Ex-post evaluation of a residential energy efficiency policy measure using empirical data

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Abstract

This paper presents an ex-post evaluation of residential building regulations for new dwellings in Ireland in terms of the energy savings that can be attributed to the policy. According to an ex-ante evaluation, the 2002 Building Regulations were expected to achieve a 20 % reduction in dwelling energy consumption compared to the previous building regulations in place since 1997. The current analysis uses metered consumption data for gas-connected dwellings to quantify the actual impact of the 2002 Building Regulations as compared to a control group of 1997 Building Regulation dwellings. Initial results focused on semi-detached dwellings in Dublin and found a substantial shortfall in the expected energy savings with a statistically significant reduction in energy consumption of just 10.1 %. A separate analysis on the level of compliance with the 2002 Building Regulations, for semi-detached dwellings in Ireland, found an 11.7 % level of non-compliance, higher than the EMEEES default value for non-compliance of 10 %.

Introduction

Increasing concerns with human induced climate change and future energy security has seen a renewal of policies aimed at reducing energy demand in all sectors of the economy (EC 2006). Between 1990 and 2008, final energy consumption in the EU12 grew by 15.7 % and in Ireland by 79.5 %; during the same period, energy growth in the household sector was 16.4 % in the EU12 and 31.5% in Ireland (Eurostat 2011). There are now in place ambitious policy targets that seek to address this energy growth in all sectors: the 2006 Energy Services Directive (ESD) has committed all EU27 member states to a 9 % reduction in total final energy consumption by 2016 (EC 2006) and the 20/20/20 climate package has set a target for each member state to reduce its energy demand by 20 % by 2020 (EC 2008). According to the Irish National Energy Efficiency Action Plan (NEEAP) drawn up to meet both these targets, there will be a significant contribution from the residential sector and a substantial contribution made as a result of building regulations for new dwellings (SEAI 2009).

Building regulations to ensure a minimum standard of energy efficiency in residential dwellings have been in place in Ireland since 1979 (OLeary, Howley et al. 2008). From that time to the present day, the stringency of the building regulations has been steadily increased. The 2002 Building Regulations were designed to achieve a 20 % reduction in energy consumption compared to the 1997 Building Regulations (DEHLG 2002) and more recent regulations introduced in 2008 were designed to achieve a 40 % savings compared to the 2002 Building Regulations (DEHLG 2008). Ireland's NEEAP contains descriptions of further buiding regulations that would achieve 60 % dwelling energy savings, again compared to 2002 (SEAI 2009). Other countries have successfully used new dwelling building standards to address growing energy demand. The US state of California has historically one the strictest building code regimes in the world (Laustsen 2008) and this has helped California maintain energy demand at relatively flat levels (Chang 2006).

Currently, residential building regulations constitute a major part of Ireland's energy savings targets with this policy alone projected to capture 14.4 % of all of Ireland's NEEAP energy savings

Table 1: U-values for 1997 & 2002 Building Regulations.

U-value (W/m^2 K)	1997 Building Regulations	2002 Building Regulations
Windows/Roof-lights	3.3	2.2
Doors (average for all doors)	3.3	2.2
Floor (ground or exposed)	0.45	0.25
Walls (exposed)	0.45	0.27
Roof	0.25	0.2

Table 2: Heat energy rating method for building regulation compliance.

Maximum Permitted Heat Energy Rating (kWh/m2/yr)	102.5	101.4	99.0	92.6	88.2	83.8	81.6
Dwelling Heat Loss Area/Building Volume (m-1)	1.25	1.2	1	0.8	0.6	0.4	0.3

in 2020 (SEAI 2009). In spite of these ambitious targets, there has been to-date no publically available ex-post evaluation of how efficacious Irish building regulations have been at achieving their target energy improvement. Although Ireland's NEEAP did model historical energy savings for the period 2002-2008, it was not based on empirical data (Rogan 2009). The question remains, how effective have building regulations in Ireland been at saving energy? This paper attempts to answer that question, by quantifying the energy savings of the 2002 Building Regulations using empirical data and using the 1997 Building Regulations as baseline. The level of compliance with the 2002 Building Regulations will be also quantified and evaluated.

The paper is organised as follows: Section 2 presents a brief review of building regulations, which is divided into a description of building regulations in Ireland, a survey of EU and international methodologies for evaluating the energy savings of building regulations and finally a literature review of some other case studies that ex-post evaluate building regulations in other countries. Section 3 describes the data that was used in this analysis, the work that was done to clean and prepare the data and the assumptions accompanying the final data sets. Section 4 outlines the methodologies used to evaluate the 2002 Building Regulations in terms of energy savings and level of compliance. Section 5 presents results and Section 6 provides a discussion of the results and concludes with recommended further work.

