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IMPACTS OF CLIMATE CHANGE ON ENERGY DEMAND IN THE GREATER DUBLIN REGION, IRELAND

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1. Introduction

The Fourth Assessment Report (AR4) from the IPCC notes that annual mean temperatures warming in Europe are likely to increase more than the global mean (IPCC, 2007). In Ireland ,temperature increase by 0.7 ºC during the period 1890-2004, at a rate of 0.06ºC per decade (McElwain and Sweeney, 2006) and are likely to continue increasing by 0.25ºC per decade over the coming century (Sweeney and Fealy, 2003). Rising temperature may change future energy consumption patterns of our cities. For example, a 1ºC increase in temperature is projected to decrease energy consumption required for heating by 10% and increase energy used required for cooling by 28.4%, assuming a business-as-usual scenario in Greece (Cartalis et al, 2001). In the US, Rosenthal et al. (1995) estimates that a 1ºC warming would reduce energy expenditures by $5.5 billion and primary energy use by 0.70% in 2010 relative to a non warming scenario. For a 3ºC increase in the mean daily maximum temperature at Toronto in summer, the increase in mean peak power demand was 7% (1200MW) while the increase in the standard deviation of peak power demand was 22% (Colombo et al, 1999). Research also had been taken to aggregate house and building models to analyze the effect of improvements in energy efficiency of homes and buildings (Frank, 2005; Gaterell, 2005). Christenson et al. (2005) indicate that future space heating demands in buildings in Switzerland are likely to decrease by between 13-87%. Important factors include building quality, location and, most importantly, the magnitude of future warming. In addition, energy demand sensitivities to climate and climate change should be performed at regional scale because global climate change is anticipated to have geographically distinct impacts. (Ruth and Amato, 2005).

The Greater Dublin region, which accounts for almost half of the Republic of Ireland’s population and employment, is chosen as study area to analysis the relationship between energy consumption and climate variables with approximately 50 years of daily temperature data (1960-2006) and 16-year daily energy consumption data (1989-2006).The paper is structured as follows. The following sections will describe the energy consumption pattern in Ireland and the data used in the study. The relationship between energy demand and temperature is then analyzed in section 4. Section 5 will introduce the projection of future energy demand response to climate change.

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2. Energy demand in Ireland

Energy use in Ireland can be categorized according to its mode of application; that is, whether it is used for mobility (transport), power applications (electricity) or for thermal use (space or process heating) (SEI, 2005). Figure1.shows in 1990 thermal uses for energy accounted for a significant proportion of all primary energy (44%), with electricity accounting for 34% and transport 22%. This contrasts with the situation in 2005 when there is almost equal amounts of primary energy used by each of the applications – thermal 34%, electricity 33% and transport 33% (SEI, 2005). Reducing energy usage in the transport and electricity sectors is a costly process that will take many years to achieve. The energy demand for space heating and cooling, however, is one area where significant reductions can be attained in a cost-effective manner. By improving the thermal properties of a countries building stock through the use of better insulation in the building envelope combined with the use of more energy efficient domestic appliances, significant savings in energy usage can be achieved.

One factor which affects energy demand is local climate (Warren, 1981; Lehman, 1994; Yan, 1998; Valor, 2001). The energy demand for space heating and cooling is sensitive to climate variables, e.g. air temperature radiation and wind seep and so on. Of particular importance for thermal comfortable in the built environment are heating degree day and cooling degree day both accumulated from base temperature(Douglas, et al.,1981). Heating degree day can be used to determine space heating demand, while the cooling degree days can be employed to determine the cooling energy load for a building. The detail information about the degree days shows as the following section.

Aside from the local climate, realizing the potential reductions in energy consumption available within the domestic building sector requires an understanding of the profile of the housing stock (Considine, 2000; Gaterell, 2005; Bojić, et al., 2007). The current profile of the house stock in terms of age, dwelling type and floor area need to be considered as they are related to the thermal properties of building which affects the building energy demand for space heating and cooling.

