22.29	251.6
Aug	20.8	192.8	22.05	189.7
Sep	16.5	151.6	15.13	157.3
Oct	9.0	98.0	11.95	72.7
Nov	2.0	53.6	9.20	37.7
Dec	-2.4	38.0	3.19	18.6

House in Montreal

The model of the case study house is developed based on the form and dimensions of an existing house of about 190 m² of heated floor area, built in Montreal (Caunesil et al. 2004) that complies with the minimum thermal resistance of exterior walls and roof (Quebec 2005). For instance, the overall RSI-value of the exterior walls of heated spaces is equal to 3.6 m²·K/W. The air infiltration rate is assumed equal to three air-changes per hour (ach) measured at 50 Pa pressure difference with a blower door, or 0.15 ach of natural air infiltration at 4 Pa pressure difference. This value corresponds to the average air leakage of houses built after 1994 in Montreal area. The house is divided into two heated thermal zones: zone no.1 on the ground floor and zone no.2 in the basement; and two unheated zones: zone no.3 (garage) and zone no.4 (attic). The electric baseboard heaters operate between October 1 and April 30 to maintain the indoor air temperature of the ground floor space at 20ºC. The mechanical ventilation system supplies 0.35 ach in the living spaces. A heat recovery ventilator with an average thermal efficacy of 0.6 preheats the incoming cold ventilation air.

TRNSYS program estimates the annual heating energy use of the case study house at 10,252 kWh/year (54.0 kWh/m²yr) for the present climate and 9,012 kWh/year (47.4 kWh/m²yr) for the future climate. Hence, the reduction of heating energy use due to climate change is 12.1%.

The monthly total energy use and monthly average outdoor air temperature are extracted from the TRNSYS simulation results for 2007, and used to estimate the characteristic coefficients, a and b, of the house energy signature (Table 2). The use of synthetic data of monthly energy use mimics the use of utility bills in the proposed method.

Table 2

Characteristic coefficients of the house energy signature in Montreal using monthly data

Period	a (kWh/(ºC·day))	b (kWh/day)	R^2 (-)
2007	-2.57	43.38	0.94
2050	-2.47	43.84	0.92

For comparison purposes only, the a and b coefficients are also estimated using the weather data for 2050 (Table 2). The results support the assumption that the energy signature does not change with the year of simulation.

The energy signature method using monthly data estimates the annual heating energy use in 2050 at 8,981 kWh, or a reduction of 13.1% from 2007, compared to 12.1% reduction predicted by TRNSYS (Table 3).

Table 3

Reduction of annual heating energy use in Montreal. TRNSYS vs energy signature method

Period	Heating energy use (kWh)	
	TRNSYS	Energy signature
2007	10,252	10,252
2050	9,012	8,981
Difference (%)	- 12.1	-13.1

House in Lyon

The house in Lyon has about the same footprint, however, the basement is not heated. The total heated floor area is about 100 m². The wood studs construction with insulated cavity, as used in Montreal for exterior walls, is replaced with bricks of 30 cm width, with the RSI-value of 2.5 m²·K/W. The overall U-value of exterior walls of the heated spaces is equal to 0.36 W/m²·K that complies with the maximum acceptable value of 0.47 W/m²·K (RT 2005).

The electric heaters operate between October 15 and April 30 to maintain the indoor air temperature of the ground floor space at 19°C during the day and 16ºC at night. A mechanical ventilation system supplies 0.31 ach in the living spaces, without a heat recovery unit. The natural air infiltration rate is 0.6 m^3/h per m^2 of cold wall (0.22 ach) at 4 Pa pressure difference.

TRNSYS program estimates the annual heating energy use in 2007 of the case study house at 4,960 kWh or 49 kWh/m^2, which is less than the reference value of 64 kWh/m^2 (IFEN 2008). For the year 2050, the annual heating energy use is estimated at 3,685 kWh (scenario A2) and 3766 kWh (scenario B2). Hence, the reduction of heating energy use due to climate change is 25.7% for A2 and 24.1% for B2. These estimates are about 100% greater than the results for Montreal (12.1%).

The characteristic coefficients of the house energy signature are estimated based on the monthly total energy use and monthly average temperature for 2007 (Table 4).

Table 4
Characteristic coefficients of the house energy signature in Lyon using monthly data

Period	a (kWh/(ºC·day))	b (kWh/day)	R^2 (-)
2007	-3.89	44.35	0.94

The energy signature method estimates the reduction of annual heating energy use in 2050 between 26 % and 28.4%, compared to 24.1% and 25.7% as predicted by TRNSYS (Table 5).

Table 5
Reduction of annual heating energy use in Lyon. TRNSYS vs energy signature method

Period	Heating energy use (kWh)	
	TRNSYS	Energy signature
2007	4,960	4,960
2050-scenario A2	3,685	3,552
Difference (%)	-25.7	-28.4
2050-scenario B2	3,766	3,669
Difference (%)	-24.1	-26

At the same variation of 1°C of the monthly average temperature in Montreal and Lyon, the ratio between the slopes of energy signature (the a coefficient) is 2.57/3.89=0.66, while the ratio of corresponding number of degree-days is about 4652/2625=1.77. Therefore, the house in Lyon, a warmer climate, is more sensitive to outdoor conditions than the house in Montreal, a colder climate. This result could be explained by the higher level of thermal insulation and airtightness, and the use of heat recovery ventilator to preheat the ventilation air for houses built in Montreal compared with Lyon.

CONCLUSIONS

The utility companies that have large databases of energy use in existing residential buildings should use the proposed method to estimate the impact of climate change.

The difference between the predictions of the proposed method and those from detailed modelling with TRNSYS is 1% for the case of the case study house in Montreal, and between 1.9 and 2.7% for Lyon.

The comparison between the annual heating energy use in the present climate and of the future predicted climate of 2050 shows a reduction of 13.1% for the case study house in Montreal, and 26 to 28.4% in Lyon.

Future work will cover the change over time of energy signature due to (1) the modification of thermal quality of building fabric and (2) the change of energy efficiency of heating system due to the degradation or replacement with equipment.

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