Building regulations

This section reviews building regulations as they exist in Ireland; it describes how this policy achieves energy savings, and how compliance is calculated. The section then reviews some of the evaluation methodologies for calculating ex-post performance of building regulations, both in the EU and internationally. The section closes with a literature review of some case studies that have already calculated building regulation energy savings.

BUILDING REGULATIONS IN IRELAND

Throughout the 1980's and 90's, the energy conservation element in building regulations in Ireland was steadily improved with increasingly stringent U-values for building fabric elements (OLeary, Howley et al. 2008). An implementation period for building regulations is typically between six months to a year and enforcement is at a local level. The legislation documents are accompanied by a Technical Guidance Document (TGD), which contains practical and detailed information on dwelling design, construction and standards for a host of building properties such as maximum heat loss values for separate building elements, thermal bridging limits, maximum air filtration rates, minimum insulation thickness, etc.

The 2002 Building Regulations succeeded the 1997 Building Regulations, and contained U-values which, by being more stringent than the previous building regulations, provide for a 20 % reduction in dwelling energy consumption (DEHLG 2002), see Table 1. The 2002 TGD contained three methodologies for meeting the new minimum energy standard: (1) a maximum average U-value for the entire building, (2) maximum individual U-values for separate building elements, or (3) a heat energy rating standard, which relates the maximum permitted $kWh/m^2/yr$ to the quotient of building heat-loss area (m^2) and building volume (m^3), see Table 2 (DEHLG 2002).

The EU 2002 Energy Performance of Buildings Directive imposed a number of requirements on Ireland, one of which was an updated methodology for evaluating building regulations. In Ireland, the Dwelling Energy Assessment Procedure[1] (DEAP) was developed to meet this requirement. The 2005 Building Regulations were updated to incorporate the DEAP methodology for assessing building regulations (DEHLG 2006). In 2007, the DEAP software programme also became the default methodology for determining the energy asset rating, or Building Energy Rating (BER) of a dwelling (DEHLG 2006). The DEAP programme will be discussed in more detail in the Methodology section.

EVALUATION METHODOLOGIES

There are many good arguments in favour of standardization with regard to measuring energy efficiency. A proven methodology will ensure confidence and interpretability to the results. It will also maximize the usefulness and accuracy of results as can be used in energy modelling of scenarios and in international reports such as the IPCC. A reliable methodology will also give every chance to financial backing, by minimizing the uncertainty due to methodological inconsistencies. However, while there is no universally accepted standard, there are a number of methodologies, some of which are proposing themselves as standards, in the public domain:

1. Available for free download at http://www.seai.ie/Your_Building/EPBD/DEAP/Download/

- ESD on Energy End-Use Efficiency
- EMEEES
- European Ex-Post Evaluation Guidebook
- IPMVP

ESD on Energy End-Use Efficiency

While the current Irish building regulations contain a methodology for assessing compliance, the first specific obligation to report on energy savings achieved came from the 2006 ESD on Energy End Use Efficiency (EC 2006). The ESD required each member state to prepare a National Energy Efficiency Action Plan (NEEAP) that would achieve a 9 % reduction in energy consumption in 2016, relative to 2008. As part of this plan, rigorous measurement on the progress towards the 9 % reduction target must be reported on an interim (2011) and final (2016) basis (EC 2006). This report is required to have "a thorough analysis and evaluation of the preceding EEAP", which will include "the final results with regard to the fulfilment of the energy savings" calculated according to a framework that measures energy with bills or energy sales data, is normalized for weather, occupancy, etc. and accounts for uncertainty in a statistically quantified way (EC 2006). While the ESD requires a certain degree of rigor, it doesn't contain specific detail on measuring and verifying energy savings from particular types of policies. In November 2006, the Evaluation and Monitoring for the EU Directive on Energy End Use Efficiency and Energy Services (EMEEES) project was launched specifically for this purpose (EMEEES 2009).

EMEEES

The EMEEES project was set up to produce harmonized indicators that will enable cross country comparison, as stipulated in the ESD (EC 2006). As of April 2009, it had finished its work and had produced many reports on how to measure energy savings for specific energy policies. EMEEES has a detailed description of how evaluate and report on building regulations: savings are calculated with respect to a baseline that effectively excludes autonomous development of energy efficiency measures; the baseline is the situation in a member state at the moment when the building regulations are implemented for the first time and it is not dynamic; a time-lag, with a default value of two years, must be taken into account for new building regulations to take effect in building production; non-compliance with the building code should also be taken into account and a default value of 10 % is recommended unless empirical data can substantiate another value; square metre of conditioned floor space is the preferred unit of measurement rather than dwellings or buildings as a unit; the rebound effect is not taken into account (Maas and Monne 2009). Unlike the ESD itself, this guide doesn't contain any detail on quantifying or expressing uncertainty.

