CAN WE IMPROVE THE IDENTIFCATION OF COLD HOMES FOR TARGETED HOME ENERGY EFFICIENCY IMPROVEMENTS?

Alphabetical by institution

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ABSTRACT

Objective To investigate the extent to which homes with low indoor temperatures can be identified from dwelling and household characteristics.

Design Analysis of data from a national survey of dwellings, occupied by low income households, scheduled for home energy efficiency improvements.

Setting Five urban areas of England: Birmingham, Liverpool, Manchester, Newcastle, Southampton.

Methods Half-hourly living room temperatures were recorded for two to four weeks in dwellings over the winter periods November to April 2001-02 and 2002-03. Regression of indoor on outdoor temperature was used to identify cold homes in which standardized daytime living room and/or nighttime bedroom temperatures were <16 degrees Celsius (when the outdoor temperature was five degrees Celsius). Tabulation and logistic regression was used to examine the extent to which these cold homes can be identified from dwelling and household characteristics.

Results Overall, 21.0% of dwellings had standardized daytime living room temperatures <16 Celsius, and 46.4% had standardized nighttime bedroom temperatures below the same temperature. Standardized indoor temperatures were influenced by a wide range of household and dwelling characteristics, but most strongly by the energy efficiency (SAP) rating and by standardized heating costs. However, even using these variables, along with other dwelling and household characteristics in a multi-variable prediction model, it would be necessary to target more than half of all dwellings in our sample to ensure at least 80% sensitivity for identifying dwellings with cold living room temperatures. An even higher proportion would have to be targeted to ensure 80% sensitivity for identifying dwellings with cold bedroom temperatures.

Conclusion Property and household characteristics provide only limited potential for identifying dwellings where winter indoor temperatures are likely to be low, presumably because of the multiple influences on home heating, including personal choice and behaviour. This suggests that the highly selective targeting of energy efficiency programmes is difficult to achieve if the primary aim is to identify dwellings with cold indoor temperatures.

Keywords: indoor temperature, energy efficiency, prediction, targeting

INTRODUCTION

Poor energy efficiency of housing is one of the principal factors contributing to fuel poverty,[1] low winter indoor temperatures,[2] and cold related morbidity and mortality in Britain.[3] [4] It was thus welcome that in 2000 the UK government launched a new Home Energy Efficiency Scheme for England, now known as *Warm Front*. To date the scheme has funded the energy efficiency up-grading of over 600,000 dwellings, with apparent benefit to the health and well-being of many grant recipients.[5]

Eligibility criteria for a *Warm Front* grant ensure that the scheme is targeted at low income households. However, a 2003 National Audit Office report highlighted concerns that the scheme is not effective in reaching the very fuel poor who might benefit from it most.[6] This has raised questions of whether targeting can be improved.

In 2001, a national evaluation of the health impacts of the *Warm Front* programme was initiated, part of which entailed the collection of detailed temperature data from a subset of dwellings in addition to information about each property and household. These measurements were made in dwellings which were awaiting or had recently received *Warm Front* improvements to the heating system, home insulation or both. In this paper, we present an analysis of the relationship between property and household characteristics on the one hand and low indoor temperature on the other. Its results have bearing on the issue of whether cold homes can be more effectively identified for inclusion in the *Warm Front* programme.

METHODS

The *Warm Front* health impact study included dwellings undergoing grant funded improvements over the winters of 2001-02 and 2002-03 in five urban areas of England: Birmingham, Liverpool, Manchester, Newcastle and Southampton. The only dwellings included in this paper are a subset of 470 dwellings which had both indoor temperature measured and had not yet undergone heating system improvements ('pre-improvement dwellings').