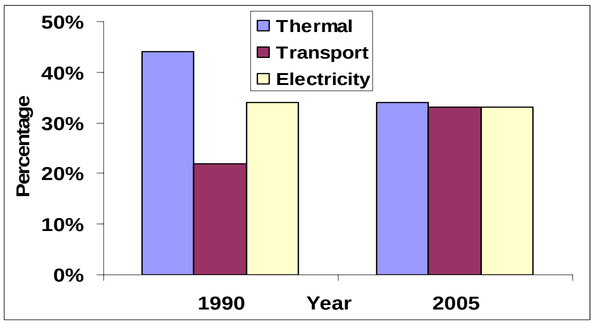

Fig. 1 Energy use by mode of application

In 2006, there were about 600,000 households in Greater Dublin region. Figure 2 shows the profile of current housing stock. A profile of dwelling in terms of both dwelling type and age is illustrated in this figure. More than half of the current housing stock was built before 1990, a period in which thermal standards of construction were lower than they are today. Since 1990, the Building Control Act has significantly contributed to improving the thermal standards of all buildings through better construction standards. During 1991-2000, more dwellings were built compared with other time period. Therefore, there is a greatest potential for energy saving

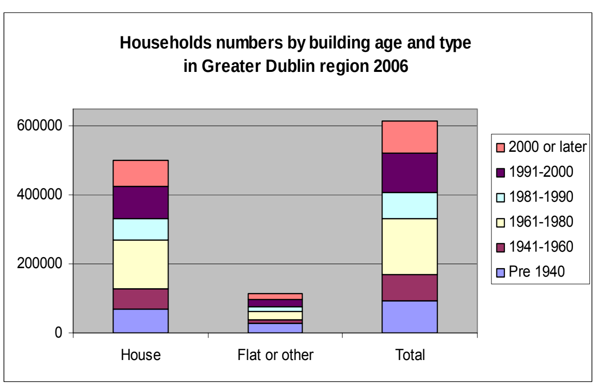

Fig. 2 Profile of Irish hosing stock

in existing housing stock by improving the energy efficiency.

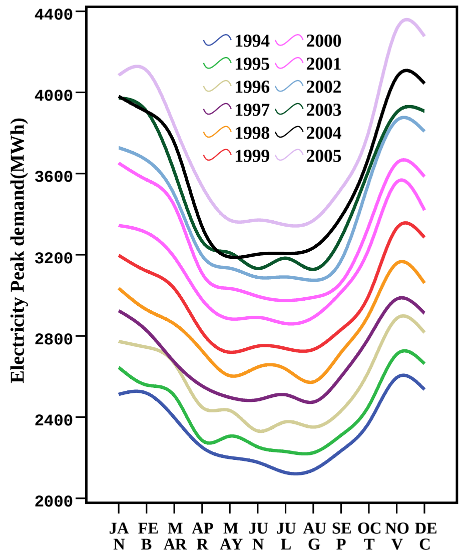

Fig. 3 Daily Electricity Peak Demand, 1994-2005

Building with different thermal insulation levels and solar or internal gains will have different base temperature, which need to be factored into the degree-day method for the determination of energy demand.

3. Data description

a. Energy data

A series of national daily electricity peak demand, spanning the period from January 1994 through December 2005 has been used in the study. The data comprise the electricity consumption in all economic sectors (industrial, residential and commercial) for Ireland. Regional or sectorially disaggregated data are not currently available. The electricity consumption data was obtained from Ireland's National Grid. (see Figure3).

Electricity peak demand shows a significant increasing trend that is likely due to the changes in the size of local population combined with changes in household sizes, building stock and increased proliferation of electric heating and air-conditioning, as well as increase in overall economic activity in the county. The monthly shows a maximum electricity peak demand in January, which decreases until May. Then the electricity peak demand begins to slightly increase from the use of air conditioning systems until August. In September and November, increases are again evident due to increasing demand from electric heating appliances. The electricity peak load decrease slightly in December due to the reduced economical activities because most people in Ireland are on Christmas Holiday this month.

Natural gas is one of the primary heating fuels in Ireland. Daily natural gas sales to residential and non-residential users for Dublin area, from December 1989 to December 2006 were obtained from The National Gas Board (Bord Gais Eireann). Figure 4 illustrates residential gas sales which have a regular seasonal change with temperature, while the power station sector has no significant response to climate.