European Ex-Post Evaluation Guidebook

The European Ex-Post Evaluation Guidebook for DSM and EE Service Programmes was produced by SRC International in 2002 and was co-authored by a committee of mostly European energy experts (International 2001). It doesn't contain measure specific methodologies but it does contain methodologies that can be adapted to different measures depending on the level of accuracy required and the amount of data that is available.

The Guidebook proposes a two-way taxonomy of evaluation methods. The first method is an "engineering simulation", which is best used to quantify the ex-ante impact of a measure. The second method is "statistical" with a number of variations: the simple comparison can be a time-series comparison, which is expressed as the same people at different times, or a cross-sectional comparison, which is expressed as different people at the same time. There is also a weather-adjusted comparison and the last statistical method suggested is a multivariate analysis, which the Guidebook deems the most accurate method (International 2001).

IPMVP

The International Performance Measurement & Verification Protocol (IPMVP) is an international measurement and verification standard maintained by the Efficiency Valuation Organization. It is now a much used international standard for verifying energy efficiency savings (Vine 2005). It has three volumes: Volume III, Part I is "Concepts and Practices for Determining Energy Savings in New Construction," a 34-page report on evaluating the efficacy of building standards for energy savings for both commercial and residential buildings. Volume I of IPMVP "Concepts and Options for Determining Energy and Water Savings" contains an extensive appendix for quantifying uncertainty in energy efficiency programmes.

CASE STUDIES

Case studies of residential energy efficiency in the literature tend to favour retrofitting and improvement of existing dwellings over building regulations for new dwellings. Despite the growing reliance on building regulations as a policy for addressing energy demand of the residential sector, there has been to-date a shortage of case studies examining their ex-post impact (Jacobsen and Kotchen, 2009). The papers that do exist, offer different results of dwellings both achieving and under-achieving their building regulation target savings. This divergence of results highlights the need for more ex-post analysis since there is little certainty about how building regulations will achieve their respective ex-ante targets.

In a US study that examined the period from 1979 to 1988, it was concluded that the building codes under investigation had no effect on energy consumption; this result was deemed in-part to stem from the codes not being strict enough (Jaffe and Stavins 1995). On the other hand, a study on a sample of Florida dwellings in a single town for both gas-connected and electricity-connected dwellings found that the actual performance was "reasonably close" to the predicted improvement of 4 %, as calculated by an engineering simulation. The authors noted that the state of Florida is "known to have generally strict enforcement of building codes" (Jacobsen and Kotchen 2009). In a study of German dwellings after 1961, it was concluded that dwellings were under-achieving their energy targets because their insulation levels were far below the technical simulation (Schuler, Weber et al. 2000).

Case studies on where the shortfall is, in terms of behaviour aspects such as rebound or building regulation non-compliance are rare but important. For space heating in Austria, (Haas and Biermayr 2000) determined a 20-30 % rebound value and in the context of the rebound effect value "eating into" energy savings, concluded that building regulations remain one of the most im-

portant energy policies. Vine conducted a survey of compliance with building regulations in three US states[2] and found evidence for varying levels of compliance that corresponded with the existence or absence of utility-sponsored residential new construction programmes, which offer credits to builders to exceed the minimum building regulation standards (Vine 1996).

Data

The evaluation period for the 2002 Building Regulations was from 2004, when they were deemed to be fully implemented, until 2009, when a newer set of building regulations[3], introduced in July 2008, had supplanted them. Four separate data sets were available for this five year evaluation time period:

1. Metered gas consumption
2. Building energy ratings
3. Dwelling floor area
4. Degree days

METERED GAS CONSUMPTION

Bord Gáis Éireann[4] provided the authors with a data set of metered consumption for all residential gas customers for each year between 1990 and 2009: in 1990, there were 139,000 customers and in 2009, 566,000 customers; since this data set contains all gas customers, in data terms it is a population rather than a sample. For each customer, the data set included (1) the metered gas consumption for each calendar year; (2) the type of dwelling; (3) the number of bedrooms in the dwelling; (4) the date the dwelling was connected to the gas grid and (5) an anonymised district level address.

Data preparation: Prior to this data set being used in this analysis, some filtering and preparation was necessary: firstly, to remove outliers, 2.5 % of the largest and 2.5 % of the smallest values were trimmed from the data set; then, any outstanding negative values were removed; finally, vacant dwellings were identified as dwelling without consumption or with zero consumption for any full year, and were removed.

Assumptions: It was assumed that the year-of-connection to the gas network, as specified in the above data set, was the same as the year-of-construction of the dwelling.