Dwelling and household characteristics

Data relating to the household were collected by computer assisted personal interview of one household member (usually the head of household) per dwelling. Each of the properties also underwent a physical survey by a trained surveyor. This provided the basis for calculation of the Standard Assessment Procedure (SAP) rating of energy efficiency[7] and a standardized heating cost also calculated using the SAP algorithms. The SAP rating is a measure of home energy efficiency, based on a logarithmic scale (range 1 (poor) to 120 (excellent)), which reflects the energy used by a household for space and water heating normalized for floor area. The mean national SAP score for England was 51 in 2001 (EHCS 2003). The standardized heating cost is the predicted cost of providing space and hot water heating to a standardized comfort temperature for average UK weather conditions and standard hot water demand assuming standard fuel costs. Unlike the SAP the standardized heating cost increases for larger houses because it is not normalized for floor area.

In addition to these survey data, we used the seven-digit postcode of residence to link each dwelling to its Super Output Area, for which we obtained the 2004 Index of

Multiple Deprivation (IMD) as a measure of socio-economic status. The IMD is based on six area-based parameters: income; employment; health & disability; education, skills training; housing; and geographical access to services.[8]

From these surveys we used for analysis a subset of variables which theoretical considerations and previous tabulations suggested were most likely to influence indoor temperature: property type and age, socio-economic deprivation, size of household, age, sex and educational attainment of the oldest family member, central heating, self-reported satisfaction with the heating system, SAP rating and standardized heating cost.

Classification of homes by indoor temperature

Detailed measurements of temperature were made using Gemini TinyTag data loggers, which were placed away from direct sources of heat and light on a sideboard or shelf at around waist height (approximately one metre from the ground), as previously described.[2] A logger was left in the main living room and also in the main bedroom, and measurements recorded at half-hourly intervals for periods of two to four weeks. Simultaneous measurements of outdoor temperatures were also recorded in a central location in each of the survey areas.

Indoor temperatures were standardized as follows. First, we excluded data from any day when the maximum temperature was above 15 degrees Celsius (the temperature at which the heating system would not normally be on because incidental heat gains from for example, lights and appliances, would provide adequate heating), and from any period of monitoring if the coldest day during that period had a maximum temperature above 7 degree Celsius. These criteria led to the exclusion of 30% of data, but they ensured that we analysed only those temperature readings made during periods of true cold. For each dwelling, we then regressed the indoor temperature on the outdoor temperature, including quadratic terms of outdoor temperature to allow for non-linearity of the relationship. For each dwelling, this regression was used to identify homes in which (a) the daytime (8 am to 8pm) living room temperature and/or (b) the nighttime (8pm to 8 am) bedroom temperature was colder than 16 Celsius under standardized measurement conditions – i.e. when the outdoor temperature was 5 °C.

Statistical analysis

The relationship between household and dwelling characteristics and being a cold home was investigated by tabulation and logistic regression. A cold home was defined to be one in which the standardized temperature (living room or bedroom) was below 16 Celsius – a temperature which is lower than recommended for the elderly population.[1] We developed three regression models based on selections of explanatory variables as follows. Model 1 included three variables available to a local authority without need to visit to the property: property age, type and the index of multiple deprivation for the super output area of residence. Model 2 used the same variables as model 1 plus five other variables readily available from short interview of the householder: age, sex, educational attainment, household size and self reported satisfaction with the heating system. Model 3 used the same data as model 2 plus the SAP energy efficiency rating and the standardized heating cost which are, at present, only obtainable from a detailed property survey. Regression models were implemented using Stata statistical software, from which test characteristics (sensitivity, specificity, predictive values) were obtained for the fitted logistic model using the `lstat` command.[9] Tabulated values are based on models which used a probability of 0.25 as the cutoff for determining whether an observation has a predicted positive outcome.