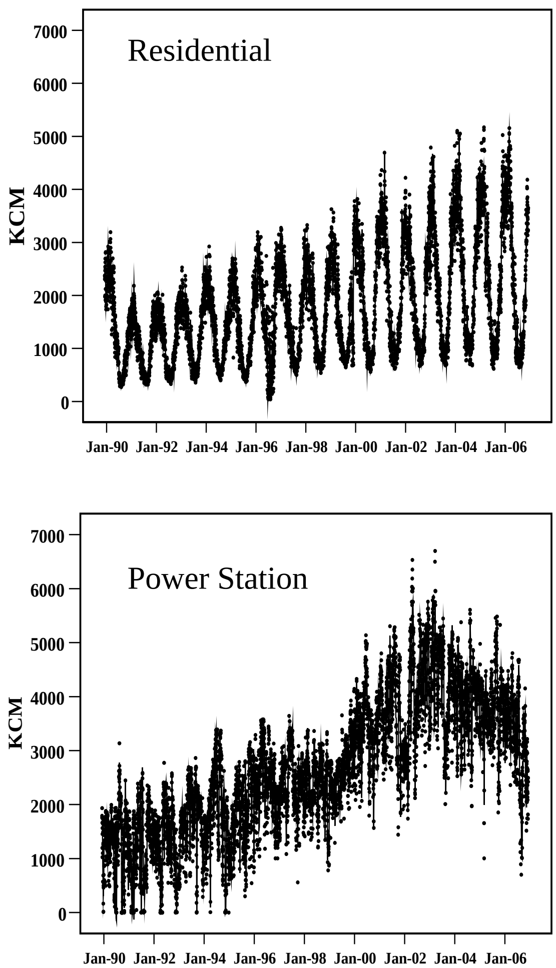

Fig 4. Daily Residential and Power Station Natural gas sales, 1990-2006

Figure 5 shows the daily average energy consumption per capita for each day in a week calculated from the whole sample. From this, it can be seen that energy demand falls on Saturday and more so on Sunday, both for electricity peak demand and domestic gas sales. Energy consumption is also lower on Monday in relation to the other working days, because of the inertia caused by the reduced economic activity over the weekend. Energy consumption also decreases for holidays placed from Monday to Friday; this also affects the working day after a holiday and working days working days between two holidays.

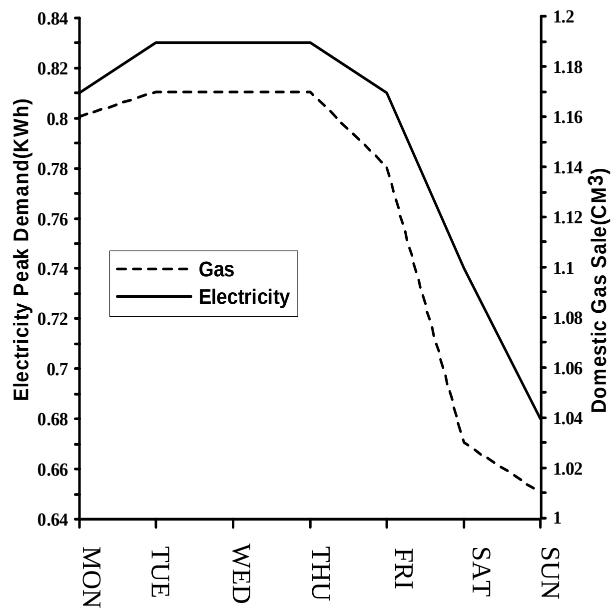

Fig. 5 Daily Average Energy Consumption per Capita in a Week, 1990--2006

b. Climate Data

The climate data consist of daily maximum and minimum temperature from the Irish National Meteorological Service (Met Éireann). Based on that data, monthly and daily degree days for the base temperature of 15.5ºC were calculated. Additionally, scenarios of future daily temperature and degree days for Greater Dublin region, using regional scale outputs from our Irish Climate Analysis Research Units downscaling of the Hadley Centre global climate model (HadCM3) (Fealy and Sweeney, 2007). Degree days are defined as the difference between the mean daily temperature and a base temperature. The base temperature can be physically interpreted as the outdoor temperature at which solar and internal gains (by electric lighting, equipment and people) offset losses. The reference temperature depends on the characteristics of building construction and the kind of activity developed in a building. As a consequence, different climatic regions and different building types can have different base temperature (Ruth and Amato, 2005). For this study, a base temperature of 15.5ºC was used. The degree day index was found more indicative than the temperature and load relationship allow us to quantify how cold and hot the weather has been using a single index.