BUILDING ENERGY RATING

Since 1st January 2007, all new dwellings for sale or for rent in Ireland must have a Building Energy Rating (BER). On 1st January 2009, this requirement was extended to include all existing dwellings for sale or for rent (DEHLG 2006). Sustainable Energy Authority of Ireland (SEAI) is the supervisory authority responsible for managing the BER process and as part of this role they retain records of every BER assessment. An anonymised database of all BER records for the period 13/09/2007 to 01/07/2010 was provided to the authors. Each entry was generated first in DEAP[5] according to the BER methodology and the database of 125,000 records was then compiled in Microsoft Excel. A list of the main parameters used by the DEAP methodology to calculate the energy rating of a dwelling is contained in the Annex.

This data set contained nearly every field contained in a BER assessment and as a sample, represents 7 % of all dwellings in Ireland. Due to the fact that BERs have been a requirement for new dwellings for three years and existing dwellings for only one year, the data set is far more representative of newer dwellings (e.g. dwellings constructed 2001-2008 are a 24 % sample whereas dwellings constructed 1996-2000 are just a 10 % sample).

Data preparation: A considerable amount of filtering and entry-removal was required before the BER database could be used as a data set. This was done in collaboration with SEAI. A selection of the entries removed is presented below, a full account is in the Annex. The approach generally was to remove outliers that differed substantially from the average. Erroneous values were also identified and removed.

- Rating type = Provisional
- Total floor area < 30 m^2 or > 1,000 m^2
- Heating system efficiency <20 %
- Living area percent[6] >=90 % or < 5 % or = Null

Assumptions: For the purposes of calculating compliance with building regulations it was assumed that although the sample is non-random, since it is sufficiently large, it is sufficiently representative of the stock of dwellings under examination.

DWELLING FLOOR AREA

Data on dwelling floor area in Ireland is currently available from a data set of successful planning permission applications (OLeary, Howley et al. 2008). All dwellings built in Ireland must first receive planning permission from the local planning authority. The total dwelling floor area from all successful applications is compiled by the Central Statistics Office (CSO). Using date of application, dwelling type and county, this data can be linked to other data on dwelling energy consumption. The planning permission database is based on population averages (CSO 2009).

Data preparation: Data was missing for all dwelling types in 1999 and the first half of 2000 and was also missing for semi-detached dwellings for the years between 1990 and 2002. Linear interpolation was used to fill in the missing fields. In order to account for the difference between date of application and date of construction, a lag of one year was applied to the data.

Assumptions: Although not all dwellings that successfully receive planning permission are built, it is assumed that the great majority are built and so this data is representative of the actually constructed dwellings. When the data is linked to energy consumption for a particular dwelling, it is assumed that floor area is assumed to be linearly proportional to energy consumption (D. Dineen 2010).

2. California, Oregon and Washington

3. The implementation period for the 2008 Building Regulations was shortened to 12 months.

4. During this time, Bord Gáis Éireann was the only supplier of natural gas to the residential market in Ireland.

5. There are approximately 1,000 registered BER assessors in Ireland at present and this database is a compilation of all the assessments of these assessors.

6. Defined as floor of living area divided by total floor area; living area is defined as the floor area of the largest public living room, which is defined as a room for general social and leisure activities. For a more detailed explanation see SEAI (2008). Dwelling Energy Assessment Procedure (DEAP) 2008 EDITION, VERSION 3.1 Irish official method for calculating and rating the energy performance of dwellings. Dublin, Sustainable Energy Authority of Ireland.

DEGREE DAYS

In order to weather correct the gas consumption data, degree day data for Ireland was retrieved from Met Éireann. This methodology adopted the weather correction methodology as set out in Eurostat's "Temperature correction of final energy consumption"(EC 2005).

Methodology

The methodology chosen to evaluate the 2002 Building Regulations has two parts. The first part was comparing the metered gas consumption data of two appropriate groups of dwellings: one group of dwellings, built to the 2002 Building Regulations and a second group, built to the previous regulations, which in this analysis are the 1997 Building Regulations. The key to this approach was normalizing the two groups of dwellings for all energy-significant differences between them and in this way the actual impact of the building regulations could be quantified. In this Methodology section, the following sub-sections as found below are pertinent to this first part of the methodology: control group and treatment group; group normalization; checking the data; independent sample T-test.

The second part of the methodology was examining the dwellings built to the 2002 Building Regulations in terms of an energy asset, using the BER data set. The purpose of this step was to quantify the impact of building regulation compliance as distinct from the impact of behaviour which is included in the first step. The last sub-section below, Building regulation compliance covers this second part of the methodology.