RESULTS

The distributions of standardized living room and bedroom temperatures for pre-heating system improvement dwellings are shown in Table 1. Overall, 97 (21.0%) of the 463 standardized living room temperatures were lower than 16 Celsius, and 209 (46.4%) of the 450 standardized bedroom temperatures were less than 16 Celsius. These proportions appear to be fairly high by comparison with previous research on fuel poverty.[10]

Univariate tabulation and logistic regression showed that indoor temperatures were appreciably influenced by many of the variables examined. Pre-1930 properties, which generally have poorer energy efficiency characteristics than post-1930 dwellings, appeared to be associated with a higher risk of being a cold home, although the evidence was clearer in relation to nighttime bedroom temperatures than for daytime living room temperatures (Table 2). Property type was not a clear determinant, however, nor was the index of multiple deprivation for the area of residence.

Among household characteristics, having a household member over 60 years of age appeared to increase the risk of cold nighttime bedroom temperatures, but not of daytime living room temperatures, the point estimate for which was in fact slightly lower in the 60+ age-group than it was in households with younger occupants. This supports the anecdotal evidence that many elderly people often select to sleep at lower temperatures, often with windows open. Whereas they maintain higher living room temperatures due to high levels of daytime occupancy. Sex, and educational attainment were also not strongly related to having a cold home, but single person households tended to have a higher risk of being cold than households with two or more people. Homes without central heating were also at greater risk of being cold, but dissatisfaction with the heating system was less clearly predictive.

The most impressive predictors were the SAP rating and the related standardized heating costs. For both these measures, there was strong evidence of an exposure response gradient both in relation to daytime living room temperatures and nighttime bedroom temperatures (Table 2).

The results of multi-variable analyses for low living room temperatures (Table 3) showed that simple property and area characteristics were not strong independent determinants of standardized temperatures below 16 Celsius. Having a household member over 60 years, a household size of two or more members, and central heating all appeared to decrease the risk of being a cold home (Table 3, model 2), but in model 3 with all selected variables the SAP rating remained the strongest predictor (Table 3, model 3).

Predictive characteristics of the fitted models

Despite the strength of association for several of the explanatory factors, the performance of the multi-variables models for predicting cold homes was limited. This is illustrated in Table 4 using, as an example, a probability threshold of 0.25 to classify dwellings as being at 'high probability' of being cold. Although the predictive value increases with the addition of more model parameters, a significant proportion of the true cold homes (column 1 data) would be 'test negative' (row 2 data). And to increase the proportion of true cold homes that are correctly identified (i.e. to increase the test sensitivity) we have to lower the threshold probability, which increases the overall number of homes that would be included.

The effect of this is shown in Figure 1 where we graph the percent of homes that would need to be targeted in order to achieve varying levels of sensitivity for identifying homes that are truly cold. The models which include household characteristics (model 2) and/or energy efficiency parameters (SAP rating and standardized heating cost - model 3) as well as property age and type and area deprivation score appear to perform significantly better than model 1 (property age and type and area deprivation score only). But even with the full model 3, it would be necessary to include more than half of all dwellings to ensure that at least 80% of homes with cold living room temperatures are captured. For nighttime bedroom temperatures, more than 65% of dwellings would have to be targeted to ensure inclusion of 80% of the cold dwellings (Figure 1(B)). Thus, if it is important to avoid excluding cold homes from grants, it would be necessary to offer improvements to a high fraction of those who apply for them.

DISCUSSION

This analysis provides new insights into the targeting of grants for energy efficiency improvements such as those offered as part of England's *Warm Front* scheme. Its evidence suggests that even quite detailed information about a property and its occupants provides only a moderate indication of how cold the dwelling will be on cold days. In consequence, there appears no very reliable way to identify the coldest dwellings (if that is an important aim of targeting) unless there is direct measurement of indoor temperatures, although a number of property and household characteristics clearly influence the probability of a home falling below a 16 Celsius threshold for the living room or bedroom.