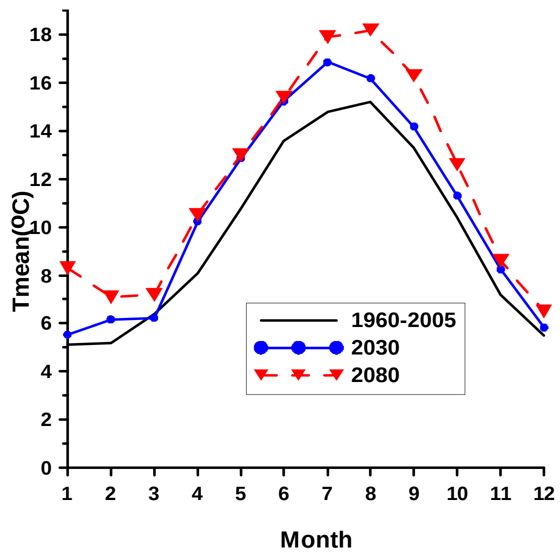

Figure 6. Projected Increases in Mean Monthly Temperatures for Dublin.

Figure 6 displays that the 1961-2004 average, projected increases of 0.4ºC and 3.1ºC, respectively for 2030 and 2080 period. Monthly degree days are derived from the projections of daily temperatures (see Figure 7). An appreciable increase in heating degree days occurs in the winter. For instance, January heating-days are projected to decrease from the historic average of 412 to

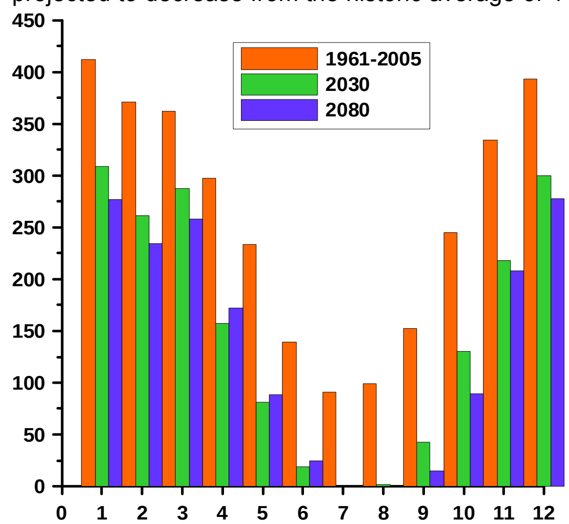

Fig. 7 Monthly degree-day changes in Dublin

309 in 2030 and fall to 277 by 2080. An annual decrease in heating degree-days of 42% and 47%, for the 2030 and 2080, respectively relative to the 1961-2004 average, are projected to occur.

Radiation, another climate-related variable that is likely to have an effect on energy demand, is also considered. Radiation is very location specific and it also affects the regional domestic energy consumption. The historical data show radiation has a weak negative linear effect on energy demand.