For both parts of this methodology, the semi-detached dwelling is the dwelling type investigated. In Ireland, the semi-detached dwelling is typically two-storey, has one or two walls adjoined to another dwelling, has three to four bedrooms and its average size ranges between 90 m^2 and 140 m^2. Although the dwelling type (semi-detached) and fuel consumed (natural gas) is the same in both parts of the methodology, because one part is using consumption data and the other part is using BER data, the two methodologies give different energy consumption results for ostensibly the same dwelling type. This is because the two data sets are generated separately to each other and for alternative purposes than the analysis at hand; for annual dwelling consumption, the metered consumption data set, for a semi-detached dwelling has an average value of 12.08 MWh, whereas the BER data set, for the same dwelling type, has a value of 32 MWh. The purpose of the BER calculation is to derive an 'asset rating' that will make the dwelling comparable to other dwellings. As such, it has standardized assumptions about the use of that building in terms of occupancy and internal temperature. There are limitations with using the BER data set in modelling actual energy consumption and it is intended in the future to build a better relationship between the BER data set and the metered consumption data set.

Many parts of the methodology were taken from the documents described in the Evaluation Methodology section and where this was done, will be highlighted; key differences in methodology and results will also be highlighted. The software chosen was Microsoft Excel 2008 for data storage and data filtering and IBM PASW 18 for all statistical testing and manipulation.

CONTROL GROUP AND TREATMENT GROUP

The methodology chosen was to compare a group that hadn't adopted the policy (control group) to a group that had adopted the policy (treatment group). This methodology is a composite of the cross-sectional comparison and the weather-adjusted comparison methods described in the European Ex-Post Evaluation Guidebook (SRCI 2001). Fundamental to this approach is that the two groups "share a wide variety of characteristics" (International 2001). Working from the metered gas consumption database, the control group and treatment group were examined for the same year of consumption (2006) and both groups were defined by the same dwelling type (semi-detached), bedroom number (three) and location (Dublin).

The key difference between the groups, by which the impact of the building regulations was pinpointed, was dwelling connection year. The control group, dwellings built to 1997 Building Regulations, were chosen as dwellings connected in 1998. The 1997 Building Regulations themselves allow six months for implementation (DEHLG 1997), so a one-year lag was applied to allow that set of building regulations come fully into force. The treatment group, dwellings built to the 2002 regulations, was defined as dwellings connected in 2004; although the 2002 regulations were legally in force from 1st January 2003, there was a waiver for certain dwellings completed after this date if planning permission had been granted before the 1st January 2003 cut-off point (DEHLG 2002), so 2004 was deemed to be an appropriate year when the 2002 Building Regulations would be fully implemented.

It was also necessary to investigate whether the gas consumers in each group used other heating types as well, i.e. were their dwellings only partially heated by natural gas? Since the metered consumption data set didn't contain information on non-gas heating sources, a separate data set was utilized. For semi-detached dwellings in Dublin, with natural gas as the main heating type, the BER database contains a 9 % sample for 1998 dwellings and a 2 % sample for 2004 dwellings. For each dwelling assessed, it contains data on fuel types used as main and supplementary, space and water heating. For dwellings built in 1998, a 55 % share had natural gas as a secondary space heating fuel and main water heating fuel; for the same dwellings built in 2004, a 56 % share had natural gas as a secondary space heating fuel and main water heating fuel. This small difference, suggests that both the control group and the treatment group dwellings had very similar share of natural gas in their fuel mix.

The population of the control group was approximately 5,000 and the population of the treatment group was approximately 6,000. All of the original dwellings from the control group (connected in 1998) and the treatment group (connected in 2004) were found to be still connected in 2006. As was stated in the Data section, the metered consumption data sets are populations, so both the control group and treatment group include all dwellings in their respective categories. This mitigates possible variation between the groups that inappropriate sampling would cause. However, due to a lack of survey, it wasn't possible to characterize the two dwelling groups according to their occupants in terms of energy behaviour and income levels.

GROUP NORMALIZATION

Once the control group and treatment group were defined so as to share many characteristics, the two groups were normalized such that any outstanding differences between the groups,

Table 3. Statistical tests of integrity.

	1997 BR	1997 BR (sqrt)	2002 BR	2002 BR (sqrt)
Kurtosis	3.28	1.17	3.68	1.07
Skewness	1.15	-0.23	1.32	0.7

except that of building regulations, were excluded. This meant normalizing for floor area and weather. For floor area, the planning permissions data set was used. Finally, a weather correction using degree days was applied to the data.

Dwelling floor area

Since the primary data source in this analysis, the metered gas consumption, does not contain any linked data field on floor area it had to be externally sourced and linked to the consumption data. In terms of connection year, there are six years between the control group and the treatment group, and it is known that average floor areas for houses[7] in Ireland have increased by 6 % during this time (CSO 2010), making it essential to normalize the two groups for floor area. As outlined in the Data section, floor area data was linked to the consumption database but certain properties of the planning permission database add uncertainty to the final result.