There are, however, a number of limitations of this analysis. First, it must be remembered that all the data available for it relate to households in the *Warm* Front evaluation, and hence all of them had already applied for (and been awarded) a grant for energy efficiency improvements. Its evidence is therefore only directly applicable to the comparatively restricted question of whether it is possible to distinguish from within grant applicants those with the coldest homes who might, for example, be targeted for larger grants and more comprehensive improvements. Its relevance to wider issues of targeting is less direct. Second, it considers only the issue of indoor temperature rather than heating cost, fuel poverty or other potential measures of need. Being able to maintain an adequate indoor temperature is important for health[3] but, as we have argued elsewhere, fuel poverty may independently be detrimental to health for reasons relating to the affordability of healthy choices in other areas of household expenditure.[11] Third, our analysis was not a true test of prediction, but rather an assessment of the accuracy of classification of dwellings based on their fitted probabilities within a regression model. A true test of predictability would require a completely independent sample as a test of its accuracy, and with such a test the performance for prediction would almost certainly be appreciably worse than the classification of fitted values of one model. On the other hand, the data and methods for estimating indoor temperatures are some of the most detailed that have been used for the UK stock, being based on around 1000 measurement points for each dwelling and using regression-based methods of standardization that allow for variation in outdoor temperature, seasonal timing and time of day of measurement. They are therefore likely to provide as good an indication of a cold home as most other assessments.

Several of our chosen variables (property age, household size, lack of central heating, SAP rating and standardized heating costs) appear to be quite strong determinants of a cold home, although socio-economic deprivation was not. This last observation may relate to the fact that all households in our sample were necessarily on benefit (so there may not have been much differential) although it is also consistent with previous reports of limited socio-economic gradient in indoor temperatures[3] and winter mortality.[12, 13] It is perhaps not surprising that SAP rating and standardized heating costs performed particularly well. But even when using all of variables (which would require fairly detailed property survey) it appears that the overall accuracy of prediction is fairly limited. Thus, to maintain high sensitivity (so that few high risk dwellings are missed) it would be necessary to target a high proportion of all dwellings. The reasons for this include the fact that many factors influences indoor temperatures, including personal behaviours/choice. Thus, some householders will choose to heat the home well even if it is expensive to do so, while others may choose to maintain low temperatures from personal volition or habit.

Of course, identification of low temperature homes is not necessarily the appropriate principal objective of a targeting policy. For one thing, on health grounds, there is evidence that people with cold, but not necessarily the *coldest*, homes may also benefit from home energy efficiency improvements: we have insufficient evidence to say whether an increase from a standardized temperature of 14 to 16 degrees Celsius achieves more than an increase from 16 to 18 Celsius, for example, and we have already noted that health benefits may accrue through pathways other than the increase in temperature. We have also made arguments that the problem of winter related mortality and morbidity is widely distributed in the population and not confined to those in fuel poverty,[12] [13] [14] and unrestricted heating does not remove the risk of winter death.[15]

It is of course desirable that those in greatest need receive the greatest part of energy efficiency grants, but from a utilitarian perspective, it may be that the cost of carrying out surveys to improve targeting may not be justified by the gains.[4] And the issue is further complicated by the variation in the cost and feasibility of up-grading properties, and the potentially high turnover of occupants in the medium term i.e. should schemes target the combination of a particular occupant and building when the occupant may move on in several years to be replaced by a completely different occupant?

In conclusion, this study suggests that property and household characteristics provide only limited potential for identifying dwellings where winter indoor temperatures are likely to be low, presumably because of the multiple influences on home heating, including personal choice and behaviour. In consequence, the highly selective targeting of energy efficiency programmes is difficult to achieve if the primary aim is to identify dwellings with cold indoor temperatures.

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Conflicts of interest

None.

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Table 1. Distribution of living room and bedroom temperatures in pre-intervention dwellings.

		Living room temperature /degrees Celsius	Bedroom temperature /degrees Celsius
mean		18.2	16.4
	1%	10.0	9.5
	5%	12.6	11.4
	10%	14.1	12.4
	25%	16.5	14.4
Percentile	50%	18.5	16.3
	75%	20.2	18.8
	90%	21.8	20.4
	95%	22.9	21.1
	99%	24.0	23.1

Table 2. Percent of homes with standardized daytime living room and night time bedroom temperatures below 16 degrees Celsius. Odds ratios adjusted for area and year.