4. Relationship between Energy demand and Degree day

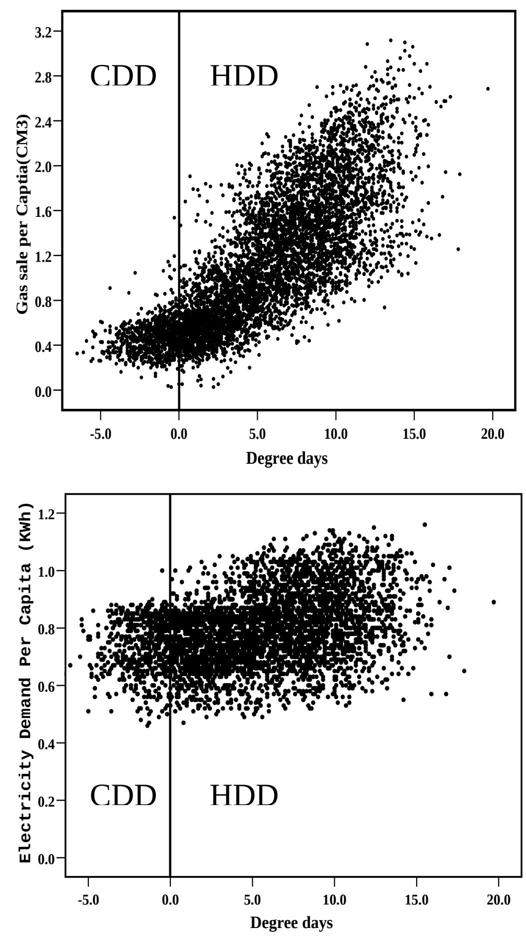

Fig. 8 Relationship between energy demand and degree days

A strong linear correlation between daily heating degree days and daily gas sales is evident from the data, a weak correlation with electricity, due to its many uses other than space heating (see Figure 8). There is very low correlation between the value of cooling degree day and energy demand. It is difficult to access the cooling energy demand since the daily mean temperature in Ireland seldom goes above 15.5ºC. However, it is likely that the values of CDD will increase over time with the effect of climate change.

We proposed a component of the regression model that includes the effect of the HDD, CDD and GNP (Gross national product) values as well as one climate-related variable namely radiation. The predicted daily electricity demand per capita E_{elec} and daily gas sales per capita E_{gas} can be formulated as follows:

$$(E_{gas})^{\frac{1}{2}} = \alpha_0 + \alpha_1 DD + \alpha_2 GNP + \alpha_3 Ra + \alpha_4 H$$

$$(E_{elec})^{\frac{1}{2}} = \alpha_0^{'} + \alpha_1^{'} DD + \alpha_2^{'} GNP + \alpha_3^{'} Ra + \alpha_4^{'} H$$

where α_n are constants and Ra is radiation. The variable H takes on a value of 1 if the day is a holiday and a value of 0 if the day is a working day. The value of degree days (DD) is positive (HDD), then the energy is required for heating purpose, where the value of DD is negative (CDD), the energy need for cooling.

The regression results for daily electricity peak demand per capita and daily natural gas consumption per capita are shown in the Table 1. The constant term together with the annual GNP per capita variable is representative for non-weather sensitive energy demand. The co-efficient of the annual GNP variable indicate that increase in real annual GNP per capita of €1000 will be companied by an increase of 33.1% in daily electricity peak demand and 1.7% in daily gas usage. The results suggest that future increases in GNP may be accompanied by increase in non-weather sensitive energy demand.

The t-ratio is the ratio of the estimated parameter value to the estimated parameter standard deviation. The larger the ratio, the more significant the parameter is in the regression model. Table 1 shows the α_1 has the largest ratio, while α_4 has the smallest value. This suggests that degree day is the dominant variable in the daily gas usage regression model and that the holiday value has very little influence on the demand. For the daily electricity peak demand regression model, the variable of GNP appears more important than the climatic variables, since the peak demand is strongly related to the change in population and economic activities compared with the residential sector. This may suggest that the climate variables are important to the residential sector of energy demand, while no significantly impacting on industrial and other sectors.

Both regression models can explain over 85% of the historical variety in per capita daily energy demand.

5. The projection of energy use under future climate scenarios

a. The projection without insulation scenarios

In this part of the analysis, the regression results for electricity and natural gas demand are employed in order to determine future energy demand for the Greater Dublin region in conjunction with the climate change scenarios. The socio-economic parameters are held constant to better illustrate the effects of changes in climatic variables on energy demand. The projection for monthly energy demand is shown in Figure 9. The energy scenarios for the 2030 and 2080 project a decrease in residential energy demand during the winter months by 15% and 23%, respectively, relative to the energy demand in 2005. For example, the monthly electricity peak demand per capita is high in January at 785 kilowatt-hours a person, which would decrease to 688 and 578 KWh under the projected climates of 2030 and 2080. The annual electricity peak demand is also projected to decrease with increase in temperature. Annual electricity energy demand is expected to decrease by 10% by 2030 climate scenarios and 18% by 2080.