Weather correction

In weather terms, 2006 was a mild year, with 1,971[8] national degree days and so required minimal weather correction. As per (EC 2005), a regional weather adjustment was applied to the data, rather than a nationally weighted average. This enabled a weather correction specific to the Dublin region, one of the defining properties of the control and treatment groups. The weather correction was applied to Dublin as a whole, no climatic variation within the Dublin region was incorporated in this analysis. The degree days for Dublin airport for 2006 were 2,124, 8 % higher than the nationally weighted degree day figure for Ireland in 2006.

CHECKING THE DATA

Before any statistical tests could be applied to the data to check the differences between the control group and the treatment group, the data itself had to investigated and characterized. The first task was to check the data for normality.

Testing for normality

An initial visual assessment of both the control group and treatment group showed that both distributions were significantly negatively skewed and had long positive tails. A number of data transformations were explored and a square root transformation was found to produce a normal distribution. A condition of using the square root transformation was cleansing the data of values less than one, as their presence would disturb the resulting transformation (Osborne 2002). The square root transformation significantly improved the kurtosis and skewness of the data, see Table 3. A Kolmogorov-Smirnoff test for normality was successful at 5 % significance. These results favoured a parametric test.

Homogeneity of variance

Before any comparison could take place between the two groups, it was important to analyze the variance in both groups for the level of differences in the variance between the groups would determine what statistical test was appropriate. Levene's test for homogeneity of variance was used and for each group, was successful at 5 % significance. This effectively characterized both data sets as homoscedastic.

INDEPENDENT SAMPLE T-TEST

The successful findings in the previous section indicated that a parametric test was an appropriate test for this data. Therefore, the independent sample T-test was used for comparing the means of the two independent groups. The test was performed in IBM PASW 18 at 5 % significance level, which included measures of standard error and thus enabled the calculation of precision as required by the ESD (EC 2006) and recommended by the IPMVP (EVO 2007). This comparison effectively pinpointed the differences between the groups in terms of the impact of building regulations.

BUILDING REGULATION COMPLIANCE

A separate methodology and data source was used to quantify the level of compliance of the 2002 Building Regulations; the methodology was an engineering simulation and the data source, the BER database. The baseline for an assessment of non-compliance with the 2002 Building Regulations was full compliance with the same regulations. This was modelled by calculating the energy consumption of a dwelling according to full compliance with maximum U-values. Comparing this baseline to the empirical situation, as determined from the BER database, enabled the quantification of the level of building regulation compliance.

DEAP

As described in the Building Regulation section, DEAP is the software now used in Ireland to determine the Building Energy Rating (BER) of a particular dwelling and its compliance with the 2005 or 2008 Building Regulations. The 2005 Building Regulations, that DEAP measures compliance with, are in U-values terms, effectively the same as the 2002 Building Regulations. The only difference between these two sets of regulations is a minimum boiler standard required by 2005 Building Regulations and the use of the DEAP software to measure compliance.

DEAP is an engineering simulation programme that calculates the energy performance of a dwelling using a large variety of input data for such parameters as floor area, dwelling orientation, glazing area, building element U-values, heating controls and a host of other factors. A more complete list can

7. Houses defined here as all detached, semi-detached and terraced dwellings.

8. Average annual national degree days for the period 1990–2008 was 2,035.

Table 4: U-values used for Building Regulation Compliance Investigation.

U-value (W/m2 K)	2002 BR (full compliance)	2002 BR (BER empirical values)
Windows/Roof-lights	2.2	2.12
Doors (avg for all doors)	2.2	2.53
Floor (Ground or Exposed)	0.25	0.3
Walls	0.27	0.36
Roof	0.2	0.22

Table 5. T-test results.

	1997 BR (MWh)	2002 BR (MWh)	ΔMWh	Δ%
Actual	13.43	12.08	1.35	10.1%
Target		10.75	2.68	20%

be found in the Annex. It incorporates standardized values for occupancy, internal temperature and heating usage patterns. It also incorporates many calculation methodologies and data tables from the equivalent UK programme: Standard Assessment Procedure (SAP).

As per the control group and treatment group shared characteristics, the dwelling type chosen was semi-detached. The semi-detached dwelling is not intended to be representative of other dwelling types, it was chosen for investigation as it represents the largest share of new dwellings (DEHLG 2010). In this paper, it is indicative of possible levels of compliance in other dwelling types. In future work, it is intended to separately investigate each dwelling type for levels of non-compliance.