	Daytime living room temperature			Nighttime bedroom temperature		
	N	Percent <16˚C	Odds ratio (95% CI)	N	Percent <16˚C	Odds ratio (95% CI)
Property & area characteristics						
Property age						
pre 1930	179	25.7	1	171	54.4	1
1930-1965	212	17.9	0.65 (0.39, 1.07)	212	44.3	0.69 (0.46, 1.04)
1966+	72	18.1	0.63 (0.30, 1.29)	67	32.8	0.47 (0.25, 0.86)
Property type						
terrace or back-to-back	150	22.0	1	141	47.5	1
semi, detached, end-terrace	284	20.1	1.00 (0.60, 1.66)	280	46.4	0.96 (0.63, 1.46)
purpose-built or other flat	29	24.1	1.68 (0.61, 4.60)	29	41.4	1.14 (0.48, 2.69)
IMD						
Quartile 1 (least deprived)	105	21.9	1	104	35.6	1
Quartile 2	116	25.0	1.00 (0.51, 1.94)	114	50.9	1.66 (0.95, 2.92)
Quartile 3	120	18.3	0.84 (0.42, 1.68)	116	52.6	1.89 (1.07, 3.33)
Quartile 4 (most deprived)	116	19.0	0.58 (0.29, 1.18)	110	44.5	1.18 (0.66, 2.10)
Household and house characteristics						
Age (max age group)						
0-59	114	27.2	1	108	43.5	1
60+	196	20.4	0.65 (0.37, 1.16)	193	61.1	2.03 (1.23, 3.33)
Sex						
Male	113	19.5	1	112	56.3	1
Female	197	24.9	1.30 (0.71, 2.38)	189	54.0	0.91 (0.56, 1.48)
Educational attainment						
Yes	121	27.3	1	118	48.3	1
No	188	20.2	0.72 (0.40, 1.28)	182	58.8	1.53 (0.94, 2.50)
Household size						
1	109	27.5	1	107	68.2	1
2	91	18.7	0.52 (0.25, 1.08)	90	55.6	0.56 (0.31, 1.03)
3	46	23.9	0.69 (0.29, 1.62)	44	50.0	0.42 (0.20, 0.88)
4+	64	20.3	0.63 (0.28, 1.38)	60	33.3	0.22 (0.11, 0.44)
Central heating						
No	291	26.1	1	281	59.8	1
Yes	172	12.2	0.40 (0.23, 0.70)	169	24.3	0.22 (0.14, 0.34)
Dissatisfied with heating						
No	88	18.2	1	87	44.8	1
Yes	222	24.8	1.39 (0.72, 2.70)	214	58.9	1.60 (0.95, 2.71)
Property survey data						
SAP rating						
Quartile 1	115	37.4	1	110	67.3	1
Quartile 2	119	19.3	0.40 (0.21, 0.73)	118	52.5	0.55 (0.32, 0.95)
Quartile 3	114	15.8	0.31 (0.16, 0.60)	113	36.3	0.29 (0.16, 0.50)
Quartile 4	112	9.8	0.18 (0.08, 0.41)	106	29.2	0.23 (0.12, 0.43)
Standardized heating cost						
Quartile 1	100	10.0	1	95	34.7	1
Quartile 2	117	17.9	2.00 (0.87, 4.60)	114	39.5	1.12 (0.62, 2.01)
Quartile 3	120	18.3	2.10 (0.92, 4.79)	121	47.1	1.47 (0.83, 2.62)
Quartile 4	113	37.2	5.37 (2.44, 11.8)	108	63.9	2.87 (1.58, 5.20)

* -- *Standardized indoor temperature*

Table 3. Predictive models for low (<16 degrees Celsius) standardized daytime living room temperatures