b. The projection with insulation scenarios

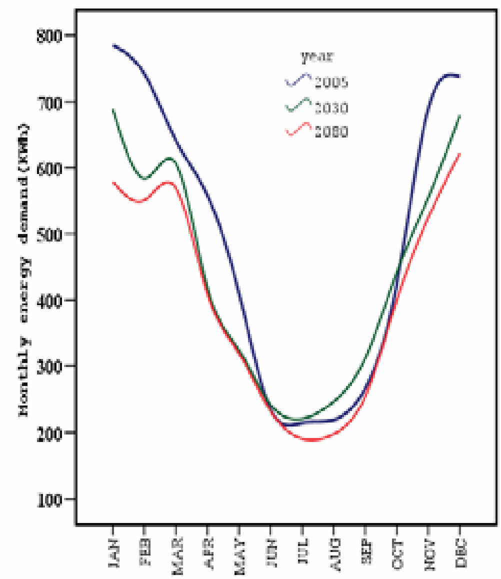

Fig. 9 Projection for monthly energy demand

Building with different thermal insulation levels and solar or internal heat gains will have different base temperatures for space heating and cooling. Climate and housing type may interact to determine the future energy consumption pattern. Therefore, there is a need to study

Table 1 Regression statistics results for energy demand

Daily Gas usage per capita (CM^3)			Daily Electricity peak demand per Capita (KWh)		
Variable	Value	t-ratio	Variable	Value	t-ratio
α_0	0.480	66.155	α_0	20.640	257.944
α_1	0.045	116.345	α_1	0.111	33.610
α_2	0.017	72.273	α_2	0.331	120.558
α_3	-0.009	-37.275	α_3	-0.096	-44.925
α_4	-0.075	-24.183	α_4	-2.187	-81.289
R^2	0.864		R^2	0.842	

Table 2 Average Floor area and U-value for different dwelling

Housing type	Floor area (M2)	Wall U-value (W/m2K)	Ground floor U-value (W/m2K)	Roof U-value (W/m2K)	Window U-value (W/m2K)
Room 1-4	**50**	**0.44**	**0.25**	**0.26**	**2.2**
Room 5-6 (Pre90) (2 stories)	**107**	**0.60**	**0.25**	**0.35**	**2.2**
Room 5-6 (91-00) (2 stories)	**94**	**0.60**	**0.25**	**0.35**	**2.2**
Room 5-6 (01or later) (2 stories)	**99**	**0.27**	**0.25**	**0.21**	**2.2**
Room7-8(Pre 90) (2 stories)	**125**	**0.60**	**0.25**	**0.35**	**2.2**
Room7-8 (91-00) (2 stories)	**145**	**0.60**	**0.25**	**0.35**	**2.2**
Room 7-8 (01or later) (2 stories)	**164**	**0.27**	**0.25**	**0.21**	**2.2**
Apartment (Pre90)	**62**	**0.60**	**0.25**	**0.35**	**2.2**
Apartment (91-00)	**56**	**0.60**	**0.25**	**0.35**	**2.2**
Apartment (01 or later)	**98**	**0.27**	**0.25**	**0.22**	**2.2**

how climate change impacts on heating energy demand for different type buildings in Dublin region.

The heating of a building is essentially an energy balance. To maintain the internal space at a constant temperature the heating inputs into the building must balance heat losses. Heat inputs include—input from the heating system, solar gains and input from occupancy including the use of energy. Heat losses include—heat loss through the fabric including loss at thermal bridge and ventilation losses.

As this is an energy balance then all the losses and gains must equate to zero.

$$\sum Q = 0$$

By working out all the other loads and gains associated with the building, the heating load can be specified. Once heating load has been determined the heating energy consumption is found from

$$Q_h = Q_l - \eta Q_g$$

Where Q_h is heating energy demand, Q_l the total losses and Q_g total gains. The factor of η is added to account for the non steady state nature of the gains over time t and is a “utilisation factor” (which partly takes into account the thermal capacity of the building). While the actual heating load calculation may be complex, the approach taken is ultimately a simplification of reality. The detail of the heating energy calculation can be found from the Building Regulation 2002, Part L (Development and Housing, 2002).

Table 2 shows the case study houses which are categorized into 10 housing classes in term of floor area, housing age and type and insulation standards according to Building Regulation 2002. U-values measures how well a building component, e.g. a wall, roof or a window, keeps heat inside a building. The higher the U-value the more heat that is lost to the exteriors. In this study, the new houses built after 2000 were considered to have better insulation than the older housing stock built period to the 1990s, primarily due to the Building Control Regulation 2000 (Development and Housing, 2000).