Two simulations were run: one representing the baseline situation of full compliance and the other approximating the reality. The two simulations shared characteristics that were not stipulated by the building regulations, but that do determine energy consumption, e.g. floor area, dwelling orientation, number of chimneys and open flues, living area percentage. A subset of the BER database, dwellings constructed in 2004, 2005 or 2006, was generated. From this subset, average values for all BER parameters were data mined and used to populate the both the 2002 BR (full compliance) simulation and the 2002 BR (BER empirical values) simulation. The only difference between the two simulations was the U-values, see Table 4; for all other parameter values, see Annex. For the baseline the U-values were taken from the 2002 Building Regulation TGD, the maximum values allowed according to the elementary heat loss methodology; for the simulation representing the empirical reality, these values were taken from the BER database.

Results

The two part methodology, as described above, produced two notable results. The first was for the T-test that compared the control group to the treatment group. The results indicate to what extent the 2002 Building Regulations have achieved the target of a 20 % reduction in dwelling energy consumption. The second result quantified the level of compliance with the 2002 Building Regulation; this empirical result will be compared to the default level of non-compliance found in the EMEEES report of building regulations.

T-TEST

According to the independent sample T-test, for a gas connected, three-bedroom semi-detached dwelling in Dublin, the difference in average gas consumption during 2006, for a dwelling constructed to 1997 Building Regulations to a dwelling constructed to 2002 Building Regulations was substantially below the expected improvement. The target saving per dwelling was 2.68 MWh, whereas the mean saving, with 95 % confidence was just 1.35 MWh±20.3 %. While the target improvement per dwelling was a 20 % reduction, there has only been a 10.1 % improvement, see Table 5. Before an investigation of this discrepancy is undertaken, the uncertainty associated with this result will be outlined.

For the 2002 Building Regulations, the baseline for a 20 % improvement was the 1997 Building Regulations. The baseline used in this study, comprised dwellings built to those regulations, but it is possible that since original construction of 1997 dwellings, further work has been done to them to upgrade their energy efficiency. That both groups have a similar normal distribution as shown in the Checking the data section suggests that this is minimal, but this is only an indicative result. The EMEEES guideline for assessing building regulations in new dwelling specifies a zero level for autonomous improvement (Maas and Monne 2009). Other potential differences between the treatment group and the control group are the impact of different incomes and the difference in occupancy. Possible next steps for investigating these issues further are included in the Discussion section.

LEVEL OF COMPLIANCE

For a semi-detached dwelling constructed to the 2002 Building Regulations, the normalized average consumption, according to DEAP simulation should be 29.1 MWh. This is the baseline, i.e. what the dwelling energy consumption should be with full building regulation compliance. The actual performance of the 2002 Building Regulations, according to the data from the BER database, was 32.5 MWh. Compared to the target consumption, this represents a total energy consumption of 111.7 %, see Table 6, which is higher than the default value of 10 % as recommended in EMEEES (Maas and Monne 2009). The purpose of the high EMEEES default value was to encourage data gathering and empirical analysis that would generate a more accurate result for building regulation non-compliance. As far as the authors are aware, there has been no publically available work on the level of compliance in Ireland.

Table 6. Level of compliance results.

	Annual Energy Consumption (MWh)
2002 BR (BER empirical values)	32.5
2002 BR (full compliance)	29.1
ΔMWh	3.4
Non-Compliance	11.7%

Discussion

IMPLICATIONS

While paying due regard to the uncertainty in the above results, they nevertheless give an indication that the 2002 Building Regulations are significantly underperforming in terms of energy conservation. This has many implications. If the value of the dwelling can be said to include the energy efficiency of that dwelling, then many dwellings in Ireland are overvalued, since their level of energy efficiency is below what their building specification would suggest. This implies a potential requirement for investment in energy efficiency simply to achieve the targeted BR level.

There are also implications for future policy. The current system of enforcement, building craftsmanship or resident behaviour has not been successfully addressed by policy. Newer building regulations have by and large increased the severity of the energy savings but have done nothing to ensure compliance. There is therefore a risk that there will be a growing divergence between the actual energy performance of a dwelling and the stipulated energy performance according to the appropriate building regulations.

Finally this has implications for energy modelling. Current assumed defaults will need to be updated and the behavioural aspect can no longer be ignored with future energy projects. In terms of energy targets too: in order for Ireland to meet the targets as stated in the Energy Services Directive, it will need to either improve and outperform targets or make up lost ground with other policy instruments.

CHALLENGES

The key challenge in conducting an ex-post analysis is sufficient data to reach robust and useful conclusions. This study was greatly enabled by access to a metered consumption data set for all natural gas consuming households in Ireland. However there remained limitations with this large data-set. Appropriate survey containing information such as how space heating is used, i.e. what internal temperatures are and how the dwelling is heated would have greatly aided the analysis.