	N	Odds Ratio (95% CI)		
		Model 1	Model 2	Model 3
Property characteristics				
Property age				
pre 1930	130	1	1	1
1930-1965	133	0.61 (0.32, 1.20)	0.68 (0.34, 1.36)	0.91 (0.45, 1.83)
1966+	36	0.86 (0.33, 2.23)	0.89 (0.32, 2.44)	1.42 (0.52, 3.89)
Property type				
terrace or back-to-back	110	1	1	1
semi, detached, end-terr.	168	0.83 (0.41, 1.67)	0.76 (0.37, 1.59)	0.43 (0.21, 0.90)
purpose-built or other flat	21	2.71 (0.71, 10.4)	1.90 (0.45, 8.00)	1.05 (0.30, 3.68)
IMD*				
1st quartile (least deprived)	64	1	1	1
2nd quartile	80	1.62 (0.68, 3.85)	1.57 (0.63, 3.90)	1.90 (0.78, 4.66)
3rd quartile	79	1.02 (0.40, 2.62)	0.90 (0.33, 2.43)	0.95 (0.36, 2.47)
4th quartile (most deprived)	76	0.75 (0.29, 1.93)	0.68 (0.24, 1.93)	1.17 (0.43, 3.20)
House and household characteristics				
Age (max age group)				
0-59	112	-	1	1
60+	187		0.24 (0.09, 0.67)	0.24 (0.09, 0.64)
Sex				
Male	107	-	1	1
Female	192		1.00 (0.51, 1.95)	1.14(0.59, 2.21)
Educational attainment[$]				
Yes	117	-	1	1
No	182		0.75 (0.38, 1.51)	0.76 (0.38, 1.51)
Household size				
1	105		1	1
2	87	-	0.40 (0.17, 0.92)	0.50 (0.22, 1.13)
3	44		0.28 (0.08, 0.95)	0.34 (0.10, 1.12)
4+	63		0.25 (0.07, 0.89)	0.29 (0.09, 1.00)
Central heating				
No	239	-	1	1
Yes	60		0.32 (0.11, 0.92)	1.47 (0.69, 3.14)
Dissatisfied with heating				
No	86	-	1	1
Yes	213		1.49 (0.71, 3.12)	1.47 (0.69, 3.14)
Survey data				
SAP				
Quartile 1	91			1
Quartile 2	92	-	-	0.43 (0.18, 1.02)
Quartile 3	56			0.46 (0.15, 1.45)
Quartile 4	60			0.15 (0.03, 0.77)
Stand'ized heating cost				
Quartile 1	59			1
Quartile 2	71	-	-	1.13 (0.30, 4.19)
Quartile 3	83			0.52 (0.12, 2.23)
Quartile 4	86			1.46 (0.33, 6.42)

* *Index of multiple deprivation*
[$] *Of head of household*

Table 4. Modelled *vs* measured probablility of a low standardized living room temperature <16 degrees Celsius.

Model 1*

		Standardized living room temperature <16 Celsius: + ('true cold')	-	Total
Modelled probability of low indoor temperature >0.25	+ ('test positive')	4	11	15
	-	17	68	85
	Total	21	79	100