The potential percentage of reducing energy demand for space heating with different climate and insulation scenarios is shown as Figure 10. To test the potential impact of installing energy efficient measures in buildings, two insulation scenarios were chosen, cavity wall insulation and double glazing. The U-value was considered as 0.15 W/m^2K for walls and 0.1 W/m^2K for windows in the thermal analysis. It can be seen that apartments are more sensitive to climate and insulation standards than houses. If temperature increases by 1ºC, the energy demand for space heating decreases by 8%. These results indicate heating energy demand may decrease 15%-28 with a temperature increase of 1ºC combined with improved insulation. If insulation standards on houses built before 1990 were improved, an opportunity exists to save energy and reduce the overall energy demand. The thermal measures may have more impacts on the energy saving than climate variables.

6. Conclusions

In this study, a methodology for assessing energy demand responses to climate change, with daily climate data and daily energy consumption data, has been developed. Results indicate that residential energy

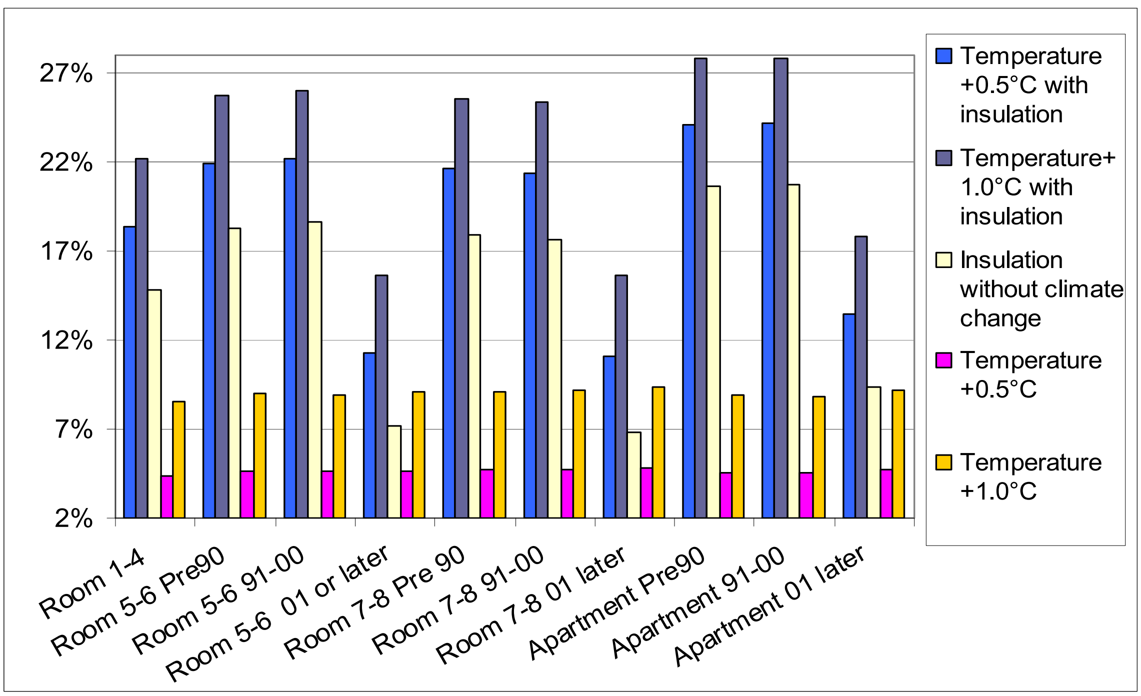

Fig. 10. Climate change impact with the insulation improvement

demand in the Greater Dublin region are sensitive to climate and that a range of future climate scenarios of climate change may noticeably decrease winter heating energy demands. For example, the scenarios for 2030 and 2080 project to decrease residential energy demand during the winter months by 15% and 23%, respectively, relative to the energy demand in 2005. The impact of building insulation standards was also analyzed. The results show that significant savings on energy demand for space heating can be achieved with the improvement of the thermal properties of building and temperature increasing.

Irish energy policy recognizes the need to reduce energy consumption to meet both strategic and environmentally driven policy goals. The domestic sector may offer significant opportunities for reducing the overall demand. Many of the potential options available for improving the thermal performance of existing residential dwellings have long asset lives and could be particularly sensitive to climate variations. Further topics of major importance will be addressed to initiate a discussion of the climate change impact on the performance of energy efficiency measures for building.

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