MERITS

The key merits in ex-post are the results and conclusions. The findings in this study, suggest that the 2002 Building Regulations in Ireland have not met their targets and that this is both a dwelling resident behavioural issue and a building regulation compliance issue. Appropriate policy intervention to address these matters is critical if building regulations are going to contribute more significantly to energy reduction targets.

FURTHER WORK

There are a great number of aspects that need further work and in no way is this analysis final. The degree of autonomous improvement should be assessed in both the treatment group and the control group. This could be done by investigating the skewness of the distribution for each group over time. A static skewness coefficient would verify flat autonomous improvement. This is particularly important for the control group, the 1997 Building Regulations, which is effectively the baseline in this analysis.

Continuous improvement of the robustness of the current T-test and data transformation methodology are also in order. Possible use of non-parametric statistical tests on data that hasn't been transformed could offer a degree of check on the parametric T-test. Once there is sufficient confidence in the statistical work it will be in order to combine the T-test results with the compliance level results. The purpose here will be to decompose the discrepancy of the building regulations energy savings targets into non-compliance and by process of elimination, consumer behavioural impacts.

There is other work that can be done which will add data into the analysis and use other data to broaden the analysis. For the former this will mean incorporating floor area into the precision figure for uncertainty and completing a full sensitivity analysis. In the Results section, the uncertainty associated with personal incomes was mentioned. This factor could be normalized for by exploiting known work that has been done in Ireland on personal income according to different electoral areas.

Finally, as was stated in the Methodology section, this work has hitherto focused exclusively on semi-detached dwellings and for the consumption data, in the Dublin area only. The analysis, once robust, could be readily extended to include other dwelling types and all counties in Ireland. The results of this could help in the energy balance calculations and energy forecast figures that look at the aggregate impact of energy policies.

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Annex

Appendix Table 1: Removed Values from BER database prior to use in this analysis.

Parameter	Number of Entries Removed
MainFloorArea < 5m^2	93
TotalFlootArea < 30m^2	1,033
TotalFlootArea > 1,000m^2	10
RatingType = Provisional	2,501
Terrace or Semi-Detached Dwelling with TotalFloorArea > 500m^2	4
DwellingType = House	14,663
HSMainSystemEfficiency < 20%	2,424
HSEffAdjFactor < 0.7	41
WHMainSystemEff < 20% & > 450%	14
WHEffAdjFactor < 0.7	11
HSSupplSystemEff ≠ Null, 0 or <b19%	167
LivingAreaPercent >=90% or < 5% or = Null	139
HSSupplHeatFraction ≠ Null, 0, 0.1, 0.15, 0.2	434
DeclaredLossFactor > 20	152
Thermal bridging factor < 0 or > 0.15	29
YearConstructed = 2009 or 2010	3,854
Negative Energy Value	1,155

Appendix Table 2: Main Inputs for BER Compliance Simulation.

Parameter	2002 BR (full compliance)	2002 BR (BER empirical values)
Dwelling type	Semi-Detached	Semi-Detached
Total floor area (conditioned)	104m^2	104m^2
Living area	20m^2	20m^2
Number of chimneys	0.43	0.43
Number of open flues	0.24	0.24
Number of intermittent fans and passive vents	6.24	6.24
Number of flueless gas fires	0.23	0.23
No. of storeys	2	2
Structure type	Timber or steel frame	Timber or steel frame
Percent of windows & doors draughtstripped (%)	97	97
No. of sides sheltered	2	2
Ventilation type	Natural ventilation	Natural ventilation
Dwelling orientation	SE/SW	SE/SW
Window area (m^2)	86.47	86.47
Window U-value (W/m^2 K)	2.2	2.12
Exposed door area (m^2)	36.84	36.84
Exposed door U-value (W/m^2 K)	2.2	2.53
Exposed floor area (m^2)	56.9	56.9
Exposed floor U-value (W/m^2 K)	0.25	0.3
Exposed wall area (m^2)	999	999
Exposed wall U-value (W/m^2 K)	0.27	0.36
Exposed roof area (m^2)	603	603
Exposed roof U-value (W/m^2 K)	0.2	0.22
Thermal bridging factor (W/m^2 K)	0.14	
Water storage volume (l)	138	138
Insulation type	Factory insulated	Factory insulated
Insulation thickness	35.18	35.18
Proportion of low-energy light bulbs (%)	36	36
Thermal mass category	High	High
Heating system control category	2	2
Heating system responsiveness category	1	1
Central heating pump	1	1
Oil boiler – pump	2	2
Gas flue pump	0	0
Efficiency of main space heating system (%)	80	80
Fraction of heat for supplementary heating system (%)	10	10
Efficiency of supplementary space heating (%)	30	30
Main space heating type	Natural Gas	Natural Gas
Supplementary space heating type	Solid Multi-Fuel	Solid Multi-Fuel
Efficiency of main water heater (%)	80	80