Model 2$

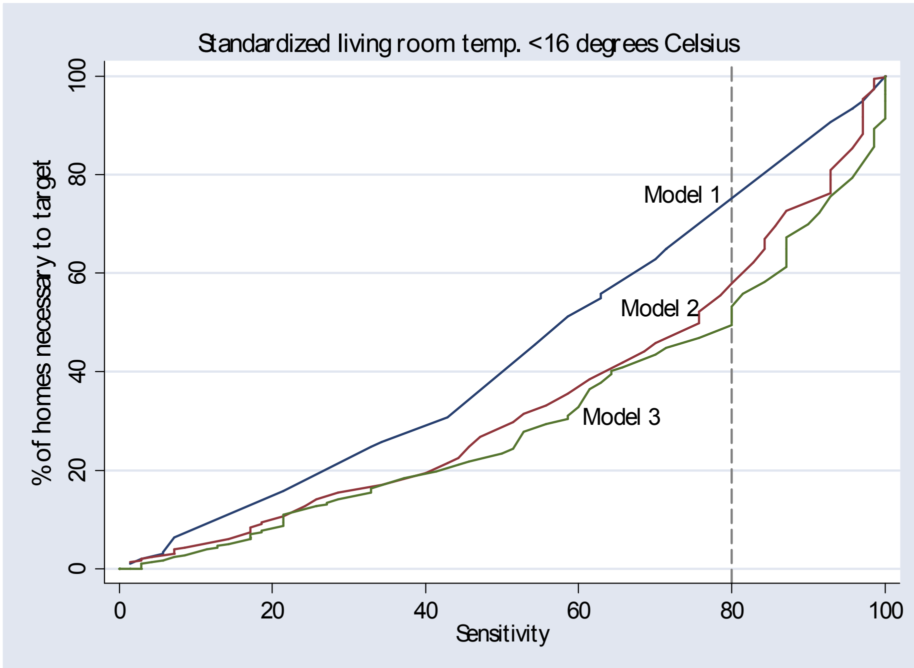
		Standardized living room temperature <16 Celsius: + ('true cold')	-	Total
Modelled probability of low indoor temperature >0.25	+ ('test positive')	15	25	40
	-	8	52	60
	Total	23	77	100

Model 3†

		Standardized living room temperature <16 Celsius: + ('true cold')	-	Total
Modelled probability of low indoor temperature >0.25	+ ('test positive')	15	22	37
	-	9	55	64
	Total	24	79	100

* – *property age and type, area deprivation*
$ – *model 1 parameters plus household characteristics*
† – *model 2 parameters plus SAP and standardized heating cost*

(A)



(B)

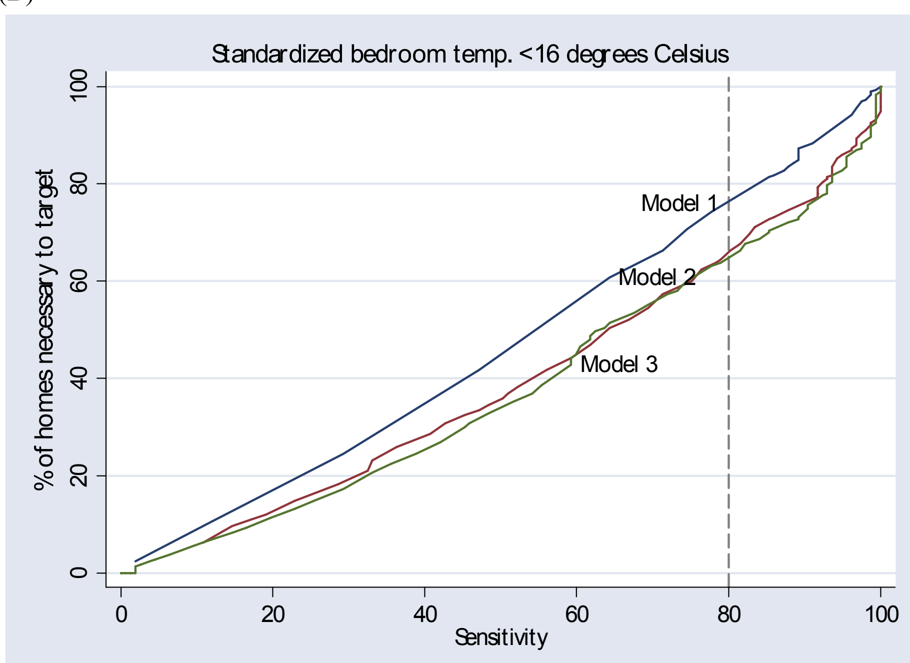


Figure. Percent of homes that need to be targeted to include 80% of homes with (A) standardized living room temperature and (B) standardized bedroom temperature below 16 degrees Celsius.